Total Maximum Daily Load For:
Oak Creek- Headwaters to the Verde River

Parameters: Total Phosphorous and Total Nitrogen

June 1999

Open File Report 09-05

NOTE: Since initial publication the contact information has been updated. For more information please contact:

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Total Maximum Daily Loads (TMDLs) for Total Phosphorus and Total Nitrogen in the Oak Creek Basin, Arizona (Including Munds Creek)

Arizona Department of Environmental Quality
3033 North Central
Phoenix, Arizona 85012
June, 1999

Acknowledgments

Early project work and sampling completed by Julie Cox, formerly of ADEQ

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Appendices A and B were directly copied from the above report.

ACRONYMS

ADEQ	Arizona Department of Environmental Quality
ALRIS	Arizona Land Resource Information System
ARCView	A GIS system that provides the framework for BASINS.
BASINS	Better Assessment Science Integrating Point and Non-point Sources (Computer Model)
CWA	Clean Water Act
EPA	Environmental Protection Agency (See USEPA)
GIS	Geographic Information System
LA	Load Allocation (Non-Point Sources)
MOS	Margin of Safety
NPDES	National Pollutant Discharge Elimination Systems
NPS	Non-Point Source
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
WLA	Waste Load Allocation (Point Sources)
WQS	Water Quality Standards (AZ)
WWTP	Waste Water Treatment Plant
cfs	cubic feet per second (commonly used discharge measurement unit)
mg/l	milligrams per liter (commonly used concentration measurement unit)
μg/l	micrograms per liter (another commonly used concentration measurement unit)
kg/day	kilograms per day (commonly used load measurement unit)

I EXECUTIVE SUMMARY

An assessment of the water quality of Oak Creek canyon is necessary to clearly identify the pollutants and conditions for which the Total Maximum Daily Load (TMDL) is being developed. The Arizona Department of Environmental Quality (ADEQ) has developed this TMDL to account for all impacts from point and non-point sources of phosphorus and nitrogen pollution. In general, a TMDL is described as the sum of the individual wasteload allocations for point sources and load allocations for non-point sources and natural background such that the capacity of the waterbody to assimilate pollutant loadings is not exceeded.

The Oak Creek Basin is located in Coconino and Yavapai Counties and is currently listed on Arizona's 1998 Water Quality Limited Waters List (also known as Arizona's 303[d] list) as being water quality limited due to phosphorus. A TMDL for nutrients was originally established in 1987, but stakeholders have requested that ADEQ recalculate the TMDL using a more sophisticated simulation that includes allowances for non-point sources. The TMDL addresses both phosphorus and nitrogen due to their linkage as nutrients in the ecosystem.

Oak Creek arises from the southern rim of the Colorado Plateau about 6 miles southwest of Flagstaff, Arizona and flows approximately 21 miles in a southwestern direction to join the Verde River near Cornville, Arizona. Oak Creek drops 2500 feet through a steep-walled canyon in the upper reaches to more gently rolling hills and plateaus in the lower reaches. The majority of land within the watershed is dominated by open space consisting of forestland, rangeland, and barren land. The creek originates from springs located just above Sterling Springs Fish Hatchery and is augmented by discharge from West Fork of Oak Creek, Munds Creek (tributary to Oak Creek below Slide Rock), and springs near Indian Gardens, and additional springs located near Page Springs Fish Hatchery and Spring Creek. Oak Creek drains a 464 square mile watershed, most of which is within the Coconino National Forest.

The Arizona Water Quality Standards classify Oak Creek and the West Fork of Oak Creek as Tier III Unique Waters subject to special protection and standards. The Tier III Unique Waters designation is interpreted by ADEQ to preclude any new pollutant sources in Oak Creek or West Fork Creek. Other tributaries including Munds Creek, Dry Creek, and Spring Creek have only “regular” (non-Unique Waters) status and standards, but new sources in these streams may be limited beyond “regular” standards unless it is shown that there will not be any degradation to Oak Creek.

The NPDES-permitted facilities in the Oak Creek watershed are: Pinewood Wastewater Treatment Plant (WWTP) (permit application in process), Sedona Venture WWTP, and the Page Springs Fish Hatchery. The Sterling Springs Fish Hatchery does not require nor hold a National Pollution Discharge Elimination System (NPDES) permit, but was included in the simulation because its discharge is the most upstream point source in the watershed. The Kachina Village WWTP discharges to a wetlands, does not require nor hold a NPDES permit, and is therefore excluded from consideration as a point source.

The septic systems are primarily located in the Slide Rock and Sedona sub-watersheds. ADEQ applied estimated numbers for septic systems (200 in Slide Rock segment, 50 in the Sedona segment). While these systems may not be fully utilized due to the seasonal nature of canyon residency, for purposes of conservatism in the model, ADEQ considered all to be fully used.

The waters of Oak Creek are of generally high quality. All available acceptable data demonstrates that the Oak Creek basin is in compliance with the site-specific (Oak Creek is a Tier III Unique Water) Arizona Surface Water Quality Standards for phosphorus and nitrogen. The Oak Creek watershed model was simulated for the 1991-1995 period. Using conservative "worst case" assumptions in the model did not cause statistically significant exceedences of the applicable Arizona Surface Water Quality Standards. The few exceedences observed in the simulation are too low in number to be significant and are considered a result of conservative model assumptions and minimal available precipitation data.

This TMDL has been calculated based on real and simulated loads using the formula:

$$\mathbf{TMDL = \sum WLA + \sum LA + MOS}$$

where WLA is the wasteload allocation consisting of loads from point sources, LA is the load allocation consisting of non-point source loads (including natural background), and MOS is a Margin of Safety which serves to address uncertainties in the analysis and the natural system.

A portion of the margin of safety (MOS) is built in to the model through the use of conservative assumptions, the remainder of the margin of safety is calculated for both point and non-point sources and allows for system and model variability, and natural increases in loads. There can not be any allowance in the margin of safety for future point sources due to ADEQ's interpretation of the Tier III Unique Waters status of Oak Creek.

Appropriate TMDLs for nitrogen and phosphorus in the Oak Creek watershed can be represented as follows:

Nitrogen TMDL = 440 kg/day =
(67 kg/day point sources) + (365 kg/day non-point sources) + (8 kg/day margin of safety)
Phosphorus TMDL = 58 kg/day =
(13 kg/day point sources) + (43 kg/day non-point sources) + (2 kg/day margin of safety)

Modeling results do not justify alteration of existing NPDES permit discharge limits. No new limits on existing septic systems are justified at this time. However, should the results of the Coconino County septic census differ significantly from the model assumptions, this issue could be revisited.

Conclusions

The primary conclusions to be derived from this TMDL analysis are as follows:

- Watershed simulation of conditions in the Oak Creek system over a five-year period suggests that there are few standards violations and that there is no exceedence of existing water quality standards. The available water quality monitoring data suggest the same.
- ADEQ interprets the Antidegradation rule to mean no new or additional loading sources for Oak Creek, nor for any tributaries should the tributary loads affect Oak Creek.
- The current Oak Creek watershed model is capable of indicating relative trends and impacts from the point and non-point sources of pollution.
- The 1987 TMDLs ignored non-point sources and ADEQ proposes their replacement with these new TMDLs. Non-point sources are the primary contributor of nitrogen and phosphorus in the watershed.

General Recommendations for Future Watershed Analysis

- ADEQ will remove the phosphorus listing of Oak Creek and Munds Creek from the 303[d] list. This TMDL analysis will have no effect on either stream's listing for other parameters; i.e., bacteria (both), and turbidity (Oak Creek).
- Modeling results do not justify alteration of existing NPDES permit discharge limits.
- Septic systems have been simulated as point sources due to modeling constraints. No new nutrient limits on existing septic systems are justified at this time.
- Oak Creek's status as a Unique Water requires a comprehensive water quality and hydrologic monitoring program. During the course of developing this TMDL, several deficiencies have been observed in the available data. Stakeholders should work together with ADEQ to fill the data gaps and develop a comprehensive understanding of the watershed. The following suggestions for monitoring are intended to help develop a plan to fill the existing data gaps. Unfortunately, ADEQ does not have the resources to conduct this type of monitoring by itself and suggests that local groups research the possibility of using grants to pay for such monitoring. ADEQ can offer advice to potential grant applicants. The point of contact is:

  ADEQ
  Watershed Unit
  Deborah Patton, Environmental Program Specialist
  3033 N. Central Ave.
  Phoenix, AZ 85012-2809-33
  ADEQ main telephone number: 1- (800) 234-5677

- Establish multiple monitoring sites on the creek and its major tributaries for long-term (five or more years) periodic monitoring. Monitoring should be conducted during the various precipitation regimes including: winter precipitation, snow melt, spring dry, monsoon, fall dry, fall precipitation.

- Implement a strategy to capture data during 5 to 10 significant precipitation events per year at several of the sites suggested above.
- Maintain an inventory of multiple short-term (approximately two years) monitoring sites draining relatively homogeneous land uses (e.g. golf courses, urban areas, agricultural areas, forested areas, etc.) throughout the watershed. Conduct special studies for other related areas such as septic system efficiencies and recreational impacts.
- Locate and monitor, on an occasional basis, the major springs and other sources of groundwater to the creek in order to assess their load contributions.
- Work with the Oak Creek Flood Warning System to improve their precipitation gage network and data management system. This system could be an extremely valuable source of data for watershed modeling.
- Continue to build the Oak Creek watershed model established for this TMDL.

II PROBLEM STATEMENT

An assessment of the water quality of Oak Creek canyon is necessary to clearly identify the pollutants and conditions for which this nutrient (nitrogen and phosphorus) Total Maximum Daily Load (TMDL) is being developed. Arizona Department of Environmental Quality (ADEQ) has developed this TMDL analysis to account for all impacts from point and non-point sources of the phosphorus and nitrogen pollution.

The significant point sources in the Oak Creek Basin are: Sterling Springs Fish Hatchery - located on lower Pumphouse Wash, Pinewood (Munds Park community) WWTP - located on Munds Creek adjacent to the I-17 crossing, Sedona Venture (Sedona Shadows community) WWTP - located on Dry Creek, and Page Springs Fish Hatchery - located on Oak Creek. The loads associated with each source are displayed in Table 4 (page 21).

Septic systems are considered non-point sources (NPS), but for purposes of modeling, they are treated as point sources. Estimates vary as to the total number of septic systems along the creek; therefore ADEQ has assigned two hundred septic systems to the subwatershed between the mouth of West Fork Oak Creek and the mouth of Munds Creek, and fifty septic systems were assigned to the subwatershed between the mouth of Munds Creek and the Sedona USGS gage (approximately the Highway 179 bridge).

Runoff from the various land uses within the watershed is handled within the model as non-point sources.

The applicable Arizona Surface Water Quality Standards are displayed as part of Table 1 (page 11) are the TMDL analysis does not demonstrate statistically significant exceedences; i.e., to the extent of being indicative of a water quality impairment.

III INTRODUCTION

The Clean Water Act (CWA), §303[d] and its Significance.

The CWA, §303[d][1][A] requires that "Each State shall identify those waters within its boundaries for which the effluent limitations...are not stringent enough to implement any water quality standard applicable to such waters." This act also requires states to establish TMDLs for such waters.

The CWA, §303[d] requires states to submit to the Environmental Protection Agency a list of the surface waterbodies for which the designated use (e.g. irrigation, partial body contact, etc.) of that waterbody is impaired or is "water quality limited". Surface water quality data are compared with water quality standards and other criteria to determine whether the waterbody is meeting its "designated uses." The ADEQ publishes a report on the status of surface water and groundwater quality in Arizona every two years, in accordance with the CWA, §305(b), and from this report derives the “Impaired Waters” or “303[d] List”.

The TMDL process provides a flexible assessment and planning framework for identifying load reductions or other actions needed to attain surface water quality standards; i.e. water quality goals to protect aquatic life, drinking water, and other water uses. The CWA established the TMDL process to guide application of state surface water quality standards to individual waterbodies and their watersheds.

TMDL Defined

The requirements of a TMDL analysis are described in 40 CFR §130.2, & §130.7, in addition to CWA, §303[d]. A TMDL is described as "the sum of the individual wasteload allocations for point sources and load allocations for non-point sources and natural background" and a margin of safety such that the capacity of the waterbody to assimilate pollutant loadings is not exceeded. Represented as a mathematical equation:

$TMDL = \sum WLA + \sum LA + MOS$,

where WLA is the wasteload allocation consisting of loads from point sources, LA is the load allocation consisting of non-point source loads, and MOS is a Margin of Safety which serves to address uncertainties in the analysis and the natural system.

Due to ADEQ's interpretation of the Tier III Unique Water status of Oak Creek, neither assimilative nor loading capacities were calculated. This is explained in greater depth in Section V, Description of the Oak Creek Watershed, subsection titled: Unique Waters Designation. (Page 17)

Overview of the Oak Creek TMDL

The Oak Creek Basin is located in Coconino and Yavapai Counties and is currently listed on Arizona's 1998 Water Quality Limited Waters List (also known as Arizona's 303[d] list as being water quality limited due to phosphorus. A TMDL for nutrients was originally established in 1987, but stakeholders requested that ADEQ recalculate the TMDL using a more sophisticated simulation that includes allowances for non-point sources. The TMDL analysis addresses both phosphorus and nitrogen due to their linkage as nutrients in the ecosystem.

Efforts to protect Oak Creek by the US Environmental Protection Agency (USEPA) and the ADEQ require the development of TMDLs for various pollutants, including the nutrients nitrogen and phosphorus. These loads represent the maximum daily allowable load carried by the creek and they are developed through an analysis of watershed and stream conditions.

The overall goal of this TMDL analysis is to construct nutrient load allocations for Oak Creek. Computer models, such as BASINS 2.0 used in the Oak Creek TMDL, allow ADEQ to create a simulated stream system to view the pollutant loads to waterbodies and track the movement within those waterbodies. Interpretation of this simulated system allows for determination of the loads and their allocation to a variety of sources. This model is capable of providing a sufficiently accurate depiction of the Oak Creek watershed in order to help develop nutrient TMDLs and is flexible enough to be modified when more information becomes available.

IV THE TMDL PROCESS

A TMDL analysis is a tool for implementing state surface water quality standards and is based on the relationship between pollution sources and in-stream water quality conditions (USEPA, 1991). The TMDL process is a method used in balancing the pollution concerns for a waterbody and evolving a pollution reduction approach for point and non-point sources of pollution. TMDL development allocates the acceptable pollutant loads among the different point and non-point sources allowing the selection and implementation of suitable control measures to attain water quality standards.

In implementing TMDLs, certain criteria must be taken into account. These criteria include the load allocation, wasteload allocation, natural background, and the margin of safety. The loading capacity is the greatest amount of loading that a waterbody can receive without violating water quality standards, but is not considered at a level higher than ambient in the Oak Creek TMDL analysis due to the limiting nature of the Unique Waters designation. Load allocation is the portion of a receiving water's loading capacity that is attributed either to one of its existing non-point sources of pollution or to natural background sources. The portion of the receiving waters' loading capacity that is attributed to existing point sources of pollution is known as the wasteload allocation. Finally, the margin of safety is the factor that accounts for any uncertainty in the relationship between the pollutant loads and the quality of the receiving waterbody. (40 CFR, §130.2[f-g])

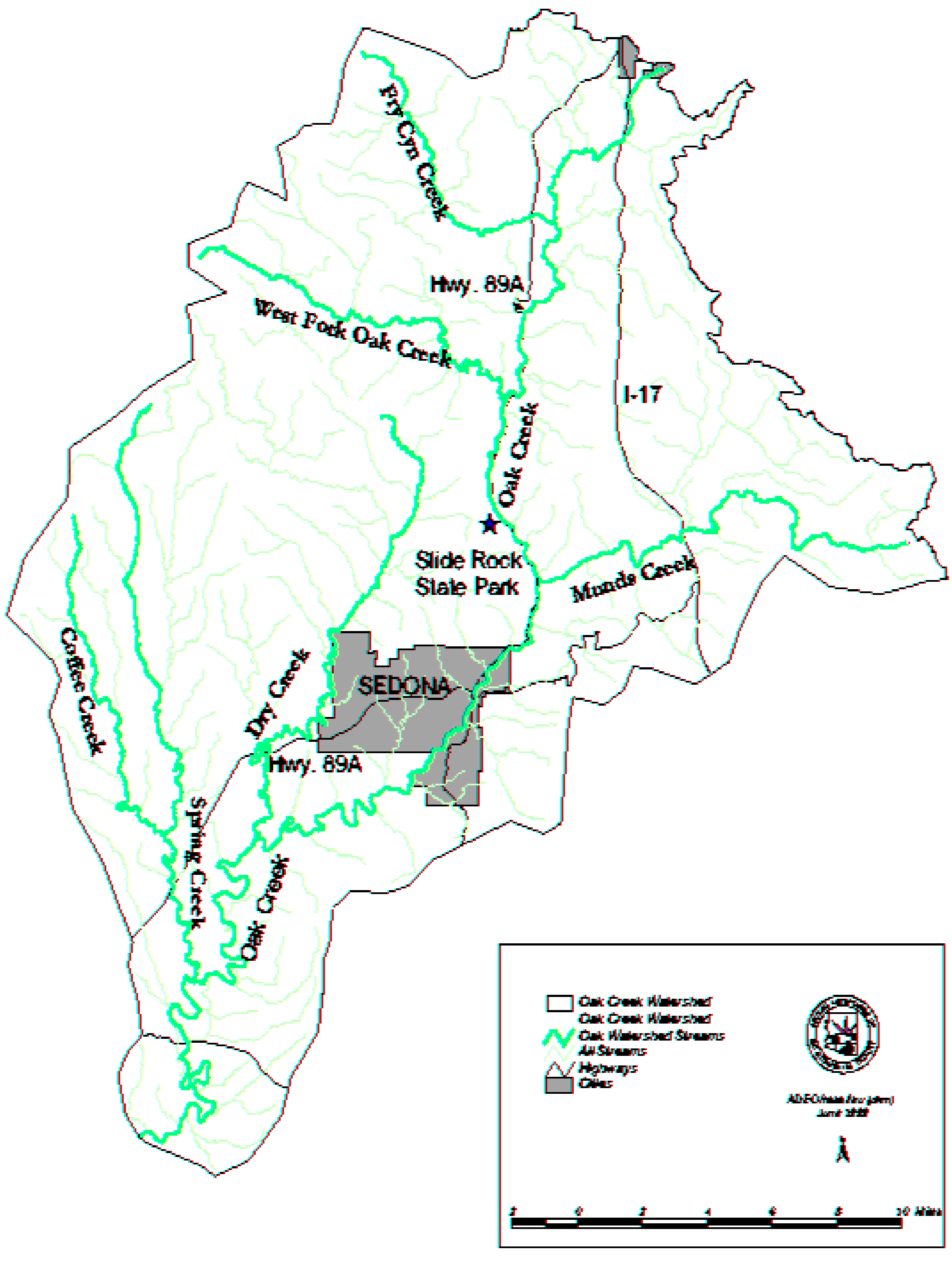
The TMDL process apportions the waterbody's ambient loads to different pollution sources. Total pollutant loads are determined by combining the point, non-point and background sources of pollution. The TMDL includes waste load allocations that confirm existing limits.

In order to maintain Oak Creek's ambient water quality, human-induced point and non-point sources, natural background sources, and a margin of variability or safety must be considered.

TMDLs are used to consider the effects of processes or activities that contribute to the degradation of water-quality conditions in a waterbody. Once TMDLs are developed for all the water-quality problems, they are submitted to the EPA for review and approval. Implementation of TMDLs occurs after pollutant load allocations have been approved by the USEPA. Measures for implementing TMDLs are not limited to NPDES-related actions. State and local authority may also be applied to point and non-point source pollution through state and local water-quality management plan updates.

The TMDL process is not complete once waste load allocations and load allocations have been determined. Assessment of the TMDL effectiveness must be made. Ideally, this would begin within two years after implementation and continue for the period necessary to measure effectiveness.

Figure 1. Oak Creek Watershed



V DESCRIPTION OF THE OAK CREEK WATERSHED

Overview

Oak Creek arises from the southern rim of the Colorado Plateau about 6 miles southwest of Flagstaff, Arizona (Figure 1). The stream flows approximately 21 miles in a southwestern direction to join the Verde River near Cornville, Arizona. Oak Creek drops 2500 feet through a steep-walled canyon in the upper reaches to more gently rolling hills and plateaus in the lower reaches. The creek originates from springs located just above Sterling Springs Fish Hatchery and is augmented by discharge from West Fork of Oak Creek, Munds Creek and springs near Indian Gardens, and additional springs located near Page Springs Fish Hatchery and Spring Creek. Oak Creek drains a 464 square mile watershed, most of which is within the Coconino National Forest.

Topography

The elevation of the Oak Creek watershed ranges from 8460 feet on Mormon Mountain east of Munds Park to about 3180 feet at the confluence with the Verde River. The Mogollon Rim, an escarpment that runs through Arizona from the west-northwest to the east-southeast, divides the watershed. Elevations above the Rim (to the north) range from about 6000 to 8000 feet and elevations below the Rim range from approximately 3500 to 5000 feet.

Ecology

The vegetation of Oak Creek watershed has been divided into five major communities by Aitchison and Theroux (1972). Beginning at the head of the canyon and moving downstream, the communities are: Ponderosa Pine-Douglas Fir Forest, Chaparral, Pinyon-Juniper Woodland, Oak Woodland, and Cypress-Juniper Woodland. Oak Creek takes its name from dense stands of Gambel's Oak and Arizona Oak. Riparian communities along the creek are divided into upper and lower, with the West Fork serving as a demarcation. The upper riparian community is dominated by alder, box elder, and ash. The lower community is dominated by sycamore, cottonwood, and walnut. Below Sedona, the channel slope becomes shallow as the creek passes through semi-desert grassland before reaching the Verde River corridor, which is again dominated by sycamore and cottonwood, in addition to willow.

Geology

Oak Creek Canyon resulted from uplift of the 600 million year old Colorado Plateau near Flagstaff. This edge is distinguished by the Mogollon Rim, an erosional rampart 900-4500 feet high. The contemporary canyon follows an earlier Oligocene canyon and fault. Near its head, Oak Creek Canyon is 1500 feet deep and relatively narrow; descending about 12 miles to Sedona, the Canyon drops to 2500 feet and opens to almost a mile across. As the creek flows south it is flanked by 600 foot tall colorful cliffs of Permian-age Kaibab Limestone, Toroweap Formation, and Coconino Sandstone.

Near Slide Rock, a series of deep pools were formed in the red sandstone of the Supai Formation. Farther downstream, near Wilson Canyon, the creek has carved a gorge in the exposed Redwall Limestone. Approaching the town of Sedona, the canyon opens to a spectacular series of high red sandstone buttes (part of the Supai Formation). South of Sedona, the creek has developed incised meanders, flowing across an ancient lakebed (Verde Formation). Parts of this area are capped by gray lava buttes and mesas with chalky gray-white lake deposits. (Twenter and Metzger, 1963) (Levings, 1980) (ADHS, 1985).

Soils

Soils in the watershed vary considerably with elevation and terrain (Arizona Dept. of Water Resources, 1990). The soils southeast of Flagstaff, where the elevations range from 4700 to 6500 feet tend to be shallow and have textures ranging from gravelly loam to clay and overlie limestone or calcareous sandstone bedrock. South and west of Flagstaff, where the elevations range from 6500 to 7500 feet, the dominant soils are moderately deep to deep and are moderately fine or fine textured. In the higher elevations below the Rim the soils are moderately deep to deep, gently sloping to steep and lying on granite, schist and basaltic bedrock. Further south the soils are part of the Rough Broken land association that make up the canyon walls and cliffs of the Sedona area. Further south yet the soils tend to be medium to fine textured, shallow to moderately deep soils over gently sloping to steep limestone and sandstone hills. The southernmost portions of the watershed are shallow to moderately deep calcareous soils on dissected limestone and sandstone hills.

For hydrologic purposes, the Natural Resources Conservation Service classifies soils by their general proclivity to produce runoff. In general, the shallow soils in the northern areas of the watershed (mostly above the Rim) have a higher runoff potential than those in the south.

Land Use

The majority of land within the watershed is managed by the Coconino National Forest and is dominated by open space consisting of forestland, rangeland, and barren land. Above the Mogollon Rim forest lands are managed for wildlife and timber production. A few grazing allotments are located in the upper watershed. There is relatively little private land within the upper watershed. The communities of Kachina Estates, Mountainaire, and Munds Park, each 5-10 miles above the Rim, drain to Oak Creek via either Pumphouse Wash or Munds Creek.

Munds Creek is tributary to Oak Creek below Slide Rock. Upper Oak Creek Canyon from the Mogollon Rim down to Pine Flats Campground is also almost entirely publicly owned under the management of the US Forest Service. The only development above Pine Flats is a fish hatchery at Sterling Springs, owned and operated by the Arizona Game and Fish Department since the early 1900s. There are a total of 435 acres of private lands within the Canyon, 545 structures exist, including single family dwellings, mobile homes, travel trailers, resort facilities, and commercial buildings. (NACOG, 1978; CCEHS, 1984)

Highway 89-A is a major north-south artery cutting through the watershed. The Forest Service estimates that 7 million people visit Sedona/Oak Creek throughout the year of which approximately 1 million visit publicly owned recreation sites in Oak Creek Canyon, and 300,000 visit Slide Rock State Park (Stafford, 1993). Recreation in the form of camping, picnicking, fishing, and swimming is a major use within the canyon.

In order to characterize land uses throughout the Oak Creek watershed, two sources of land use data were utilized: the Arizona Land Resource Information System (ALRIS), and data provided with the BASINS 2.0 watershed modeling system (Primarily compiled by the U.S. Geological Survey). BASINS 2.0 is discussed in more detail in Appendices A and B. The spatial distribution of land uses as provided by BASINS is shown in Figure 2. Land use distribution is displayed in Table 1.

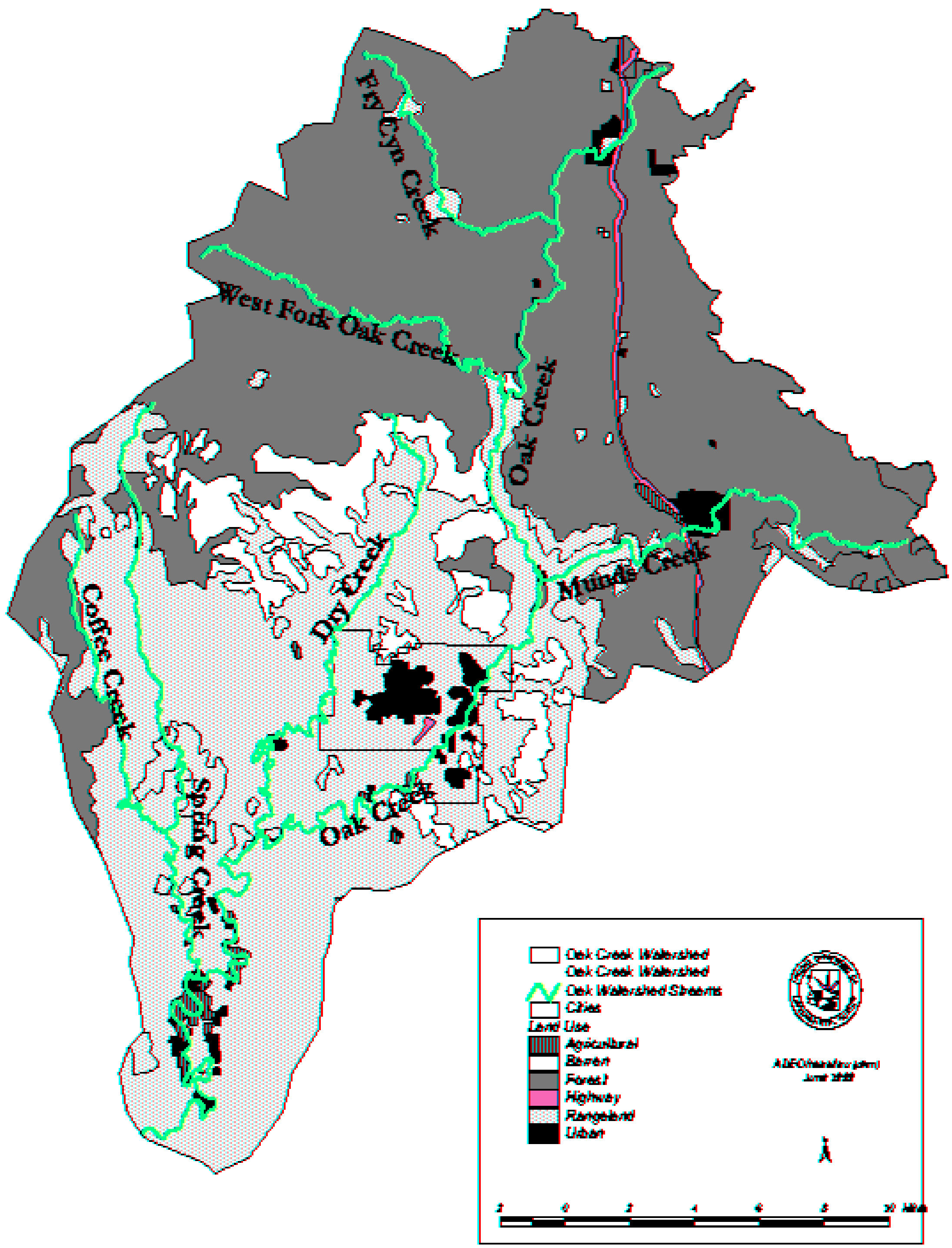
Table 1 -- Land Use Acreage by Type Within Oak Creek Watershed

Land Use Type	Total Acreage	Area in Square Miles	Percent of Watershed
Urban or Built-up	7,065	11.04	2%
Forest Lands	160,546	250.9	52%
Agricultural Lands	1,835	2.9	<1%
Rangeland	117,528	183.6	38%
Barren Lands	20,799	32.5	7%

Residential Development

The total population of the Oak Creek watershed including Sedona and smaller communities is easily less than one-hundred thousand. However, the annual influx of tourist visitorship may reach seven million people (Stafford, 1993). The primary urban / residential areas within the watershed include Sedona, development within Oak Creek canyon proper, Cornville, Indian Gardens, Kachina Village, Munds Park, Page Springs, and Sedona Shadows. Pockets of private land are interspersed with Forest Service land and State parks. As of 1982, Coconino County ordinance specified that all development of private lands within Oak Creek Canyon would be restricted to single family uses at a density not to exceed one unit per "net developable acre" (the gross or total land area proposed for development minus that portion of the property within the floodway of Oak Creek and that portion where existing slopes exceed 25 percent) (CCEHS, 1984).

Figure 2. Oak Creek Watershed Land Use



Climate

Due to the approximately 5300 foot relief in the watershed, climatic conditions vary greatly. The climate is characterized by extreme temporal and spatial variations in precipitation and temperature. Winter storms commonly distribute low-intensity precipitation over a large area and may last for several days. Major flooding can occur when rain falls on snow or when rainfall is abnormally intense. During July, August, and September (Arizona's "monsoon season"), localized storms of short duration and high intensity are common. The upper portions of Oak Creek Canyon receive approximately the same precipitation as the Mogollon Rim (35 inches/year), falling predominantly as snowfall. Near the mouth of the canyon at Sedona, precipitation is approximately 17.5 inches/year, with about 60% falling as snow. The lowest section of Oak Creek receives approximately 12-15 inches/year, almost all of which is rainfall.

Hydrology

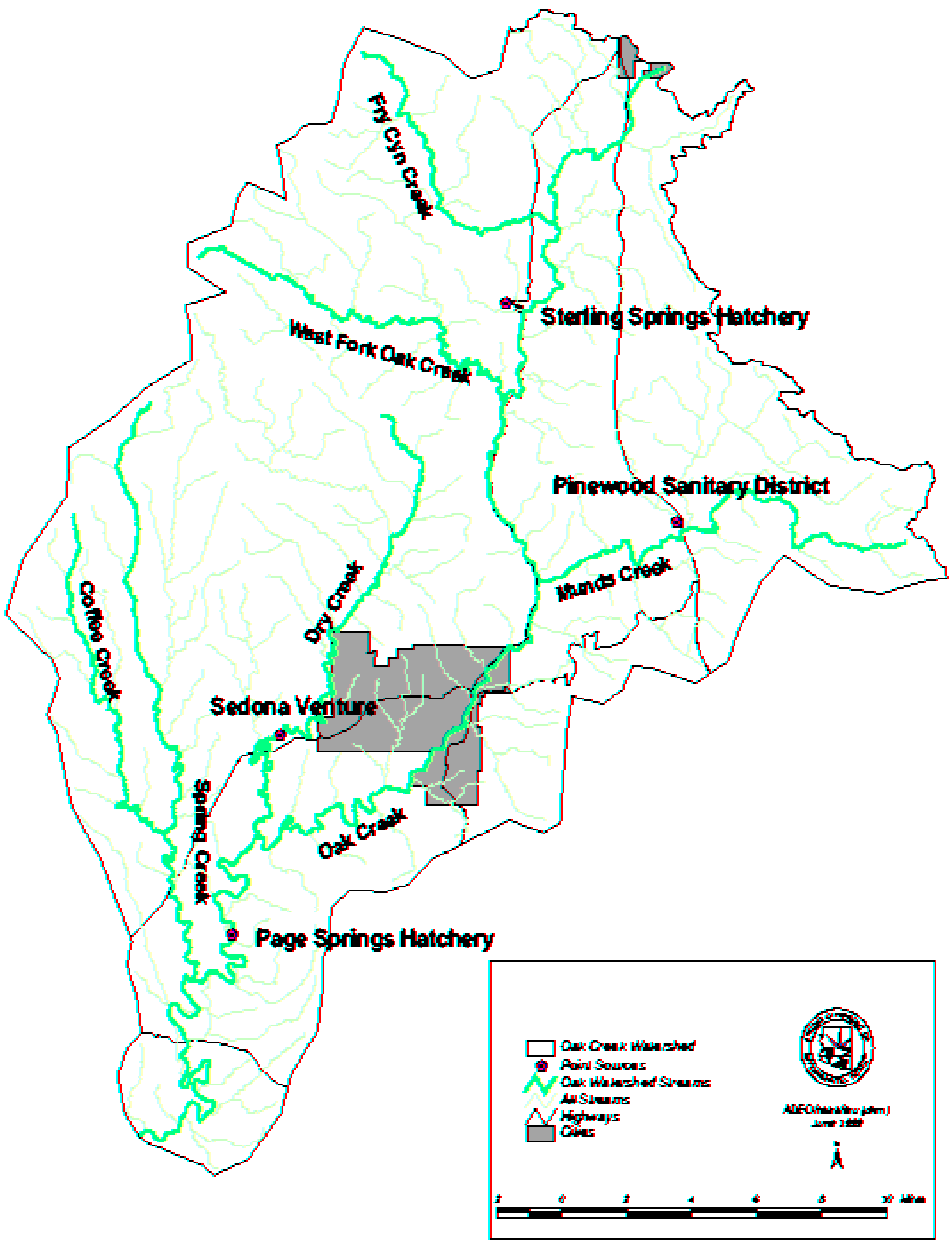
The Oak Creek watershed is shown in Figure 1. The watershed area is approximately 464 square miles and its elevation varies from 8460 feet to 3180 feet. Oak Creek arises from a series of springs at the head of Oak Creek Canyon. Water recharging from the Mogollon Rim percolates through the Coconino Sandstone and fractures along the Oak Creek fault, feeding the upper reaches of Oak Creek. The regional aquifer is composed of the Verde Formation, Coconino Sandstone, Supai Formation, Redwall Limestone, Martin Formation, and Tapeats Sandstone. Regional ground water flow is to the southwest, with the exception of a small region of north and northeasterly flow above the Rim. Groundwater depths ranging from 200 to over 500 feet below land surface. Seeps and springs feed the alluvium along the Creek, supplementing baseflow from the regional aquifer. The portion of the watershed below the Rim experiences little or no recharge since in most months evaporation exceeds precipitation. However, during the winter months there may be some recharge since precipitation exceeds evaporation.

There are five major tributaries to Oak Creek: Pumphouse Wash, West Fork, Munds Canyon, Dry Creek and Spring Creek. Oak Creek and West Fork have perennial flow while the remainder are intermittent. The areas draining into the upper reaches of Oak Creek are characterized by high relief, with a multitude of steep-walled side canyons. The lower portion of the watershed (roughly below the Mogollon Rim) is dominated by lesser relief. Severe monsoons in summer and high runoff periods in spring generate frequent flooding in the lower floodplain, and these events easily change the stream geometry throughout the watershed.

Baseflow near the headwaters of Oak Creek is approximately 3-5 cubic feet per second (cfs). With tributary and ground water contributions, baseflow increases to approximately 18 cfs at Slide Rock and 24 cfs at the Sedona gage. From Sedona to Cornville, Oak Creek is a losing reach as baseflow near the Verde River drops to 21 cfs. The average discharge of Oak Creek at the Cornville USGS gage is 83.4 cfs, with a maximum of 12,000 cfs, showing the extreme variability in seasonal flow.

Surface water within the watershed is chemically similar to ground water (ADHS, 1985).

Figure 3. Oak Creek Watershed Point Source Discharges



Pollution Sources.

Figure 3 shows the approximate location of distinct point source discharges within the Oak Creek watershed. The majority of septic systems that are within 200 feet of the Oak Creek channel lie between the confluence with West Fork and Sedona. Non-point sources of pollution are generally attributed to erosion, decaying vegetation, recreation, and animal wastes. More detailed information about these sources is presented in Appendix A.

Current Water Quality Standards and TMDLs

Arizona water quality standards for total phosphorous and total nitrogen and the previous (1987) TMDLs are listed in Table 2. The 1987 TMDLs were calculated with the 90-percentile standards and the 7-day, 10-year low flows (7Q10) at Red Rock Crossing near Sedona (ADHS, 1981; USEPA, 1987).

The 7-day, 10-year low flow is the 7-day average streamflow that occurs, on average, every 10 years. In other words, this is the 7-day average flow that one might expect to occur one week out of 520 weeks and is considered a design flow, opposite in magnitude but similar to the "100 year flood".

Table 2 -- Arizona Water Quality Standards and 1987 TMDLs Applicable to Oak Creek.

Constituent	Mean Annual Concentration (mg/L)	90 Percentile Concentration (mg/L)	Single Sample Maximum (mg/L)	1987 TMDL (kg/day)
Total Nitrogen	1.0	1.5	2.5	55.5
Total Phosphorus	0.1	0.25	0.30	10.9

NOTES:
mg/L = milligrams per liter; kg = kilograms
The 90-percentile standard is the value below which 90 percent of occurrences must lie.

Existing Conditions - Water Quality Monitoring Programs in the Oak Creek Watershed

Several water quality monitoring programs have been active in the Oak Creek watershed. Table 3 briefly summarizes the most significant. A review of the data shows that nutrient concentrations are low, in general, and violations of standards are rare. Elevated concentrations occasionally occur in Munds Creek and Pumphouse Wash under low flow conditions, but are of such low frequency of occurrence to not be of concern. Data from these programs is voluminous and has not been included in this report. Interested parties may contact ADEQ, AZ Game & Fish, or the National Monitoring Program for copies of data and any reports.

The data required for calibrating a comprehensive watershed model need to be very extensive in spatial and temporal extent and detail. The available databases are limited in certain crucial areas and were therefore not directly used in the modeling effort (see section 5 and Appendices A and B). However, the existing data were useful as a means of general comparison to verify that the model was producing nitrogen and phosphorus concentrations within a realistic range.

Table 3 -- Summary of Water Quality Data for the Oak Creek Watershed

Data Collection Program/Agency	Dates of Available Data	Types of Water Quality Data	Comments
Oak Creek Canyon National Monitoring Project (Donald et al., 1998)	1994-1998	Nitrate Ammonia Phosphate Flow	Samples were taken typically twice monthly – not triggered by flow conditions. Sample sites were upstream-downstream pairs for 4 critical sites. Few, if any violations of standards. All sites above Sedona. May be most useful data, but flow range is very limited.
ADEQ TMDL Program	1998	TKN Nitrite/Nitrate Ammonia TP Flow	These data are from a number of locations in Oak Creek, Munds Creek, and Pumphouse Wash. Few violations of standards. High values tend to be from tributaries under low flow conditions.
ADEQ (various)	1987-1999	TKN Nitrite/Nitrate Ammonia TP Flow	These data are from a number of locations in Oak Creek, Munds Creek, and Pumphouse Wash. Few violations of standards. High values tend to be from tributaries under low flow conditions.
Page Springs Fish Hatchery	1993-1997	TKN Nitrite/Nitrate Phosphate	Samples taken in Oak Creek above and below Fish Hatchery, as well as from inflows and discharges. Only Oak Creek values are discussed here. Few, if any, violations of standards.
Sterling Springs Fish Hatchery	1989, 1996 (one day)	TKN Nitrite/Nitrate Ammonia Phosphate	Samples taken in Oak Creek above and below Fish Hatchery, as well as from inflows and discharges. Only Oak Creek values are discussed here. Few, if any, violations of standards. Only three samples above the Fish Hatchery.

Unique Waters Designation

The Arizona Surface Water Quality Standards classify Oak Creek and the West Fork of Oak Creek as Tier III Unique Waters subject to special protection and standards (Title 18: Environmental Quality, Chapter 11: Department of Environmental Quality Water Quality Standards, Article 1: Water Quality Standards for Surface Waters, §R18-11-107[D], §R18-11-112[E], and §R18-11-112[F]).

The Unique Waters designation and associated Antidegradation rule have been consistently interpreted by ADEQ to preclude any new or additional pollutant sources in Oak Creek or West Fork Creek. Other tributaries including Munds Creek, Dry Creek, and Spring Creek have only “regular” (non-Unique Waters) status and standards, but any sources in these streams may be limited beyond “regular” standards unless it is shown that there will not be any degradation to Oak Creek.

ADEQ views assimilative and loading capacities as different forms of calculations of the maximum load a waterbody can carry without exceeding applicable water quality standards. However, in the case of a Tier III Unique Water (such as Oak Creek) ADEQ interprets antidegradation to refer to **ambient** conditions, not potential. Therefore, if ambient conditions are within water quality standards (as is the case with Oak Creek) there is no reason to determine assimilative or loading capacities as part of the TMDL analysis because, in order to preserve ambient conditions, this capacity is not available for use.

The ADEQ Triennial Review process is currently underway and is the best forum for addressing issues such as the Unique Waters designation and Antidegradation rule. The ADEQ Triennial Review contact is:

Steve Pawlowski at 1-(800) 234-5677 extension 4219.

VI WATER QUALITY IN OAK CREEK: NITROGEN AND PHOSPHORUS

Overview

The waters of Oak Creek are of generally high quality (Darr, 1989). Available data indicate that, in general, exceedences of standards for nitrogen and phosphorus are statistically insignificant. A primary component of this TMDL is the use of a watershed model to simulate the hydrology and nutrient transport characteristics of Oak Creek and its watershed.

Nitrogen and Phosphorus as Water Pollutants

Nutrients include nitrates found in sewage and fertilizers and phosphates commonly found in detergents and fertilizers. These nutrients, when found in excess in receiving waters, can cause excessive blooming of aquatic plants and algae. This excessive growth can then deplete dissolved oxygen concentrations as they decompose, clog waterways, and block light to deeper waters. These effects can seriously affect the aquatic ecosystem, lead to reduced ecosystem diversity, and limit use for fishing and recreation.

The reader interested in a more detailed explanation of nitrogen and phosphorus dynamics in a stream system may refer to "A Watershed Model for Developing Total Maximum Daily Loads (TMDLs) for Nutrients in Oak Creek, Arizona - May, 1999", Stephan J. Nix, et. al.

Nitrogen

Nitrogen containing compounds act as nutrients in streams, rivers, and reservoirs. The major routes of entry of nitrogen into bodies of water are municipal and industrial wastewater, septic tanks, feed lot discharges, animal wastes, runoff from fertilized agricultural fields and lawns. Ammonia is present naturally in surface waters, as well as at elevated levels in sewage. (APHA, 1995). Although excretions from aquatic organisms are rich in ammonia (NH_3), the amount of nitrogen they add to water is usually small, unless large bird populations are present.

Nitrogen in the form of NH_3 and NO_3 causes eutrophication (a process which promotes plant growth and decay) and acts as a plant nutrient.

Analytically, organic nitrogen and ammonia can be determined together and have been referred to as "Kjeldahl nitrogen" or TKN, a term that reflects the technique used in their determination (APHA, 1995). The total amount of nitrogen in a water sample is known as total nitrogen (TN). Adding TKN, nitrite-N (NO_2), and nitrate-N (NO_3) will yield TN.

Phosphorus

Phosphorus is the most studied nutrient in freshwater systems. Additionally, it is one of the key elements needed for growth of plants and animals; it functions in the storage and transfer of a cell's energy and in genetic systems. Phosphorus from detergents and fertilizers has been the significant nutrient source in many lakes and streams by stimulating the growth of algal blooms, frequently of the nitrogen-fixing blue-green algae. In the aquatic environment, phosphorus becomes available to plants by weathering and is taken up and converted into organic phosphorus.

Phosphorus oxidizes readily and occurs naturally in the earth's rocks principally as orthophosphate (PO_4^{3-}), also referred to as inorganic phosphate. Phosphates exist in three forms: orthophosphates, condensed phosphates (pyro-, meta-, and polyphosphates), and organically bound phosphates. Orthophosphates are produced by natural processes and can typically be found in wastewater effluents. Condensed phosphates are used in treating boiler waters and in detergents. Organically bound phosphates are formed primarily by biological processes and are contributed to sewage by body wastes and food residues, and also may be formed from orthophosphates in biological treatment processes or by receiving water organisms (APHA, 1995).

When determining phosphorus in water two avenues of analysis are generally used; the conversion of the phosphorus form of interest to orthophosphate, and total phosphorus (TP).

VII NUMERIC TARGETS

All available acceptable empirical and simulated data demonstrates that the Oak Creek basin is in compliance with Arizona Surface Water Quality Standards for phosphorus and nitrogen. Using conservative "worst case" assumptions in the model did not cause statistically significant exceedences of the Water Quality Standards.

The intent of calculating numeric targets is to establish goals that will ensure pollutant loads are in compliance with standards, which is applicable to instances where standards are currently or could foreseeably be exceeded. Calculating numeric targets by multiplying the standards by critical flow(s), would establish targets in Oak Creek **higher** than current loadings. Such targets would effectively cause degradation of ambient water quality by allowing additional pollutant loads to be input to Oak Creek. This would be interpreted by ADEQ as a violation of the Arizona Surface Water Quality Standards for a Tier III Unique Water. Therefore, the calculated TMDL will effectively act as a numeric target and protect Oak Creek from future (additional) human-induced water quality degradation.

VIII SOURCE ANALYSIS

Neither the simulation nor monitoring data indicate statistically significant exceedences of water quality standards for nitrogen or phosphorus in Oak Creek. The few exceedences observed in the simulation are too low in number to be significant and some are a result of conservative model assumptions and minimal precipitation data.

The point and septic sources are shown in Figures 3 and 4 and applicable loads are displayed in Table 4. The NPDES-permitted facilities are Pinewood WWTP (permit application in process), Sedona Venture WWTP, and the Page Springs Fish Hatchery. The Sterling Springs Fish Hatchery does not require nor hold a NPDES permit, but was included in the simulation because its discharge is the most upstream point source in the watershed. The Kachina Village WWTP discharges to a wetlands, does not require nor hold a NPDES permit, and is therefore excluded from consideration as a point source.

The septic systems are primarily located in the Slide Rock and Sedona sub-watersheds (figure 4). ADEQ has received a range of estimates (between 200 and 400+) for the number of septic systems along Oak Creek. A Coconino County septic census is in process; therefore ADEQ applied estimated numbers for septic systems (200 in Slide Rock segment, 50 in the Sedona segment). While these systems may not be fully utilized due to the seasonal nature of canyon residency, for purposes of conservatism in the model, ADEQ considered all to be fully used.

Since ADEQ's interpretation of Oak Creeks' Unique Waters status precludes any new sources of pollutants, future human-induced point sources were not incorporated into the model thus leaving only an allowance, or margin of safety, for natural and model variability. However, future natural sources were allowed for in the margin of safety (MOS) because of the possibility of wildfire or other runoff-altering natural events.

Non-point source contributions are primarily affected by land use and precipitation. The primary landuses in the watershed are forest and rangeland (figure 2 and table 1). The model was run using conservative assumptions and with minimal precipitation data (see section IX and Appendices A & B). Nitrogen and phosphorus loading rates were applied by land use type in the model using values derived from available literature. The previous (1987) TMDL did not consider non-point sources which contribute a significant load to the total.

The point and non-point source contributions to each sub-watershed are displayed in table 4. Without statistically significant exceedences of water quality standards, there is no benefit to be gained from linking sources with effects and in-stream conditions beyond what the model has generated. Further, while seasonal variations exist, there is no apparent gain from splitting the TMDL along seasonal lines. It is apparent that non-point sources contribute approximately five times more nitrogen and three times more phosphorus than point sources, even when considering septic systems as point sources for modeling purposes.

Table 4 -- Watershed Loads by Subwatershed and Source.

Subwatershed (model segment)	Non-Point Source Nitrogen (kg/dy)	Non-Point Source Phosphorus (kg/dy)	Point source Nitrogen (kg/dy)	Point source Phosphorus (kg/dy)	Point Sources
FC (Fry Creek)	51.67	5.10			
UPW (Upper Pumphouse Wash)	51.68	6.25			
LPW (Lower Pumphouse Wash)	59.08	6.86	2.16	0.22	Sterling Sprgs FH
WF (West Fork)	24.10	2.48			
SR (Slide Rock)	25.63	2.25	6.72	1.34	200 Septic Sys.
MC (Munds Creek)	51.11	7.04	0.50	0.71	Pinewood WWTP
SE (Sedona)	9.59	1.27	1.68	0.34	50 Septic Sys.
RR (Red Rocks)	25.61	4.17			
DC (Dry Creek)	38.06	3.96	1.20	1.53	Sedona Venture WWTP
PS (Page Springs)	0.21	0.06			
UC (Upper Cornville)	0.26	0.08	55.20	9.35	Page Springs FH
CC (Coffee Creek)	6.17	0.64			
US (Upper Spring Creek)	20.28	2.07			
LS (Lower Spring Creek)	0.10	0.03			
LC (Lower Cornville)	1.23	0.39			
Avg Daily (rounded from model)	365	43	67	13	Total Daily (rounded from model)

- See Figure 4 for segment locations
- Point Source loads are either maximums derived from NPDES permits or averages calculated from monitored data.
- Non-Point Source loads are calculated by the model as part of the simulation.

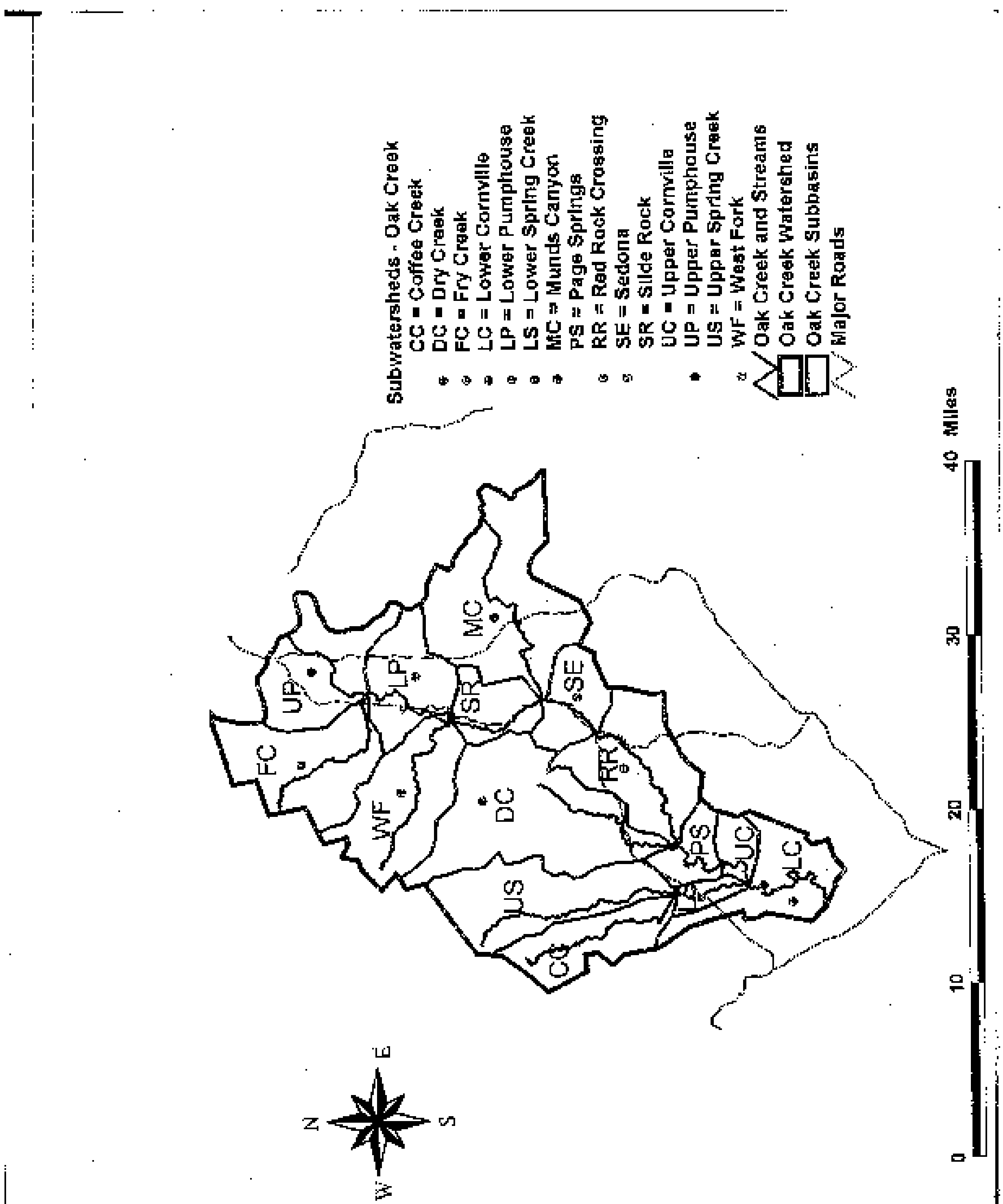


Figure 4 Oak Creek Model segments & Subwatersheds

IX MODEL

Watershed Modeling

(from report titled, "A Watershed Model for Developing Total Maximum Daily Loads (TMDLs) for Nutrients in Oak Creek, Arizona - May, 1999" completed under agreement 98-0187 by Stephan J. Nix, Ph.D. - Team Leader)

Overview

The quality of Oak Creek's waters is a direct function of the Oak Creek watershed, meteorological conditions, and human activities in and adjacent to the creek and throughout the watershed. In order to understand how this complex system works and determine the appropriate TMDLs a watershed-based water quality model is required.

A model is a representation of a system in some form other than the system itself. The system in this case is the watershed. Mathematical models use mathematical relationships to represent, or simulate, the behavior of the system. It is important to remember that a mathematical model may be as simple as one equation or be comprised of hundreds or thousands of relationships. Most mathematical models are executed on a computer.

A watershed water-quality model simulates the movement of runoff and transported materials through a watershed - which includes the catchment and the receiving water body (e.g., stream, river, estuary, or lake) -- in response to precipitation events and watershed conditions. A computer model can be a valuable tool to predict a watershed's behavior under a variety of conditions. In simulating the watershed's behavior, a model can answer questions that would be impractical to answer through field measurements and observations. This is the essential value of a computer model--it serves as an electronic laboratory. The simulation experiments conducted in this "laboratory" are not unlike those carried out in any laboratory.

The model itself limits the use of a mathematical model to conduct simulation experiments on a watershed (just as the experimental setup in a laboratory limits the kind of experiments that can be performed). Every model, whether designed and built by the person using it or acquired from another source, contains the biases and limitations of its designer(s). Even the most sophisticated models are "wrong" to some degree in their representation of the watershed. The model user must always interpret the results of a simulation experiment with a keen awareness of model limitations and assumptions, just as a scientist in the laboratory must be aware of the limitations of his or her equipment and methods. In short, applying the same rigor to simulation experiments as one would to laboratory experiments will go a long way toward a successful modeling project.

In addition to the limitations discussed above, these additional constraints should be heeded:

- A watershed model cannot improve the database with which it is working. A model can extract information from a database, but cannot overcome data inadequacies.

- Output produced by a computer model is no more accurate than numbers produced by hand calculations, just faster. Placing a mathematical model on a computer does not improve that model. The computer model just makes the large number of calculations tractable.

The most important point to remember is that even in a data scarce environment a model can lend useful insights.

After reviewing these modeling packages and weighing their capabilities with the criteria listed above (See Appendix C), BASINS 2.0 was selected to develop the Oak Creek Nutrient TMDL Model. BASINS 2.0 is capable of the continuous simulation of surface and subsurface hydrologic processes, surface pollution build-up and wash-off, and pollutant transport processes in the receiving water body. Considerable use is made of GIS-based data sources. In addition, BASINS 2.0 is capable of statistically analyzing the simulation results.

The BASINS 2.0 modeling package was developed to meet the needs of water pollution control agencies; both state and federal, to use watershed and water-quality based assessments and analyses of point and non-point sources of pollution. Additionally, BASINS 2.0 was developed to support the development of TMDLs, which require a watershed approach. BASINS 2.0 can support the analysis of a variety of pollutants at multiple scales, using tools that range from simple to sophisticated. Most importantly it is capable of continuous simulation, which is essential to the modeling approach required in this study.

BASINS 2.0 use a vast amount of geospatial, environmental and meteorological data to feed three modeling packages within an ARC View GIS environment. The first, Non-point Source Model (NPSM), estimates land use specific non-point loadings for selected pollutant in a watershed. This model uses landscape data such as watershed boundaries and land use distribution to automatically prepare many of the input requirements. The NPSM combines a WINDOWS interface with HSPF. HSPF is a USEPA program for simulation of watershed hydrology and water quality (including both conventional and toxic organic pollutants). This model uses time histories of hourly rainfall, daily temperature extremes, and solar radiation, as well as land surface characteristics and land management practices, to simulate watershed processes. HSPF has the capability to simulate streamflow routing and the transport of pollutants in receiving water bodies. The HSPF system is designed so that various simulations and utility models can be conveniently invoked and includes an internal database management system to process the large amounts of simulation input and output. The other two modeling packages are QUAL2E/U and TOXIROUTE - both are intended for simulating receiving water quality under steady state conditions. Neither will be used in this study.

BASINS 2.0 has considerable graphical capabilities for viewing model output. The user can select output data sets, define output scales, and overlay multiple graphs and management scenarios.

The documentation for BASINS 2.0 is extensive and is not included with this report. The project team referred to the following documents:

- Bicknell, B.R. et al. 1996. Hydrological Simulation Program - FORTRAN, User's Manual for Release 11. US Environmental Protection Agency, Athens, Georgia.
- Lahlou, M. et al. 1998. Better Assessment Science Integrating Point and Non-point Sources, BASINS, Version 2.0, User's Manual. EPA-823-R-98-006, US Environmental Protection Agency, Athens, Georgia.
- Tetra Tech, Inc. 1998. BASINS Training Course. Prepared for the Navajo Nation Environmental Protection Agency, Window Rock, Arizona.

Simulation Results (detailed in Appendices A & B)

The Oak Creek watershed model was simulated for the 1991-1995 period. Even though it is a slightly wetter period than normal, this period was chosen because of the availability of concurrent, high-quality data at three different meteorological stations with hourly data. Much of the reason that this period is wetter than normal is an unusually moist event which occurred from December 1992 to February 1993.

The 1991-1995 period includes six of the top ten flows occurring over the 49-year record (10/1/48 to 9/30/97) at the USGS gage near Cornville (just upstream of Page Springs). The 7-day, 10-year low flow at this same station is about 13 cfs. The 1991-1995 time period includes approximately 50 days with flows less than 15 cfs and at least one week that averages 13 cfs. The 1991-1995 period, while not perfectly typical of the long-term climatic pattern of the Oak Creek watershed, is reasonably representative and includes much of the range of high and low flows experienced in the watershed.

The subsection titled "Selection of Appropriate Meteorological Data" in Appendix A discusses this issue in more depth.

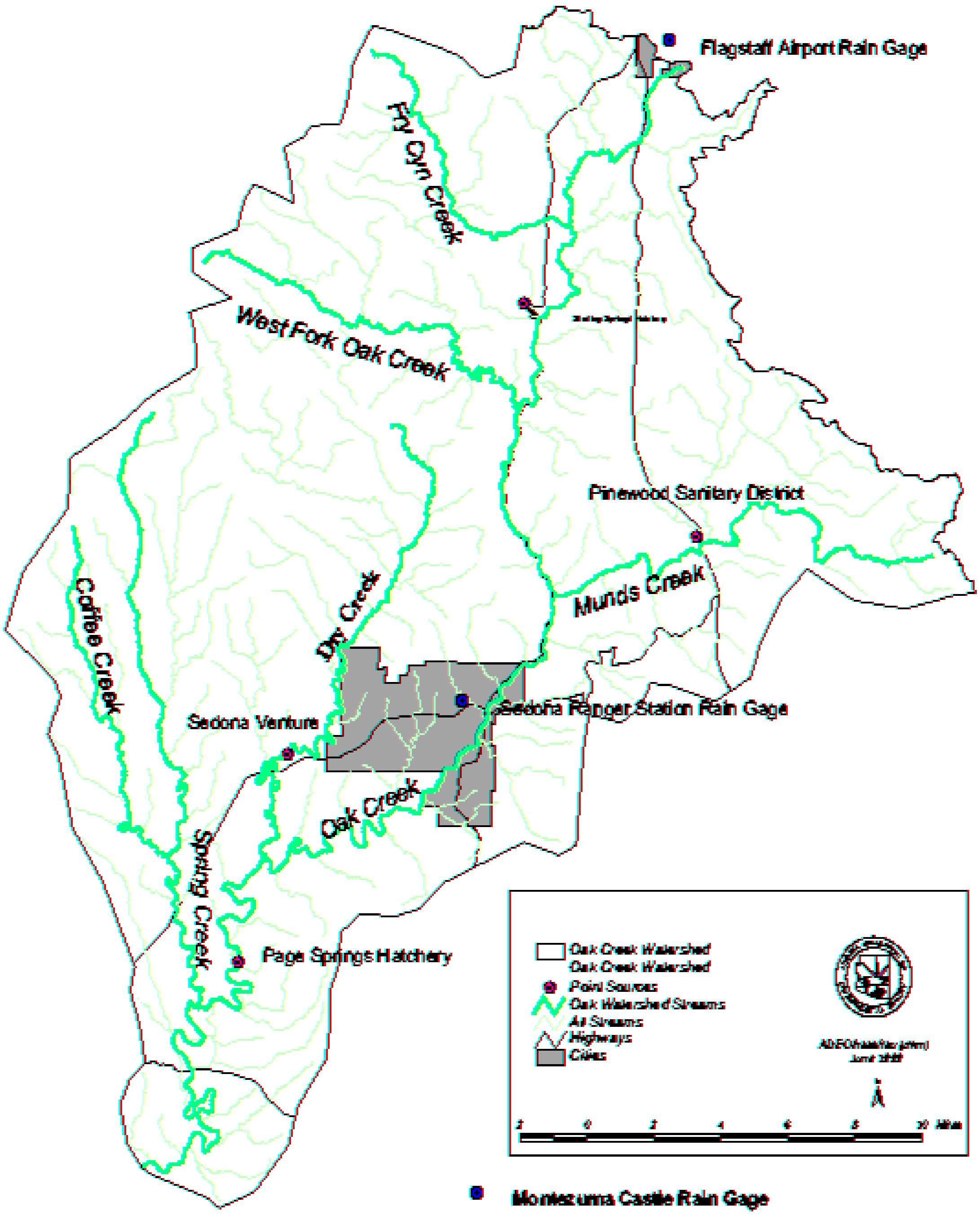
The simulation results (and the water quality monitoring data) suggest that current nitrogen and phosphorus levels in Oak Creek are not problematic, in that they very rarely exceed the single sample and 90-percentile standards, and they do not often exceed even the mean annual standards. While the simulation results show a very small number of high concentrations occurring during wet-weather periods, the general effect of wet weather is to dilute the point source contributions.

As displayed in Table 4, simulated total nitrogen (TN) loads to the creek are 365 kg/day from non-point sources and 67.5 kg/day from point sources and septic systems. Simulated total phosphorus (TP) loads are 43 kg/day from non-point sources and 13.5 kg/day from point sources and septic systems. The sums of these loads are several times the previous TMDLs of 55.5 kg/day and 10.9 kg/day for TN and TP, yet the simulation results and the empirical data suggest no significant standards violations. This disparity is most likely a result of shortcomings of the 1987 TMDL.

The current water quality database is insufficient to support a comprehensive model. Numerous conservative assumptions were used to develop the pollutant loads to the Oak Creek system to compensate for the lack of data. This approach also made sense considering Oak Creek’s status as a designated Tier III Unique Water (no degradation permitted) and adds to the "margin of safety". With the “worst case” as a starting point in the simulation, exceedences of standards were expected and model parameters could be gradually adjusted to be less conservative until results were in general agreement with monitoring trends. The worst case option simulation not only is in general agreement with observed trends, but also meets water quality standards.

Given the outcome that Oak Creek currently meets water quality standards for nitrogen and phosphorus, ADEQ considers this ambient condition as that to be protected by the Antidegradation rule.

Figure 5. Oak Creek Watershed with Rain Gages



X MARGIN OF SAFETY

This TMDL has been calculated based on real and simulated loads. A portion of the margin of safety (MOS) is built in to the model through the use of conservative assumptions, the remainder of the margin of safety is calculated for both point and non-point sources and allows for system and model variability, and natural increases in loads (especially pertinent to non-point source in the Oak Creek area with its wildfire susceptibility). No allowance for future sources was provided in the margin of safety due to ADEQ's interpretation of the Unique Waters status of Oak Creek. An initial margin of safety of 2% was used to calculate rough numbers which were then rounded to the nearest whole number.

Major Modeling Assumptions

- Meteorological Data: The selected model (BASINS) requires extensive hourly meteorological data. The nearest National Weather Service station providing this level of data is at Pulliam Airport in Flagstaff (just outside the upper edge of the watershed). Additionally, the most important of these data sets, precipitation, was determined during early model runs to be insufficient to the needs of the model for such a large watershed.
  - Data from the single gage at Flagstaff was augmented with records from the Forest Service Ranger Station in Sedona and Montezuma Castle National Monument (southeast of the watershed). The three gages were assigned to the 15 watersheds according to proximity and geographical similarities (Figure 5). The simulation period was limited to the five-year period of 1991-95. This period was chosen because of the availability of hourly, concurrent, and relatively high-quality data at all three stations and the availability of supplemental data from the Oak Creek Flood Warning System. The simulated (hydrologic) data behave similarly to the actual data and therefore demonstrate that the model is capturing the hydrologic behavior of the watershed adequately for the purposes of this study.
- Load Data: All point source and septic system flows and loads were assumed to remain constant throughout the simulation period. The loads are based on average discharge characteristics (from monitoring records) or NPDES permit limits (if appropriate).
  - For modeling purposes, two groups of septic systems were input to the model as "point sources". All flows and pollutant loads from septic systems were assumed to find their way to Oak Creek with no reduction in nitrogen or phosphorus loads. This modeled lack of nutrient reduction is one of the very conservative modeling assumptions as some nutrient uptake, etc. would be expected to occur. This conservative assumption also helps to allow for the possibility that more septic systems are actually present than are included in the model.

- No decay of nitrogen and phosphorus in the creek's waters was assumed, any assimilation was considered a result of dilution in the stream. This is a very conservative assumption primarily included to allow for natural variability and also for the septic system population uncertainty.
- Non-point sources discharge at a rate considered typical (as reported in the literature) for watersheds in the Western US. (Rast & Lee, 1983)

- Groundwater Interactions: Oak Creek receives flow from and recharges a regional groundwater aquifer system (Darr, 1989). In general, the portion of the creek above Sedona receives a net flow from groundwater. The portion of the creek below Sedona experiences a net loss to groundwater. Phosphorus and nitrogen concentrations were assigned to these flows in the simulation.

These assumptions produce a model in which the relative magnitude of the pollutant load sources can be assessed. A more detailed discussion of the modeling process is provided in appendices A and B.

XI TMDL CALCULATION

Based upon the existing data and the simulation, there are no nutrient water quality-limited segments in the Oak Creek watershed. The 1987 TMDL did not account for non-point source pollutant loads and ADEQ was asked to recalculate and update the TMDL analysis. For this new analysis, ADEQ chose to establish a TMDL for the entire watershed both because there are no nutrient water quality-limited segments (or sub-watersheds) and to provide a more comprehensive planning tool to the public and local government.

As discussed previously, the TMDL equation can be represented as follows:

$TMDL = \sum WLA + \sum LA + MOS$,

where WLA is the wasteload allocation consisting of loads from point sources, LA is the load allocation consisting of non-point source loads (including natural background), and MOS is a Margin of Safety which serves to address uncertainties in the analysis and the natural system. Table 5 displays the calculation worksheet for both the nitrogen and phosphorus TMDLs based on the data generated from the model and depicted in table 4. For both nutrients, the TMDLs would be expressed as:

Nitrogen TMDL = 440 kg/day =
(67 kg/day point sources) + (365 kg/day non-point sources) + (8 kg/day margin of safety)
Phosphorus TMDL = 58 kg/day =
(13 kg/day point sources) + (43 kg/day non-point sources) + (2 kg/day margin of safety)

Table 5 -- TMDL & MOS Calculations

Avg Daily NPS TN (kg/dy):	365	From simulation (see Table 4)
TN (NPS) (kg/dy) 2% MOS:	7.30	365 x .02
TN (NPS) (kg/dy) Rounded MOS:	7	rounded
TN (NPS) actual % MOS:	1.92 %	7 ÷ 365
Avg Daily PS TN (kg/dy):	67	From simulation (see Table 4)
TN (PS) (kg/dy) 2% MOS:	1.34	67 x .02
TN (PS) (kg/dy) Rounded MOS:	1	rounded
TN TMDL (PS) actual % MOS:	1.49 %	1 ÷ 67
TN (kg/dy) MOS:	8	MOS for total nitrogen.
Avg TN % MOS:	1.71 %	Approximate percentage of MOS.
Avg Daily NPS TP (kg/dy):	43	From simulation (see Table 4)
TP (NPS) (kg/dy) 2% MOS:	0.86	43 x .02
TP (NPS) (kg/dy) Rounded MOS:	1	rounded
TP (NPS) actual % MOS:	2.33 %	1 ÷ 43
Avg Daily PS TP (kg/dy):	13	From simulation (see Table 4)
TP (PS) (kg/dy) 2% MOS:	0.26	13 x .02
TP (PS) (kg/dy) Rounded MOS:	0	rounded
TP (PS) (kg/dy) Adjusted MOS:	1	rounded up to next whole number.
TP TMDL (PS) actual % MOS:	7.69 %	1 ÷ 13
TP (kg/dy) MOS:	2	MOS for total phosphorus.
Avg TP % MOS:	5.01 %	Approximate percentage of MOS.
TN Load (NPS) (kg/dy)	365	
TN Load (PS) (kg/dy)	67	
TN TMDL (@approx. 1.7%) MOS	8 +	
TN TMDL (kg/dy) + MOS	440	Total Nitrogen TMDL.
1987 TMDL TN (PS only)	55.5	
TP Load (NPS) (kg/dy)	43	
TP Load (PS) (kg/dy)	13	
TP TMDL (@approx. 5%) MOS	2 +	
TP TMDL (kg/dy) + MOS	58	Total Phosphorus TMDL.
1987 TMDL TP (PS only)	10.9	

Where:
TP = Total Phosphorus
TN = Total Nitrogen
NPS = Non-Point Source
PS = Point Source
MOS = Margin of Safety

XII CONCLUSIONS

The primary conclusions to be derived from this TMDL analysis are as follows:

- Watershed simulation of conditions in the Oak Creek system over a five-year period suggests that there are few standards violations and that there is no exceedence of existing water quality standards. The available water quality monitoring data suggest the same.
- ADEQ interprets the Antidegradation rule to mean no new or additional loading sources for Oak Creek, nor for any tributaries should the tributary loads affect Oak Creek.
- The current Oak Creek watershed model is capable of indicating relative trends and impacts from the point and non-point sources of pollution.
- The 1987 TMDLs ignored non-point sources and ADEQ proposes their replacement with these new TMDLs. Non-point sources are the primary contributor of nitrogen and phosphorus in the watershed.
- Appropriate TMDLs for nitrogen and phosphorus in the Oak Creek watershed should be 440 kg/day and 58 kg/day respectively

XIII GENERAL RECOMMENDATIONS FOR FUTURE WATERSHED ANALYSIS

- ADEQ will remove the phosphorus listing of Oak Creek and Munds Creek from the 303[d] list. This TMDL analysis will have no effect on either stream's listing for other parameters; i.e., bacteria (both), and turbidity (Oak Creek).
- ADEQ interprets the Antidegradation rule to mean no new or additional loading sources for Oak Creek, nor for any tributaries should the tributary loads affect Oak Creek.
- Modeling results do not justify alteration of existing NPDES permit discharge limits.
- Septic systems have been simulated as point sources due to modeling constraints. No new nutrient limits on existing septic systems are justified at this time. However, should the results of the Coconino County septic census differ significantly from the model assumptions, this issue could be revisited.

- Oak Creek's status as a Unique Water requires a comprehensive water quality and hydrologic monitoring program. During the course of developing this TMDL, several deficiencies have been observed in the available data. Stakeholders should work together with ADEQ to fill the data gaps and develop a comprehensive understanding of the watershed. The following suggestions for monitoring are intended to help develop a plan to fill the existing data gaps. Unfortunately, ADEQ does not have the resources to conduct this type of monitoring by itself and suggests that local groups research the possibility of using grants to pay for such monitoring. ADEQ can offer advice to potential grant applicants. The point of contact is:

    ADEQ
    Watershed Unit
    Deborah Patton, Environmental Program Specialist
    3033 N. Central Ave.
    Phoenix, AZ 85012-2809-33
    ADEQ main telephone number: 1- (800) 234-5677

    - Establish multiple monitoring sites on the creek and its major tributaries for long-term (five or more years) periodic monitoring. Monitoring should be conducted during the various precipitation regimes including: winter precipitation, snow melt, spring dry, monsoon, fall dry, fall precipitation. The types of data collected by the Oak Creek National Monitoring Program (Donald et al., 1998) are a good starting point. This network could establish long-term trends and provide better characterization of low and moderate flows.
    - Implement a strategy to capture data during 5 to 10 significant precipitation events per year at several of the sites suggested above. A characterization of wet weather periods is vital to determining the true impact of non-point sources when their contribution of pollutants is greatest.
    - Maintain an inventory of multiple short-term (approximately two years) monitoring sites draining relatively homogeneous land uses (e.g. golf courses, urban areas, agricultural areas, forested areas, etc.) throughout the watershed. Conduct special studies for other related areas such as septic system efficiencies and recreational impacts. These will serve to more firmly establish non-point source loads and their relationships to land uses. The goal would be to capture as many precipitation and discharge events as possible.
    - Locate and monitor, on an occasional basis, the major springs and other sources of groundwater to the creek in order to assess their load contributions.
- Work with the Oak Creek Flood Warning System to improve their precipitation gage network and data management system. This system could be an extremely valuable source of data for watershed modeling.

- Continue to build the Oak Creek watershed model established for this TMDL. The BASINS software is extremely flexible and much of the "overhead" costs needed to get it in working order have been expended. It is ready to be used in other applications in the Oak Creek watershed.

XIV PUBLIC PARTICIPATION & RESPONSIVENESS SUMMARY

Development of the Oak Creek Watershed TMDL included public participation in accordance with 40 CFR Parts 25 & 130.7. Public participation included review and input from stakeholder groups. Multiple presentations and meetings were held by the ADEQ in 1997, 1998, and 1999. These groups consist of pollutant source owners/operators, property owners; environmental groups; representatives of local, state, and federal agencies; and other interested members of the public. Written documentation of public participation is on file with ADEQ's Hydrologic Support and Assessment Section, located at 3033 North Central Avenue, 3rd Floor, Phoenix, Arizona.

Oak Creek Nutrient TMDL Comment Response - comments are presented in subject order.

Thank you to all for your interest and comments.

If ADEQ made editorial changes to the TMDL report in response to comments, those comments are not specifically addressed in this section. The remaining comments are related to procedure, concept, process, or conclusions and are grouped and addressed below.

John Garwood relates that on a visit (on or about July 5, 1999) to an Oak Creek swimming hole at the end of Chavez Ranch Road, he observed "scum on the water, what looked like foaming of detergent (which I believe may be phosphate pollution), and fermentation."

ADEQ Response: Not having seen the conditions, we can't be certain as to what was causing the problem. In general, "scum" is a subjective description that can include algae, duckweed, oils from vegetation, floating particles, or other natural material. It can also describe human-deposited material such as oils, trash, garbage, feces, or landscape waste.

"Foaming" may result from soap, detergents (including phosphates), body oils (human or animal) and other sources, both natural and human-induced. It should be noted that Arizona does not have a water quality standard for phosphates, only phosphorus. We're not sure what the commenter meant by "fermentation", but things such as odor and discoloration are covered under Arizona's narrative standards.

Any or all three observed conditions could be violations of the ADEQ narrative water quality standards and ADEQ will attempt to verify these observations.

ADEQ and other parties have conducted chemical analyses of Oak Creek's waters and not found statistically significant exceedences of standards. We do have a complaint investigation mechanism and these comments have been forwarded (7/13/99) to the appropriate ADEQ personnel for action.

Jacqueline Monro requested the addition of the following recommendation: "Require homeowners to be educated about the dangers of overuse of fertilizers and pesticides."

ADEQ Response: ADEQ offers educational materials to interested parties; requests for educational information should be directed to either the ADEQ Watershed Unit or Ren Northup, both through 1 (800) 234-5677.

Jacqueline Monro wants to know why a pesticide TMDL is not being prepared for Oak Creek instead of waiting for a problem to develop.

ADEQ response: A TMDL is a response to a problem serious enough to cause listing as an impaired water body; i.e., the 303[d] list. ADEQ is not aware of any surface water quality standards violations for pesticides in Oak Creek.

George Morrison emailed: In the June 1999 Confluence newsletter, you discussed the TMDL process. You mentioned that Native American reservations were exempt from having to assess data on bodies of water. Why? Water on reservations is just as critical to total state use of water as any other bodies. Rainfall on reservations help fill all aquifers. In order for your study to mean anything, all bodies of water need to be assessed and the data put into all planning efforts. Let's get things right now so we don't have to go through law suits later.

ADEQ response: ADEQ has no regulatory or enforcement authority of any kind on Native American reservation land. ADEQ will attempt, when relevant and available, to use the appropriate Native American environmental department-collected data to help develop TMDLs on non-reservation land. There are no tribal reservations within the Oak Creek Watershed. "Confluence" is a publication of the Verde Watershed Association.

City of Sedona Wastewater Department, James C. Johnson, Director, Wastewater Treatment Plant is concerned that the TMDL merely acknowledges the existence and load contribution of the Pinewood Wastewater Treatment Plant (WWTP) without making a judgement as to its legality or attempting any restriction.

ADEQ response: The TMDL must take all sources whether natural, human-caused, legal, or illegal into account. ADEQ's role is to establish the maximum allowable loads to aid local government in their decision-making process. Any "illegal" sources of pollutant load identified by ADEQ will be referred to the appropriate entity for compliance/enforcement actions.

The Pinewood WWTP is currently working through the application process for a NPDES permit and adjustment to the 208 plan. The ADEQ NPDES Program is directing this process. The legality of the Pinewood WWTP discharge is a matter for the NPDES application review process. The nutrient TMDL analysis indicates there is no current exceedence for nitrogen and phosphorus.

Michael White, John Garwood, Lori Larson, and Jeff Haworth have concerns regarding agricultural areas or recreation uses, especially golf courses, that may contribute to the nutrient load. They either request that ADEQ review existing and proposed uses and determine impacts, or, that ADEQ increase the margin of safety to allow for these and other future nutrient sources.

Sonja Gasser feels development of new golf courses should be halted and review of septic systems should be completed.

Jacqueline Monro expressed concern about golf courses and that they "significantly contribute to the nitrogen and phosphorus pollution, due to their excessive use of fertilizers." She also requested the addition of the following recommendation: "Require a comprehensive analysis of impact to the Oak Creek watershed before any new golf courses or other significant sources of nitrogen/phosphate pollution is constructed." She further suggested golf courses and home owners be encouraged to use "alternative methods of pest-control and fertilization".

ADEQ Response: According to the United States Geological Survey (primary compilers of the Land Use Database for the BASINS model), the land use classified as urban area (including golf courses) is approximately 2% of the total Oak Creek watershed area. This area is included in the simulation, but it is insignificant compared to other non-point sources in the watershed, both in area and effect on water quality.

Regulation of land use is a local issue. ADEQ does not have enforcement powers related to non-point sources such as golf courses or the authority to require an impact analysis for non-point sources.

The Unique Waters status of Oak Creek is interpreted by ADEQ to mean no new loadings can be added to Oak Creek's waters. Therefore, should golf courses, or any other nutrient sources, be created, they can not cause an increase in the nutrient load carried by Oak Creek. It is up to the local governments to determine allocation of available loads among different sources. ADEQ's role is the establishment of the maximum allowable loads to aid the public and local government in the decision process.

ADEQ has recommended in this TMDL report that monitoring of runoff from various land uses (which could include golf courses) be conducted in order to determine watershed-specific values to loading factors. These factors could be used by the public and local authorities to aid their decisions.

John Garwood feels that ADEQ should establish testing sites along Oak Creek and that we should look at the "whole of the waterway", not just Slide Rock.

William Bennett expresses concern about sufficient monitoring being conducted and desires a more extensive look at causes of degradation in Oak Creek.

ADEQ Response: As the TMDL report states, ADEQ and the National Monitoring Program have established and monitored sites at numerous locations along Oak Creek, The data from these sites were used to perform this TMDL analysis.

The TMDL recommends further regular, long-term monitoring of Oak Creek with a goal of quantifying loading from various sources. Unfortunately, ADEQ does not have the resources to conduct this type of monitoring by itself and suggests that local groups research the possibility of using grants to pay for such monitoring. ADEQ can offer advice to potential grant applicants. The point of contact is:

ADEQ
Watershed Unit
Deborah Patton, Environmental Program Specialist
3033 N. Central Ave.
Phoenix, AZ 85012-2809-33
ADEQ main telephone number: 1- (800) 234-5677

John Garwood relates personal anecdotal evidence of degradation to Oak Creek's water which he attributes to growth/development in the Sedona area. He asks if ADEQ has studied population trends and made predictions for future septic tank construction.

ADEQ Response: ADEQ has not studied population trends as part of this project or made predictions for future septic tank construction. Coconino County is in the process of taking a septic system census. According to the United States Geological Survey, the land use classified as urban area is approximately 2% of the total Oak Creek watershed area. This area is included in the simulation, but it is insignificant compared to other non-point sources in the watershed, both in area and effect on water quality.

Michael White, Lori Larson, and Jeff Haworth have related concerns regarding septic systems. They would like to see review of existing septic systems to ensure their efficiency in preventing nutrient loads reaching Oak Creek, are concerned that septic systems close to the Oak Creek channel are not efficient in preventing nutrient pass-through, and that septic systems, non-point sources, and general human impacts to Oak Creek be monitored or similarly addressed.

ADEQ Response: As detailed in the TMDL report, ADEQ has simulated septic systems in Oak Creek and even with 100% design use and 0% efficiency (a very conservative assumption), septic systems do not cause a nutrient standard exceedence in Oak Creek.

As delegated authorities, Coconino and Yavapai Counties are the appropriate starting point for requesting review of septic systems in the Oak Creek Basin. The only septic systems under

ADEQ authority, are those inside the Sedona city limits.

Coconino County Environmental Health Services, Dan Smith, Division Manager states that loads from septic systems downstream from Sedona were not included in the model.

ADEQ response: Based on casual conversations with local inhabitants and with Dan Salzler (ADEQ), there are too few septic systems to be effectively modeled that are within 200 feet of the stream channel below the mouth of the canyon.

Lori Larson requests testing for Total Maximum Daily Loads and alludes to problems beyond the Slide Rock area.

Coconino County Environmental Health Services, Dan Smith, Division Manager asks what impact these new standards will have on ADEQ's existing "1990 Oak Creek Policy" in particular the requirement for all new developments to reduce nitrogen by 80%, and the "1999 Guidance Document for the Repair and Upgrade of Existing Onsite Wastewater Treatment Systems in Oak Creek Canyon". Commenter does not want TMDL to cause change to either of these documents.

ADEQ Response: TMDLs are not directly enforceable as are standards, but should be viewed as a planning tool for use in aiding local decision making.

As the report details, ADEQ has examined the entire Oak Creek watershed and the Oak Creek Nutrient TMDL applies to the waterbody as a whole and discharges are only viewed as they contribute to the whole. The TMDL will not supersede any standards (local, state, or federal) unless applying those standards allows the TMDL to be exceeded. If this should occur, it will be up to the local governments to determine allocation of available loads among different sources. ADEQ's role is the establishment of the maximum allowable loads to aid local government in its decision process.

William Bennett wishes to know why, if nutrient levels are acceptable both in simulation and monitored data, is Oak Creek listed for phosphorus?

Hydrometrics, Inc, Brian Munson, Phoenix Office Manager questions why the TMDL analysis covers the entire watershed, when current 303[d] listing for phosphorus is only for the uppermost Oak Creek reaches and Munds Creek. He further notes that the draft TMDL report stated that the simulation and actual data do not exhibit statistically significant exceedences of the standards and wants to know if Oak Creek will be delisted during the next statewide assessment. He also asks why a TMDL was even done, if no exceedences were found to exist.

ADEQ response: ADEQ discovered an error in the interpretation of the original listing data (Phosphate data was not reduced to phosphorus) and will remove the Oak Creek and Munds Creek phosphorus listings from the 303[d] List for this reason. This omission was discovered after the project entered into its final stages and ADEQ felt the original reason for completing the TMDL was compelling enough to continue the effort. The original TMDL did not take non-point sources into account, nor did it include the additional flow contributed by the point sources. At the request of local interested parties, ADEQ had agreed to recalculate the Oak Creek TMDL using modern simulation methods. ADEQ included nitrogen in the Oak Creek TMDL due to its close ecological relationship to phosphorus and its potential as a similar limiting factor.

Loyd Barnett is concerned that non-point source calculation is more of an academic exercise than a useful planning tool until more data is collected. He is also concerned that simulation factors for nutrient outflows from non-point sources are based on literature values from non-Arizona areas of the western U.S. with little local data for calibration. He further takes issue with the use of four significant figures in displaying data, implying a precision that may not exist. He recommends that more attention be paid to significant digits and that not more than two significant digits be used. He feels that using these simulation results to calculate standards exceedence probabilities appears imprecise and possibly misleading. What actual data validates the conclusions?

ADEQ response: As is always the case, local site-specific loading factors would be extremely useful information to have for this TMDL analysis. However, ADEQ is satisfied that the simulation has performed acceptably inside the limiting factors of time, money, and data volume. ADEQ recommends collection of additional data, particularly measurement of the runoff potential from various land uses (especially golf courses) which should be very useful in calibrating future model simulations.

On the subject of the number of significant digits, ADEQ believes the commenter is referring to the graphs displayed in appendix B. These are copies direct from the computer model (BASINS 2.0) which does not have the flexibility necessary to change the display. While we understand and generally agree with the commenter's concern with perception of the generated data, note that ADEQ has rounded to whole numbers in the actual TMDL calculation.

Using these simulation results to calculate exceedence probabilities is the ultimate test of the simulation because comparing these probabilities to the actual data is the "validation". ADEQ feels confident in this, but agrees that the number of simulated data points greatly exceeds the number of observed data points and the empirical data was collected during relatively low flows only (safety concerns). This is a valid concern and one that can only be alleviated through the collection of five or more years of data during a variety of flow rates and volumes.

For the purposes of this TMDL, ADEQ accepts the model-derived conclusions, especially considering the very conservative assumptions made for the simulation runs. ADEQ has also added a margin of safety which further allows for model and system variability.

Loyd Barnett is concerned about the choice of the Sedona precipitation data being applied to the West Fork and Munds Canyon sub-watersheds instead of the (geographically closer) Flagstaff precipitation data.

ADEQ response: The Flagstaff rain gauge was used in initial model runs, but was found to generate simulated flows that varied significantly from USGS gauge data, particularly during the summer months. Using the Sedona gauge brought the simulated hydrographs closer to the observed hydrographs for all seasons.

Loyd Barnett takes issue with a soils description, “soils derived from granite or schist”, in the watershed description section of the draft TMDL report.

ADEQ response: The soils information was derived from an Arizona Department of Water

Resources report.

Hydrometrics, Inc, Brian Munson, Phoenix Office Manager asks why neither loading capacity or apportionment of assimilative capacity were addressed as the draft TMDL implied they would.

He further questions ADEQ's interpretation of the Unique Waters and Antidegradation rules and feels a study of assimilative capacity should be undertaken to aid in defining "degradation" versus additional loading. He also feels that it is incorrect to assume that allowing new pollutant loads would violate water quality standards and that it is also incorrect to assume degradation would occur without knowledge of the assimilative capacity of Oak Creek. He maintains that degradation is not merely addition of loads, but an exceedence of standards.

Oak Creek Canyon Property Owners Association, Inc., Morgan Stine feels that load capacity and assimilative capacity should be determined for each of the 15 model segments of Oak Creek. He has several related questions, each of which are covered by the response below.

ADEQ response: Both loading and assimilative capacity are measurements of what the waterbody can hold and not have exceedences of Arizona Surface Water Quality Standards. This is not consistent with ADEQ's view of Tier III Unique Water to mean no degradation to **ambient** quality, which ADEQ has consistently interpreted to mean no new sources. Therefore, degradation is interpreted by ADEQ to not be limited to only the violation of water quality standards, but for a Tier III Unique Water such as Oak Creek, it is **<u>any</u>** reduction in water quality.

The ADEQ Triennial Review process is currently underway and is the best forum for addressing issues such as the Unique Waters designation and antidegradation rules. The ADEQ Triennial Review contact is:

Steve Pawlowski at 1-(800) 234-5677 extension 4219.

Hydrometrics, Inc, Brian Munson, Phoenix Office Manager also feels ADEQ is over-relying on the history of the Oak Creek Unique Waters issue and using the NACOG 208 plan to justify no new sources. The better way would be present the new findings to NACOG for use in reviewing and updating the 208 plan for managing the watershed.

ADEQ response: We are relying on our interpretation of the Arizona Surface Water Standards. ADEQ encourages local government to utilize this TMDL analysis in the 208 process and other Oak Creek water quality issues.

Oak Creek Canyon Property Owners Association, Inc., Morgan Stine mentions his estimate of septic system population in Oak Creek and questions ADEQ's assignment of 200 in the Slide Rock segment and 50 in the Sedona segment.

ADEQ response: ADEQ found various sources (including Mr. Stine) with septic system population estimates varying from 200 to 400 for the same segment. In the absence of actual septic system population data, estimates based on conversations with Dan Salzler, ADEQ and Coconino County were used.

Oak Creek Canyon Property Owners Association, Inc., Morgan Stine provided background material from the State of Washington suggesting that nitrogen removal efficiencies for septic systems could range from 60% to 100% and asks why ADEQ chose to use the zero removal scenario for septic systems.

ADEQ response: Using zero removal is one of the conservative assumptions inherent to the margin of safety.

As delegated authorities, Coconino and Yavapai Counties are the appropriate starting point for requesting review of septic systems in the Oak Creek Basin. They would be the appropriate bodies to initiate an Oak Creek specific study similar to the Washington study.

Oak Creek Canyon Property Owners Association, Inc., Morgan Stine asks why nutrient loading resulting from recreation uses was not included.

ADEQ response: This data is not currently available; therefore, ADEQ has added a recommendation to the final TMDL report that long term monitoring include measurement of the load due to recreational uses.

Oak Creek Canyon Property Owners Association, Inc., Morgan Stine asks if Federal regulations allow point source loads be switched to non-point source loads?

ADEQ response: Assuming Mr. Stine is referring to the modeling of septic systems as one input to a segment, the USEPA-developed BASINS 2.0 model used for this TMDL analysis only permits inputs to each stream segment as a single input for each point source and a single input for all of the model-generated non-point sources. This is possible because the point sources have known load and flow contributions. Non-point source loads are generated by the model based on the various land uses for each segment watershed, but are added to the stream segment by the model as a single input.

ADEQ chose to represent the septic systems as single point sources input to the relevant stream segments because the alternative is to create one stream segment, and its corresponding watershed for each septic system, which is of limited use given the lack of data, and time and budget constraints.

ADEQ created enough model stream segments to cover as many of the land uses and major load inputs as practical.

Oak Creek Canyon Property Owners Association, Inc., Morgan Stine included some documentation of historical discussions, activities, agreements, and other items related to Oak Creek and requested ADEQ forward this material to USEPA for review with the final TMDL report.

ADEQ did so, but has not included this additional material in the final TMDL report. Interested parties can contact either Mr. Stine or ADEQ.

Response to USEPA Comments on Oak Creek Nutrient TMDLs
Stephan J. Nix, Ph.D., July 27, 1999.

Chair and Professor
College of Engineering and Technology
Department of Civil and Environmental Engineering
Northern Arizona University
Flagstaff, Arizona

The following items are responses from Stephan J. Nix (Oak Creek TMDL modeler) to certain USEPA comments on the draft Oak Creek Nutrient TMDL report. Where appropriate, changes have been made to the report. The headings and numbered items below are taken from the USEPA document.

USEPA: 2 1991-1995 was the timeframe used for modeling and simulation purposes. ADEQ should address whether this 5-year period captures low flow as well as high flow conditions that are historically representative for the watershed. What is the basis for considering this period representative of ambient and climatic conditions?

Response: The 1991-1995 period was a compromise. Even though it is a slightly wetter period than normal, this period was chosen because of the availability of concurrent, high-quality data at three different meteorological stations with hourly data. Much of the reason that this period is wetter than normal is an unusually moist event which occurred from December 1992 to February 1993.

The 1991-1995 period includes six of the top ten flows occurring over the 49-year record (10/1/48 to 9/30/97) at the USGS gage near Cornville (just upstream of Page Springs). The 7-day, 10-year low flow at this same station is about 13 cfs. The 1991-1995 time period includes approximately 50 days with flows less than 15 cfs and at least one week that averages 13 cfs. The 1991-1995 period, while not perfectly typical of the long-term climatic pattern of the Oak Creek watershed, is reasonably representative and includes much of the range of high and low flows experienced in the watershed.

The subsection titled "Selection of Appropriate Meteorological Data" in Appendix B has been modified to better discuss this issue.

USEPA: 3 Page 12 - The seasonal variations, particularly periods of high flow conditions, should be characterized in more detail. The document refers to seasonal conditions in numerous places without discussing in sufficient detail the degree of variation on flows and the impact on water quality conditions. Discussion of seasonal variations should include an explanation of how the model accounts for seasonal variations in flow rates, as well.

Response: The modeling approach taken here was to look at the behavior of the watershed over a fairly long period. By definition this approach includes the dynamic behavior of the watershed. Such an approach is superior to the identification of special "conditions" in which the specific hydrologic conditions are difficult to link with specific water quality loads. The resulting combination of conditions is statistically inappropriate and undefined. The approach in this study looks at the response of the watershed in an integrated fashion, so that a statistical analysis of this response reveals more useful and valid information. Concentration-duration information is displayed extensively throughout the report. This information is the summary of this dynamic behavior of this system and displays the response to the wide variety of conditions experienced by the watershed.

USEPA: 4 Page 68 - Rangelands and barren lands were treated as forested lands for the purpose of calibrating the model. Is this a reasonable substitution since cattle grazing can produce additional nitrogen and phosphorus? The basis for this substitution should be further explained.

Response: The source used for calibration - the work by Rast and Lee (1983) - distinguished between forested lands and agricultural lands. Cattle grazing in the area, while spatially extensive, is not a high-density use. In fact, much of the forested area in the watershed is also used for cattle grazing. Agricultural lands, due to the application of fertilizers, usually have significantly higher loads than other land uses. It seemed unreasonable to assume that a large portion of the watershed experiences these heavy loads. Therefore, forestlands, barren lands and rangelands were treated as "forested". However, we used the high-end values for TN and TP loads suggested by Rast and Lee.

USEPA: 5 Page 72 - The explanation given for the high concentrations associated with low flows and warmer months for Munds Creek and Dry Creek does not adequately explain why it is reasonable to disregard this exception.

Response: In the model Munds Creek and Dry Creek are only fed by runoff and treated sewage flows. The model does not account for any baseflow in either creek nor does it account for any decay. The model also assumes that the Pinewood WWTP (Munds Park) operates year round, when, in fact, it operates in only in the winter months (the effluent is used for golf course irrigation in the warmer months). The model results for these two tributary creeks should be viewed cautiously. The watershed model is not highly detailed. The results are generally more valid as the areal extent of the modeled watershed becomes larger. The simulated loads from Munds and Dry Creeks contribute to the conservative assumptions desired for Oak Creek. However, because of the lack of detail, the results in these tributaries are less useful (and less valid) than the results for Oak Creek.

The subsection titled "Simulation Results" in (Appendix B) has been modified to better discuss this issue.

USEPA: 6 Generally, the tables and data produced by the model require further explanation in order to be meaningful. For example:

USEPA: 6 a) In the phosphorus portion of the "Concentration-Duration Analysis," displayed in Tables 8.1 to 8.7, many of the tables appear to indicate that the model predicted violations for more than 10 percent of the time for phosphorus. If this interpretation of the charts is correct, it appears to undercut the conclusion that the stream is not expected to exceed the water quality standard for phosphorus. How do the new load allocations account for this issue? This could be an argument for increasing the Margin of Safety in the TMDL calculations.

Response: The results for the Oak Creek segments displayed in these tables (Slide Rock, Sedona, Page Springs, Upper Cornville, and Lower Cornville) show that the mean annual standard for TP, 0.1 mg/L, is exceeded 5.4 to 15.9 percent of the time. The mean, of course, is not the same as the median and, thus, it should not be concluded that since these numbers are much less than 50 percent that the annual standard is satisfied. However, for the Lower Cornville segment the average of the simulated TP concentrations is 0.089 mg/L. This segment is generally the most "stressed" of all the Oak Creek segments and this average value is additional evidence that the annual standard will probably not be violated. (The mean concentrations for the other segments are lower.) For the Oak Creek segments the 90-percentile TP standard, 0.25 mg/L, is exceeded 0.6 to 1.5 percent of the time - clearly less than the 10 percent of the time the standard demands.

The modeling results for Munds Creek and Dry Creek do show violations, however, these results are deceptive (see discussion above).

Explanatory notes have been added to these tables, as well as the mean concentrations. The subsection "Implications for Oak Creek TMDLs" in (Appendix B) has been slightly modified for clarification.

USEPA: 6 b) The "Flow Duration Analysis" in Table 7.5 on page 66, appears to indicate a weaker correlation between the model values and actual data on high flow events during the dry season. Is this significant for purposes of the TMDL analysis? How do the assumptions made in the analysis account for this?

Response: This is probably the main instance in the modeling study that runs counter to the desire to use conservative assumptions. The model produces, especially during the dry summer months, a number of flow events not seen in the actual flows. This is due to the use of only three rain gages. Such a small number of gages does not allow for adequate spatial characterization of precipitation patterns, thus isolated events occurring over an individual gage are applied to a large part of the watershed. This phenomenon will cause simulated flows to be greater than actual flows and thus create an unwarranted dilution effect. It is difficult to assess the effect of this phenomenon on the TMDL analysis. Again, it is important to remember that very conservative assumptions were used wherever possible and we feel confident that the fundamental conclusions of the study remain valid.

USEPA: 11 Page 22 - The discussion of the Margin of Safety and how it was calculated should be consolidated in one section of the document. The explanation should include a summary of the uncertainties that the Margin of Safety is designed to address along with an explanation of any assumptions made in the model or in the final analysis that add to the Margin of Safety. The numeric allowance for the Margin of Safety seems very low.

Response: The major uncertainties that the Margin of Safety should be designed to address are the

- lack of a water quality data base to provide the required spatial and temporal detail,
- the simple mechanisms used to simulate non-point source loadings, and
- the lack of an adequate precipitation gage network. The conservative assumptions used in the model are summarized on page 106 of Appendix B. These all add to the Margin of Safety.

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Appendix A
The Oak Creek Watershed Model

From Section 7 of : “A Watershed Model for Developing Total Maximum Daily Loads (TMDLs) for Nutrients in Oak Creek, Arizona - May, 1999”completed under agreement 98-0187 by:

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Note to reader: Appendix page numbers are not consistent with body of report.

Appendix B
Simulation Results: Implications for Nutrient TMDLs in Oak Creek

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Appendix C
Selection of Modeling Software

From Section 5 of : "A Watershed Model for Developing Total Maximum Daily Loads (TMDLs) for Nutrients in Oak Creek, Arizona - May, 1999" completed under agreement 98-0187 by:

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Selection of Modeling Software

No model software is perfect and each has its advantages and liabilities. The selection of a modeling package is not a trivial exercise and paying it little attention can result in a poor experience. An ill-suited model may well be worse than no model at all.
A common mistake is to build a model that is more sophisticated than the objectives of the study require or that the available database will support.

Building a Credible Model

All watershed water quality models are imperfect representations of the real thing. In addition to structural misrepresentations, errors associated with model parameters and input data can cause models to poorly depict watershed behavior. Therefore, in most applications, a model must be massaged into a working, useful tool. Further complicating the matter is the fact that field data (what will be used to characterize "true" watershed behavior) are themselves flawed.
The first, but often overlooked, stage in building model credibility is verification. Verification is defined here as the process of "checking out" a model to insure that it behaves as intended. A useful technique is to exercise the model with a well-known case study or a simple hypothetical application. By doing so the user is able to examine the model output with a confident and critical eye. This process also allows the user to more efficiently learn how to manipulate and manage the model.
The next stage in building a credible model is validation. Validation is the process of collecting data to describe the inputs to and outputs from the watershed (i.e., precipitation, runoff quantity, water quality, etc.) for a wide range of conditions and adjusting the model parameters so that the model adequately replicates the watershed as depicted by these data.
"Validation" is not the term that most water quality modelers prefer to describe this process. Many refer to this process as "calibration and verification". This phrase refers to a process in which the model parameters are first adjusted so that the model agrees with, or is calibrated for, one set of system data (e.g., a year of streamflow) and then verifying the "calibrated model against an independent set of data (e.g., another independent year of streamflow). This is probably poor terminology. First, the process of adjusting model parameters so that the model adequately simulates the system is actually an iterative process involving a lot of "calibration" and "verification" with several independent sets of data. Second, the validation process includes the important tasks of calibration/verification and the collection of data appropriate for the process. This more encompassing term, i.e., validation, is used here to help make it clear that these two activities are closely intertwined. Each helps to guide the other.

Modeling Approach

The general modeling approach used to help meet the project objectives will need the attributes discussed below:

Continuous simulation is used to develop frequency-duration information for nitrogen and phosphorus concentrations in the Creek. Conventional approaches to waste load allocation problems have been based around the analysis of specific streamflow conditions and assumed loadings. This approach is fundamentally flawed.

Complex systems like watersheds have many inputs, states, and outputs. Any number of watershed properties can be defined as a function of these factors. For the development of TMDLs the property of interest is the concentration of a pollutant in the receiving water body, in this case Oak Creek. Since the pollutant concentration is a complex function of the meteorological conditions, the state of the watershed, and receiving water body conditions, one needs to analyze the characteristics of the pollutant concentration, not the influencing factors. For example, we can identify the 7-day average, 10-year low flow for Oak Creek, or the mean flow, or any particular flow condition we wish. However, what are the accompanying conditions for other factors? If we choose to develop TMDLs based on some defined "low" flow, the mean flow, and a "high" flow, what pollutant loads do we associate with these flow conditions? If we attempt to associate loads with these flow conditions, the result, at best, is a very contrived (and fundamentally indefensible) set of scenarios. With long-term continuous simulation, the characteristics of what we are interested in, the pollutant concentration, can be analyzed directly and with far less tortured logic. This is the approach taken in this study.

Continuous simulation, especially when the simulation covers many years, has been viewed as too difficult and computationally expensive. True, continuous simulation can have greater data requirements (especially meteorological data), but modern computer technology renders the concern about computational effort irrelevant.

All major point and non-point sources are included. Oak Creek remains a reasonably pristine water body treasured for its beauty and recreational value. The monitoring data suggest that background and non-point contributions levels of nutrients are not insignificant, at least when compared with the water quality standards. In some considered and consistent manner, the loads other than from point sources must be included in the analysis and the development of the TMDLs. The model must be able to simulate the long-term continuous non-point contributions from a complex watershed.

The modeling approach is as simple as possible, while remaining credible. The ideal model is the one that maximizes the net gain of conducting the simulation experiments. It is very difficult to identify the "maximum net gain", but a good rule of thumb is to use the simplest model that will still meet the needs at hand. Many models are burdened with trying to simulate detailed facets of watershed hydrology or water quality processes - often without the data necessary to support the complexity. The preferred, and more defensible approach, is to build a simpler model and to account for the uncertainties associated with the simplicity by using sensitivity analysis.

Building a model to account for process details for which there are no supporting data does not reduce the uncertainty - it just adds more model parameters to (poorly) defend. This is similar to trying to use two data points to build a parabolic model. How many parabolas can go through two points? An infinite number. In this case, the model has too many degrees of freedom for the data!

Geospatial data are organized and interfaced to the model with a geographic information system (GIS). GIS allows a great deal of power and flexibility to analyze changing watershed conditions, since the user is not required to manually change a large number of watershed parameters. Geospatial data organized with a GIS can be manipulated quickly to produce the appropriate model input.

Given the modeling objectives and approach outlined above, as well as the overall project objectives, the modeling software selected to construct the Oak Creek Nutrient TMDL Model must meet the following criteria:

- ability to comprehensively model a watershed and its stream system;
- ability to model nutrient load generation and transport in the stream system;
- capability for continuous simulation; and
- excellent software availability and support.

Selection of Modeling Software

Fourteen (14) modeling software packages were considered for use in helping to determine TMDLs for total nitrogen and total phosphorus in the Oak Creek watershed. They are:

- AGNPS - AGricultural Non-Point Source
- AUTO-QI - Automated Q-ILLUDAS
- BASINS 2.0 - Better Assessment Science Integrating point and Non-point Sources
- BLTM - Branched Lagrangian Transport Model
- GWLF - Generalized Watershed Loading Function
- HSPF - Hydrologic Simulation Program -- FORTRAN
- PC-QUASAR - QUAlity Simulation Along Rivers
- QHM - Continuous Watershed Modeling- Storm Management System
- QUAL2E - Enhanced Stream Water Quality Model
- QUAL2EU - Enhanced Stream Water Quality Model - Uncertainty Analysis
- SPARROW - SPAtially Referenced Regression On Watershed attributes
- STORM - Storage, Treatment, Overflow, Runoff Model
- SWRRBWQ - Simulation for Water Resources in Rural Basins - Water Quality
- WASP5 - Water Quality Analysis Simulation Program.

After reviewing these modeling packages and weighing their capabilities with the criteria listed above, BASINS 2.0 was selected to develop the Oak Creek Nutrient TMDL Model.