ANALYSIS OF CENTRAL ARIZONA ANGLER OPPORTUNITY AND BENEFITS GAINED BY INSTALLING ARTIFICIAL HABITAT IN SAGUARO LAKE, BASED ON ADAPTATION OF THE COMPREHENSIVE MANAGEMENT PLANNING MODEL, RIOFISH

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DISCLAIMER

ABSTRACT

The New Mexico based fishery planning model, RIOFISH, was modified and applied to Saguaro Lake (near Phoenix, Arizona) to evaluate the effects of several probable events on estimates of angling opportunity and economic benefit (consumer surplus) gained from adding artificial habitat to Saguaro Lake. We developed model senarios for Saguaro Lake based on assumptions that restricted parking lot size limits lake use and provision of artificial habitat will double fish catchability by concentrating fish near the new habitat. Five hypothetical but probable conditions were tested for no effect on the benefits generated by the artificial habitat including 1) variable water supply, 2) variable nutrient concentration, 3) increasing human population density, 4) decreased largemouth bass mortality, and 5) increased lake surface area in nearby Lake Pleasant. All five hypotheses were rejected -- all five factors were influential. Parking lot size, low lake fertility and attractive fishing at substitute lakes (especially Lake Pleasant) caused lower than expected estimated economic benefit from artificial habitat placed in Saguaro Lake. Model results call into question estimates of benefit:cost that exclude consideration of important variables that influence the dynamics of the entire system of fishery sites from which anglers choose to fish.

Keywords: Model, sport fisheries, benefit-cost, fish habitat

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INTRODUCTION

SAGUARO LAKE HABITAT MANAGEMENT PROPOSAL

In 1989, the Tonto National Forest (U.S. Forest Service), in cooperation with the Arizona Game and Fish Department, and Anglers United, introduced artificial cover for sportfish into the littoral waters of Saguaro Lake impounded by Stewart Mountain Dam near Phoenix, Arizona (Anonymous 1989). The Saguaro Lake Fish Habitat Improvement Project was initiated after considering management costs, angler benefits, and a unique window of opportunity provided by a temporary drawdown of lake levels for modification of Stewart Mountain Dam.

An assortment of artificial habitats, including plastic trees and other refuges, were placed in littoral waters while the lake was drawn down. The artificial cover was located strategically to improve fisheries access to anglers. Only 2 percent of the Saguaro Lake shore is accessible from roads; therefore, shore anglers are concentrated intensively. One intent of the artificial cover was to concentrate fish near fishable shore areas, where both shore and boat angler opportunity would be improved. Other improvements will eventually accompany the habitat development, including doubling the present parking area, and building new fishing docks and trails.

The artificial habitat was placed in Saguaro Lake because of the belief that fish catch rate could be increased substantially as fish concentrated near artificial cover placed where natural cover was generally sparse (Warnecke 1990). The rationale was based on past observations of fish concentration at artificial structures (Unger 1966 and Reeves, et al. 1977). Because catch rate depends on sportfish density, the artificial cover was expected to increase fish catchability and catch rate near the cover and increase the total yield as harvest efficiency and the potential yield increased. It was also anticipated with less certainty that the artificial cover would increase young-of-year and older sportfish survival into catchable size categories and increase sportfish potential yield. Anticipated increased yield was translated into an estimate of increased angler economic benefit based on the number of angling days associated with mean per capita yield rates and a standard benefit/ angler day estimate.

The estimated demand for sportfishing projected in the project proposal is high, partly because Saguaro Lake is close to the Phoenix area, one of the fastest growing metropolitan areas in the U.S., where nearly 350,000 anglers are expected to expand to 500,000 anglers by the year 2000. The estimated habitat and access management cost was over $1,000,000. Over a 10-year period, the ratio of angler benefits to project costs was estimated to be over 8:1.

REFINING FISHING OPPORTUNITY AND BENEFITS ESTIMATION

A single project proposal benefit:cost ratio was estimated for the Saguaro Lake Fish Habitat Improvement Project given the best information available at the time. Tonto National Forest personnel became interested in refining estimates of sportfishing opportunity and benefits when they learned that the fishery management planning model, RIOFISH (Cole et al. 1990a and b), was designed to simulate angler opportunity and benefits generated by management for New Mexico reservoirs, and that RIOFISH could be applied to Saguaro Lake after certain data were accumulated and model modifications were made. The Tonto National Forest contracted with New Mexico State University, through the Water Resources Research Institute, to apply RIOFISH to Saguaro Lake, with minimal modifications of RIOFISH structure, but on the basis of information already available for Saguaro Lake and vicinity.

The contract work required hydrologic and economic data for model inputs and program changes for the economic model. Records of reservoir morphology, hydrology, material concentration (nutrients, organic matter, suspended solids) in tributaries, temperature, and illumination over a 40-year period were needed to identify past hydrologic states in the Salt River system's reservoirs under a variety of conditions associated with climate, water supply, and material loading into reservoirs. Data on human population distribution and the quality of the fishing environment at Saguaro Lake were accumulated and integrated into the model. Also obtained were initial measures of fish composition, densities of angler use rates, and fish harvest rates.

Because RIOFISH was developed specifically for New Mexico analyses in a user-interactive APL-language base, certain parts of the biological and economic models had to be reprogrammed in FORTRAN before simulations could proceed. Over 300 calibration and simulation runs were made in the total analysis, the results of which are reported here.

THE PURPOSE OF RIOFISH

RIOFISH was designed to simulate comprehensive management planning systems for large reservoirs. The simulated system includes the physical habitat (hydrology) linked to the biologic community (ecosystem) and the angler benefits (consumer surplus) associated with the fisheries (Cole et al. 1990a and b). In RIOFISH, the ecosystem and the angler-use system, including substitute fishing sites, are integrated with management strategies, such as modifying nutrient concentrations (e.g., fertilization), stocking, altering water levels, altering fish population survival, and other tactics used to increase fishing opportunity. The result is a comprehensive planning system simulation that allows analysis of system-wide impacts on the cost-effectiveness of any particular proposed management activity.

RIOFISH simulates movements of anglers among reservoir fisheries as they adjust to changes in the relative attractiveness of reservoir fisheries following changes caused by natural events and management. Model users can estimate the effects of management or natural events at substitute fisheries on the angler use and benefits gained from management at a particular fishing site, such as habitat management applied to Saguaro Lake.

Several general conclusions have resulted from using RIOFISH in New Mexico. Probably the most important conclusion is that providing fishing opportunity economically benefits anglers most when the opportunity is distributed optimally. The distribution of new fishing opportunity must coincide with angler preferences for sites of different fishing quality and the costs anglers are willing to incur to obtain their preferred fishing experiences. RIOFISH can be used to estimate the optimum distribution of fishing opportunity for maximum angler benefit (consumer surplus). RIOFISH also reveals that opportunity is increased by management only when factors that limit opportunity are managed appropriately.

Because RIOFISH is designed to analyze the effect of management on opportunity and benefits for a wide variety of possible future conditions, it allows an array of benefits to be estimated for all the possible future conditions selected. This benefits array more realistically assesses the possible benefit: cost ratios for a proposed management activity than a single estimate of benefit:cost. RIOFISH was used in this study to evaluate the effects an uncertain future could have on the benefits realized from increased catchability of fish generated by artificial habitat placed in Saguaro Lake.

SAGUARO LAKE SIMULATION EXPERIMENTS

The umbrella premise we tested with RIOFISH was that projections of angler opportunity and economic benefits generated from habitat improvement at Saguaro Lake are independent of the planning environment conditions that could occur over the next decade. We established a series of hypotheses to test this premise. Model simulation experiments were conducted to test the hypotheses associated with assumptions that were originally made by the Forest Service when the benefits of habitat management at Saguaro Lake were first estimated.

We began with the null hypothesis that all background conditions would have no impact on the estimated fishing opportunity, or consumer surplus generated by artificial habitat, assuming that the artificial habitat doubled sportfish catchability. All of the planning scenarios framed for the hypotheses testing could happen in reality. In fact, any one or a number of the scenarios most probably will happen over the next 10 years. The specific hypotheses are these:

1) Background variations in regional reservoir water levels have no effect on the catchable stocks, angler days, and consumer surplus generated by installation of artificial habitat at Saguaro Lake.

2) Variation in nutrient concentrations of Saguaro Lake do not affect the catchable stocks of sportfish, angler days, and consumer surplus when generated by installing artificial habitat at Saguaro Lake.

3) Changes in human population density and the fraction of anglers that fish do not affect the catchable stocks, angler days, and consumer surplus generated by installation of artificial habitat in Saguaro Lake.

4) Increased survival of fingerling and older fish by 25 percent does not affect the catchable stocks, angler days, and consumer surplus generated by installation of artificial habitat in Saguaro Lake.

5) Water-level management at an alternative Phoenix fishery, Lake Pleasant, does not affect the catchable stocks, visit rates, and consumer surplus generated by installation of artificial habitat in Saguaro Lake.

Model experimental results presented here rejected all five hypotheses. The estimated gain in benefits associated with installation of artificial habitat at Saguaro Lake will be influenced by an assortment of probable events in south-central Arizona and uncertainties in habitat characteristics.

The degree of influence varies, however, among the scenarios. The results show potential utility of comprehensive management models for evaluating the best distribution of fishing opportunity for maximum angler benefit from an angler system of substitute fishing sites. The results also suggest research needs for more cost-effective management decision making.

METHODS

THE REAL WORLD PLANNING SYSTEM

Saguaro Lake, located in south-central Arizona, is the last of a series of four major reservoirs on the Salt River upstream from its confluence with the Gila River. Saguaro Lake is one of two lakes closest to Phoenix in an arc of warm-water reservoirs mostly northeast of Phoenix. The reservoirs in the arc provide angler choice, or substitute fishing sites, for warm-water fishing opportunities in Arizona's most densely populated areas. These reservoirs, to varying extent are substitute fishing sites for Saguaro Lake. From north to east they include Lake Pleasant, Horseshoe Reservoir, Bartlett Reservoir, Theodore Roosevelt Lake, Apache Lake, Canyon Lake, Saguaro Lake, and San Carlos Reservoir. Alamo Reservoir and all Colorado River reservoirs were excluded from the substitute system of reservoirs for Saguaro Lake because of their considerable distance from Phoenix. They may have had some effect on Saguaro Lake use, however, particularly the exceptionally large ones, Lake Mead and Lake Powell. In the arc of lakes near Phoenix, all but Lake Pleasant and San Carlos Reservoir are bounded by the Tonto National Forest.

Saguaro Lake is one of the smallest lakes among the Phoenix area recreational reservoirs; Theodore Roosevelt Lake is the largest (Table 1). Although all reservoirs are accessible to anglers, some are more accessible than others. Annual water supply is variable among the reservoirs. As a fraction of mean surface area, the instantaneous surface areas of the largest

Table 1. Mean surface area and access of Saguaro Lake and lakes considered to be substitute fishing sites for Saguaro Lake.

Lake	Mean Surface Area (hectare)	Concrete Boat Ramps	Approximate Percent Accessible Shoreline	Travel Time from Phoenix (hours)	Water and Land Management Authority
Saguaro	475	2	2	1.0	Salt River Project and Tonto Nat'l Forest
Pleasant	810	3	30	0.8	Maricopa County and Central Arizona Project
Horseshoe	720[1]	0	20	1.5	Salt River Project and Tonto Nat'l Forest
Bartlett	1,035	1	5	1.3	Salt River Project and Tonto Nat'l Forest
Theodore Roosevelt	6,706	4	40	2.0	Salt River Project and Tonto Nat'l Forest
Apache	1,050	2	2	1.7	Salt River Project and Tonto Nat'l Forest
Canyon	400	3	5	1.5	Salt River Project and Tonto Nat'l Forest
San Carlos	3,700	3	7	2.2	San Carlos Apache Tribe and Bureau of Reclamation

[1] Dries up in average to low runoff years and does not sustain a fishery most of the time. Recent years have been exceptional.

reservoirs generally vary more than the surface areas of the smallest reservoirs. Horseshoe Reservoir is an exception. It dries up in most years and has had good fishing only in wet years. In recent decades, except for periods of dam modification, the mean monthly volume held in Saguaro Lake has remained comparatively stable, as it has for Canyon and Apache reservoirs.

The angler days of use are exceptionally high at Lake Pleasant (Table 2) and Theodore Roosevelt Lake. Close proximity to Phoenix is a major factor explaining high visits at Lake Pleasant. Large surface area and good access explain the high visitation at Roosevelt Lake. Catch and harvest rates also have been high at Lake Pleasant in recent years (Table 2). Sportfish harvest rate also was substantially greater at the two most visited lakes. Saguaro Lake harvest rates are dominated by sunfish (Lepomis spp.) compared to Theodore Roosevelt Lake, where most harvested fish were species other than sunfish.

The chain of three reservoirs downstream from Theodore Roosevelt Lake on the Salt River, including Saguaro Lake, are operationally unique because they have pump-storage functions for electric generation. Surface elevations of Apache, Canyon, and Saguaro Lake fluctuate daily, up to 2 or 3 meters, usually more than their mean monthly levels fluctuate. The pump-storage facilities are not constantly operated; summer operation is more usual than winter operation. Typically, when the pump-storage

Table 2. Angler visits/year, catch rates/hr, and harvest rates/hr at Saguaro Lake and substitute sites with data available from the Arizona Department of Game and Fish records.

Lake	Angler Days/Yr	Total Harvest Rate	Sportfish Harvest[1]	Total Catch Rate
Pleasant				
87-88	434,615	0.42	0.20	1.02
88-89	398,738	0.50	0.25	1.44
Bartlett				
1984	19,405	0.26	0.22	0.33
Roosevelt				
88-89	262,054	0.31	0.24	0.41
Apache				
Mar-Dec 89	23,988[2]	0.16	0.08	0.44
Canyon				
88-89	27,009	0.15	0.10	0.32
Saguaro				
Feb-Sept 89	25,338[3]	0.33	0.14	0.54

[1] Sportfish exclude carp, bullhead, sunfish and buffalo.
[2] The annual estimate is about 26,000 based on seasonal variation at other lakes.
[3] The annual estimate is about 32,000 anglers based on seasonal variation generally observed at other lakes.

facilities are operating, Saguaro Lake is drawn down at night and refilled the next day. The impact of water-level fluctuation on recreational use or on sportfishery abundance has not been investigated extensively. Fish populations appear to be sustained without continuous stocking. Past introduction of smallmouth bass (Micropterus dolomieui) and white bass (Morone chrysops) have failed in Saguaro Lake, however.

Rinne (1973) measured light transmission in the four reservoirs. The greatest light transmission was in the lowest end of Apache Reservoir where the euphotic zone (to a depth where 1 percent of surface light remains) averaged about 14 m to 16 m deep compared to 10 m to 12 m in the deeper parts of Roosevelt Reservoir. Light transmission was lower in Canyon and Saguaro Lakes, averaging 6 m - 8 m deep. Rinne(1973) suspected some of the variations in light transmission were caused by planktonic productivity and climatic events that mixed the lakes.

All Salt River lakes stratified before pump-storage operation began in the 1970s. The thermocline of the three lower reservoirs formed at 6 m to 7 m, while it formed in Roosevelt Lake at about 10 to 12 m. Oxygen was depleted in the hypolimnia of the lower reservoirs. The effect of pump-storage operations on mixing has not been clearly documented. We assumed in RIOFISH that stratification continues to occur in the lakes when pump-storage operations are in effect. Warnecke, et al. (1990) documented that thermal stratification and oxygen depletion occurred in Saguaro Lake in 1989.

Rinne (1973) measured chlorophyll and net plankton. These appeared to be much more variable within lakes than between lakes. No clear trend could be seen that indicated a decrease in planktonic biomass or primary production with progress down the series of lakes. Based on depth of light transmission and average chlorophyll concentration reported by Rinne (1973), photosynthesis appeared to be greater in Theodore Roosevelt and Apache lakes than in the lower lakes, in agreement with the observed decrease in nutrient concentration. The lower light transmission observed by Rinne (1973) in Saguaro Lake is not explained by chlorophyll concentration or sedimentation rates. Primary production in the Salt River reservoirs in 1971 appeared to be similar to or higher than estimates made in New Mexico reservoirs in the early 1980s (Cole et al. 1985).

Historically, relatively little has been done to manage the warm-water reservoirs of central Arizona for fisheries and the harvest rates shown in Table 2 were sustained by natural reproduction. Fish have been introduced on a number of occasions, but warm-water species are not stocked routinely. Water-level fluctuation apparently has had relatively little impact on reproductive success, at least in recent years. Walleye (Stizostedion vitreum) fry and Rainbow trout (Onchorhyncus mykiss) are stocked in Apache and Canyon lakes when fish are available. A grow-out trout fishery is being tried in Apache Lake. Neither stocked species contributes much to the total kept catch and neither species has been reported in recent Saguaro Lake catch statistics.

The expansion of Lake Pleasant for storage of Central Arizona Project (CAP) water will have a major impact on the water distribution among the system of substitute fishing sites. After 1994, anticipated surface areas will annually fluctuate between 1,600 and 4,000 hectares. This should increase Lake Pleasant's fishable surface area by about 3 times in a typical year and it will increase the total area of substitute sites by nearly 25 percent in average water years. In relation to Saguaro Lake, an expanded Lake Pleasant could provide about five times the fishable surface compared to the present 1.6 times (average). Lake Pleasant's impact on angler benefits derived from management at Saguaro Lake could be as important as any other in the next decade.

Poor access at Saguaro Lake limits angler-use rates. Only the lower part of the lake is accessible to automobile traffic. Parking space holds up to 200 cars and is filled to capacity early in the morning on summer weekends. Although the Saguaro Lake project plans to double parking lot size at Saguaro Lake by 1992, parking could continue to limit visit rates.

MODELED PLANNING SYSTEM

RIOFISH is described in detail in Cole et al. (1990a and b) and Green-Hammond et al. (1990). The following brief description is oriented toward the specific use of RIOFISH for Saguaro Lake fishing opportunity and benefits analyses. This description is intended to identify important assumptions and limitations as well as general operational characteristics.

Figures 1 and 2 demonstrate the general structure of the system modeled for Saguaro Lake. RIOFISH simulates energy flow from solar energy to potential sportfish production (Figure 1). The actual fraction of the solar energy captured by photosynthetic production is limited (controlled) by the combined effects of phosphorus or nitrogen nutrient concentration, water temperature, concentration of light-occluding suspended matter loaded into the system, the exchange rate (storage ratio), and basin morphology. When the photosynthetic efficiency is not limited by any ecological factor, the maximum seasonal trophic transfer efficiency is assumed to be 2 percent. The simulated system habitat can be "managed" by the model user at this point. Nutrient concentrations can be augmented or depressed, and water supply and level can be modified. In addition to photosynthetic production, allochthonous organic loads contribute to the total organic potential energy consumed by invertebrate and vertebrate herbivores (such as shad, Dorosoma spp), most of which comprise forage for sportfish.

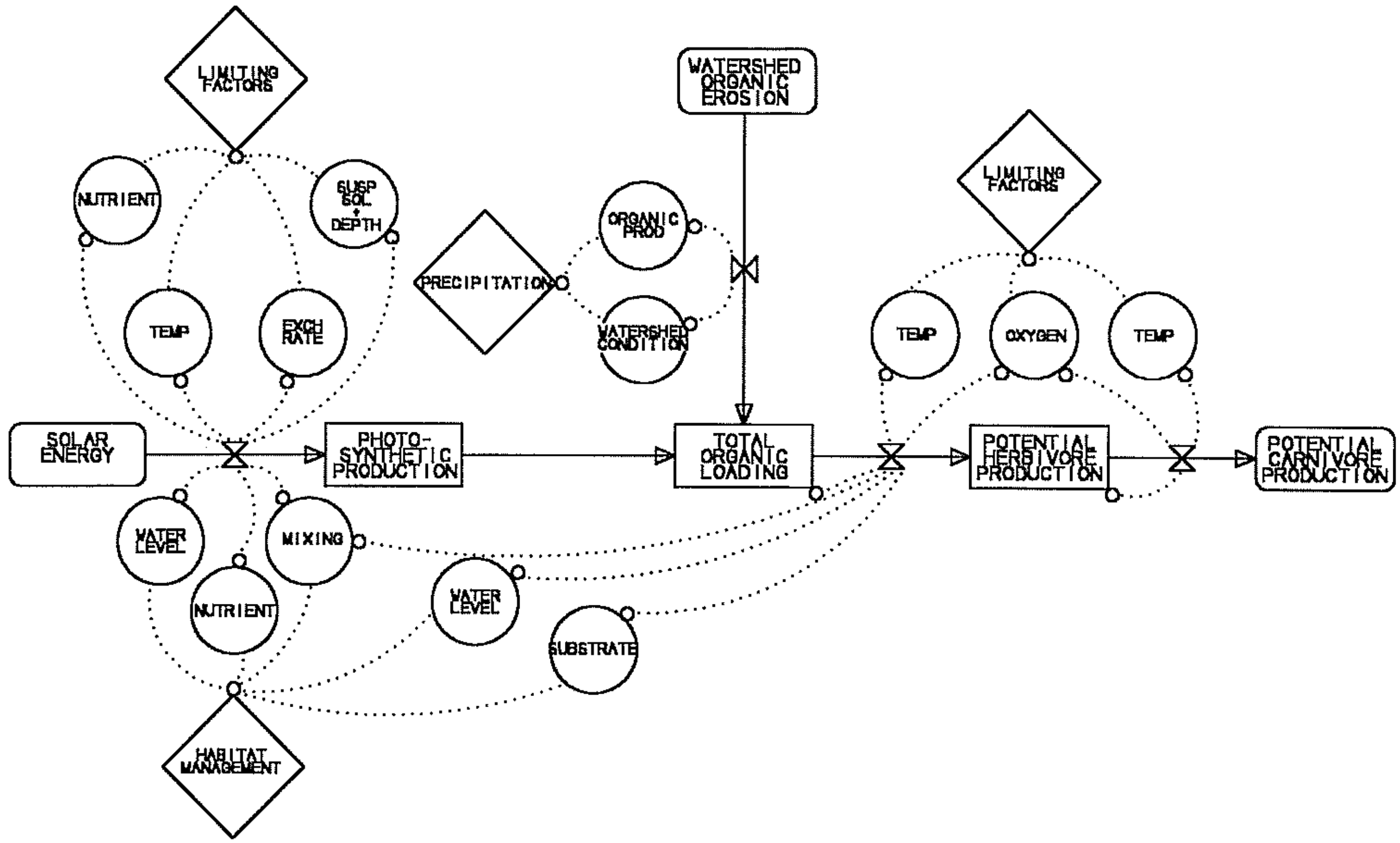

Figure 1. Schematic overview of the potential fish production simulation model elements used in RIOFISH.

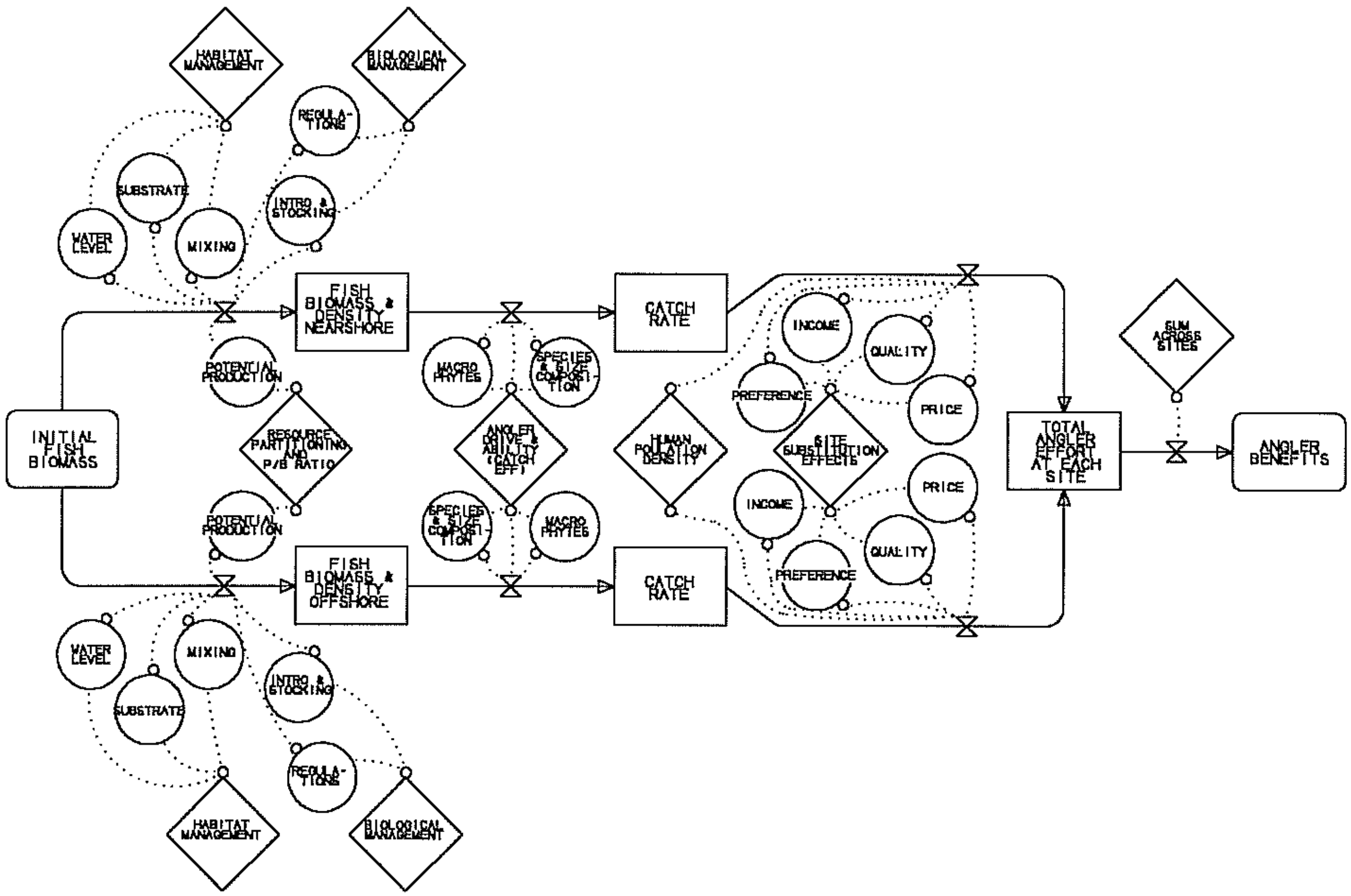

Figure 2. Schematic overview of the realized fish population production, yield and angler benefits.

Several factors in RIOFISH reduce the maximum possible trophic transfer efficiency between organic load and herbivore production. Whether or not the reservoir stratifies and becomes oxygen depleted is critical. The fraction of the lake that is severely oxygen depleted below 2 mg liter^{-1} and the length of severe oxygen depletion limits the trophic energy transfer efficiency. Also, water temperature and the organic loading rates control the trophic transfer efficiency. Maximum transfer efficiency (25 percent) is approached when lakes are continuously well mixed, temperatures are sustained near 30° C and organic loading is very low. Efficiency is much reduced as rate of organic loading and anoxia rise and temperature falls (we assume that no waters exceed 30° C mean seasonal temperature at any time). Our uncertainty and assumptions about the pump-storage effects on stratification of Saguaro Lake could have model simulation consequences.

The transfer efficiency from trophic level to trophic level can be altered through manipulation of modeled habitat and biology. Although live macrophytes can be introduced or controlled in RIOFISH, artificial cover can not be provided. In RIOFISH, high abundances of macrophytes limit trophic efficiency more than if algae dominated the primary production. Live macrophytes also reduce fish catchability when they are dense enough. In RIOFISH, live macrophytes affect survival little, mostly of young-of-year fish, and low densities of macrophytes have little effect on fish catchability. We assumed that macrophyte abundance in Saguaro Lake was low (less than 5 percent of lake volume occupied) and had negligible model effects.

RIOFISH can be used to analyze the effect of the artificial habitat management by modifying fish catchability and mortality coefficients, as was done for this study. In RIOFISH, lakes can be mixed to eliminate low oxygen effect, but were not in this study (although there is some question about pump-storage effects). Also, RIOFISH water levels and exchange rates may be modified, thereby changing habitat availabilities that favor various modeled species. Reducing modeled reservoir water levels and raising modeled reservoir exchange rates sometimes eliminate stratification and oxygen depletion in modeled reservoirs, depending on extent and basin morphology.

Herbivores can be introduced to or removed from RIOFISH lakes. For example, shad could be reintroduced, if they died, or removed to simulate control effects. Introductions at the herbivore level alter the partitioning of energy resources to various sportfish and non-sportfish pathways.

Carnivorous fish at the next trophic level include sportfish and other species. The same factors limit carnivore transfer efficiency as limit herbivore transfer efficiency. Because the biological model is based on mean seasonal values, variations in prey size structure are assumed to be small and are ignored, which greatly reduces model complexity. A potential sportfish production is estimated for each habitat present (habitats are based on light transmission), for each life stage (larvae, young-of-year juvenile, year-old and older), for each food category consumed (plant, detritus, zooplankton, invertebrates, zoobenthos, fish), and for each species.

At this time in a model run sequence, the production submodel in RIOFISH is completed and the population submodel is initiated (Figure 2). The potential fish production is only realized when all habitat niches are filled with equilibrium biomass and appropriate foods are available for all life stages present. In the population submodel, production is distributed among all fish populations present according to a maximum production:biomass function for all ages of each species that feed on a specific food type. No fish production can occur if no fish are present in the system, thus initial fish densities must be identified by the model user. Figure 2 simplifies the actual species partitioning in RIOFISH by representing only a division into offshore and on-shore fisheries. In Saguaro Lake, the offshore fishery is dominated by yellow bass, which is not expected to respond to on-shore habitat management. Up to 23 species are identified in RIOFISH. Each species' initial density is specified by the model user. Because exact data are rarely available, density is estimated for the reservoir's conditions. The initial population estimates come into a dynamic equilibrium with modeled habitat and community conditions. For this reason, annual fish changes early in the model run of several years can be strongly affected by the initial density estimate.

Through length-weight relationships assigned to each modeled species, an initial biomass is estimated in RIOFISH and the fish growth is determined by the mortality and the production rates assigned to each age class. Natural mortality varies below age 1 in RIOFISH and depends on food supply as well as predation. Above age 1, the natural mortality remains constant, but the total mortality is modified by fishing mortality.

Young-of-year mortality also is influenced by reproductive failure associated with seasonal water-level variation. High seasonal fluctuation during spawning seasons substantially reduces reproductive success of species that spawn near shore in RIOFISH. Other species are less affected. Because net seasonal water-level fluctuation is small in Saguaro Lake, this source of mortality is small in RIOFISH applications to Saguaro Lake (as it is suspected to be in the actual reservoir).

More important is larval fish starvation; particularly when larval abundance exceeds zooplanktonic food supply. RIOFISH larvae starve or are preyed on when growth is too slow (larvae must reach 25 mm within 6 weeks or die). Similarly, if juvenile fish do not reach minimum size unique for that species by winter, they will die during winter. Depending on relative food availability and other species present to share it, the model user can stock young-of-year fish and bypass water-level or food bottlenecks at the larval stage.

The kept catch rate is a function of the mean fish size, fish density, angler skill catching fish, angler density, fish species composition and the retention of fish once caught. A catchability coefficient unique for each species is included for all fish over a certain size. The model user can adjust the degree to which fishing mortality is compensatory or additive. Hooking mortality is assumed to be incorporated in the estimate of natural mortality assigned to each species.

At this stage of model development, the total angler visitation is estimated for fishing sites identified in the model. Although zero catch rate over the long run should produce only incidental fishing effort (not quite zero because some people may not know better), site visitation also is influenced by travel costs and site quality factors other than harvest rate. In New Mexico, anglers appear to tolerate variation in harvest rate of keeper-size fish over a range from 0.3 to 0.8 fish/hour without much adjustment of visit rate. The catch rate of non-harvested fish, those returned to the lake, has no effect on visit rate in this version of the model.

The species composition of the harvest in the New Mexico version of RIOFISH does not influence fishing site attractiveness other than categorizing fish into game fish, which are attractive to anglers, and other harvested species not attractive to anglers. In New Mexico, the game fish did not include sunfish (Lepomis spp), crappie (Pomoxis spp), channel catfish (Ictalurus punctatus), bullheads (Ictalurus spp), or carp (Cyprinus carpio) and suckers (Ictiobus spp). We assumed for Saguaro Lake that panfish were just as attractive to anglers as the gamefish species in another set of scenarios. Saguaro Lake gamefish were specified to be largemouth bass (Micropterus salmoides), crappie, channel catfish, yellow bass (Morone interrupta) and sunfish, while carp, suckers, and bullheads were excluded. This decision was made on the basis of the catch and harvest composition reported for Arizona lakes.

Reservoir surface area is a critical variable. Larger lakes sustain yields and therefore attract larger numbers of anglers where conditions are otherwise similar. (Assuming the same density of catchable fish at Theodore Roosevelt Lake and Saguaro Lake, the average potential yield is 15 times greater at Theodore Roosevelt Lake). Larger lakes also may have more diverse recreational outlets available, enhancing their attractiveness. Other factors include road access, boat access, site fees, and site closures. However, RIOFISH does not incorporate limits set by available parking space, which may be critically important at Saguaro Lake where roughly a 200-car visitation limit exists at any one time. Parking limited user rates on busy weekends and holidays. Even with the doubled parking capacity expected in the future, parking could continue to limit use. To accommodate the parking limit effect, we assumed that the user rate limit would double when the parking lot size doubled.

A substitution effect is associated with each fishing site in RIOFISH. Substitution effects link reservoir angler use rates together. Anglers choose new sites from among the substitute sites when management or natural events change substitute fishing site quality and attractiveness. Where substitution effects are high, angler effort at a stable site may vary substantially as other sites vary in their attractiveness. Where substitution effects are low, variation in site quality and attractiveness affect angler visit rates relatively little. Management activities at a particular site may have little impact on angler benefits (consumer surplus) if other sites remain more attractive and have strong substitution interaction.

The major factor influencing substitution effect in New Mexico is the lake size. Anglers move among lakes as lake sizes change. Anglers move toward substitute lakes when their surface areas increase faster than the managed site's surface area. For Saguaro Lake, the future water-surface areas of Lake Pleasant and Theodore Roosevelt Lake are particularly relevant. Because of yearly variation in relative quality of substitute reservoirs caused by factors like water level, model anglers may move to and from a managed site in ways that appear unrelated to fishery management activity.

Total angler effort is not differentiated according to species in RIOFISH, thus the angler days of use are not estimated for each species. Although harvest is partitioned by species in RIOFISH, the model does not identify where each harvested species came from in the lake.

Angler benefit is the estimated consumer surplus, which is the total estimated willingness and ability to pay more than the actual costs for fishing at all substitute sites. For any given site, the angler willingness and ability to pay more for their fishing varies with changes in fishery quality at that site. The price paid by anglers for the fishery varies mostly with the distance they must travel to their fishing sites. Managers can increase angler benefit by increasing fishing quality and decreasing price (mostly travel costs). The functions derived for the economics submodels are based on observed New Mexico angler behavior. Except for the parking lot limits, we assumed that Arizona anglers behaved similarly to anglers we have observed in New Mexico (Cole et al. 1990).

RIOFISH also simulates the well-documented effect of intense fishing mortality on fish population density. When angler travel distance is short and the site quality is high angler use is intense and catchable stocking can be severely exploited. This over-exploitation is simulated in RIOFISH, causing sharp declines in fish population densities and the consumer surplus derived from the fishery. When lakes are intensively fished, management decisions increasing fish capture vulnerability (their catchability coefficient in RIOFISH) may increase the rate of fish exploitation faster than potential yield is increased. In the long-run, such over-exploitation in RIOFISH decreases catchable fish density, the catch rate and angler benefits.

In the short-run, over one to two years, increasing fish catchability to exploitive levels may temporarily increase consumer surplus. However, in the long-run the average consumer annual surplus can markedly decrease as populations are decimated by fishing unless catchable fish are stocked (usually too costly for warm-water species) or protective regulations are applied. Protective regulations may not entirely counter the loss in benefits, however.

The RIOFISH user selects the relative impact of fishing mortality by deciding whether it is compensatory or additive with respect to natural mortality. If not altered, a compensatory mortality is assumed where fishing impacts are assumed to be minimal. Selecting an appropriate fishing mortality effect is important for estimating long-term benefits precisely. Understanding fishing mortality effects is rudimentary, and a fundamental factor limiting precise estimation of management effects on angler benefits.

MODEL INPUTS

For the experimental scenarios in each of the hypotheses tested in RIOFISH, certain conditions were established given available data. Where data were not available, and where modeled conditions were not like New Mexico fisheries, certain assumptions were made to execute the model.

Hydrology Submodel

Three water-level scenarios of 10 years each were developed for the four reservoirs on the Salt River. A plot of total system storage for water years from 1940 through 1988 was used (Appendix 2, Figure A1) to choose years that represented low, average and high storage levels. Water years 1979 through 1988 were years of high storage as well as the last years of record. Water years 1946-1951 and water years 1956-1959 were low-water storage years. The average water years selected were 1944-1945, 1952-1954, and 1960-1965.

To simulate as closely as possible actual system operation, the inflows and outflows for the corresponding water years for each 10-year scenario were used, with the following exceptions. Inflows and outflows from water year 1958 were substituted for inflows and outflows for water year 1952 and water year 1968 was substituted for water year 1960. These substitutions were made in the average water storage scenarios to prevent reservoir filling and to sustain simulation of an average water-level condition. The modifications were needed because reservoir inflows and outflows do not always balance within a single water year.

A mass-balance approach was used to model the reservoirs with the change in storage equal to the sum of all inputs and outputs. Inputs include inflows and precipitation and outputs include outflows and evaporation. Inflow data are only available for Tonto Creek and Salt River above Theodore Roosevelt Lake. Outflow is available only as the release from the downstream reservoir, Saguaro Lake. No intermediate inflow and outflow data were available. We assumed intermediate inflows were negligible.

Mass-balance of Theodore Roosevelt Lake indicated unaccounted inputs to the lake. The values of missing inputs were highly correlated with measured Tonto Creek inflows. Optimization based on matching reported and measured volumes was used to estimate the unaccounted inputs as a function of Tonto Creek flows. A value of 1.03 was used as a multiplier for Tonto Creek flows to estimate unmonitored watershed inflows to Theodore Roosevelt Lake. This adjustment was a small percentage of the documented flows.

Using mass-balance to model the hydrology of the lower three lakes was not as successful as experienced for New Mexico reservoirs. Pump-storage operation at the lower lakes complicates RIOFISH's mass balancing of the lakes. With no information on specific pump-storage inflows and outflows from these lakes, little could be done to model the volumes and match predicted values with the measured volume. (This does not mean, however, such modeling could not be done with the appropriate information). Therefore, the lake volumes for the lower three lakes used in all model scenarios tested for this study are the measured volumes for the given time period and not those computed by RIOFISH. Inflows and outflows to the three lower lakes were assumed to be equal to the outflow from Saguaro Lake. The use of actual flow records should not diminish the validity of the model scenarios tested because they represent a wide range of flow and storage conditions.

Water quality modeling of the lakes was based on a submodel developed for New Mexico reservoirs. Loading rates of nutrients and suspended sediment into Theodore Roosevelt Lake were based on

USGS measurements of concentrations in Tonto Creek and Salt River. Loading rates of the three downstream lakes were based on the concentrations calculated in Theodore Roosevelt Lake and, subsequently, the concentration calculated for each lake in the series above Saguaro Lake as the nutrients and sediment settled out of the water column.

Ordinarily, loading-concentration submodels would be calibrated to conditions that exist in each of the reservoirs, but the data available for the lower three reservoirs were inadequate. To evaluate the possibility of different reservoir dynamics in the Salt River reservoirs, compared to New Mexico reservoirs (Bolin et al. 1987), the sedimentation rate for each modeled constituent was doubled and halved to assess the effect on predicted reservoir concentrations. Thus, three nutrient concentrations were calculated for each reservoir to reflect the uncertainty that exists in knowledge about the reservoirs fertility.

USGS data collected from Saguaro Lake outflows then were contrasted with model-calculated concentrations in Saguaro Lake (Table 3). To simulate lake fertility more in keeping with the observed level in the outflow, we multiplied the concentrations generated by the hydrology submodel by three. In the final lake calibration, the scenarios with the lowest sedimentation rate for phosphorus generated concentrations most like those actually observed for Saguaro Lake over the past decade. The other two

Table 3. Measured and simulated total phosphorus concentrations (mg/l).

	Measured Concentration			Modelled for Saguaro Lake		
Measure	USGS Tonto Creek	USGS Salt River	USGS Below Saguaro	High Settling Rate	Average Settling Rate	Low Settling Rate
Mean	0.04	0.14	0.04	0.004	0.006	0.015
Minimum	0.01	0.00	0.01	0.001	0.001	0.001
Median	0.03	0.06	0.03	0.002	0.003	0.010
Maximum	0.14	3.80	0.17	0.008	0.049	0.208
Std Dev	0.03	0.04	0.03	0.004	0.007	0.019

nutrient scenarios generate somewhat lower fertilities. The hydrology scenarios are shown in Figures A2-A13 (Appendix 2). Phosphorus concentrations shown in the Appendix figures have not been multiplied by 3, as they were for the final calibration.

Biology Submodel

The biology submodels include loadings of suspended organic matter, which were estimated from the data available and observations in New Mexico. Mean seasonal concentrations of suspended organic carbon were assumed to average 1.0 g/m^3 of tributary input (Tonto Creek and the Salt River) in all seasons. All suspended organic carbon entering Roosevelt Lake was assumed to be trapped in the lake. This value for allochthonous organic loads approximates mean annual estimates in New Mexico waters and generates, with the simulated primary productivity, reasonable simulations of fish density and biomass.

The mean seasonal air temperature was approximated from elevations of sites (in RIOFISH) and U. S. weather stations. Solar radiation estimates were from U. S. Weather Service records. The values are summarized in Table 4. Seasonal air temperature and radiation were assumed to be constant from year to year (in reality, they vary slightly).

After calibrating the model to establish a reasonable approximation of an "equilibrium" density, initial fish densities were estimated (Table 4). In reality, equilibrium is never obtained because of environmental and population dynamics. All

Table 4. Biological values used in RIOFISH simulations.

	Winter	Spring	Summer	Fall	Year
Suspended Organic Carbon (g/m^3) in tributaries	1.0	1.0	1.0	1.0	
Solar Radiation (kCal/day)	4,000	6,500	6,000	5,000	
Temperature[1]	17	22	26	23	
Initial Catcahable Fish Densities (number/hectare)					
+*Largemouth bass					14
*Crappie					15
*Channel catfish					8
+*Yellow bass					22
*Sunfish					30
Bullhead					3
Carp-buffalo					10
Threadfin shad (not catchable)					150

[1] Mean water temperature was determined by elevation and model generated stratification.

+ Sportfish designated for the economic submodel based on New Mexico observation.

* Sportfish designated for the economic submodel based on Saguaro Lake observations.

lakes were assumed to have the same species to simplify the analysis, and scarce species requiring intense management to maintain populations were left out, including, most importantly, Walleye and Rainbow Trout.

All other coefficients were left as they are in RIOFISH as described in Cole et al. (1990). The biological model was calibrated so that simulated sportfish catch was close to that measured by the Arizona Department of Game and Fish in the late 1980s. We were not concerned with simulating the exact species composition of sportfish catch because RIOFISH assumes that all fish deemed to be of sportfish quality contribute equally to angler attractiveness in relation to their combined mean weight and density. This means that five yellow bass weighing 0.3 kg each are as collectively attractive to anglers as one largemouth bass weighing 1.5 kg. Bullhead, carp, and buffalo were not considered sportfish in simulations for Saguaro Lake.

To calibrate Arizona waters, the sportfish catchability was adjusted to 10 percent of the catchability we observed in New Mexico waters. In reality, lower catchability may occur at Saguaro Lake because Arizona anglers focused more on catching and keeping somewhat larger fish than anglers at the New Mexico waters simulated by RIOFISH, where average retained catch was about 275 mm. In all experimental scenarios presented here, sportfish catchability was reduced to 10 percent of the RIOFISH values used for New Mexico waters before catchability was doubled to simulate artificial habitat effects.

Economic Submodel

Submodel Structure: The economic submodel of RIOFISH is described in detail in Cole et al. (1990a). In brief, three major data sources were required to estimate the fishing visitor use and benefits model for New Mexico. First, a New Mexico statewide telephone survey has been conducted since 1988 on a monthly basis to assess individual angler fishing patterns. Anglers report where they live, sites they fished over the previous year, and size and number of all species caught during the latest trip.

Second, data were collected to characterize important quality attributes of the most heavily fished sites in New Mexico. Attributes include surface acres and volume of water, average fish catch rates, ease of access, distance from urban areas, number and quality of boat ramps, and the spatial arrangement of substitute sites for each important fishing site.

Third, information was obtained about each county of angler origin, including number of anglers in the county, distance to the site in question and its substitutes, and county demographic features that could affect fishing demands, such as its population density.

The economics submodel for New Mexico reservoirs predicts trips per angler from each of 22 zones of origin and to each of 21 major fisheries. Additionally, for each site the model predicts the sum of trips per angler to the remaining 20 substitute sites. Predicted trips per angler to any given site depends exclusively on characteristics of the angler site and its substitutes. Sites are defined exclusively by their bundle of measurable characteristics.

Together with angler characteristics, the site characteristics provide all the information sufficient to predict angler use rates. The model assumes that no fishery has any significant features not already included in the measured site characteristics. Because each site is represented by a bundle of characteristics, the same economics submodel is repeatedly applied for all zones of origin and all sites in question.

The predicted number of trips per angler to any fishing site in question and its substitute sites depends on prices, recreational travel expenditure, the site quality attributes, and angler characteristics that vary by zone of origin.

The price is defined for each site in question for anglers from each zone. The price includes the estimated trip travel cost, including the opportunity cost of travel time and any site entry fees charged. Recreational expenditure is defined as the annual sum of observed trips times mean trip price, summed over all sites.

The economics submodel in RIOFISH uses five site characteristics to represent each site's quality and one characteristic for the substitute site's quality. Characteristics for the managed site (Saguaro Lake in this research) include average water volume in acre-feet during the peak fishing period and the average biomass of sportfish harvested hourly. For the New Mexico model, sportfish included all species of trout, bass, northern pike, and walleye and excluded sunfish and crappie. Sportfish designation was modified when calibrating Saguaro Lake, as described previously. Other site characteristics included percentage of shoreline accessible from a vehicle, presence of substitute sites within 50 miles, and the number of concrete boat ramps weighted by spacing and quality factors (boat ramps lumped together are not as useful as boat ramps spread apart).

Currently, the only site characteristic for the substitute site used in RIOFISH is the number of weighted surface acres of fishable water at all substitute sites during the peak fishing period. Multiple regression analysis revealed it to be the only significant variable in New Mexico, where harvest rates were similar among sites. Weighted surface acres are calculated as the sum of surface acres at all substitute sites multiplied by the observed angler use rates at those substitute sites. Thus, surface acres of water are weighted most heavily at those substitute sites that attract the most anglers. The effect of this weighing procedure is to assign greater weight in surface acres to sites most important to anglers.

Six angler zones-of-origin characteristics are used in the economic model. Zones are defined as aggregates of one or more counties. Zone characteristics include the presence of good fishing within 15 miles, presence of good fishing within 50 miles, presence of numerous fishing substitutes for a given site, average angler expenditures on fishing equipment by zone, percentage of retirees residing in the zone, and the percentage of the zone's population living in an urban area.

Total predicted angler days at each site are calculated by multiplying trips per angler at the nth site predicted by the model by estimated angler days per trip, then summing over all zones. A calibration factor is applied to total predicted angler days to make them correspond to angler days estimated from the New Mexico Game and Fish mail survey of angler use.

Angler benefits are defined as the total willingness of anglers to pay for a policy that changes site prices (effective access) or site quality characteristics. The concept of willingness to pay for environmental quality improvements with application to amenity forest values are discussed in reports by Rosenthal, et al. (1986) and Sorg and Loomis (1984). Benefits are only defined for policies in which something about a site is changed, including a policy that considers eliminating a site altogether. If a policy changes neither a price nor a site characteristic, angler benefits are by definition zero.

For the economics submodel, benefits for a typical angler are measured using an estimated expenditure function. The expenditure function represents the minimum amount that the typical angler must spend on all fishing trips taken in a year to sustain a reference level annual welfare after a fishery management policy becomes effective. As management provides better fishing, the minimum expenditure by anglers required to support a reference annual welfare level decreases. The reference level is that level of welfare received by the angler under baseline (before management) fish management conditions.

The typical angler's benefit is measured as the difference between actual angler expenditure and minimum expenditure needed under the new management policy to sustain the reference level of welfare described above. As management provides continually higher fishing quality, the typical angler's total travel expenditure stays constant, while the minimum expenditure needed to sustain the reference level of welfare decreases, thus benefits increase. At Saguaro Lake, artificial habitat was developed given the assumption that more fish could be caught each trip, thus fewer trips would be required to benefit anglers to the same extent as before management. Thus, the minimum expenditure needed to sustain their reference level of welfare before habitat development was expected to decrease following management.

For example, suppose water A yields 0.10 kg of game fish/hour for the typical angler in the absence of a habitat improvement policy, and 0.20 kg/hour with habitat improvement. Anglers benefit when they have access to the new opportunity. However, anglers are worse off when they are denied the new opportunities provided by the habitat improvement. Suppose further that the typical angler annually spends $200 for travel to fish all sites, whether or not habitat is improved at a particular site. Suppose the expenditure function analysis indicates that anglers can obtain pre-management welfare under the managed fishing conditions by spending only $170 each in annual travel costs. For these anglers, the benefits of the policy are actual expenditure ($200) minus expenditure needed to sustain the reference welfare ($170). Thus, the benefit each angler gained from managed fishing is $30/year.

The economics submodel computes benefits per angler in this manner for various combinations of site access, water levels, population growth, and other fishing quality improvements. Total benefits are computed by multiplying per angler benefits by the total population of anglers residing in the given zone. Statewide benefits are found by summing over the zones of origin. Additional details on the method for computing angler days and benefits are provided in a mathematical appendix for RIOFISH provided by Cole, et al. (1990a).

Application to Saguaro Reservoir: Many features of the Phoenix area and Saguaro Lake are similar to the Albuquerque area and some of its lakes so that an approximate translation was possible. One major problem at Saguaro Lake not present in New Mexico, however, is parking limitation. Recent annual fishing at Saguaro Lake has been about 30,000 angler days (Warnecke, et al. 1990). Preliminary runs using RIOFISH indicate a lake of Saguaro's size located within 30 miles of a major metropolitan area, with about 240,000 anglers, should attract over 200,000 angler days/year. A significant limiting effect at Saguaro Lake is a low-capacity parking lot (200 cars) and high competition of anglers with non-angling boaters in the summer months. Arizona Game and Fish (Joe Janish, personal communication) has observed that most anglers not on the lake by 9:00 a.m. on summer weekend mornings will be crowded out of fishing until night.

Parking limitations at Saguaro Reservoir required that a calibration adjustment be made to RIOFISH so it would reduce demand at Saguaro Lake to the 1989 observed level of 30,000 angler days. This was done by raising the effective travel cost per fishing trip at Saguaro Lake from $12 to $45, holding all other demand predictors constant, including substitute site prices and qualities. Thus, the access/crowding limitations at Saguaro Lake were treated as having the same effect as tripling the travel distance from Phoenix.

With the exception of increasing the travel cost from Phoenix from $12 to $45 per trip to account for severe crowding/access limitations at Saguaro Reservoir, no other adjustments were made in translating the economics submodel from New Mexico to Arizona.

SETTING UP HYPOTHESES

Twenty-one pairs of model runs were made to create 21 scenarios for the five hypotheses tested over a 10-year period. For each pair, benchline runs were made at catchability levels simulated for pre-management conditions and calibrated to provide the 1989 observed catch rate. For the run that represented a management policy, the catchability for all sportfish was doubled to simulate an expected concentration effect caused by the artificial habitats. The doubling of catchability was a reasonable estimate based on past reports, but somewhat arbitrary, because only limited data were available to estimate the effect of artificial habitat on fish catchability. We ran other scenarios in which the catchability was changed to determine the relative impact it would have on predicted opportunity and benefits.

Water Supply and Nutrients

Nine scenarios were developed (Table 5) to test hypotheses that variations in water supply and water quality (nutrient concentration) have no impact on the opportunity and benefits generated by Saguaro Lake habitat management. All water supply scenarios were selected given the total volume of water in the Salt River system reservoirs. The high-water years in the scenario are the 10 years of record from 1979-1988 for the Salt River reservoirs. For low-water and intermediate-water years, the records since 1945 were searched to find 10 low and 10 intermediate volumes for the Salt River reservoirs as described in the hydrologic inputs earlier in the report. Low- and intermediate-water years at Saguaro Lake did not always match the low and intermediate years at other reservoirs.

On the basis of past occurrences since 1945, low-, intermediate- and high-water years have similar probabilities of occurring during the next decade. Most probably over the next

Table 5. Scenarios developed for experimental analysis with RIOFISH to test the hypothesis that opportunity and benefits generated at Saguaro Lake are independent of variation in the planning environment. For each scenario, pairs of runs were made. In the first run catchability was held at pre-management levels. In the second run catchability was changed to two times the pre-management catchability simulating one possible post-management effect of artificial habitat for each of the scenario conditions. The changes in opportunity and benefits generated by the altered catchability were used to judge the impact of the planning environment on management effectiveness.

<u>Hypothesis 1 and 2 (Water supply and nutrient concentration)</u>

1. Ten low-water years (Saguaro Lake) since 1945 and 2X RIOFISH sedimentation coefficient (lowest fertility).

2. Ten intermediate-water years (Saguaro Lake) since 1945 and 2X RIOFISH sedimentation coefficient (lowest fertility).

3. Ten high water years (Saguaro Lake) since 1945 (1979-88) and 2X RIOFISH sedimentation coefficient (lowest fertility).

4. Ten low-water years (Saguaro Lake) since 1945 and 1X RIOFISH sedimentation coefficient (medium fertility).

5. Ten intermediate-water years (Saguaro Lake) since 1945 and 1X RIOFISH sedimentation coefficient (medium fertility).

6. Ten high-water years (Saguaro Lake) since 1945 (1979-88) and 1X RIOFISH sedimentation coefficient (medium fertility).

7. Ten low-water years (Saguaro Lake) since 1945 and 0.5X RIOFISH sedimentation coefficient (highest fertility).

8. Ten intermediate-water years (Saguaro Lake) since 1945 and 0.5X RIOFISH sedimentation coefficient (highest fertility).

9. Ten high-water years (Saguaro Lake) since 1945 and 0.5X RIOFISH sedimentation coefficients (highest fertility).

<u>Hypothesis 3 (Human population effect)</u>

10. Ten low-water years with 0.5X RIOFISH sedimentation coefficient and 16% more people at end of decade.

11. Ten low-water years with 0.5X RIOFISH sedimentation coefficient and 33% more people at end of decade.

Table 5. (Continued)

12. Ten intermediate-water years with 0.5X RIOFISH sedimentation coefficient and 16% more people at end of decade.

13. Ten intermediate-water years with 0.5X RIOFISH sedimentation coefficient and 33% more people at end of decade.

14. Ten high-water years with 0.5X RIOFISH sedimentation coefficients and 16% more people at the end of decade.

15. Ten high-water years with 0.5X RIOFISH sedimentation coefficients and 33% more people at end of decade.

Hypothesis 4 (A 25 Percent Decreased Largemouth Bass Mortality)

16. Ten low-water years with 0.5X RIOFISH sedimentation and decreased mortality.

17. Ten intermediate-water years with a 0.5X RIOFISH sedimentation and decreased mortality.

18. Ten high-water years with 0.5X RIOFISH sedimentation and decreased mortality.

Hypothesis 5 (Different Surface Area Managements for Lake Pleasant)

19. Intermediate-water years for Tonto National Forest Reservoirs, 0.5X RIOFISH sedimentation and low surface water in Lake Pleasant.

20. Intermediate-water years for Tonto National Forest Reservoirs, 0.5X RIOFISH sedimentation and 3x intermediate surface water in Lake Pleasant following the filling behind a new dam in 1995.

21. Intermediate-water years for Tonto National Forest Reservoir, 0.5X RIOFISH sedimentation and 3x high-water levels in Lake Pleasant following filling behind a new dam in 1995.

* Experimental results will vary depending on which water years are used in each scenario.

decade, a mix of water volumes would occur, resulting in an average condition most like the intermediate-water-level scenarios. The high-water years from 1979-88, although representative of recent measured conditions, have a low probability of being repeated in the next decade. Similarly, a 10-year sequence of low-water years is an extreme condition with low probability. The mean opportunity and angler benefits that actually materialize from non-habitat management in the next decade should be bracketed between the low-water and high-water extremes. However, the future fertility will modify the expected range in opportunity and benefits.

Given the uncertainty of available data and the model structure for the Salt River reservoirs, we varied the sedimentation coefficient settling rate to create three different concentrations in Saguaro Lake: 2X, 1X and 0.5X RIOFISH sedimentation coefficient for New Mexico lakes. The 2.0X RIOFISH coefficient, which reduced nutrient concentration by increasing sedimentation from the water, generated concentrations of phosphorus closest to those observed model concentrations in the outflow from Saguaro Lake once the concentrations were calibrated to Salt River conditions by multiplying by 3.

Rinne (1973) suspected that long periods of low nutrient concentrations can occur in the Salt River reservoirs because of intermittent nutrient inputs. We therefore created scenarios with lower-than-measured phosphorus concentrations by using the New Mexico sedimentation coefficient (1X) and an even greater sedimentation rate (2X) for phosphorus. These lower concentrations reduced primary productivity and represented moderate and low-fertility scenarios that could be contrasted with the scenario closest to past observed concentrations in the outflow from Saguaro Lake.

Water supply and fertility were expected to be interactive; therefore, the water supply and phosphorus sedimentation coefficients were varied in combination. Because of scarce nutrient data, the actual behavior of phosphorus sedimentation is uncertain. Given the available data, the most probable mean water condition expected over the next decade would be intermediate-water levels with the lowest phosphorus sedimentation coefficient (highest fertility).

Human Population

Human population growth effects were superimposed on the three water-level conditions held at 0.5 X RIOFISH phosphorus sedimentation rates. For one set of scenarios, we assumed the human population in Arizona would grow at 33 percent/decade, similar to 1980-1989. We also contrasted the 33 percent rate with a more modest estimated growth rate of 16 percent. These two groups of human growth rate scenarios also were contrasted with the water supply and quality scenarios, in which the 0.5X RIOFISH sedimentation coefficient was used and no population increase was assumed.

We varied water supply while holding nutrient sedimentation coefficient constant for each of the human population projections. This revealed the interactive effects between population growth and water surface area in determining the benefits gained by doubling fish catchability in Saguaro Lake through habitat management.

Largemouth Bass Mortality Decreased

Many unanswered questions remain about the effects of artificial habitat on fish mortality and production. In this scenario, we assumed that the natural mortality of largemouth bass (juveniles through adults) was reduced 25 percent by habitat protection of bass from predation. Natural mortality of other species remained the same.

RIOFISH does not include submodels that directly influence natural mortality, which is assumed to be constant for fish older than one year. However, management scenarios can be examined once the management effect on mortality is estimated. A 25 percent decrease in natural mortality was arbitrarily chosen, and was considered a high effect, based on the relatively small range of previously reported natural mortalities. These scenarios were run with three different water levels and the highest level of fertility.

Lake Pleasant Management

Those scenarios evaluated the impact of differently managing a very attractive substitute fishery in the future. Intermediate-water levels in waters other than Lake Pleasant and a 0.5X RIOFISH nutrient sedimentation coefficient were used as background for the scenarios. The three scenarios included management of Lake Pleasant at low levels (unlikely), and projected intermediate- and previous low-water, high-water levels following filling behind a new dam in 1995. The low-level scenario was based on years when Salt River reservoir volume was lowest, thus were not always the lowest on record for Lake Pleasant. New impoundment volumes were estimated by multiplying historical volumes by three.

RESULTS

RELATIONSHIP BETWEEN PRICE AND VISIT RATE

Figure 3 shows the relationship estimated in RIOFISH between price (trip cost plus access fees) and expected angler days at Saguaro Lake. RIOFISH identified a price of $12/visit for Saguaro Lake, without limited parking or other constraints using the New Mexico-based economics submodel. At $12/visit, about 250,000 angler days of use would be expected at Saguaro Lake under conditions like those existing in recent years.

In reality, Saguaro Lake provided about 30,000 angler days in recent years, about 12 percent of the expected activity based on RIOFISH predictions. The observed angler use rate based on the New Mexico model, was the equivalent of about $46/trip, far more than expected for the typical angler's 30-mile drive.

Lake Pleasant, a similar distance from Phoenix and about 1.6 times as large, attracted about 400,000 anglers in recent years. Lake Pleasant has no access limitations to inhibit use. After consideration, we concluded that the limited parking space was the most likely factor constraining use rates at Saguaro Lake to levels much lower than those predicted by RIOFISH and observed at Lake Pleasant.

The Saguaro Lake project plan called for doubling parking lot size at Saguaro Lake. We assumed that if the parking lot were the only limitation, parking lot expansion would allow up to 60,000 angler days at Saguaro Lake. Because RIOFISH does

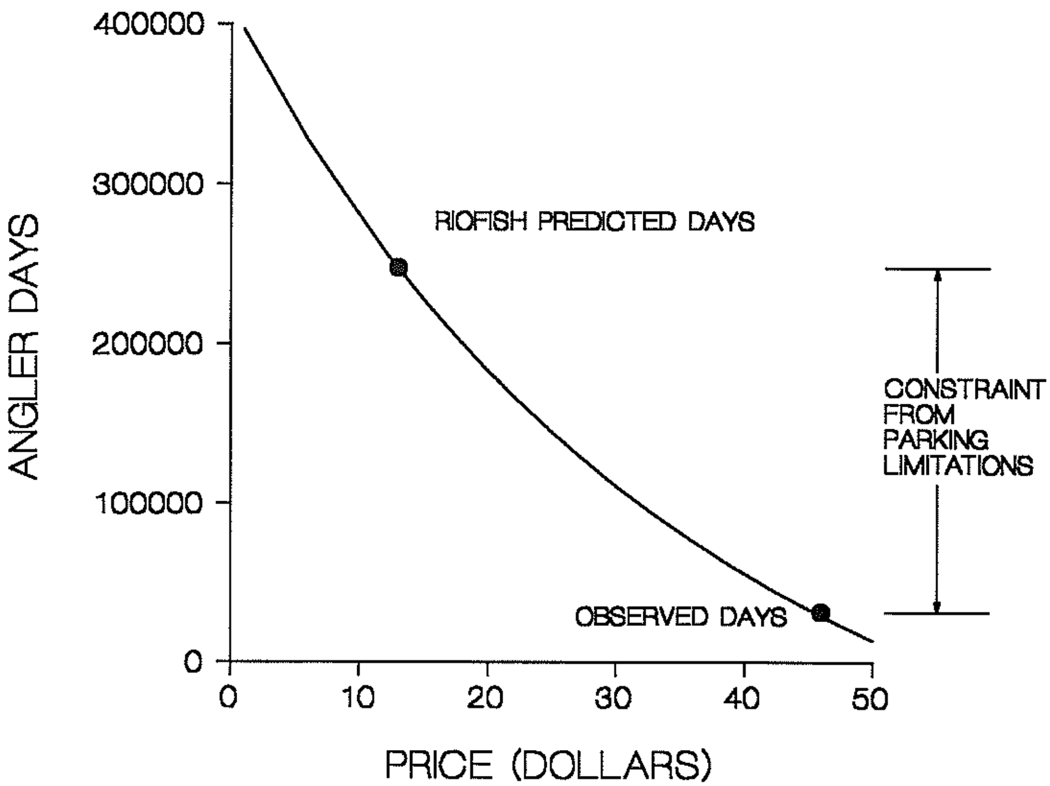

Figure 3. Relationship between trip price (dollars) and the use rate included in the New Mexico version of RIOFISH.

not account for parking lot limitations, we created an analogous condition in which the price of using Saguaro Lake with an expanded parking lot was made equivalent to determining about 60,000 angler days of use. Therefore, in the experimental scenarios, a baseline price of $39/trip was used to account for the expected effect of parking lot enlargement on limitation.

THE EFFECT OF FISH CATCHABILITY

For all experimental scenarios, we assumed that fish were concentrated enough by the artificial habitat to double their vulnerability to capture (catchability). Figures 4 and 5 illustrate the effects that the estimated catchability of sportfish has on the estimated benefits when three different prices are assumed for Saguaro Lake and people generally keep what they catch. No limits were placed on the fishing. In Figure 4, with economic considerations alone, the prices chosen generate about 30,000, 60,000, and 90,000 angler days at Saguaro Lake at the observed catch rate. When RIOFISH is run with economic consideration alone, we assume that anglers have no impact on the underlying fishery and the fishery composition remains constant.

Figure 4 shows that angler benefits increased almost linearly with increased catch rate. If all parking constraints were removed and the price were $12/visit, the benefit of sustaining a doubling of the fish rate would average about $400,000/year (discounted at zero percent) or $4 million over 10

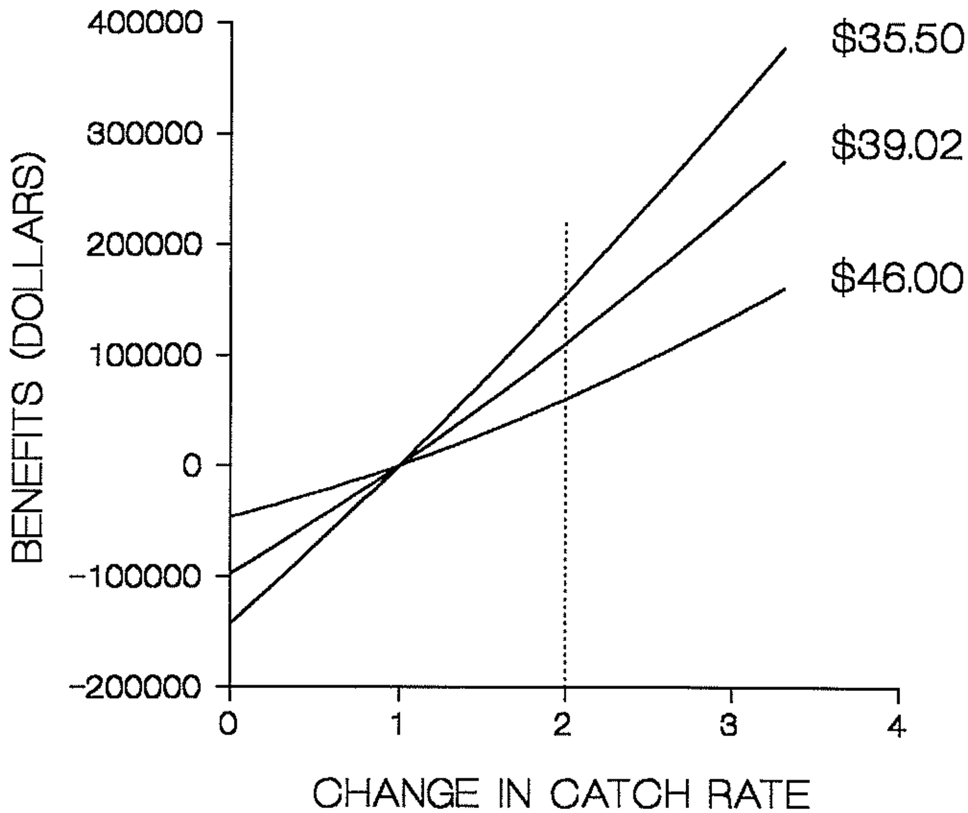

Figure 4. Relationship between mean annual angler benefits (dollars) over a ten year period and a change in catch rate for sites with three different prices representing 30,000; 60,000; and 90,000 user days assuming there is no angler feedback to the fishery to limit catch rates.

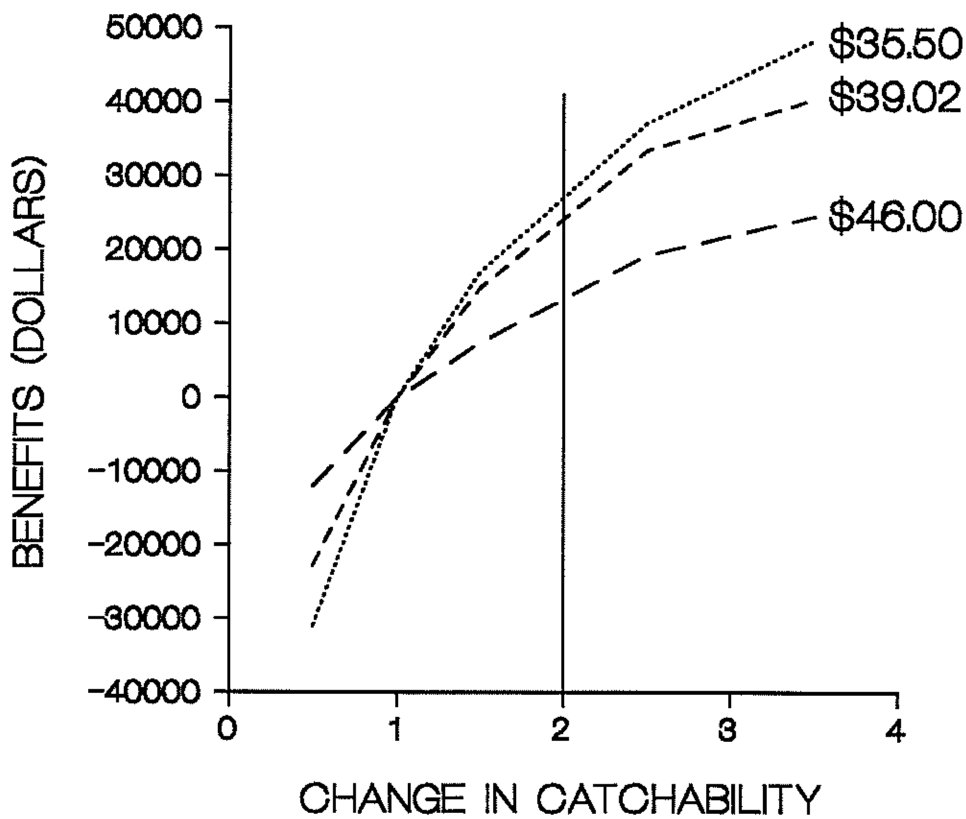

Figure 5. Relationship between mean annual angler benefits (dollars) over a ten year period and a change in catchability for sites with different prices. In this case the angler effect feeds back to the fish population and constrains benefits.

years. This would be the maximum possible benefit estimated under the most unlimited condition. However, because of the inability to sustain the fishing pressure, it is doubtful that such a benefit could be provided at Saguaro Lake even if the parking space were increased to eight times its present size.

Figure 5 includes an angler effect on the fish populations that illustrates how fertility can limit the benefits gained from increasing catchability. Figures 4 and 5 show that the feed-back effect on the fish populations from fishing mortality, substantially reduces the expected benefits compared to a non-limited situation represented in Figure 4. The loss in benefits from the fishing mortality effect for any particular catch rate can be roughly estimated from the differences shown in Figures 4 and 5.

Another way to view the fishing mortality effect is to consider how many catchable size fish should be stocked to eliminate the fishing mortality effect shown in Figure 5 and sustain the catch rate at levels shown in Figure 4. Close examination reveals that the high cost of such a fish stocking program would exceed benefits at reasonable estimates of increased catchability generated by the artificial habitat at Saguaro Lake. Roughly 400,000 fish weighing about 0.4 kg would have to be stocked annually to sustain 250,000 angler days of pressure based on this scenario.

We used a catchability multiplier of 2 to simulate the concentration effects of artificial habitat at Saguaro Lake. The management effects generated in the scenarios that follow can, however, be modified to approximate roughly other catchability multiplier values. For example, a catchability increase of 1.5X would result in benefits about 60 percent as large as 2X values when the price used created 60,000 angler days in a parking-lot limited situation (price of $39).

Figures 4 and 5 also illustrate the expected negative values generated if artificial habitat somehow reduced fish catchability in Saguaro Lake. This is an unlikely outcome at Saguaro Lake, but could occur where structures are too densely concentrated and anglers hook "bottom" routinely.

WATER LEVEL AND NUTRIENTS

Table 6 summarizes the changes in the estimated opportunity and the benefits gained from a 100 percent increase in sportfish catchability at Saguaro Lake as water level or sedimentation rate of phosphorus changes. Generally, as the water supply increases from low and medium levels to high supply for each nutrient sedimentation rate, there is an increased angler effort and the benefits gained by artificial habitat provided at Saguaro Lake. When the water supply is greatest at substitute sites, as it was for 1979-1988, the substitute sites with highest water are most attractive to anglers because of their large surface areas. Then the benefits gained by provision of artificial habitat at Saguaro Lake should be least.

Table 6. Angler visitation, fish biomass, Fish harvest rates and angler benefits (10-year mean) generated from artificial cover improvements (2 X catchability) at Saguaro Lake under selected combinations of water levels and nutrients for Salt River reservoirs as simulated by RIOFISH, and assuming a doubled parking lot size allowing 60,000 angler days/year.

Water Levels	Nutrient Sediment Rate	Added Angler Days/Year	Added Fish Biomass (kg/hectare)	Added Fish Yielded/Day/ Angler	Added Angler Benefits $
High	High	1019	-13.1	0.18	12,170
High	Medium	1275	-10.5	0.18	14,880
High	Low	1195	-34.6	0.38	16,948
Medium	High	534	- 4.5	0.03	6,570
Medium	Medium	594	- 5.1	0.04	7,335
Medium	Low	942	-14.3	0.15	12,815
Low	High	597	- 3.9	0.03	7,770
Low	Medium	617	- 4.0	0.04	8,110
Low	Low	632	- 4.8	0.05	8,495

This substitute effect was not clearly evident, however, because habitat fertility indirectly affects the use rate. Under high-water conditions, fertility is increased substantially. Saguaro Lake's higher fertility during high-water years outweighed the effect of substitute lake size. Theodore Roosevelt Lake is particularly important as a substitute site during high-water supply years.

When water surface area is low to intermediate at Saguaro Lake and the substitute sites, anglers are benefitted least by habitat management at Saguaro Lake because it is less able to sustain fish production. This occurs because the relatively low fertility of Saguaro Lake during years of low to intermediate-water supply limits the benefits anglers obtain from habitat management.

High-water extremes nearly double the benefit gained by Saguaro Lake habitat provision compared to low-water extremes. Little difference resulted between intermediate and low-water years. This reflects both non-linear relationships included in RIOFISH, and the relationship between water volume and surface area. Anglers respond most strongly to surface area among the site-quality factors of substitute sites in New Mexico.

The actual benefit gains were small in each hypothetical scenario perhaps partly because the parking lot at Saguaro Lake creates a crowding effect that limits angler use, but also because of fertility limits. The highest estimated benefit gained from habitat provision among the nine water supply and nutrient scenarios was $169,480 over a 10-year period (discounted at zero percent) and the lowest was $65,700 over 10 years. A range of $103,700 simulated over the estimated 10-year benefits was predicted, depending on the water supply and nutrient conditions that might occur.

The catchable stocking biomass is affected by nutrient loading and water supply interactions. When they combine to increase productivity, a higher biomass and angler pressure can be sustained at Saguaro Lake. This in turn affects the catch rate. Generally speaking, if a management activity increases opportunity and catch rate, the benefits should increase; but the results may be short lived if opportunity and catch rate cannot be sustained by the lake system's underlying productivity.

The results shown in Table 6 indicate that, in high-water years, the opportunity (biomass of catchable stocks) and catch rate would be depressed more than in low-water years. In RIOFISH simulations, this results because the initial biomass is greater in high-water years and more fish can be removed while yield is sustained. The fish biomass is highest in high-water years because the nutrient loading rate in Saguaro Lake is highest in high-water years.

The increased vulnerability of fish introduced in the model experiments (2X catchability) was reflected by an elevated mean daily catch rate/angler. But, the greatest sustained increase in catch rate occurred in the high-water scenarios when nutrient loading supported the greatest potential fish yield. The increase in angler visit rate at Saguaro Lake also was greatest at that time. Angler visits to Saguaro Lake would have increased more if water surface area at substitute fisheries had not also increased in high-water years.

When nutrient sedimentation rates in RIOFISH are varied, as shown in Table 3, Saguaro Lake fertility changes. A high sedimentation rate leads to low nutrient concentrations and low fertility. Based on USGS data, the low sedimentation rate generates a phosphorus concentration closest to what was observed over the last decade in the Saguaro Lake discharge. As the sedimentation rate increases and fertility decreases, the ability of the fishery to be sustained under the angler pressure decreases. Thus, less fish biomass can be given up to angler pressure without depleting the fishery. More anglers are likely to substitute sites for Saguaro Lake when low fertility occurs. Fertility affected fish yield rate and benefit more than it affected angler days of use. Fertility effects were greatest at intermediate-water supply. This may indicate that anglers would benefit most from provision of artificial habitat if fertilization occurred during intermediate water years. The data also suggests that the benefits gained from fertilization are small under the conditions tested and that any further expenditure for fertilization would not be justified.

RIOFISH, in separate analyses, indicates that increasing fertility by about five times will double sustained catch rate of fish. The concentration in Saguaro Lake would have to be sustained at 0.15 mg/liter of phosphorus (and appropriate proportions of nitrogen) to attain a doubled catch rate over the entire lake.

HUMAN POPULATION GROWTH

The estimated benefits gained from habitat management at Saguaro Lake are influenced by human population growth rates as shown in Table 7. The angler population growth projections may make the difference between a cost-effective project and a non-cost-effective project. Comparison to the benefits gain shown in Table 6, for which populations were not increased, shows that population increase changed benefits proportionally upward by 10 percent for a 33 percent change in population and by 5 percent for a 16 percent change in population. The 10 percent and 5 percent gains in benefit are lower than the average decade increase in human population because the increased fishing pressure somewhat reduces the sustained fish catch in RIOFISH scenarios.

As angler visit rates increased, sustained catch rates went down as a consequence of greater angling pressure. The benefits therefore, did not increase in direct proportion to the human population increase at either 16 percent or 33 percent projections. Because of the limited parking lot capacity and the depressed fish biomass and catch rate, the increase in a population does not increase use rate (angler days) or benefits as much as it would if the parking space or harvest rate was not

Table 7. Angler visitation, fish biomass, fish harvest rate and angler benefits generated (10-year mean) by artificial cover improvements at Saguaro Lake under selected combinations of water levels and Phoenix area population growth rates as simulated in RIOFISH, and assuming that parking lot size is doubled, allowing 60,000 angler days/year.

Water Supply[1]	Population Growth/ Decade (%)	Additional Angler Days/Year	Additional Fish Biomass (kg/hectare)	Additional Fish Yielded/ Day/Angler	Additional Angler Benefits $
High	33	1301	-31.4	0.23	18,645
Medium	33	1142	-14.8	0.10	15,540
Low	33	821	- 6.1	0.05	10,020
High	16	1242	-33.4	0.30	17,730
Medium	16	1046	-14.3	0.12	14,210
Low	16	727	- 5.3	0.05	4,650

[1] All water supply held at 0.5 X RIOFISH phosphorus sedimentation rate.

limiting. Preliminary runs of the economic model without the capping effect of the parking lot showed that angler days at Saguaro Lake would have increased in proportion to the human population increase if the parking limitation did not exist, and if the fishery could fully support the added fishing pressure.

Because human use is projected to change little at Saguaro Lake even when human population numbers increase as much as 33 percent over the next decade, the catchable fish density and yield are not nearly as affected by fishery management as they would be without parking space limitation on use rates, even with a doubling of lot size. If angler-use rates were unfettered by the parking limit, at some point fishing mortality would drive catch rate down enough to cause benefit gains to reverse and become negative.

DECREASED MORTALITY OF LARGEMOUTH BASS

If the artificial habitat decreases largemouth bass mortality by 25 percent, biomass of catchable stocks increases, and the catch rate and benefits also increase. The water supply (at highest fertility) indicated in Table 8 impacts the benefits generated, but affects opportunity and angler use rate relatively little. Altering mortality as such has a substantial positive effect. Decreased mortality increased benefits associated with 2X catchability in high-water years, when nutrient loads were high, but not in medium- to low-water years.

Table 8. Angler visitation, fish biomass, fish harvest rate and angler benefits (10-year mean) generated by artificial cover at Saguaro Lake that increases survival of fingerlings and older largemouth bass by 25 percent at three selected water levels simulated by RIOFISH.

Water Levels[1]	Additional Angler Days/Year	Additional Fish Biomass (kg/hectare)	Additional Fish Yield/ Day/Angler	Additional Angler Benefits $
High	1365	-29.8	0.42	18,820
Medium	714	-10.0	0.17	9,810
Low	416	- 3.6	0.04	5,450

[1] Phosphorus sedimentation coefficients held at 0.5 X RIOFISH values.

A comparison with Table 6 results shows that the low sedimentation scenarios alone generated $16,948, $12,815, $8,445 in benefits per year from artificial habitat at high, medium, and low water. Decreased mortality increased artificial habitat benefits to $18,820 from $16,948 ($1,872) in high-water and decreased benefits to $9,810 (-$3,005) and $5,450 (-$2,995) in medium- and low-water years.

In RIOFISH, compensations occur as food supply for more fish decreases. More larval fish die and older fish grow slower, reaching catchable size and reproductive age later. Thus, changes in natural mortality at one stage of life tend to be compensated at other stages of life, thereby dampening the effect.

A water-supply effect occurs because of the combined effects of angler substitution and productivity. Overall, a change in older fish natural mortality affects opportunity and benefits slightly. This implies that, even if artificial habitat decreases natural mortality, the increased survival of older fish does not greatly increase opportunity and benefits because of compensatory factors. Also, under most fertility conditions modelled for Saguaro Lake, a reduction of mortality in young-of-year and older fish ends up backfiring because larval growth and early mortality more than compensate for higher survival later in life.

Once again, model experimental results depend on the reliability of the estimated nutrient concentrations in Saguaro

Lake. If, in fact, organic loading is substantially greater than assumed, economic benefits would be higher than indicated by these RIOFISH scenarios.

LAKE PLEASANT EFFECT

Lake Pleasant management measurably affects the estimated benefits gained by habitat management at Saguaro Lake. If Lake Pleasant is managed at low-lake levels, the benefits gained by managing Saguaro Lake are greater than when water level is managed at a high level in Lake Pleasant (Table 9). An anticipated increase in Lake Pleasant water volume in 1995, by three times present volume, is likely to decrease the estimated benefits gained by concentrating fish at the artificial habitat in Saguaro Lake when otherwise average water conditions occur in the system of substitute fisheries. Again, the influence of Lake Pleasant can be deduced by referring to scenarios in Table 6.

Under Saguaro Lake medium water supply, low nutrient sedimentation rate and no difference in Lake Pleasant management, \$12,815/year are generated at Saguaro Lake by provision of artificial habitat. Extreme low-water, if it occurs (unlikely) at Lake Pleasant, will increase the benefits to \$14,020 (\$1,205) while high-water starting in 1995 will decrease the benefits gained to \$11,680 (-\$1,135). Therefore, RIOFISH predicts that water management at Lake Pleasant will decrease the estimated project benefits gained at Saguaro Lake up to 20 percent under the extreme range of possibilities tested in the RIOFISH

Table 9. Angler visitation, fish biomass, fish harvest rate, and angler benefits (10-year mean) by artificial cover at Saguaro Lake under selected water levels managed at Lake Pleasant as simulated by RIOFISH.

Management Activity at Lake Pleasant[1]	Additional Angler Days/Year	Additional Fish Biomass (kg/hectare)	Additional Fish Yield/ Day/Angler	Additional Angler Benefits $
Old Dam; Low-Water Level Management	938	-14.2	0.14	14,020
New Dam in 1995; Intermediate-Water Level	947	-14.3	0.17	12,235
New Dam in 1995; High-Water Level	987	-14.3	0.20	11,680

scenarios.

Because of differences between Arizona and New Mexico substitute systems, we believe this RIOFISH prediction is conservative. The effect of Lake Pleasant surface-area management is likely to be more than RIOFISH predicts.

Lake Pleasant water-level management is an important Saguaro Lake management consideration, but future benefits gained from Saguaro Lake management probably depend most on the crowding effect of the limited parking site capacity at Saguaro Lake. Because of the simulated parking lot limits in RIOFISH, angler use does not change much as Lake Pleasant expands or contracts. If future management reduces parking lot crowding more or less than expected, the relative influence of Lake Pleasant management could also change.

DISCUSSION

Given the information available at the time (September 1990), and the window of opportunity provided, the introduction of artificial habitat at Saguaro Lake made sense for these reasons:

1) Expected increases in fish catchability should increase consumer surplus for participants even if the number of participants was limited by parking space.

2) Angler populations were expected to increase in nearby Phoenix.

3) The proposed habitat management was a "one-time" effort that requires little operational maintenance cost.

4) Some relief for parking limitation on population use of lake reservoirs also was included in the project plan.

5) Use rates and fishery dynamics at Lake Pleasant indicated that Saguaro Lake was not yielding its potential.

However, RIOFISH simulation results did not support the assumptions made initially in the Saguaro Lake habitat management project about the benefits expected from introducing artificial habitat into Saguaro Lake. In the modeled system, expected angler benefits were influenced by the planning environment and the model estimated benefits were substantially less than the Forest Service's $8 million initial estimation. The rationale behind these model results is complex, because of the numerous interactions that occur in the planning environment of Saguaro

Lake and because sparse data sometimes lead RIOFISH to unreliable predictions.

PRICE AND CATCHABILITY

The assumption that the parking space limits angler use rate is important in determining the estimated angler benefits. If an unidentified factor limits the use rate instead of parking space, increasing parking lot size will have little or no effect and the model predictions of benefits gained would be substantially more than the benefits actually generated.

Also, we used what we believed was a high estimate of angler use if the parking lot size is doubled. We assumed that angler use rate is limited because all non-angler and angler recreationists compete for parking space year-round. If in reality, the non-angler:angler ratio increases in summer more than in other seasons, and crowding is restrictive only in summer, angler use will not double by doubling parking space.

If management activities somehow favored a decreased non-angler:angler ratio, the angler use could more than double by doubling parking space. That could happen, for example, if boater use was limited by lake size, which will not change in the future. Trail construction is expected to increase substantially non-angler hiking activity. That could raise the non-angler:angler ratio.

Without a complete data set and a prediction model for all recreational users, the simplest assumption for RIOFISH scenarios was that angler use would double when parking space doubled. Estimated benefits would rise or fall as the angler use changed from that estimated for the scenario (equivalent to 60,000 angler days/year assuming only price effect).

We assumed that the artificial habitat would double fish catchability. This was a reasonable but arbitrary figure based on past observed fish concentrations and catch rates. However, the data are scanty in this regard. To double the fished density of fish, the average angler would have to fish where the average density had doubled. Also, regardless of fishing mortality or other effects, the remaining fish population would have to maintain a doubled concentration around the habitat.

Fish certainly move, but whether or not they would move enough to sustain an average doubled density in the coves is not well understood. Fish concentrate to much higher than 100 percent of initial densities around unfished structures and 10 times the density may even occur. If this happened, short-term benefits would go up quickly as would angler use at the lake, but long-term benefits would most likely decrease as the fish population became overexploited.

In RIOFISH, a doubling of Saguaro Lake catchability takes into account depression of fish density by angler effort and results in an annual mean catch rate increase of about 20 percent when fish populations are under-exploited. Although catch rate at least in the short-term appears to about double near artificial structures, once the structures are provided, the entire lake catch rate for the year could only double if everyone fished at the artificial habitat and new fish rapidly moved into the habitat as old fish were removed. A 20 percent increase in lake annual mean catch rate may be conservative. However, even if catch rate should double, RIOFISH predicts that benefits would not quite double. This could raise the benefit:cost ratio from 0.2 to 0.4 under the most optimistic conditions.

We did not experiment with regulations, because of extra effort required. We expect that regulations will help sustain angler benefits somewhat when reproductive stocks are protected from over-exploitation and depress benefits when fish populations are not fully exploited.

BENEFIT DIMENSIONS

Even with protective regulations, we doubt the total angler benefits generated over 10 years are likely to exceed the $1 million cost expected for the project. If fish could be stocked free of charge, no parking lot limitations existed, catch rate doubled, and the angler population increased by 33 percent, RIOFISH indicates that almost $8 million in benefits would result over 10 years. Attainment of $8 million in benefits would require that the catchability of suitable fish would be more than quadrupled by artificial habitat, and that Saguaro Lake could accommodate over 300,000 angler days annually (about 5 times more use than the expanded lot is likely to allow).

Our results suggest when fertility averaged the equivalent of 0.03 mg/liter of phosphorus (about as it has in recent years), nearly 400,000 0.4 kg fish would need to be stocked annually to sustain a daily fish harvest of 2 fish/angler. Such stocking would cost about $1,000,000/year, providing a 0.4 benefit:cost ratio.

Further model scenarios with fertilization might reveal that substantial benefit could be gained using that strategy, if parking were not limiting. Our results indicated that a 3X change in mean fertility generated twice the benefits when parking was limiting. Other model scenarios would reveal estimates of fertility levels needed to recreate benefits at different parking lot sizes once parking space was integrated into the model.

This discussion has ignored the benefits that might be gained from non-angler recreationists, mostly from the expanded parking space and new trail. RIOFISH does not address those benefits. Depending on their dimension, non-angler benefits may raise the total project benefits substantially. The scenario examined here only considered the contribution of the artificial habitat alternative to angler benefit. We assumed artificial habitat would not affect non-angler benefits generated by the project.

Generally, RIOFISH scenario results show that the management for increased opportunity at a site does not have the same benefit when major variations in water levels occur at substitute sites. Also, the results indicate that inadequate understanding of habitat interactions, particularly interactions between cover and fertility, may have substantially affected benefit:cost estimation.

Perhaps more than any other result derived from model scenarios, the importance of the assumptions made to estimate the values of a management project became quite clear in the scenario contrasts. To properly assess the expected benefits from a management project, managers must consider uncertainty in the planning environment and planning environments with geographical areas far larger than the immediately managed site. To manage limited resources for maximum angler benefit requires a regional management perspective with an appreciation for climatic, biologic, and social forecasts.

The assumption that water supply elsewhere in the region can be ignored is risky, based on RIOFISH results. Even though the mean annual surface area at Saguaro Lake remained nearly static, the surface area variation in Theodore Roosevelt Lake and Lake Pleasant helped determine the consumer surplus angler benefits generated by management at Saguaro Lake in the modeled system. Low-water conditions are likely to diminish significantly benefits generated by Saguaro Lake habitat management, if they materialize over the next decade. However, benefits could be greater during high-water years.

Although Theodore Roosevelt Lake is three times as far from Phoenix as Saguaro Lake, the size of Theodore Roosevelt Lake is a strong attraction for anglers. Roosevelt Lake in high-water years can absorb over 20 times the fishing pressure that Saguaro Lake can support without excessive fishing mortality that eventually reduces mean long-term benefits. Roosevelt Lake also sustains a greater average density of catchable sportfish stocks because the reservoir's organic loading per unit area is substantially greater than Saguaro Lake's.

The amount of allochthonous organic matter that enters these lakes is an important factor. Although RIOFISH probably underestimates inputs into Saguaro Lake because the organic input from adjacent watersheds are not included in the model, the organic loading rate is undoubtedly much higher in Roosevelt Lake which has a much larger watershed area. Combined with higher phosphorus concentration in Roosevelt Lake, fish yield per unit area is likely to average higher than in Roosevelt Lake.

Rinne (1973) estimated mean loading into Theodore Roosevelt Lake that might exceed 1000 g $C/m^2/yr$ in certain years. Cole et al. (1990) have estimated similar levels of loadings for certain reservoirs in New Mexico. Bolton et al. (1990) reported similar behavior for Arizona watersheds. Most if not all of this organic matter is trapped in Theodore Roosevelt Lake because runoff from the adjacent desert watersheds is scarce in the lower lakes.

This watershed source of lake nutrition is believed to be negligible in Saguaro Lake.

The phosphorus levels actually observed in Saguaro Lake are estimated in RIOFISH to generate less then 200 g C/m^2/yr of organic matter that is converted ultimately to fish. Although organic loading in Theodore Roosevelt Lake exceeds loading in Saguaro Lake by several times, sportfish production would not increase proportionally. Given the functions incorporated in RIOFISH, fish production would be expected to be about twice as high in Theodore Roosevelt Lake, with a higher catch rate closely associated with the higher production.

Model results indicate that the greatest increase in fishing opportunity occurs in Saguaro Lake when water supply and nutrient concentrations are high. However, when catchable stocks are greatest due to high fertility, the benefits gained by Saguaro Lake management are somewhat restricted because people are more attracted to high-water conditions at Roosevelt Lake and other substitute fisheries during the high-water years.

Overall, the water supply scenarios indicate, for the assumptions used, that the benefit:cost ratio for the next 10 years ranges between 0.08 and 0.17 because of water supply variation alone. The probability of either extreme low or extreme high-water occurring over 10 years is lower, however, than the intermediate estimate. The benefit:cost for intermediate-water years under the most likely fertility conditions, was about 0.13, not high enough to justify the investment in artificial habitat considering average water years alone and no change in human population.

The relative nutrient concentration influences the beneficial effect of artificial habitat, if artificial habitat in fact increases the vulnerability of fish capture as modeled. When nutrient concentration and fertility are high, the artificial habitat probably will benefit anglers with a higher long-term catch rate at Saguaro Lake. When nutrient concentration is low enough, the artificial habitat increases the negative effects of over fishing and reduces the long-term opportunity and benefit. If nutrient concentrations were, in fact, about one-third of the tested lowest values, RIOFISH would predict negative benefits from the provision of artificial habitat. That would mean that the habitat not only would be unworthy of the cost, but its effects would harm angler welfare over the long run.

The actual management impact that results in Saguaro Lake depends on answers to at least three difficult fishery questions. First, how much will artificial habitat actually increase sportfish vulnerability to anglers without also depressing fish production; second, what is the actual lake fertility under different water levels; and third, to what extent is fishing mortality additive rather than compensatory with respect to natural mortality? If fishing mortality is additive (all fishing mortality is added to natural mortality), the negative impact of habitat added at low productivity will be greater than if fishing mortality is compensatory (fishing mortality replaces natural mortality until it exceeds natural mortality), and the benefit realized by habitat management at Saguaro Lake will be lower than indicated in our experiments. In RIOFISH, we used fishing mortality assumptions that were most likely to generate the least angler impact on the fish population and the highest benefits from the artificial habitat.

RIOFISH can be used to examine the effects of different estimated habitat concentration effects on fish populations and mortality effects of fishing pressure. However, RIOFISH cannot directly estimate the concentration factor nor the degree of compensation in the fishing mortality and the natural mortality. These are areas requiring more research before any model can predictively estimate them.

Artificial substrate may increase lake productivity once it is introduced. If so, the angler benefits may be increased somewhat over estimates made by RIOFISH. If the artificial habitat increases the bottom substrate surface area by 10 times and the habitat covers 2 percent of the cover area, productivity in Saguaro Lake coves could be raised about 20 percent. However, this would amount to little more than a 2 percent increase for the whole lake, an insignificant amount.

HUMAN POPULATION CHANGES

Angler population increases reflect the Phoenix metropolitan area's rapid growth in recent decades. In an under-exploited fishery in RIOFISH, the benefits provided by management go up proportionally as angler population increases. The angler population, however, also determines fish density once the potential yield approaches full use. In an overexploited RIOFISH fishery, when potential yield is exceeded, catch rates decrease and benefits fall. If management benefits become negative for some reason, an increased human population will only make benefits more negative. The increased benefits of a good management decision is magnified by a population increase while the effect of a bad management decision will be worsened by population increase.

Assuming no other limitation and an under-exploited fishery, results of increased human population experimentation in RIOFISH indicate that the relative population growth will have a proportional effect on the benefits generated by installing artificial habitat. If the human population increases 30 percent, the benefits also increase by 30 percent (or, if negative, they will decrease by 30 percent). However, benefits at all substitute sites also will increase and the larger Roosevelt Lake and Lake Pleasant will continue to attract some anglers away from Saguaro Lake.

During low-water years, when Saguaro Lake is relatively more attractive to Phoenix anglers because its surface area varies little, an increase in population of 33 percent over 10 years would increase the fishing mortality and reduce the long-term opportunity and benefit. Thus, RIOFISH predicts the mean 10-year benefit will go down as the fishery becomes overexploited from the human population increases.

The actual growth in Arizona's angler population also depends on the fraction of human population that elects to fish. Many factors can influence this. Age composition changes are important, for example. For example, the baby boom anglers who fished with their children in the 1970s and 1980s may quit fishing as their children leave home for opportunities elsewhere. Also, if the overall fishing experience deteriorates in the substitute fisheries, anglers may elect to stop fishing.

Of course, fishing regulations could be imposed to reduce fishing mortality. Experience with New Mexico model use indicates that regulations increase long-term mean benefits (we did not run that scenario for Arizona) when fishing intensity overly exploits and diminishes sportfish stock renewal rates. Unnecessary regulation, when potential yield is not used, reduces angler benefits.

Even if parking space can be increased, some physical cap on angler use may be an appropriate management choice to keep the fishery from being badly overexploited. The need for expensive regulation enforcement may decrease if angler use rates are capped by a parking lot size.

With further development, RIOFISH, or a similar model, could be used to evaluate the optimum parking lot size or other access limits suitable for sustaining a minimally regulated fishery.

REDUCED LARGEMOUTH BASS MORTALITY

When natural mortality is reduced 25 percent, more fish survive to catchable size. However, their growth may be slowed under low and infertile water conditions and larval survival may decrease. If surviving fish are smaller, fishery attractiveness may decrease depending on how much this counteracts increased density. Higher survival may lead to greater stunting because food is limited. Overall, however, RIOFISH indicates a small net positive effect on benefits. RIOFISH assumes that individual fish of all sport species are equally attractive to anglers when they are of equal weight. If, in fact, a 1 kg largemouth bass is more desirable than a 1 kg crappie, or 1 kg catfish, or 1 kg sunfish, the benefits estimation may be inaccurate. The best available data seem to suggest small biases in this regard.

At higher water levels and fertilities, enough food was available to sustain greater growth and maintain higher catches of fish. Mortality reduction will favor increased opportunity and angler benefit when food availability is not limiting. Some fishery biologists believe providing artificial cover will reduce mortality of young fish because predators will be less efficient where more refuges exist. As long as fertility is high enough to sustain growth of surviving individuals, this strategy seems promising. But when food availability limits growth rate and survival of larval fish, artificial habitat is less likely to increase opportunity.

Many unanswered questions remain about the degree to which mortality actually may be decreased by cover availability, and how cover interacts with food availability for young fish. Rinne (1973) believed that, at times, the chain of lakes below Theodore Roosevelt Lake was severely limited by nutrient availability. When that happens, RIOFISH indicates that installing artificial habitat would be inappropriate if it actually increased survivorship of juvenile and older fish by 25 percent. Food limitations caused by low fertility would cause early life-stage starvation, slowed growth rates, delayed reproduction of adults, and negative angler benefits. Also, the opportunity and benefits would decrease as the fishery is overexploited by anglers.

LAKE PLEASANT

From Phoenix, travel time to Lake Pleasant is less than to Saguaro Lake. Roughly 30 percent of Lake Pleasant's shoreline is accessible to the public compared to 2 percent at Saguaro Lake. Harvest rates were higher at Lake Pleasant and there is ample parking space. Lake Pleasant receives about 15 times the angler use of Saguaro Lake, probably because of better access and parking conditions. The results of RIOFISH experimentation indicate that, when nutrients are concentrated in Saguaro Lake and water supply is intermediate in the Salt River system, management for higher water levels than average in Lake Pleasant will reduce the cost-effectiveness of managing habitat (or other factors) at Saguaro Lake.

These results suggest that fishery management resources (not necessarily U.S. Forest Service funds) might better be applied to Lake Pleasant, if any more can be done to reduce constraints acting to limit benefits of fishing Lake Pleasant before Saguaro Lake is managed more intensively.

When Lake Pleasant water storage is reduced, the management impact on benefits generated at Saguaro Lake will increase. However, this scenario is unlikely. Much higher waters are more likely to be held in Lake Pleasant and reduce the angler benefits from any habitat augmentation, or other fishery management, at Saguaro Lake. Little can be done to project fishery management cost-effectiveness in reservoirs of south-central Arizona without first considering the water management effect of Lake Pleasant, as was initiated by Morgensen (1990). The anticipated nutrient loading rate at Lake Pleasant is an important consideration.

Morgensen (1990) has compiled data gained from Lake Pleasant, which makes it the most studied reservoir among the substitute lakes. The biomass estimates for fish in Lake Pleasant indicate reasonable model biomass estimates for catchable fish in Saguaro Lake (about 50-100 kg/ha for the most likely nutrient condition). The Lake Pleasant biomass estimate for all sportfish sizes averaged 165 kg/ha over two years.

Lake Pleasant differs from Saguaro Lake in two important ways: it has no physical limitations to angler access and it has no reservoirs upstream that intercept nutrients and organic matter in natural tributaries. Lake Pleasant phosphorus concentration averaged over twice as much as at Saguaro Lake, which should provide for higher fish production contributing to a higher yield in harvestable sportfish at Lake Pleasant, as has been observed recently (Table 2). Flash flooding in Lake Pleasant tributaries probably generates high concentrations of allochthonous organic matter as well as high phosphorus concentrations. Therefore, Lake Pleasant is limnologically more like Theodore Roosevelt Lake than Saguaro Lake.

In the future, Lake Pleasant catch rates could decrease when stored water volume increases after 1994. We doubt that concentrations of organic matter and phosphorus will be nearly as high in CAP water imported to Lake Pleasant as they are in present tributary runoff. Lake water nutrient concentrations could be diluted. Thus, the productivity could become more like Saguaro Lake and decrease its relative benefit and attractiveness to anglers. Because Saguaro Lake will still be limited by parking, as will Canyon and Apache Lakes, more people may go to Theodore Roosevelt Lake, which is more costly for anglers, or they may stop fishing entirely.

It is possible, in other words, that the proposed water level changes in Lake Pleasant could decrease angler benefits in Arizona despite the expected positive effect of increased water level near Phoenix. The result depends on the extent that fish productivity per hectare decreases at Lake Pleasant. Given appropriate data, RIOFISH could be modified to analyze these possibilities.

MODEL ASSUMPTIONS AND LIMITS

The model is limited in several ways that could affect the accuracy of results. The most important limitations regard data availability and differences between New Mexico and Arizona fisheries, including the behavior of pump-storage operations. Water levels, as modeled in RIOFISH, do not reflect the daily changes generated by pump storage. RIOFISH was developed for single pass-through reservoir operations. Although modeling of pump-storage hydrology can be done with sufficient data and time, that was not the purpose of this study. This inadequacy of the model may be irrelevant for these scenarios, however. As verified by catch records (e.g., Warnecke, et al. 1990), the daily water level fluctuations have little impact on the fish reproduction at Saguaro Lake.

The nutrient concentrations generated from the loading-concentration submodels used in RIOFISH simulate lower phosphorus concentrations in Saguaro Lake than the available data indicate actually occurred. Past measurement of actual nutrient loads have only been made for Salt River above and below the series of four reservoirs. No field measurements have been made of nutrient amounts passed between the four reservoirs. The model simulates average water column concentrations of nutrients and it does not include estimates of adjacent watershed inputs, which could be important.

The average concentration in outflows from Saguaro Lake represent concentrations that may be higher than the surface waters in Saguaro Lake. Rinne (1973), however, showed that nutrient profiles were constant from top to bottom before pump-storage began. Phosphorus outflow concentrations may reflect Saguaro Lake concentrations reasonably well. Assuming that condition, we suggest the nutrient scenario with the lowest sedimentation rate for nutrients, fits Saguaro Lake best if multiplied by a calibration factor of 3X.

We also conclude that the sedimentation rates of Salt River reservoir nutrients behave differently than in New Mexico reservoirs. Improved modeling would require more detailed understanding of hydrologic and nutrient dynamics than can be deduced from existing data.

Our modeled nutrient concentrations created for the water quality scenarios provide a probable range of nutrient concentration that could occur if Rinne (1973) was right and extended periods of very low nutrient concentrations occur in Saguaro Lake. RIOFISH results indicate that nutrient concentration has substantial impacts on the fishery. Nutrient behavior in the lakes probably deserves more attention because fertilization may be a viable management activity in the reservoirs below Roosevelt Lake during periods of low nutrient concentration. This possibility should be considered in more detail, particularly after obtaining better nutrient data.

RIOFISH also is limited because it cannot directly assess effects of artificial habitat, mostly because few good data are available to document the effects of artificial habitat on catch rates. Data gathered at Saguaro Lake may be useful for eventually incorporating those effects into RIOFISH. For now, we need to estimate the catchability effect of the artificial habitat. We used what we thought was a reasonable estimate. The most liberal estimates of catchability would at most double the estimated benefits of artificial habitat at Saguaro Lake. Studies at Saguaro Lake can provide much useful information in this regard, to improve understanding in general and, possibly to improve RIOFISH.

The substitute fishery effects of other sites are important. Although surface area is the most critical substitution factor in New Mexico, other factors appear to play greater roles in Arizona. The surface-area effect in Arizona may be greater than indicated by the New Mexico-based model.

The apparent inadequate parking at Saguaro Lake is an outstanding example of an effect not observed in New Mexico. No such limitations occur at the sites where RIOFISH was developed, thus RIOFISH could not be used to address directly the limitation effect caused by crowded parking lots.

Crowding interactions are not well understood and therefore, not incorporated in RIOFISH. For example, we assumed that a doubled parking size would allow a doubled angler use rate. This assumption presumes that the ratio of Saguaro Lake recreational users will not change, that is, the ratio of anglers, boaters, hikers, picnickers and others will remain the same in the future. The Forest Service (R. Uberauga, personal communication) is expecting more hikers to use the new trails to be installed as part of the project. Hikers could crowd anglers out of parking spaces and keep angler use rate from doubling. Until better information about crowding effects is gathered, RIOFISH will remain limited in this way.

If appropriate recreational user surveys are conducted throughout the system of substitute sites, an economic model could be tailored for Arizona fisheries. Such surveys are needed for other purposes as well, and we recommend their routine administration.

Other limitations to RIOFISH certainly exist. RIOFISH is designed to economize structure so that management can be simulated comprehensively. Detailed modeling of specific parts of the planning system was foregone in order to develop the most efficient comprehensive management model. Therefore, the direction and relative impacts of various modeled effects on opportunity and benefits should be emphasized more than precise values. In other words, the model scenarios estimated substantially lower benefits than were originally estimated by the Forest Service. But most importantly, the use of RIOFISH reveals many serious questions associated with site specific management that assumes benefits derived from management are independent from other sites. It is profoundly important to recognize the effects of planning environment events on the benefits estimated from management at any one site. This planning need is derived from the fact that the basic fishery management system is not the site, but the entire group of sites that serve as substitutes for the angler community. It is less important to stress the actual benefits values estimated. The results of RIOFISH use shown here give much room for further thought about alternative uses of management dollars for future projects like that at Saguaro Lake.

CONCLUSIONS

RIOFISH is most useful in identifying constraints in realizing benefits gained by management applied to a particular fishery. Model results for Saguaro Lake show that the constraints to realizing benefits can have more to do with angler habitat factors than fish habitat factors.

RIOFISH revealed that some factor other than fishery potential yield greatly constrains use at Saguaro Lake more than travel cost, road access to the site, and fishery quality would indicate. The most likely limitation is parking lot size, which constrains angler use rate as anglers compete for parking space with other anglers, and recreationists. If anglers were not constrained by limited parking or other unidentified limitations, RIOFISH predicts use rates could climb to about 250,000 angler days, assuming no other factor or factors become limiting, including a sustainable fishery. Such unconstrained visitation would greatly increase the benefit:cost ratio estimated for fishery management at Saguaro Lake.

Even if parking lot limitations are removed, however, angler days may not rise to 250,000 angler days, diverting users from locations like Lake Pleasant, because of other constraints. As angler use increases, the risk of fishery over-exploitation increases, and concentrating fish with artificial habitat increases the risk of over-exploitation. At some point the lake's natural fertility will limit the benefits gained by artificial habitat introduction.

With further RIOFISH analysis, an optimum catchability could be estimated for a range of probable fertilizations. Better information about nutrient status of Saguaro Lake would help clarify the probable role of fertility and fertilization in the future management of Saguaro Lake. RIOFISH results reveal that fertilization could substantially improve benefits from artificial habitat when low nutrient concentrations constrain habitat management effects. The extent to which benefits might be improved by fertilization might be considered in future uses of RIOFISH.

Even with fertilization, a big factor in the future of Saguaro Lake is the planned expansion of Lake Pleasant. Such expansion would substantially constrain the utility of an improved fishery at Saguaro Lake as the substitute effect of a larger Lake Pleasant is realized. The substitution impacts would most likely be greatest in periods of high-water as have occurred in the most recent decades. The substitution effects will vary depending upon what limits use rates at Lake Pleasant and how those limits are managed. The impacts of habitat management at Lake Pleasant and, to a lesser extent Theodore Roosevelt Lake, clearly indicate the need for a regional perspective in comprehensive fishery management planning. One potentially important factor is the organic and nutrient load anticipated for the CAP water to be stored in Lake Pleasant.

Lastly, inadequate understanding of how catchability will be influenced by artificial habitat constrains the certainty of conclusion. RIOFISH was used to judge the effect of that inadequate understanding on the benefits and opportunity estimated. Only data like that now being gathered at Saguaro Lake will reduce this constraint. It is important to assure that quality data are gathered.

The results shown here for Saguaro Lake reveal information generally needed for many comprehensive fishery management planning decisions, especially where human population growth rates are rapid and concentrated, as they are in Arizona.

RECOMMENDATIONS

1. Identify factors that limit angler benefits. In future analyses of angler benefits, more attention ought to be paid to the interaction of factors that combine to constrain angler use rates at a particular site, especially the underlying lake fertility, angler access (such as parking lot crowding) and the changing quality of substitute sites.

2. Inventory beneficial fishing opportunities. In future inventory analyses, fishery managers should focus more on estimating the fraction of the potential sustained fish yield that is actually killed by fishing at all sites in the complete system of substitute sites (not just the sites that are within some artificial political jurisdiction).

3. Acquire data comprehensively. To develop, test, and understand relationships between angler benefits and fish yield, fishery managers should develop and maintain comprehensive surveys of angler origin, angler success, angler use rates (effort), renewal rates of catchable stocks, and the fishing mortality impact on stock recruitment simultaneously at managed sites and all substitute fishing sites.

4. Manage the whole system, not just the site. In future proposals, resource managers should invest more planning time in synthesis of planning system elements, using whatever planning

tools are available or can be developed cost-effectively to forecast the angler economic benefits estimated from proposed management.

5. Gather and save useful data. Recreational researchers should carefully document all aspects of the Saguaro Lake project that appear to be important considerations to add to the availability of good data pertaining to comprehensive fishery manage- and the specific role of artificial habitat development.

6. Manage for benefit, not just opportunity. Increasing catch rate at a site when there are other limiting resources, such as a small parking lot or strong substitute sites, is an uneconomical way to increase benefits.

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APPENDIX 1

CONCEPT OF ANGLER BENEFIT

Introduction

Consumer's surplus is the main concept that is used to measure angler benefits in any cost-benefit analysis for fishery management. No angler would go on a fishing trip unless he planned to receive benefits at least as high as his total costs, including out-of-pocket expense and travel time. For this reason, actual expense paid for the trip is a poor index of its value to the angler. The fisheries manager conducting a cost-benefit calculation must go beyond a simple travel expense on fishing trips as the measure of the benefits arising from the sport fishing resource.

Consumer's surplus is the maximum sum of money an angler would be willing to pay for having access to a given array of sportfishing opportunities, less what he actually pays for the fishing license and related travel costs. If resource managers make decisions that bring fishing closer to an angler's home, that angler is clearly better off. The angler's gain in benefits from the management decision is his additional consumer's surplus.

Reference Points

The distinction between benefits and costs of sportfishing management lies in the choice of a reference point from which fishing quality changes are measured. The benefits of an improved fishery at Saguaro Lake are measured by the gain in anglers' welfare associated with installed artificial habitat compared to the lake without habitat improvement. Benefits are the equivalent of the monetary value gained by the anglers as a consequence of the habitat improvement. In a narrow sense, costs are what the Forest Service pays for the artificial habitat, including the time required to install it. In a broader sense, costs are the anglers' benefits foregone by the Forest Service by spending its resources on artificial habitat at Saguaro Lake rather than spending the money in the next-best time and place for generating anglers' benefits, for example, improvements at Roosevelt Lake.

A major factor influencing the usefulness of estimates of benefits in sportfishery management is the nature and quantity of information contained in the estimates. A statement that "all sportfishing in the Tonto National Forest Reservoirs is worth $8 million in angler benefits per year" contains little useful information for a management decision. It could be correct, for example, to infer that the $8 million benefit would disappear if all forest service fishery management were eliminated on the Tonto National Forest. However, what is much more relevant is understanding how management causes benefits to increase and decrease. Benefit estimation must meet certain minimum requirements to be of service for decision makers.

Standards

All statements concerning benefits should clearly specify the fishery quality levels being compared, both the baseline level and the improved level being considered. Additionally, they should specify the assumed levels of other important factors, such as water levels in the Salt River system and Phoenix angler population growth rates.

Although estimates of the total angler benefits provided by a site, such as Saguaro Lake, are useful to managers, measures of angler benefits described in this report are more precise, since they relate to changes in fishing quality levels brought about from habitat improvements. In other words, a measure of old and new quality of Saguaro Lake explicitly enters the analysis as a determinant of benefit gained by the change in quality.

The benefit estimates summarized in this report are based on a correctly specified theoretical model of the processes which govern individual angler decisions and behavior. Our model is based on the underlying process by which anglers substitute across a changing set of opportunities of improved fishing qualities over competing waters and site improvements. Although developed in New Mexico, we believe there is considerable useful information retained in the translation to Arizona regarding angler choices in a water-scarce environment.

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APPENDIX 2

HYDROLOGIC AND NUTRIENT DYNAMICS IN SALT RIVER RESERVOIRS

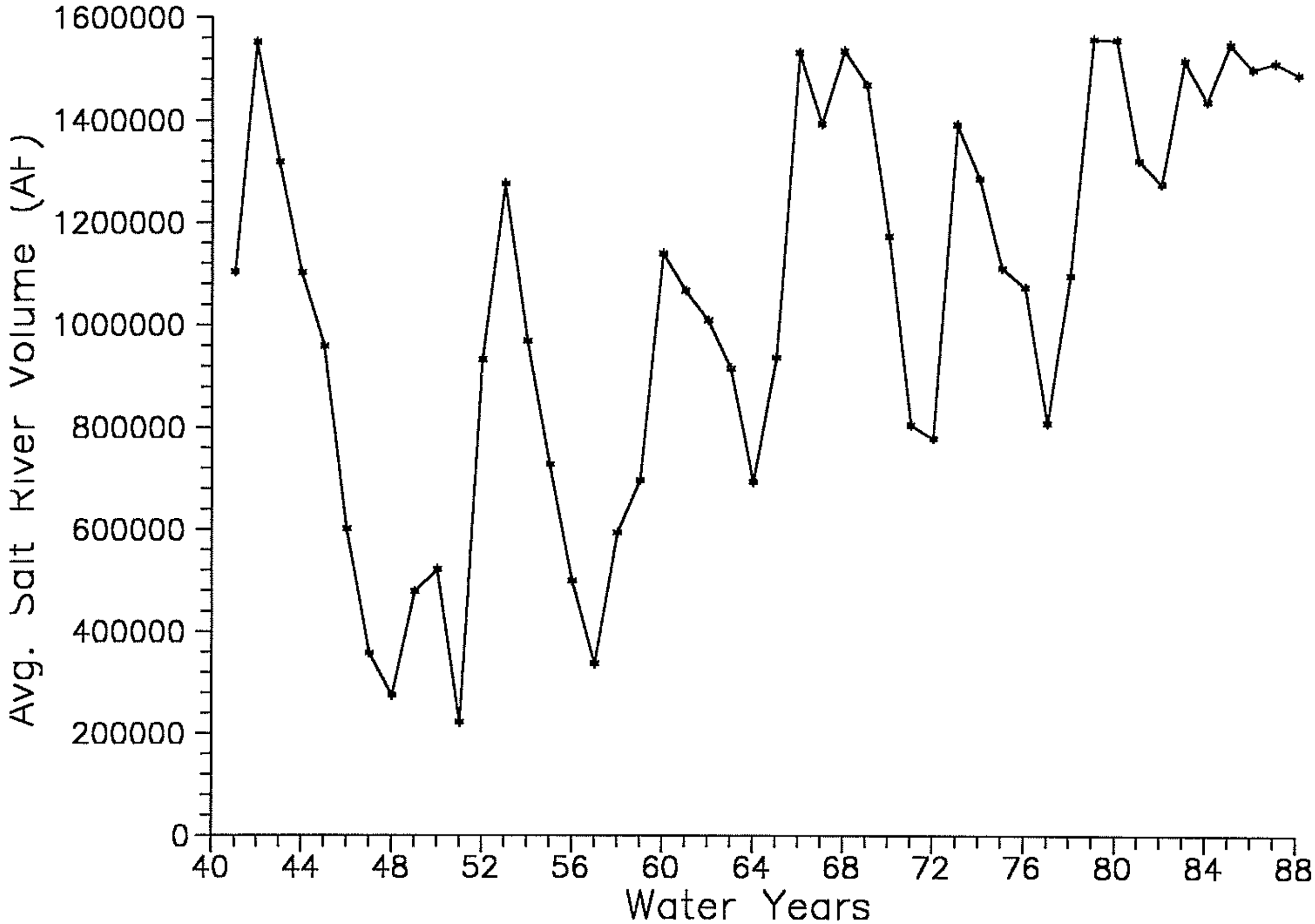

Figure A1. Volume of water stored in all four Salt River reservoirs from 1940 through 1988.

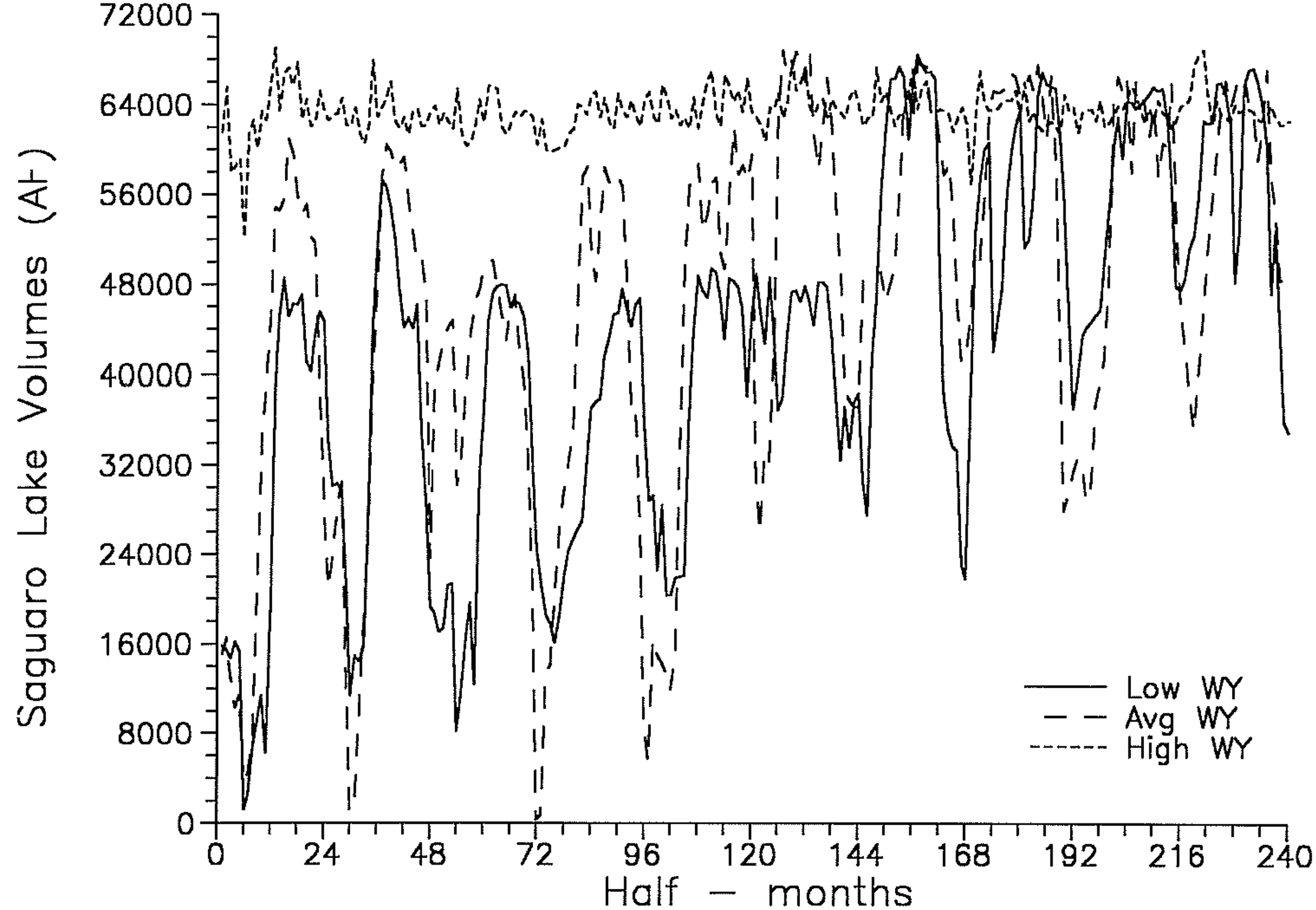

Figure A2. Volumes held in Saguaro Lake at low-, average-, and high-water years (for 10 years).

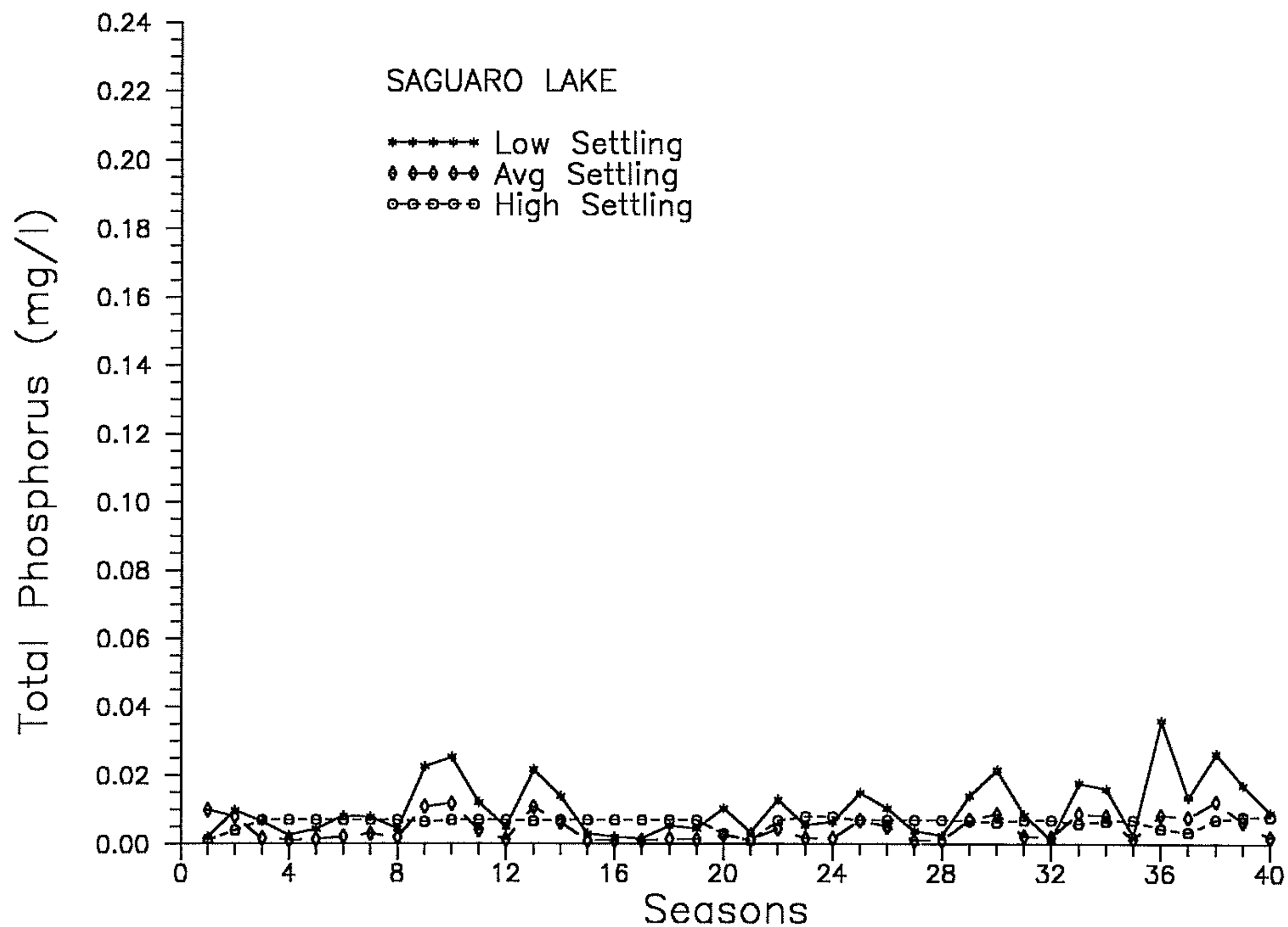

Figure A3. Phosphorus concentrations generated by low-, intermediate-, and high-settling rates used in RIOFISH for intermediate-water levels at Saguaro Lake.

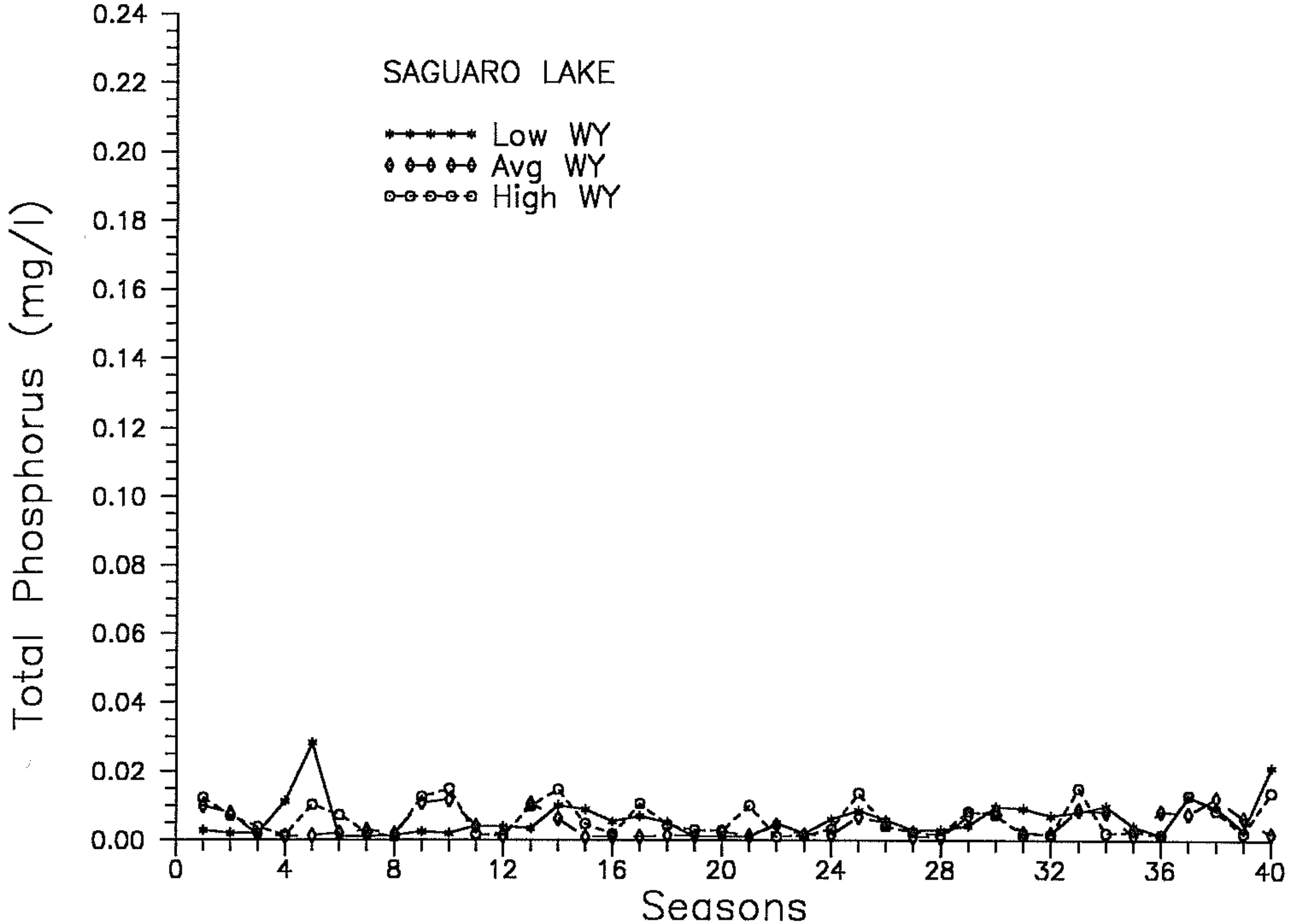

Figure A4. Phosphorus concentrations generated for different water supply conditions in Saguaro Lake assuming the RIOFISH sedimentation coefficient for phosphorus.

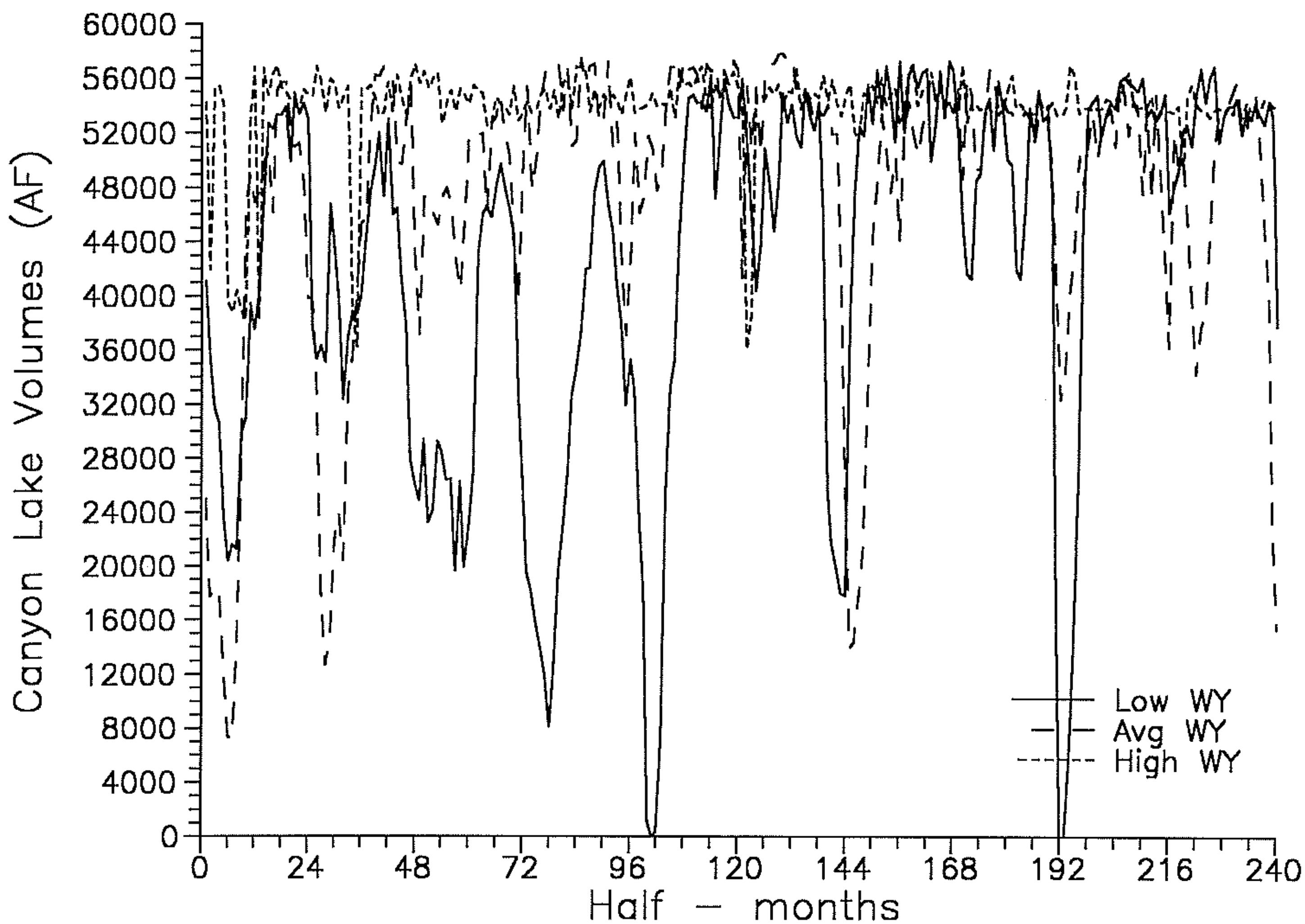

Figure A5. Volumes held in Canyon Lake in low-, average-, and high-water years (10 years).

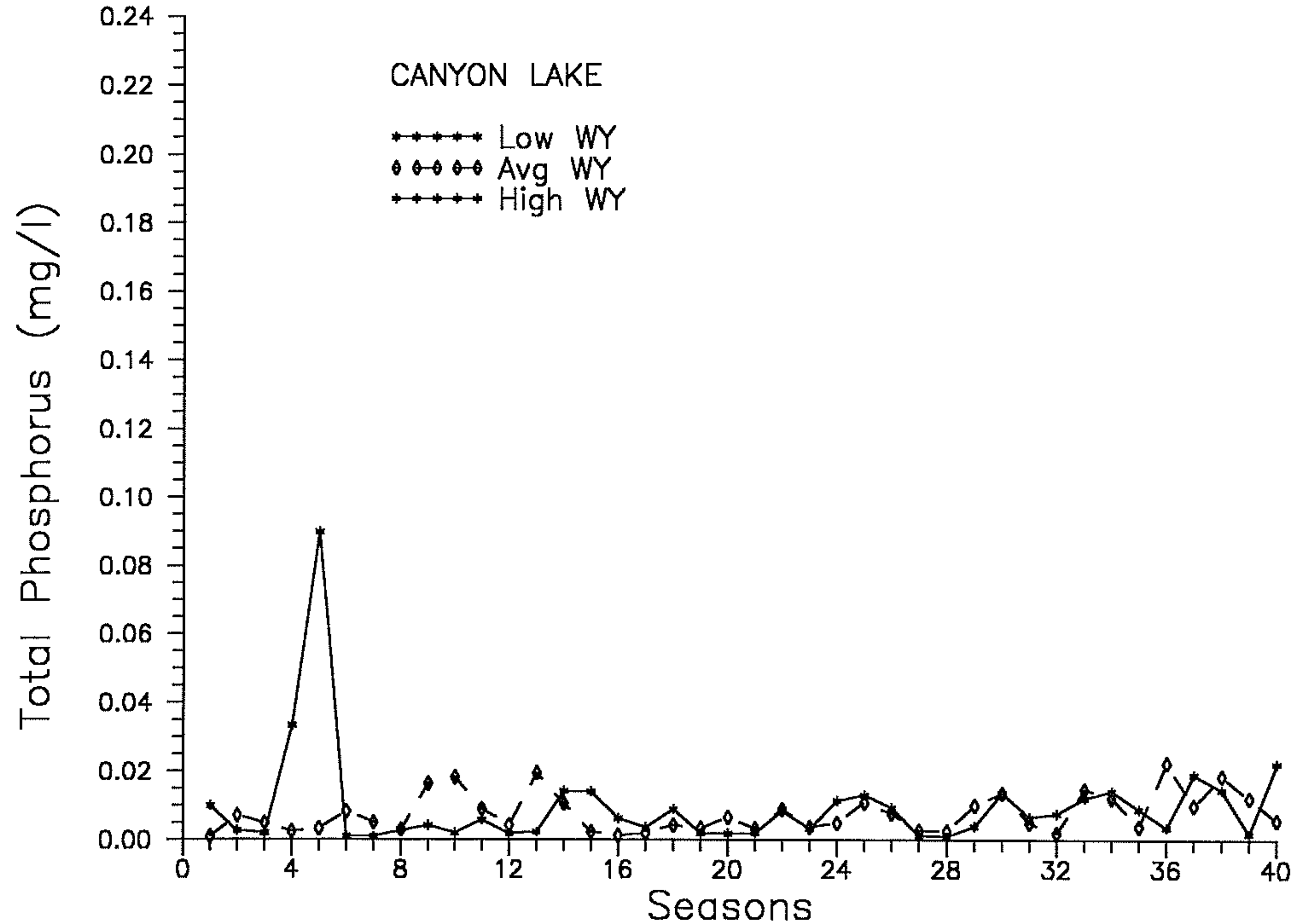

Figure A6. Phosphorus concentrations generated for different water supply conditions in Canyon Lake assuming the RIOFISH sedimentation coefficient for phosphorus.

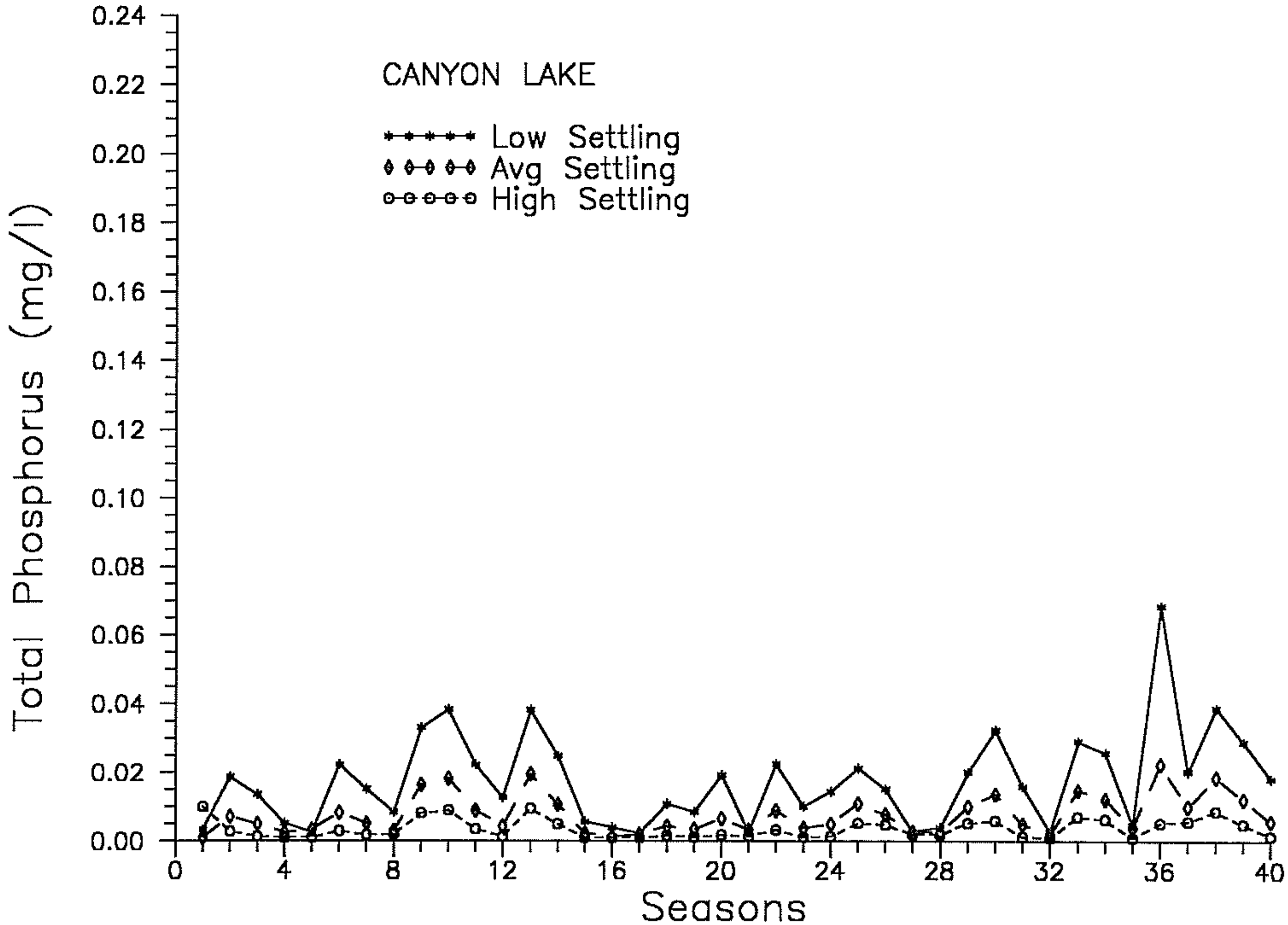

Figure A7. Phosphorus concentrations generated by low-, intermediate- and high-settling rates used in RIOFISH for intermediate water levels at Canyon Lake.

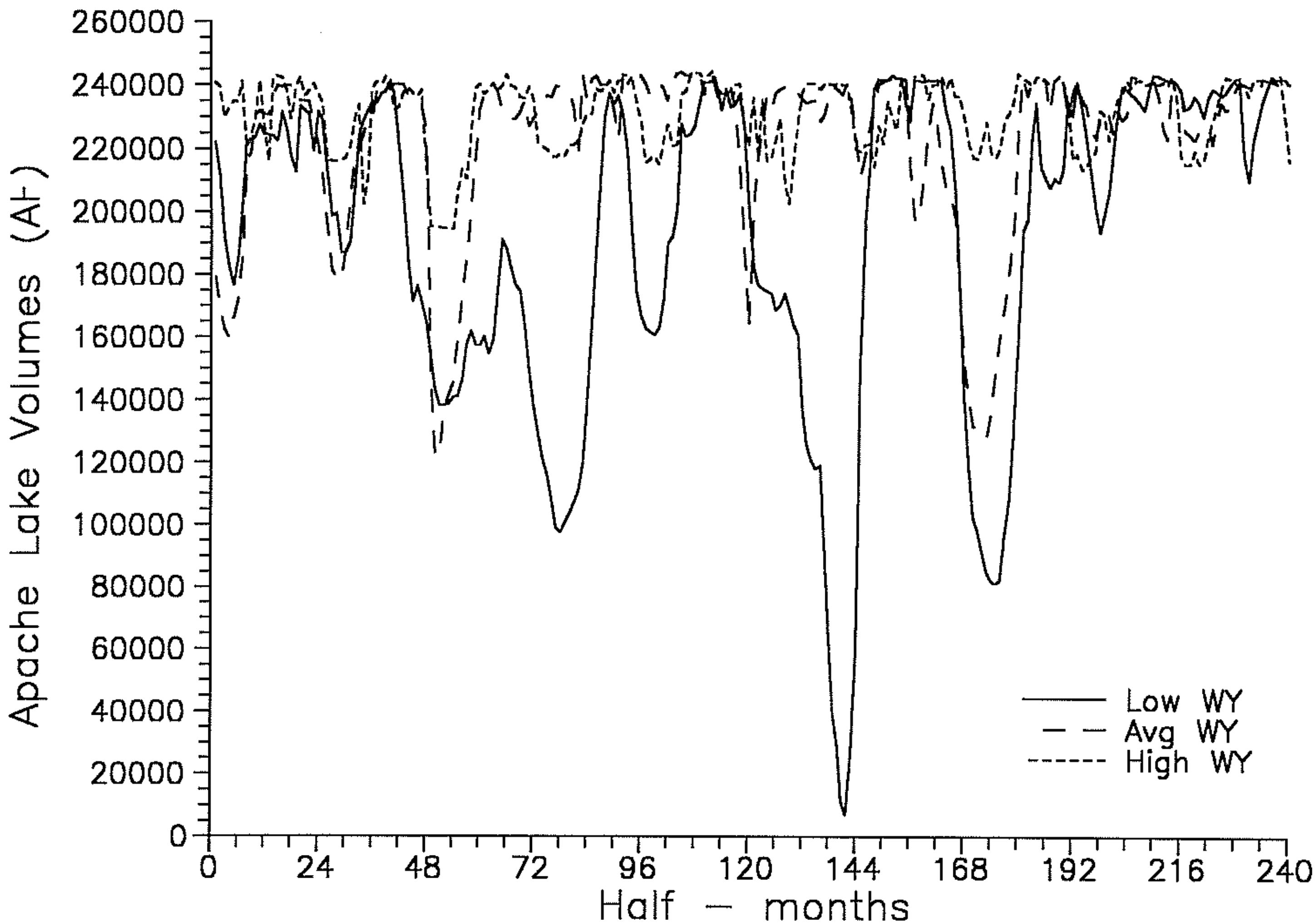

Figure A8. Volumes held in Apache Lake in low-, average-, and high-water years (10 years).

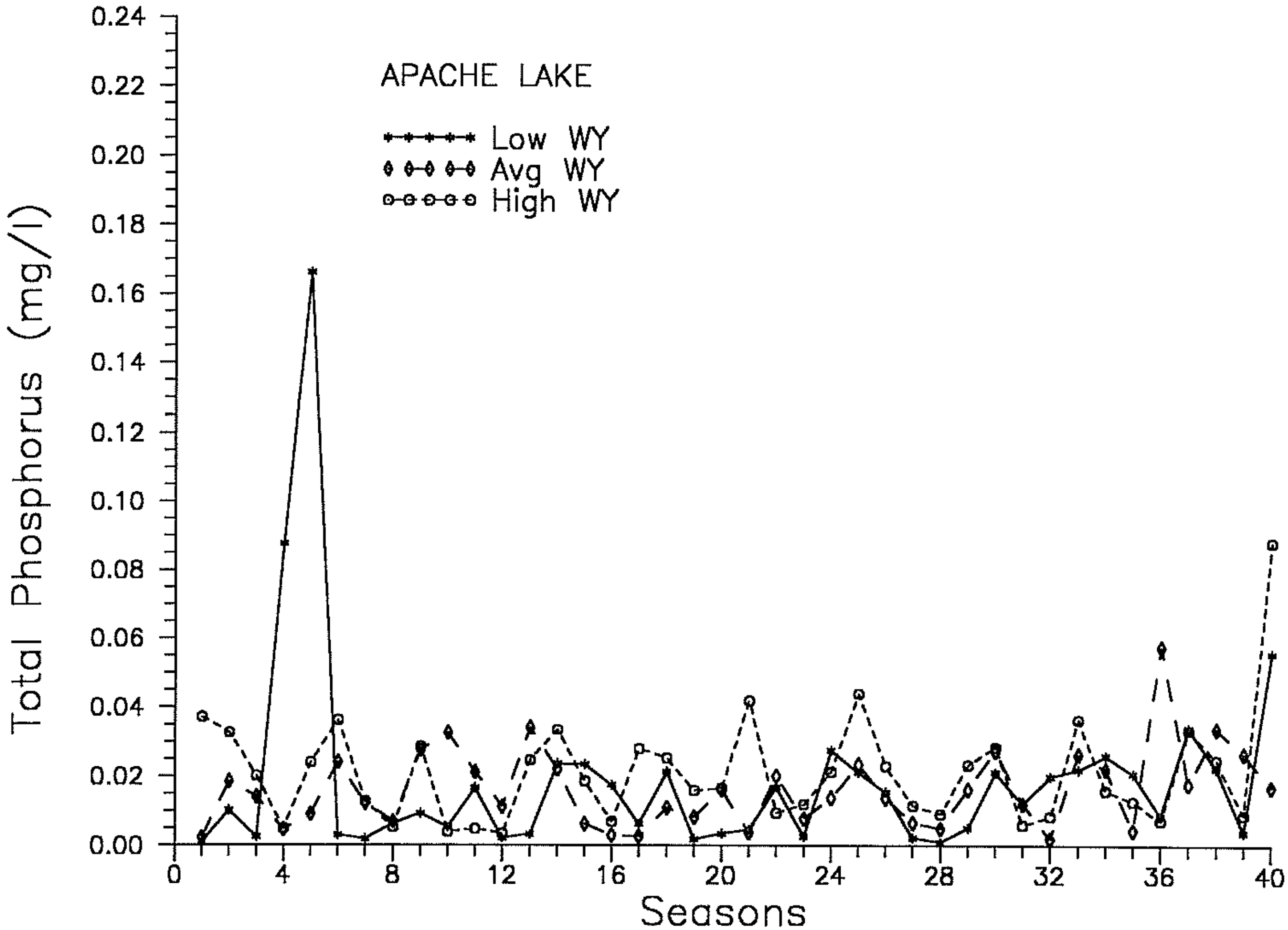

Figure A9. Phosphorus concentrations generated for different water supply conditions assuming the RIOFISH sedimentation coefficient for phosphorus.

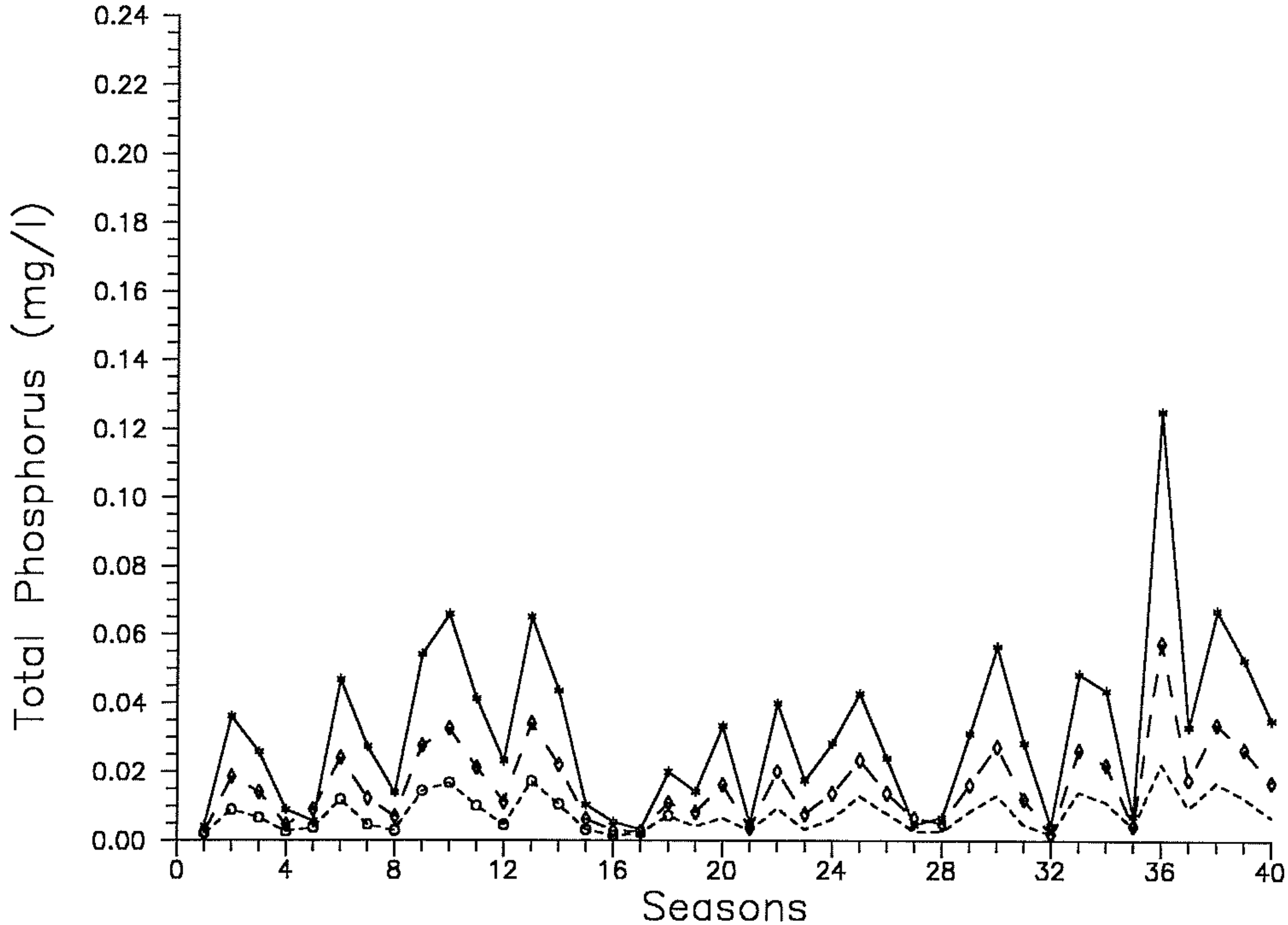

Figure A10. Phosphorus concentrations generated for different water supply conditions in Apache Lake assuming the RIOFISH sedimentation coefficient for phosphorus.

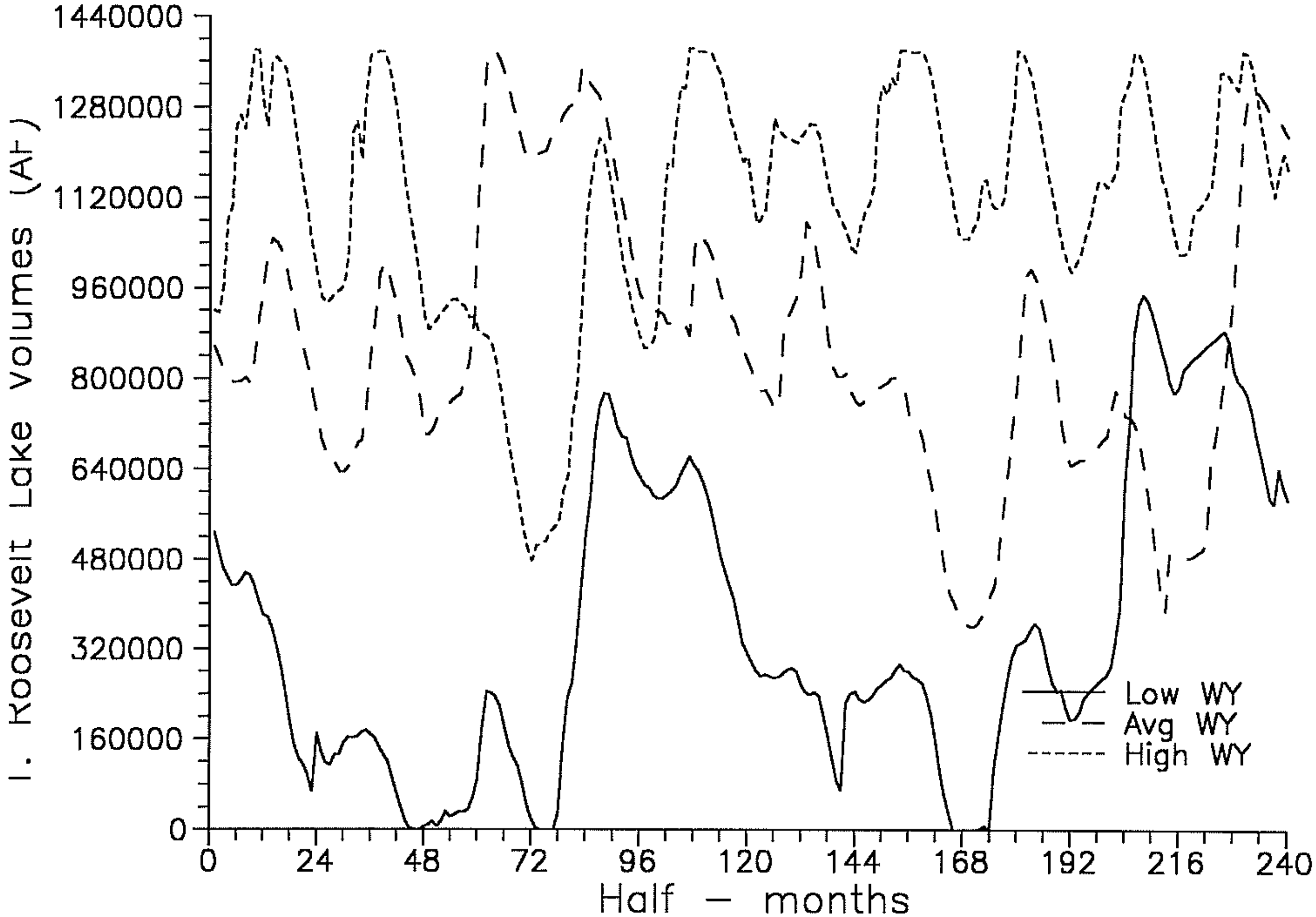

Figure A11. Volumes held in Roosevelt Lake in low-, average-, and high-water years (10 years).

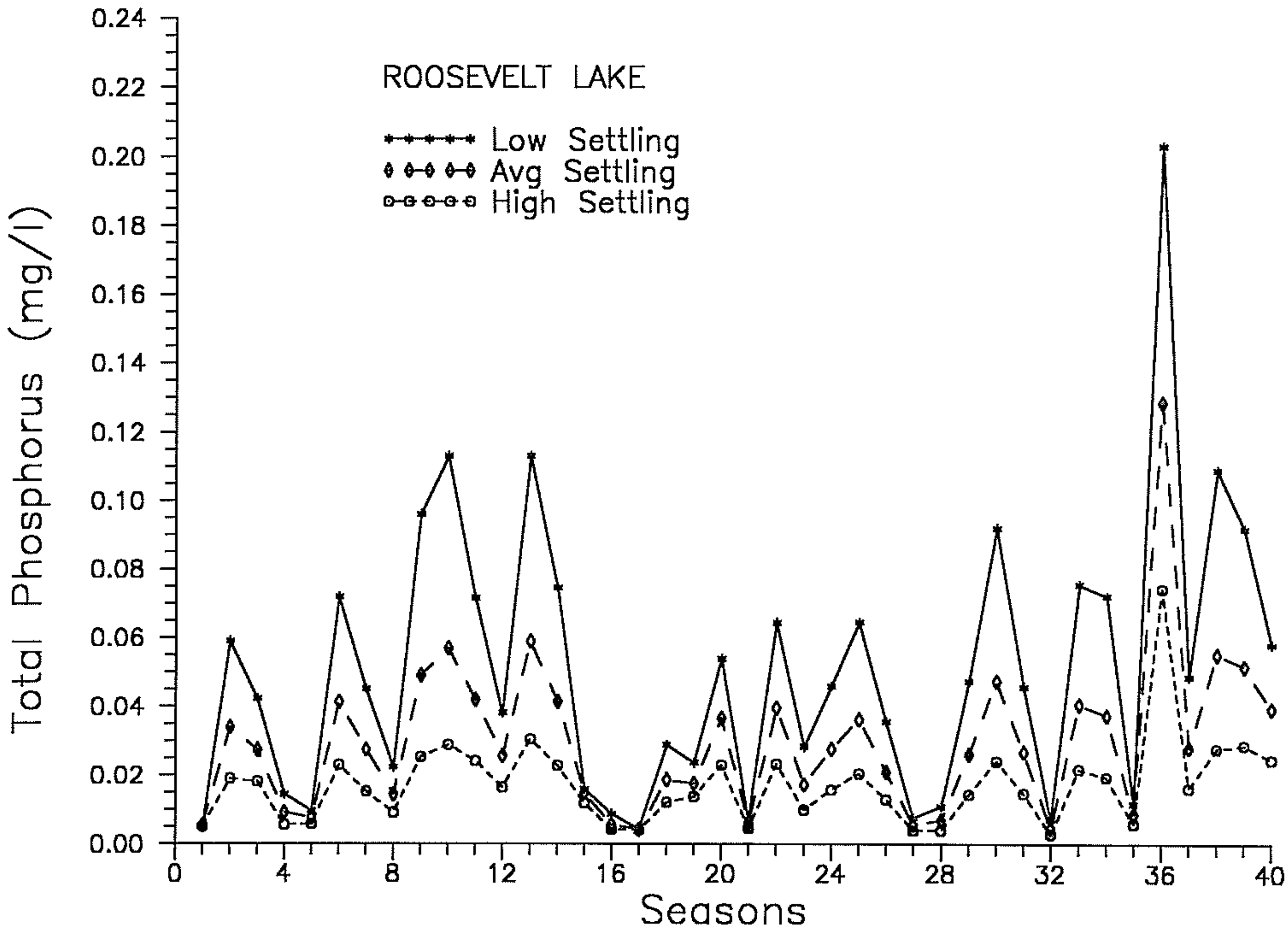

Figure A12. Phosphorus concentrations generated for low-, intermediate-, and high-settling rates used in RIOFISH for intermediate-water levels at Roosevelt Lake.

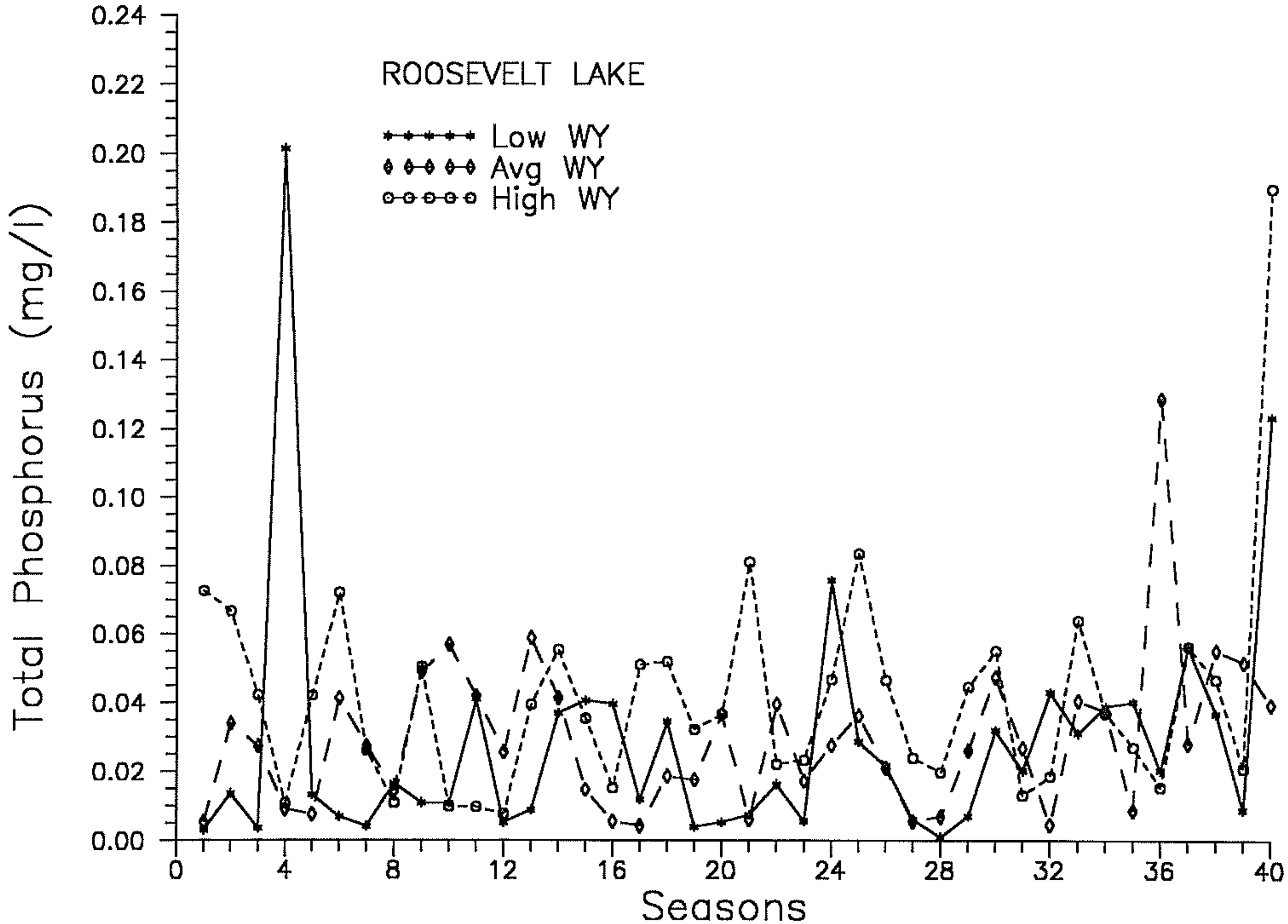

Figure A13. Phosphorus concentrations generated for different water supply conditions for Roosevelt Lake assuming the RIOFISH sedimentation coefficient for phosphorus.