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December 17, 1986

Robert J. Behnke, Ph.D.
3429 E. Prospect Road
Ft. Collins, Colorado 80525

Re: Pueblos of Acoma and Laguna v. City of Grants, et al., United States District Court No. CIV-82-1540M

Dear Dr. Behnke:

Pursuant to our discussions at the continuation of your deposition on Monday, December 15, 1986, I hereby request that you provide me with copies of the four documents you said you had available in your office. My notes from the deposition reflect that these are the four documents:

1. The report on your work for AMAX Corp. regarding water quality of the Clinton Reservoir Fishery;

2. Your 1974 report for the Pyramid Lake Ute Tribe on value of the lost fishery for the Truckee-Carson case;

3. The 1979 version of your monograph for the U.S. Fish and Wildlife Service on the native trouts of the genus Salmo of the western United States (see page 5 of your curriculum vitae); and

4. The updated (1981) version of the U.S. Fish and Wildlife monograph on native trouts of the genus Salmo of the western United States.

I would like to receive copies of these documents as soon as possible. Please send them directly to me. I will provide copies to Stacey Johnson.

If you have any questions, please contact me or Mr. Johnson. Thank you for your cooperation.

Very truly yours,

Kathleen Price Watson

Kathleen Price Watson
For the Firm

KPW:pmc

cc: Stacey A. Johnson, Esq.
Jay F. Stein, Esq.

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TELEPHONE: (505) 247-1144
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January 7, 1987

Dr. Robert Behnke
Dept. of Fishery & Wildlife Biology
Fort Collins, CO 80523

RE: Pueblo of Acoma v. City of Grants, No. CIV 82-1540 M

Dear Dr. Behnke:

Please be advised that all exhibits in the above entitled case must be submitted to opposing counsel by February 3, 1987. Please deliver to our office all proposed exhibits by the week of January 26, 1987.

Thank you for your continued assistance. If you have any questions please call our office at (505) 247-1144.

Sincerely yours,

PAYNE & RANQUIST, P.C.

Stacey A. Johnson

Stacey A. Johnson

SAJ:cjw

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Dr. Robert Behnke
Dept. of Fishery & Wildlife Biology
Fort Collins, CO 80523

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BOVERIE, JACKSON & ASSOCIATES, INC.
210 Clayton Street Suite 3 Denver, CO 80206
(303) 329-8618

January 12, 1987

Dr. Robert Behnke
3429 East Prospect Road
Fort Collins, CO 80525

Re: U.S. District Court, No. CIV-82-1540M
The Pueblo of Acoma, et al., v. City of Grants, et al.

Dear Dr. Behnke:

The transcript of your deposition is now ready for you to read and sign. I believe that Mr. Johnson will be in touch with you to make arrangements for you to read and sign his copy of the transcript.

However, if you so wish, you may come to our offices to read and sign the original transcript, you may do so. Please be sure to make an appointment, to ensure there will be someone here to assist you.

The Federal Rules of Civil Procedure allow a witness thirty days to read and sign his transcript. If we have not heard from you within the next thirty days, we will file the transcript without signature, pursuant to the Rules.

If you have any questions, please do not hesitate to call.

Sincerely,

Becky S. Jackson

Becky S. Jackson

cc: Ms. Watson
Mr. Johnson

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TELEPHONE: (505) 247-1144
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January 15, 1987

Dr. Robert Behnke
Dept. of Fishery & Wildlife Biology
Fort Collins, CO 80523

RE: Pueblo of Acoma v. City of Grants, No. CIV 82-1540 M

Dear Dr. Behnke:

Enclosed please find a copy of your Summary of Testimony in the Acoma Water Quality Case. Please review this summary in preparation for the trial beginning February 23, 1986.

If you have any questions please call our office at (505) 247-1144.

Thank you for your continued assistance.

Sincerely yours,

PAYNE & RANQUIST, P.C.

Stacey A. Johnson

Stacey A. Johnson

SAJ:cjw

Enclosure

Behnke, Dr. Robert - Limologist and Fishery Expert

Subjects: Effect of the sewage effluent on the fishery in the Rio San Jose and in lake Acomita:

Fishery losses and the reasons therefore:

Accuracy of U.S. Fish and Wildlife data used in support of the damage claim:

Support of fishery damages claims:

Estimated time:

Case in Chief:	1.5 hours
Cross examine:	.7 hours

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— My expertise area

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NATIONAL
CHILDREN'S
DENTAL HEALTH WEEK

Dr. Robert Behnke
Dept. of Fishery &
Wildlife Biology
Fort Collins, CO 80523

ASSESSMENT OF POTENTIAL FISHERY VALUES
IN RELATION TO WATER QUALITY
IN THE RIO SAN JOSE AND ACOMITA LAKE,
ACOMA PUEBLO, NEW MEXICO

Robert J. Behnke

October, 1983

ABSTRACT

Fishery and recreational values possible with improved water quality can be greatly increased above previous levels. The present limitations on fisheries in the Rio San Jose and Acomita Lake are not irreversible nor irretrievable.

OVERVIEW

From a review of literature compiled by BIA (Lt. Simpson's reconnaissance in New Mexico and Beale's account of U.S. Army's camel corps), it is clear that the Acoma and Laguana people were excellent stewards of their lands and waters and for hundreds of years they lived in harmony with nature. Under these precaucasian conditions there is no doubt that the Rio San Jose was an excellent trout stream that was not negatively impacted by pollution, erosion, or excessive flow depletion. For example, Lt. Simpson visited the Rio San Jose in September, 1849, in the vicinity of where McCarty's is now located, and found the stream to be ... "about 15 feet wide, lined with willows, and running swiftly over a gravelly bottom." He also noted that: "All along the valley (Laguna to Acoma) the land is cultivated in corn and melons, the luxuriance of their growth attesting the good quality of the soil. The cultivators of the soil are Pueblo Indians belonging to the villages of Laguna and Acoma."

E. E. Beale traveled the San Jose Valley in August, 1857, and wrote: "We find this valley, cultivated by the Indians, in far better condition than any part of New Mexico we have seen." Beale described the original condition of the Ojo del Gallo and its stream as: "A clear, sparkling stream with water as clear as crystal and very cool. It is quite deep, being in many places breast high." Beale and his men found the Rio San Jose and the stream from the Ojo del Gallo to be full of fish which they caught in makeshift nets made from gunny sacks. The fish were described as "trout" (Rio Grande cutthroat trout) and "mullet" (probably consisting of both Rio Grande chub and Rio Grande sucker).

Thus, we have an image of the precaucasian environment where although irrigated agriculture had been in existence for hundreds of years, the Rio San Jose ran clear and cold over clean gravel and contained an abundance of fish including the native cutthroat trout. It can also be assumed that the water flowing in the drainage basin was of good quality (low in dissolved salts). The luxuriant crops described would not have been possible from land suffering salt loading resulting from centuries of irrigation using water of high TDS.

The historical review in the Final Report of Aqua Science Inc., provides some insight into factors causing degregation of the Rio San Jose and the loss of trout spawning habitat. The headwater source, Bluewater Creek, was impounded in 1927, the water diverted for irrigation, and perennial flow from the headwaters ceased. Flow depletion increased from increased groundwater pumping and irrigation use. The Ojo del Gallo, which is estimated to have contributed a constant flow of 7 cfs of high quality water, ceased to flow in 1954. Surface flow from sewage discharge is reported to have first reached Horace Springs in the mid-1950's. It is estimated that the virgin flows in the Rio San Jose at the western boundary of Acoma lands was 19,710 acre feet per year (an average daily flow of about 27 cfs) and the present average annual flow is 5470 a.f. (average daily flow about 8 cfs), 30% of which comes from Grants sewer water. With reduced flows, and increased sediment and pollution loads, trout spawning habitat (clean gravel with clean, well oxygenated flows) probably disappeared in the 1940's and 50's. Perhaps the stream from the Ojo del Gallo was the last spawning habitat available and when this was lost, trout reproduction ceased. As will be discussed in more detail, this loss of spawning habitat is not irreversible nor irretrievable; the problem can be reversed when the sediment transport capacity of the steram exceeds the sediment load (degradation exceeds aggradation); but, I believe, until the problem of the suspended organic colloidal matter in the water is resolved, a "pollution blanket" would cause complete mortality of developing trout eggs.

Stocked trout can survive in the Rio San Jose and grow well under present conditions, as described in Frank Halfmoon's report of November, 1981. Survival of the stocked trout was low (probably about 1% survived for 17 months), which makes it infeasible to attempt to maintain a trout fishery by stocking under present water quality conditions.

According to Mr. Halfmoon's report, the Rio San Jose traverses 13.8 miles of Acoma land (about 20 surface acres of stream) and its fishery potential could be a valuable recreational and economic asset to the Tribe if water quality improved.

The major economic benefits to the Tribe from recreational use of Rio San Jose water has been the fishery of Acomita Lake. Acomita Lake was put into operation in 1939. The information concerning the Acomita fishery available to me covers the period from 1962 to 1982.

Lakes act to magnify nutrients and the negative effects of organic matter (ammonia build-up and oxygen depletion). Due to cursory and sporadic bits of information and data and to differences in operational regimes of the lake, in annual precipitation and temperature patterns (amount of natural runoff into lake in relation to amount of Rio San Jose water), in different stocking programs, artificial fertilization of lake, effects of introduction of crawfish, etc., it is not possible to quantitatively partition the contribution to fishery problems of the influence of the Grants Sewage Treatment Plant, but a solid scenario can be developed emphasizing that the nutrient loading and organic matter input from the STP, above natural levels, led, through time, to a very predictable chronic problem of lake water quality that severely limited the fishery potential of the lake.

In the past, although the lake was heavily used by anglers paying a fee, the Tribe realized only a small fraction of the income possible from the fishery. With improved water quality, imagination, expertise, and a more intensive and sophisticated fishery management and recreational program, the potential exists to tremendously increase tribal income from recreational use of its waters. This potential, however, cannot become a reality until the water quality in the Rio San Jose is significantly improved.

RIO SAN JOSE

As discussed above, the Rio San Jose was originally a high quality stream inhabited by the native Rio Grande cutthroat trout. The native cutthroat trout is like the canary in the mine, it is extremely sensitive to environmental disturbances and is the first species to become extirpated in a changing environment (Behnke 1979). The cutthroat trout was probably replaced by brown trout and rainbow trout in the Rio San Jose many years ago. Brown and/or rainbow trout contributed to a fishery, probably into the 1950's. A New Mexico fishing map issued by the New Mexico Game and Fish Department (no date, but probably put together in the 1950's as no interstate highways occur on map) states that there is fishing in the Rio San Jose: " ... near lava beds and on Acoma Indian Reservation. 10 miles." Mr. Halfmoon's report mentions that Dr. Koster, Univ. New Mexico, collected brown trout in the Rio San Jose in 1940's. Brown trout are rarely stocked from hatcheries, thus it might be assumed that some natural reproduction was occurring in the 1940's. Prior to an experimental stocking of brown trout in 1980, the last stocking of trout (rainbow trout by USFWS) was in the 1960's.

In June, 1980, 3,500 brown trout fingerlings (3-inch size) were stocked into the Rio San Jose (Mr. Halfmoon's report does not give the locality of the stocking, but I assume it was below the irrigation diversion downstream from Horace Springs). In November, 1981, 7 sampling sites, covering 3,430 feet of stream were sampled by electrofishing (one site sampled with rotenone). A total of 12 trout, averaging 12.2 inches were recovered.

This experiment demonstrates that trout can survive in the Rio San Jose and exhibit good growth under present water quality conditions (there is an abundance of invertebrate organisms in this enriched stream). However, survival over the 17-month period appears to be very low. It is difficult to discuss survival in quantitative terms. Only 3,430 feet of stream were sampled, of 13.8 miles (72,864 feet) of stream on the Reservation. The collection of trout, however, was not randomly distributed. Ten of the 12 specimens recovered were found in the first three sites and the remaining two at a downstream site. Thus, it appears that surviving fish stayed relatively near their release point. If a significant number of trout did survive it should have been evident from numerous reports of seeing or catching trout by Tribal members. I would estimate that the 3,500 trout stocked in 1980 suffered greater than 95% mortality over the 17-month period -- the most intense mortality probably coming soon after stocking before full acclimation to degraded water quality was developed.

The question arises on the causes of this high mortality -- habitat or food limitations, predation, chronic or acute manifestation of water quality problems? My observations along the Rio San Jose revealed many sites with deep water and abundant cover, the invertebrates inhabiting the stream are low in diversity but high in numbers. Habitat and food limitations can be ruled out as a cause of the high mortality -- and this decision is validated by the good growth exhibited by the few surviving fish. Among the other fish species known to inhabit the Rio San Jose in the section stocked with trout, one species of sucker and three species of minnows, none are predators. The opaqueness of the water and areas of cover available to the stocked trout would have provided adequate protection against predation by birds and mammals. The most likely cause of the high mortality is the water quality parameters to which the fish were exposed. The presence of an abundance of other fish species surviving in this area indicates that a massive fish kill did not occur from a pollutant, but rather the extreme physiological sensitivity of trout species to low levels of toxicants indicates that chronic sublethal exposure resulted in increased susceptibility to secondary mortality factors such as disease.

The Grants sewage effluent is highly chlorinated. This creates a "sterile" zone downstream from the outfall, free from bacteria that would digest organic matter. Thus, the typical septic zone of high BOD and recovery zone, characteristic of streams receiving organic wastes, is displaced downstream in the Rio San Jose. It was clear from my observations along the Rio San Jose downstream from the sewage plant outfall that considerable "undigested" organic matter is continually transported downstream. In areas of deposition along the streambanks, anaerobic sludge beds occur in abundance. Watersheds in this semiarid region mainly transport inorganic sediment in their stream channels. The source of such quantities of organic matter must be the sewer plant; there is no other logical explanation.

When organic and inorganic (P and N) enrichment occurs, two problems for trout survival may be expected. The enrichment will create zones of prolific algae growth. The rapidly photosynthesizing algae removes CO_2 from the water, raising the pH. The decomposition of organic matter releases ammonia. At higher pH values, a high proportion of ammonia is converted to the unionized form (NH_3) (toxicity increases by 200% from pH 7.4 to pH 8.0) which is extremely toxic to fish, especially trout. Most ammonia toxicity problems are transitory in nature and sublethal but cause increased susceptibility to other unfavorable conditions such as low oxygen levels and infection by disease organisms (Keup et al. 1967; Thurston et al. 1979; Tsai 1975).

After sunset, the algae biomass ceases photosynthesis and begins respiration, depleting the dissolved oxygen in the water. The wild swings in diurnal O_2 values characteristic of enriched waters is exacerbated with organic enrichment because of its high biological oxygen demand. In the presence of extremely low levels of unionized ammonia, oxygen uptake is inhibited in the gill filaments of trout, magnifying the harmful effects of low oxygen. I believe this same phenomenon of the synergistic effect of sublethal unionized ammonia and low diurnal oxygen is responsible for the problems of the Acomita Lake fishery also. Until the nutrient loading attributable to the Grants STP is reduced, particularly a great reduction in suspended organic matter, a viable trout fishery is not possible in the Rio San Jose.

I would point out that for reduction of nutrients in sewage effluent, typically phosphorous (P) is emphasized, but in the case of the Rio San Jose, I doubt that even a considerable reduction in P will significantly

recude aquatic plant production unless nitrogen (N) is also reduced proportionally. Typically, P becomes limiting to aquatic plant growth when its ratio to N is about 1:10. The N and P values I read for the Rio San Jose indicate the P to N values are only about 1:2-1:3. Thus, unless P were to be reduced by 4-5 times, there would still be a surplus available for plant growth. It is typical for western waters to have relatively high P values in relation to N. It is the nitrogen, not phosphorous that is the limiting nutrient.

If better water quality could be achieved, the Rio San Jose could become a viable trout fishery, but it would require additional effort to restore the stream to pre 1940(?) conditions.

Is it possible to develop a water use budget for the reservation? Most beneficial for fishery values would be a minimum flow bypass below the irrigation diversion below Horace Springs to supplement the flow of Anzac Spring and maintain some minimum flow through the Rio San Jose channel. With some constant flow (perhaps a minimum of 2-3 cfs) of clean water, silt and sediment would be continually removed from the stream channel, but only if sediment input were to be reduced. To reduce sediment input and greatly improve trout habitat, livestock should be fenced from the streambanks and all irrigated lands thoroughly checked to prevent spills of sediment laden return irrigation flows. Once erosion and sediment input are controleld and streambanks stabilized, stream improvement devices and trout spawning sites can be installed and created to establish a viable, self-reproducing trout population (Behnke and Raleigh 1979).

The Rio San Jose flows through 13.8 miles of Acoma lands and consists of about 20 surface acres. With clean water, adequate flows, and stream improvements, a yield of about 1,000 pounds of trout per year should be possible from natural reproduction, and supplementary stocking with hatchery raised trout can increase the catch as much as desired. A viable trout fishery would be a high value resource to the Tribe. Besides the recreation and food provided to Tribal members, one part of the stream could be opened to the public on a fee basis (the potential clientele for a wild trout fishery in a stream are willing to pay considerably more for this angling opportunity than are lake fishermen) and incorporated into the Tribal recreational enterprise.

Van Velson (1978) published a documented history of Otter Creek, Nebraska, a small stream that was changed from a silt laden water dominated by minnows and suckers, into a clear stream characterized by clean gravel ideal for trout reproduction. Within a few years trout became completely dominant in numbers and biomass over the minnows and suckers. This change resulted by fencing livestock from the stream which reduced sediment input, stabilized banks, restored riparian vegetation, and created improved habitat and clear water (I have a slide show of the Otter Creek Story).

ACOMITA LAKE

Acomita Lake was filled in 1939. My information on the fishery were supplied by Mr. Frank Halfmoon and are for the period 1962-1982. The lake, when full, has a surface area of about 70 acres. The present storage volume is 710 acre feet, which is 24% less than the original volume. Examination of a map depicting 1937 and 1982 contour lines of the lake bottom (Acomita Lake Sedimentation Survey) indicates an interesting phenomenon concerning the filling of Acomita Lake. The filling has not proceeded from inlet to outlet, as would be expected if inorganic sediment was the main component of the fill material, but occurs from outlet (dam) to upper end of lake. This suggests that suspended organic matter, carried in from Rio San Jose water, is the major contribution to filling of the lake.

From the early reports in 1960's, it is apparent that Acomita Lake provided an environment conducive to rapid growth of trout. Two inch fingerling trout stocked one year would average 14 inches or more the following year. Growth continued during winter months, avaraging .5 inches per month and increased to 1.5 inches per month during late spring and summer. No nutrient data are available but it is obvious from notes on fish growth, food abundance, and vegetation problems that Acomita Lake waters were enriched. This can also be assumed on the basis of comparable lakes with relatively long retention time of inflow water that through biomagnification nutrient values (N and P) can be expected to double from values in inlet water. Despite this natural enrichment, Acomita Lake was artificially fertilized in 1964 and '65 with annual applications of about 17 pounds per surface acre of P and 21 pounds per acre of N. It is interesting to note, that despite the predictable increase in plant growth and rise in pH (to 9.9), no large-scale fish kill was reported.

Acomita Lake appears to have only weak and temporary stratification in the summer. During stratification, however, the large accumulation of benthic organic matter decomposes, creating anoxic conditions and hydrogen sulfide in deeper waters. Several references are made to the foul stench (H_2S) of the outlet water. Evidently wind action would break down the stratification and aerate the lake every week or two during the summer, preventing massive fish kills. The foul outlet water removed when the lake is stratified acts to remove nutrients concentrated in the hypolimnion and this may well have prolonged the life of the lake as trout habitat.

In the early 1960's, crawfish were stocked as a control of problem macrophyte vegetation. They flourished and did the job too well. In the early 1970's most rooted vegetation was gone and the water was often a brown color (from wind action stirring bare bottom soils and/or foraging action of crawfish) and fishermen complained that crawfish stole their bait. This indicates that channel catfish did not reproduce in Acomita Lake. Crawfish are a preferred item in the diet of channel catfish and I would assume that if catfish reproduction was successful, the catfish would have increased in response to the food supply and the resulting predator-prey interaction would have kept the crawfish population under control. In a 1982 report, Mr. Halfmoon commented on the problem of macrophyte vegetation choking the lake (similar to the early 1960's). What happened to the crawfish? No mention is made of their elimination.

It is evident from the 1960's that Acomita Lake was always in a precarious state during summer months when stratification occurred. The longer the lake was stratified the greater the volume of anoxic water and production of ammonia to be converted to toxic unionized ammonia by high pH. However, large scale fish kills were never observed and survival from one year to the next appeared to be good (based on number of larger, "holdover" trout in catch). In 1960's some rainbow trout must have survived for three years or more in the lake as some fish of 24-25 inches were reported. In the 1970's, it appears holdover survival was reduced and the maximum size of trout were 18-19 inches. In 1977 the first reports of channel catfish mortality were noted, which continued through 1982. Dead catfish were found to carry <u>Aeromonas</u> bacteria but this bacteris is ubiquitous and typically contributes to mortality as a secondary factor under stressful

conditions. I would suggest that the stress would come from the synergistic interaction of low O_2 and high unionized ammonia that would be expected to be localized in shallower water where macrophyte vegetation was dense (rapid daytime photosynthesis removes CO_2 and raises pH, increasing concentration of unionized ammonia, whereas nighttime and dim light respiration causes oxygen depletion and stress on fish). These impacts would be expected to be much less severe in the deeper open water of the lake inhabited by trout.

By the late 1970's long-term survival of both trout and catfish were reduced from earlier levels and the fishery had to be maintained by stocking catchable-sized trout and catfish. The valuable fish culture capacity of Acomita Lake -- the stocking of small fingerling fish and letting them grow to a large size on natural foods for two or three years -- had been lost. Although there are no limnological data available to me to document any trends of environmental conditions, the history of fishery problems resulting from nutrient loading follows a predictable pattern and is in agreement with case history studies of other lakes (Fisher and Ziebell 1980; Taylor and Hams 1981; Vigg 1983). Figure 1 illustrates the predicted problems resulting from nutrient loading of a lake through time and the maintenance of adequate salmonid habitat during summer stratification.

I would suggest that if Frank Halfmoon has addresses for Jack Dean and Terry Merkel (former USFWS biologists involved with management of Acomita Lake) he send them copies of this report and request their comments and any additional information they might provide.

The quality of the fishery of Acomita Lake and its proximity to Albuquerque made it a highly popular fishing site. Daily permits were sold for one dollar a day or three dollars per season in the 1960's. Use and income steadily increased to 1970 when the fishery received 17,000 person-days of angling (about 70,000 angling hours or 1,000 hours of angling per surface acre) and fees collected amounted to $16,861. In FWS annual reports by Jack Dean, it was recommended another lake be constructed to take advantage of the increasing demand.

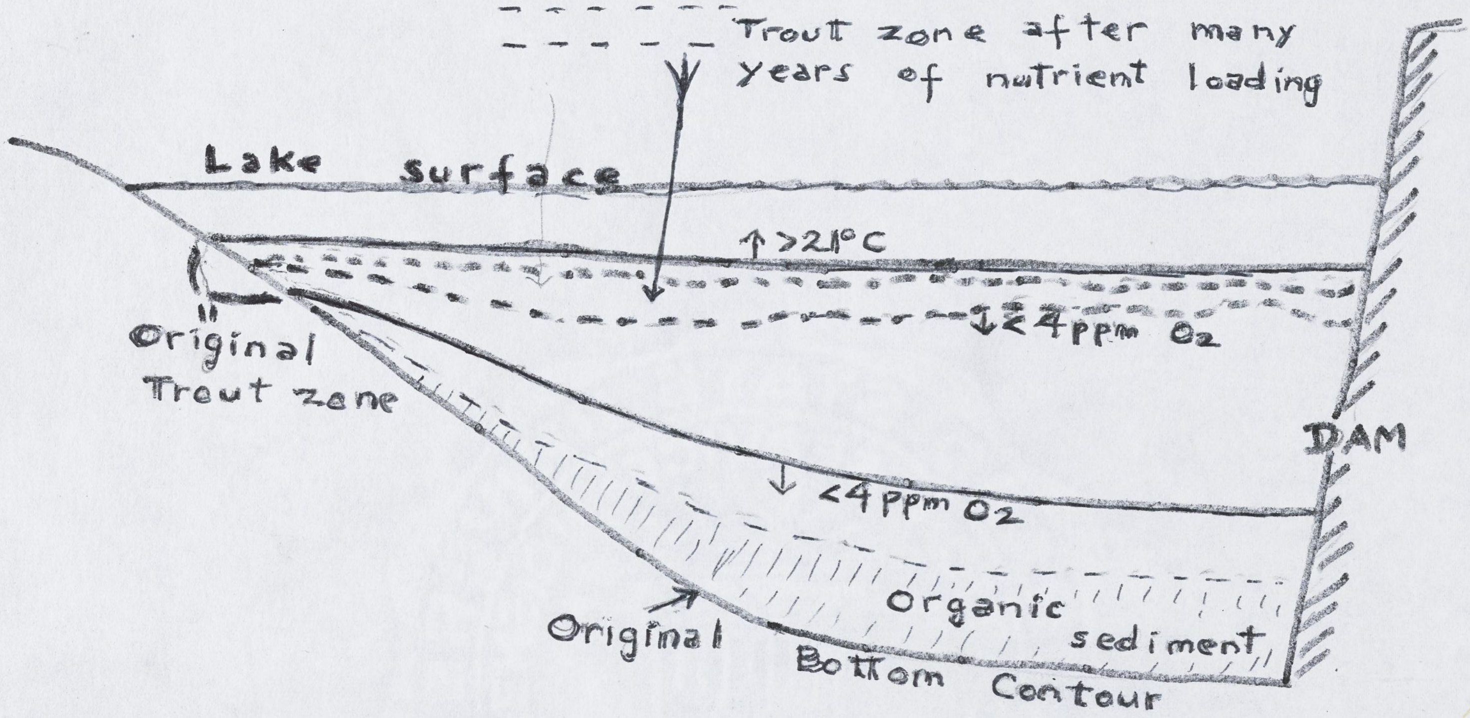


Figure 1. Illustrates a predictable course of fishery problems in an impoundment receiving waters enriched with inorganic and organic nutrients. After many years, organic sediment builds up reducing volume and depth of lake and binding nutrients that are released under anaerobic conditions. During summer stratification, the increasing BOD in the hypolimnion continually reduces the thermocline area that is inhabited by trout, defined by a combination of temperatures less than 21° C and dissolved oxygen of more than 4 ppm. Chronic problems of sporadic mortality and distressed fish may be expected for several years before a massive fish kill occurs.

Although somewhat beyond the scope of my report, I suggest that if improved water quality is available in the future in the Rio San Jose, then there are opportunities to greatly increase the economic returns from the fishery over previous levels. Until 1970 the Tribe received an average of only $1 per day of recreational use of their waters. The economic evaluation of a day's fishing can be figured in many ways, but a synthesis of all costs (fishing tackle, travel, food, lodging, license, permits, etc.) averaged about $25 per day's fishing (about 3 hours of actual angling) according to 1980 data compiled by the USFWS. A future goal should be to have the Tribe receive a significantly greater portion of the average daily cost of an angling day. A 1980 report of the Missouri Conservation Department to the Corps of Engineers documenting the value of the rainbow trout fishery in Lake Taneycomo to the local economy (based on income multiplier method), arrived at a figure of $9.9 million from 1.5 million hours of angling, or more than $6 per angler hour.

Clawson (1965) divided anglers into three basic groups for economic evaluations, casual, active, and purist. The "casual" angler chooses a recreation area because fishing is available, but the actual fishing experience and the catching of fish is not of primary importance. The "active" angler's primary concern is catching many fish and bringing home a limit. The "purist" angler's primary enjoyment concerns the angling experience of fishing for a favorite target species on artificial flies or lures, but not killing a "mess" of fish. Most of the catch of the purist is returned to the water. Both the casual and purist angler invest more, on average, for a day's fishing than does the "active" angler, and they have much less impact on the fish population. That is, each fish generates more dollars per hour of angling from the "casual" and "purist" group than it does from the "active" group. I suspect that the angler clientele of Acomita Lake has been overwhelmingly from the "active" group in the past.

Increasing the fishery valuation of Acomita Lake would require more intensive management and investment.

For the lake fishery, besides domesticated rainbow trout and channel catfish I would recommend the use of the more thermally adapted and high pH adapted redband trout (Behnke 1979) currently propagated at the Ennis, Montana National Fish Hatchery. The redband trout along with brown trout and Snake River cutthroat trout could be stocked as fingerlings and

allowed to grow in the lake. This management strategy, if successful, would greatly increase total trout production by interspecific ecological segregation (Trojnar and Behnke 1974) and provide long-lived trout that could be expected to live for several years in the lake and reach trophy sizes (trophy trout that would generate publicity for the lake's fishery and attract the "purist" group of anglers). To be maximally effective, domesticated catchable size rainbow trout could be regularly stocked from April-July for the "casual" and "active" groups of anglers. The "wild" trout, stocked as fingerlings, would be expected to have distinctly different feeding and behavior patterns and should not be excessively harvested by anglers fishing for the hatchery rainbow trout. Early, and late in the season (for example, October 1 to April 15). A special regulation trophy fishery could be instituted, for example, a bag limit of one or two trout with a minimum size limit of 18 inches, and artificial flies and lures only. This season would attract mainly the purist group. The vegetation problem that has consistently plagued Acomita Lake was controlled when crawfish were very abundant, but the lack of vegetation and excessive crawfish abundance caused other problems. The solution to this problem would be to establish balanced predator-prey interactions between fish-crawfish-vegetation. If successful, crawfish would maintain an abundance sufficient to control nuisance vegetation but when "too much" vegetation is eliminated the crawfish would be exposed to intensive predation by fish.

In the past, channel catfish and brown trout were the only species in the lake that would be expected to be effective predators on crawfish, but they did not occur at sufficient density to be effective control agents. In addition to the channel catfish, I would recommend smallmouth bass, an extremely effective crawfish predator, be stocked. Smallmouth bass would probably need protective regulations (for example, release all bass between 10-16 inches) to maintain adequate predation pressure on crawfish. The goal would be to make the crawfish an asset by being both a weed control agent and a food supply for valuable fish. Crawfish are an ideal food for fishes because they are efficient assimilators of energy from diverse trophic levels and in turn supply a large food item that favors feeding segregation between small and large trout (zooplankton feeders and "large item" feeders on crawfish and fish). I would point out that the redband trout is a specialized predator on chubs of the genus Gila.

I would also suggest the possibility of introducing a few (10-15) grass carp into the lake as a weed control agent. I have no doubt that they would survive in the lake and actively consume macrophyte vegetation. They would not reproduce and they could not reach the Rio Grande if they escaped from the lake.

With an excellent fishery with an appeal to a wide spectrum of anglers, fees and support facilities should be planned to maximize income. A parking fee could be instituted, RV and camping facilities and simple cabins could be constructed for those desiring to spend more than one day at the lake, and this would also be attractive to travelers on the interstate highway. With other services, a goal might be to average $8 to $10 return per recreational day with an annual use of 25,000 recreational days for Acomita Lake (and more if a trout fishery were to be established in the Rio San Jose).

The point is that realization of potential fishery value is dependent on better water quality (significant improvement of Grants STP). The potential gains possible with better water quality from a more intensively managed fishery and recreational enterprise (and conversely the potential loss suffered by continued poor water quality) is $100,000's annually.

RECOMMENDATIONS

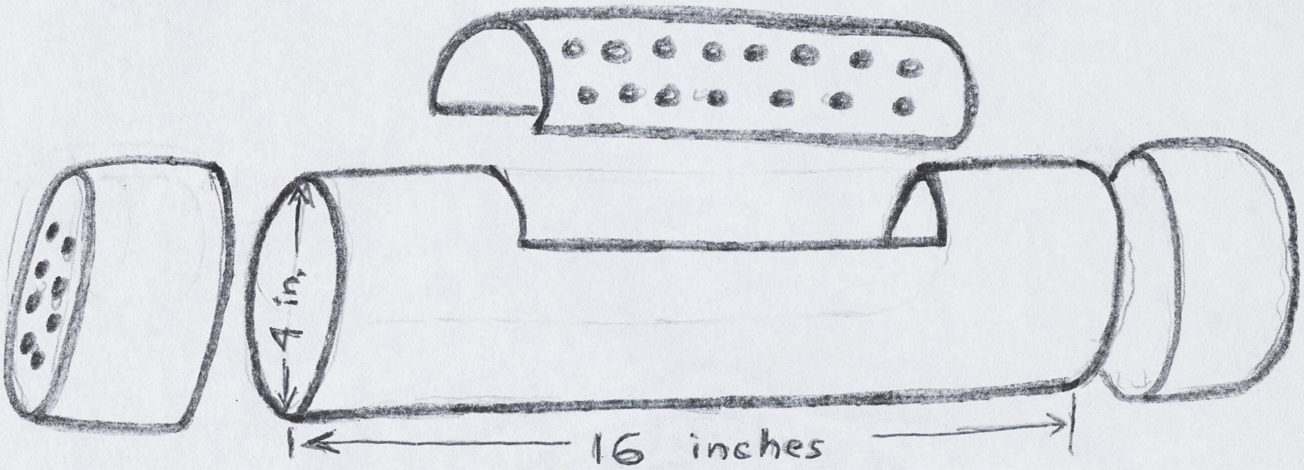
A fishery-recreational enterprise plan should be developed along the lines indicated above. Such a plan, contingent on improved water quality, would demonstrate that future options foregone by continued water quality degradation, are worth $100,000's annually to the Tribe, not simply the $10,000-$20,000 range of fishing fees formerly collected at Acomita Lake.

The plan should detail what measures might be instituted by the Tribe to greatly improve the fishery potential, such as development of a water budget recognizing fishery values by minimum flows in Rio San Jose, operation of Acomita Lake storage to increase both inflow and hypolimnetic outflow during periods of summer stagnation and a strategy to maintain certain annual levels in the lake designed to benefit the fish and fishermen. The creation of habitat improvement structures in the Rio San Jose, livestock fencing and irrigation management to reverse erosion and sediment input.

A more sophisticated stocking and management strategy for Acomita Lake that would maximize production of valuable species by utilizing interspecific niche diversity in concordance with trophic diversity and habitat diversity of the lake ecosystem. A strategy designed to appeal to a wider spectrum of anglers with a goal of greatly increasing the return to the Tribe of daily fishing expenditures. Discussion of expanding facilities to include RV and camping areas, simple cabins, etc. and the possibility of construction of a new lake after a certain level of use is attained (for example, 15,000-20,000 person days of use).

In view of the fact that water quality problems such as drastic diurnal fluctuations of O_2, pH, and uionized ammonia, that can be lethal to fish, are transitory in nature and likely to be undetected by intermittent water quality sampling, I recommend that live fish be used for continuous monitoring. Typically, fathead minnows are used for this type of monitoring, but any readily available species can be used as long as the same species or species combinations are placed in each of the live boxes. The information that can be documented by such a monitoring program includes: the distance below the sewage outfall with lethal conditions (chlorine alone will likely kill fish within 6-12 hours for a mile or more below the outlet, and the zone of lethal oxygen levels can be expected to change with the season). The frequency of lethal conditions at various downstream points through time (my observations above Horace Springs indicate that occasional fish kills occur at some regular interval); and a valuable documentation lending itself to simple charts and graphs that could be impressive evidence in court.

Live boxes can be of various sizes, shapes, and materials. Figure 2 illustrates a live box for 10 fathead minnows used by Dr. G. Fred Lee for monitoring below sewage outfalls. Typically stations are set up with an upstream or downstream station outside the limits of sewage impact to act as a control. The site downstream from the sewage outfall that is lethal to all fish in 24 hours can be first determined by setting live boxes out in a regular downstream pattern, about .5 miles apart and checking the following day. When this point is established (lethality here would be from chlorine), regular stations could be established, perhaps at the



Body is 16 in. section of 4 in. diameter PVC pipe. Ends are 4 in. end caps of PVC and cover is split PVC pipe with 1/8 in. holes.

Figure 2. Type of fish container used by G. Fred Lee (adapted from: Application of the hazard assessment approach for establishing water quality classification for Fountain Creek and appropriate water quality standards for this classification. G. F. Lee, 1980). A series of these containers, each with 10 fathead minnows, were placed below sewage outfall (one box above the outfall was control) about .5 - 1.0 mile apart to delineate lethal zone.

same sites as water quality sampling stations, fish set out and checked with frequency needed to document such aspects as sites with 50% survival for 24, 96 hours, and one week. Thereafter boxes could be checked each week (new fish added as necessary) to monitor for sporadic lethal conditions that might be missed by water quality sampling. Accurate records must be maintained from all observations and dead fish should be labeled as to site and date and frozen for possible use as evidence.

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19 Jan 84

Dear Bob:

I finally got the Acoma report and am returning it with some scribbles. Here are some general comments.

1) What is the status of R. Grande cutthroat? is there any chance of using End. Spp. Act to enforce water quality clean-up?

Were I the city of Grants I would go after the survival of 12 browns

in 3.4K feet of stream. Since these fish lived + grew well they can argue a) the H_2O quality isn't toxic and that other factors must have caused high mortality b). Perhaps most of the browns stocked moved out downstream and didn't die afterall. - Your suggestion of *in situ* bioassays should be an effective + dramatic proof one way or the other. - This is particularly important since you really are going out on a limb w/ speculation on the bottom of page 4 (I guess thats what consultants get paid for though!)

2). Without documentation of pH, NH_3, O_2 levels etc. much of what you say is generically true but - does it actually occur in Rio San Jose, or Acomita Lake? You desperately need documentation of H_2O quality if this goes to court - or perhaps one court approach is to get them to order city of Grants to give $$ for water quality study.

3) The management recs. seem good and reasonably achievable. - althou you suggest quite a potpourri of fish species. It is unfortunate, but my experience w/ Indians often indicates great recreational and economic potential, but it's seldom realized due to a) too few $$ to get it going b) lack of Tribal continuity to carry the ball. Maybe some mitigation $ awarded by court to be used *exclusively* for fish mgmt. ↓ or gained from Grants via outside of court settlement.

The costs of N removal (unless land application is used.) are very high. R. Gersberg + C.R. Goldman published a paper in recent Wat Res. (?) where they show fantastic N removal in arid areas by passing effluent thru a marsh. - Its cheap, biologically sound and creates bird + bunny habitat too.

I also got your △ LCT paper - but haven't gone over it yet. - I reviewed + gave copies to S. Vigg, PLITE + USFWS. - Did PLITE or FWS ever send you any info? Mark Coleman (702) 784-5227 FTS- 470-5227 is their expert on LCT area. He really is the one w/ the scoop on things. Maybe you should call him up? I'll get you my thoughts ASAP

Things are going along well at DRI. I wasn't quite prepared for the shambles their aquatics program was in, so I'm starting from [1] trying to update limnological methods, boost moral, instill a little professionalism, etc. I've got funding for 1 year and will give it all I've got - The potential's there. The Acoma problem sounds interesting, and you know my tendencies towards Indian resources - so if you think DRI could assist, I'd love to help get the numbers to prove (oops! "test") your statements. However, D. Porcella is a very competent, albeit expensive water quality man.

I've got two favors to ask - Could you write me letters of recommendation for two faculty positions. (Assistant Professor - for both).

Freshwater Ecologist
Dr. S. G. Fisher.
Department of Zoology.
Arizona State University.
Tempe, AZ 85287

Science Vol 223 pg 204.

Due Feb 1 - sorry for the short notice.

and appropriately enough: Freshwater Biologist
Chairman, Fresh Water Biology Search Committee.
Department of Biology.
The University of New Mexico
Albuquerque, NM 87131.

no letters

due Feb 20.

Science Vol 222 pg 1360.

I don't know how well you get along w/ Minkley, but I'm sure he will have much to say about the AZ slot. Stue Fisher tells me they want someone w/ a broad limnology background. I don't know much about the NM position, perhaps you know some of the Biology Faculty there - you might also want to tell Dave Probst about this one since he has strong interest in NM.

Eric B. tells me ole' Cook never came thru w/ money for fisheries following Posts retirement - I never trusted that fellow and am glad I made the choice I did. However, soft-money makes me feel like a used-car salesman. - I would really love a shot at a university slot - hence the continuing search for a "permanent" job.

I miss Bill McConnells cynicism terribly. He's the only one who can keep us all honest. I also sympathize w/ Eric's plite, particularly w/ Cook. - I think your approach may be the best at CSU. Give my regards to Miller, Muth, Snyder, Carlson, Fausch + the rest of the crowd - I will be back to CSU for the Ecol. Soc. meetings. + if Sponsored Research can't get my old project straightened out - probably much sooner.

Be well

David

P.S. to get you this quickly I do not included thesis but will mail separately.

DG

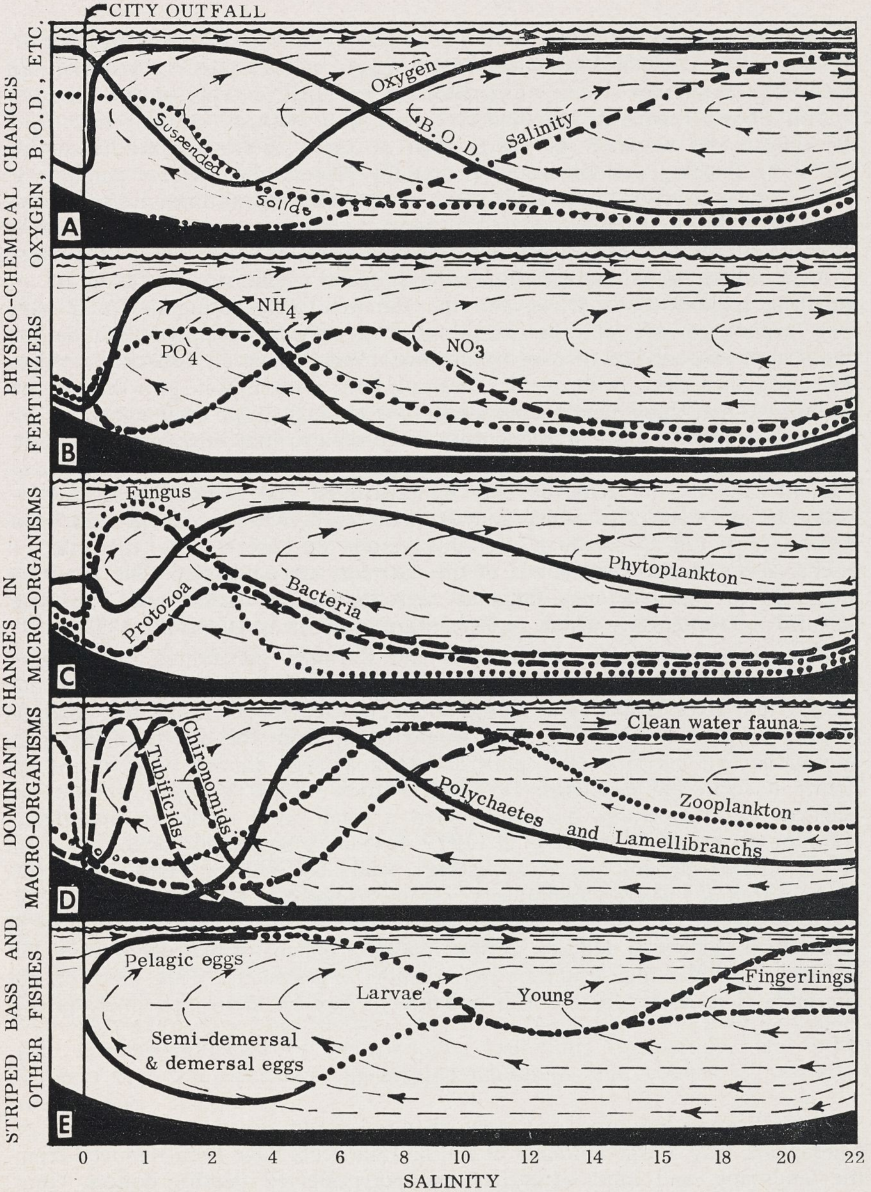

FIGURE 5. Gross simplication of hypothetical changes in a typical two-layered estuary of Chesapeake Bay brought about by mineralized fertilizers produced by man downstream from a metropolitan outfall: A and B — physical and chemical changes; C and D — changes in microscopic and larger biota; and E — relationship to species of fish spawning in tidal fresh or slightly brackish water. Based on ideas and data from Hynes, Nash, Wolman, et al., Pritchard, Massmann, et al, Frey, Newell, and original data.

et al (1957:426-9), and Pritchard (1960:25-7), with particular reference to the Potomac and Patuxent Rivers. The graph cannot possibly indicate the potentially dangerous effects of fertilization on algal growths in estuaries. As is well known, estuarine circulation results in a sort of nutrient trap, and the tidal cycles enhance the metabolism of such materials. Those estuaries with long flushing periods would potentially present the greatest dangers of forming algal concentrations, while those with short removal times might dispose of nutrients before they are effectively used. In general, a flowing system will be more productive than a standing system. Thus, the difficulties with algal growths which have increased in inland areas would not be as great in estuarine regions. Back River and the Potomac River estuaries, both with long flushing periods, may be exceptions since they are examples that harbor the disagreeable aspects of over-fertilization (Wolman, et al, 1957:426). Also, the analogous cases with water chestnut and watermilfoil growths in the Potomac estuary and upper Chesapeake, which may have been enhanced by increasing fertility, must be recognized as conditions that might become more complicated. Useful enrichment of estuarine waters by organic matter and nutrient salts can be achieved only by controlled and balanced fertilization. Pollution and fertilizers which may contain carbohydrates, phosphates, and nitrates may fail to produce desirable results because neither the rate of discharge nor the concentrations of the nutrients are controlled. The resulting inbalance of nutrients may enhance reproduction of useless and sometime harmful microorgaisms which replace the useful forms (Galtsoff, 1959:128).

The above mentioned qualifications and warnings concerning the dangers of increasing fertilization suggest the great need for model studies of the estuary and river basins. The model could be used to determine the changes in tidal range and circulation that would result from the effects of physical alterations and barriers. One constructed on a large enough scale might be useful in ecological problems. Dr. Ruth Patrick of the Academy of Natural Sciences of Philadelphia has constructed a small river model to investigate pollution problems. Wolman, et al (1957:424) have suggested the construction of a model of the Potomac River estuary, while Dr. William Hargis, Director of the Virginia Fisheries Laboratory, recently suggested that a huge model of the Chesapeake Bay system be constructed over an area consisting of several acres. Such models, in addition to illuminating problems of hydrography, might be useful in planning estuarine fertilization experiments. This kind of an approach is necessary before fish populations can be controlled in estuaries.

CONCLUSIONS

1. Civilization has produced great changes in the aquatic environments of Chesapeake Bay. Large amounts of soil and nutrients have been removed from the landscape, and most of it has markedly affected depths, bottom communities, water circulation patterns, and the species composition and abundance of estuarine biota. These changes, many wasteful, some inevitable, and others beneficial, have not overall greatly reduced the potential productivity, although the carrying capacity of the Bay has been reduced. Man has compensated for such changes by adding to the fertility of the waters. In spite of all the changes wrought by man up to now, Chesapeake Bay has been remarkably resilient, and it is still considered a relatively unspoiled region.

2. The biota has been subjected to density-independent and density-dependent factors. The former has produced permanent and devastating effects through sedimentation, pollution, wetland reclamation, and dams. Although the dams may reduce some migratory fish movements, their principal danger in the future on existing estuarine life will be the effects on the circulation, flushing, and tidal patterns through water-flow regulation upstream. Highway and general construction, detergents, pesticides, and radioactivity also loom large in the future of estuaries. Density-dependent effects produced by man's systematic seafood harvests and his meager attempts at manipulating or cultivating estuarine crops have had little effect on the long-range productivity of the Bay. Marked changes in size and age composition of fish have occurred, but total biomass is little changed by exploitation. He has yet to extirpate a species before the unprofitable return forces him to exploit another available resource.

3. A hypothesis was advanced that civilization and striped bass populations are compatible, i.e. increasing fertilization by man may be indirectly responsible for the unusual increase in number and magnitude of dominant year-classes. Human population growth has resulted in increasing loads of silt, wastes, and fertilizers in the estuary, and these have created high turbidity, low light penetration, low dissolved oxygen, high B. O. D., and excessive sedimentation in the upper estuarine spawning areas of fish. The striped bass produces pelagic eggs and larvae that are preadapted to these waters, while demersal or semi-demersal eggs deposited by other species that spawn with striped bass have less chance of hatching or surviving under these conditions. Also, probably more of the buoyant floating eggs and larvae of striped bass reach the area where salinity neutralizes and precipitates the suspended particles. Here turbidity is reduced, light penetration is optimal, and photosynthesis creates a rich productive grazing area for zooplankton. Other species, of course, reach this area, but they probably do not produce excessive competition for striped bass.

4. The problem of excessive and uncontrolled mineralized fertilization into estuaries with low flushing times is very great since they might produce tremendous algal blooms, with consequent deleterious effects on many organisms. An imbalance in such nutrients could enhance reproduction of useless or harmful micro-organisms to replace the useful forms. Beneficial enrichment of estuarine waters by organic matter and nutrient salts can only be achieved by controlled and balanced fertilization. There is an urgent need now for the construction of a huge model of the Chesapeake Bay watershed to investigate various problems of hydrography, pollution, fertilization, and other subjects that will contribute to reliable prediction and control of estuarine populations.

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evaluation of the long-term effects of the major changes brought about by man. Some are obvious, others are less so, but nevertheless important. Therefore, much of the following presentation must be regarded as provisional and suggestive, rather than conclusive.

Many people contributed facts, leads, and ideas in the development of this paper. Mr. G. Francis Beaven and Mr. Donald Meyers, biologists at the Chesapeake Biological Laboratory, have been especially helpful.

RESULTS AND DISCUSSION

Chesapeake Bay, a highly productive estuary, produces annually about 80 pounds of seafood per acre (Quittmeyer, 1957:26). The area also is used extensively by a wide variety of maritime interests (United States Army Corps of Engineers, 1961:1-57). Activity in the Susquehanna River, part of the upper watershed of the Chesapeake, has also been very great (Mansueti, 1958:1-14). The seafood harvest of Chesapeake Bay states has remained at a relatively

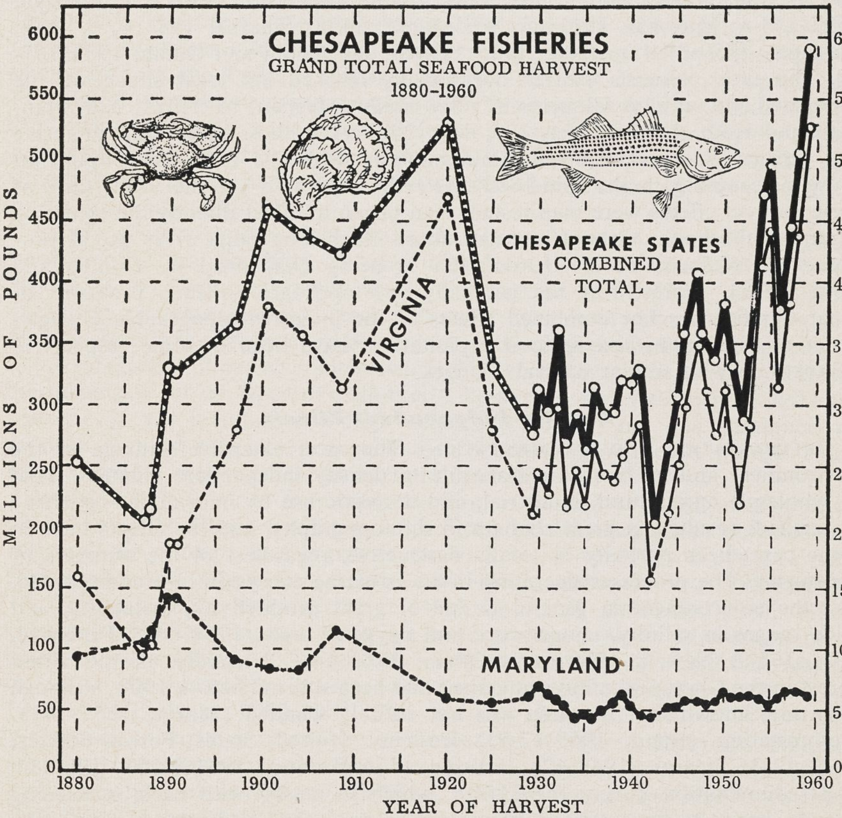

FIGURE 1. Trend of seafood harvest of all shell- and fin-fisheries in the Chesapeake Bay states for the period during which records were available. Broken lines signify lapses in the records. Data based on catch records derived from official Maryland and Federal sources.

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NITROGEN REMOVAL IN ARTIFICIAL WETLANDS

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Abstract—This report describes investigations which have demonstrated the exceptional utility of artificial wetlands for the removal of nitrate from secondary wastewater effluents at relatively high application rates. The artificial wetlands (14 in number) were plastic-lined excavations containing emergent vegetation growing in gravel. Without supplemental additions of carbon, total nitrogen removal efficiency was low (~25%) in both vegetated and unvegetated beds. When methanol was added to supplement the carbon supply and stimulate bacterial denitrification, the removal efficiency was extremely high (95% removal of total nitrogen at a wastewater application rate of 16.8 cm day^{-1}). Since methanol is a relatively expensive form of carbon, we tested the feasibility of using plant biomass, mulched and applied to the surface of marsh beds, as an alternate source of carbon. At a wastewater application rate of 8.4 cm day^{-1}, the mean total nitrogen removal efficiency for the mulch-amended beds was 86%. When the application rate was higher (16.8 cm day^{-1}) the mean total nitrogen removal efficiency was lower, 60% in the mulch-amended beds.

By using plant biomass as a substitute for methanol, the energy savings for a treatment facility serving a small community (3785 $\text{m}^3\,\text{day}^{-1}$ or 1 mgd) would amount to the equivalent of 73 l day^{-1} of methanol. As the cost of fossil fuel increases, energy cost will become a predominant factor in the selection of small (0.5–5 mgd) wastewater treatment systems. However, in many cases where natural wetlands are either geographically unavailable or protected from wastewater discharge by environmental, legal, or aesthetic restraints, artificial wetlands offer a viable alternative for energy-effective treatment of municipal and agricultural wastewater effluents.

INTRODUCTION

In arid regions, such as the Pacific Southwestern U.S., water reclamation and reuse offer great potential for replenishing surface and groundwater supplies especially where conventional water sources are scarce and increasingly more expensive to develop. In many instances, however, the beneficial reuse of both municipal and agricultural wastewaters has been hindered by the lack of cost effective and energy efficient processes to remove problem constituents such as nitrogen. In spite of this fact, the concurrent use of surface waters and groundwaters for both water supply and waste disposal is a reality in many regions and increased nitrogen loading to the environment has resulted in accelerated eutrophication of receiving waters. Additionally, in many areas where irrigated agriculture or land application of wastewater effluent has been practiced for long periods of time, high levels of nitrate have been found to contaminate groundwater aquifers. If this water is then used for domestic supply, there will be an increased risk of methemoglobinemia in human infants due to the elevated levels of nitrate in the ingested waters (Miller, 1971; Shearer *et al.*, 1972). On this basis, the Committee on Water Quality Criteria of the National Academy of Science (1972) recommended that the nitrate concentration in public water supply sources not exceed 10 mg N l^{-1}.

Recently, considerable attention has been directed towards the use of wetlands as water purification systems and nutrient sinks which could alleviate the detrimental impact of municipal and agricultural wastewater discharge to surface supplies and groundwaters (Tourbier & Pierson, 1976; Tilton *et al.*, 1976; Good *et al.*, 1978). However, it is increasingly clear that our valuable wetland habitats are becoming endangered by human perturbations, and additional modifications of these ecosystems may be undesirable. Studies of the wastewater treatment capability of artificial wetlands (Seidel, 1976; Sloey *et al.*, 1978; Small, 1976) have provided preliminary evidence that it may be possible to derive the benefits of wetland treatment in artificial systems without impairing the extent or function of natural ecosystems.

This report will describe our investigations which have demonstrated the exceptional utility of artificial wetlands for the efficient removal of nitrate from secondary wastewater effluents at relatively high application rates, and with lower associated energy utilization than alternative processes. The artificial marshes consisted of plastic-lined (Hypalon, 30 mil) excavations containing emergent vegetation growing in gravel. The marsh beds, 14 in number, were trapezoidal trenches, 18.5 m long × 3.5 m wide × 0.76 m deep. The bottoms of the trenches were sloped 1% from inlet to outlet. The nitrified effluent from the existing activated sludge (secondary) treatment plant

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Key words: denitrification, wetlands, nitrogen removal, wastewater treatment, sewage treatment, artificial wetlands, *Typha*, *Scirpus*.

Fig. 1. Photograph of artificial wetlands site at the Santee Water Reclamation Facility. For scale, note the two persons standing at right in foreground. Each of the fourteen marsh beds are 18.5 m long × 3.5 m wide; vegetation ranges from 3 to 4 m in height. The two unplanted control beds can be seen at the extreme left.

(Santee Water Reclamation Facility of the Padre Dam Municipal Water District, Santee, California) was used as the influent to the wetland beds. The vegetation was propagated in the artificial marshes by transplant of rhizome cuttings (about 10 per m^2). representing three types of vegetation. Eight beds were planted with bulrushes (*Scirpus* spp), two beds were planted with cattails (*Typha* spp) and two with reeds (*Phragmites* spp). Two beds served as non-vegetated control plots. The beds were kept flooded throughout the period of study.

METHODS

All water samples were analyzed according to EPA approved methodology (U.S. Environmental Protection Agency, 1979). Ammonia–N was analyzed with an Orion ion selective electrode. Nitrite–N was determined spectrophotometrically by diazotization. Nitrate–N was determined as nitrite after cadmium reduction. Total Kjeldahl nitrogen (TKN) was determined by Kjeldahl digestion and potentiometric analysis of ammonia with an Orion ion selective electrode. Dissolved orthophosphate was measured by colorimetric analysis of the antimony–phospho–molybdate complex. Total phosphorus was measured by persulfate digestion followed by orthophosphate analysis.

BOD (biochemical oxygen demand) was measured using a 5-day incubation at 20°C. Suspended solids (non-filterable residue) were determined gravimetrically after filtration and drying to a constant weight at 103–105°C.

Oxygen was measured using a YSI 54A Oxygen meter, calibrated weekly using the Winkler procedure. Oxidation–reduction potential was determined using an Orion 407A Ion Analyzer with redox probe, and pH was measured using an Ecolab Model 102B meter.

Weekly samples were collected by pumping water from a standpipe reaching to the bottom at the effluent end of each bed. Harvestable yield of wetland vegetation was determined by periodic harvesting of 7 m^2 quadrats at both the inlet and outlet end of the beds. Vegetation was cut approx. 30 cm above the water surface. Total biomass (wet wt) of the quadrats was measured with a spring loaded balance. Percent composition of carbon and nitrogen was determined on dried plant biomass using a Carlo-Erba Model 1104 elemental analyzer.

Flow meters (Arad Ltd, Israel) and valves at the inflow and outflow of each bed were used to regulate flow rates (application rates) and control water level.

Loading rates of plant mulch were 0.035 kg of plant biomass (dry wt) m^{-2} day^{-1}. The mulch consisted of either plant biomass produced within the marsh itself, lawn clippings from a nearby park area, or straw, and was applied to the surface of the marshes.

RESULTS AND DISCUSSION

Figure 1 is a photograph of the artificial wetland site at the Santee Water Reclamation Plant in Santee, California. Table 1 shows nitrogen removal efficiencies for both vegetated and unvegetated artificial marsh beds, determined on a weekly basis from October 1980 to September 1981. Removal efficiencies were highest for the vegetated beds in the spring and summer period when plant growth and nutrient uptake were greatest. The removal efficiencies for the unvegetated beds also show a corresponding increase during the spring–summer period, this most probably reflecting the increase in ambient water temperature and bacterial activity. For the whole year, removal efficiency for total nitrogen (TN) was 27% for the vegetated beds and 25% for the unvegetated beds. Since the mean TN removal efficiency for the planted beds was not significantly different than for the unplanted beds, it follows that plant uptake could only account for a small fraction of the overall nitro-

Table 1. Mean removal efficiencies* (±SD) for vegetated† and unvegetated (control)‡ beds with no supplemental carbon addition§

	Fall, 1980 (18 Oct.–23 Dec.)	Winter, 1981 (30 Dec.–23 March)	Spring, 1981 (31 March–23 June)	Summer, 1981 (30 June–15 Sept.)
Vegetated	14.8 ± 16.0	17.8 ± 12.4	38.2 ± 29.1	37.4 ± 18.3
Unvegetated (control)	22.4 ± 20.2	14.5 ± 4.5	30.8 ± 14.0	31.4 ± 16.0

*Expressed as percentage below level in the inflow.
†Mean value for plots 4E (*Scirpus*), 5E and 5W (*Typha*) and 6E and 6W (*Phragmites*).
‡Mean value for plots 7E and 7W (unplanted).
§Wastewater application = 16.8 cm day^{-1}.

gen removal observed. The major loss of nitrogen from the system was due to denitrification.

Denitrification is an anaerobic respiration performed only by certain genera of bacteria, whereby nitrate (or nitrite) is used as a terminal electron acceptor for the oxidation of organic compounds, and is ultimately reduced to the gaseous end products N_2O (nitrous oxide) and N_2. This process has been shown to be the most successful procedure for the removal of nitrogen from both nitrified secondary wastewaters (Sharma & Ahler, 1977) and agricultural return flows (Brown, 1975). However, since the ratio of BOD (biochemical oxygen demand) to NO_3–N in these waters is usually much lower than is optimal for denitrification (2.3 as per Narkis *et al.*, 1979), its use has been limited due to the requirement for expensive, supplemental carbon sources (such as methanol) to drive the denitrification process. Table 2 shows the mean concentrations of nitrogen, phosphorus, BOD, and suspended solids in the secondary effluent at the Santee, California treatment facility. The ratio of BOD to NO_3–N is very low, about 0.12.

When methanol was added to the artificial marshes to supplement the endogenous carbon supply, removal efficiencies were extremely high. Figure 2 shows the concentration of TN (total nitrogen) in the inflow to the wetlands as compared to the level of TN in the effluent of methanol-amended beds. At a wastewater application rate of 16.8 cm day^{-1}, mean nitrogen removal efficiencies were 95% ± 3 for TN and 97% ± 3 for TIN (total inorganic nitrogen) for the period from October 1980 to September 1981.

Tests of removal efficiency as a function of methanol feed rate showed that complete denitrification (>95% removal of TIN) was attained at wastewater application rates as high as 102 cm by using a methanol to nitrate (M/N) ratio of 4.5 or greater. This value is somewhat higher than M/N ratios of 3 to 4 normally found to be optimum for complete denitrification in anaerobic reactors (Bouck, 1978). The higher carbon demand of wetland treatment may be due to the fact that wetlands are open to the atmosphere and oxygen is found both in the overlying waters and within the substrate in the plant rhizosphere (Sherr & Payne, 1979; Oremland & Taylor, 1977). Aerobic respiration occurring in these environments within the wetlands will exert a considerable carbon demand and increase the overall M/N ratio. In our test beds, the M/N ratio was adjusted to 6.8 so that carbon would be well in excess of the amount necessary to completely satisfy the demand of denitrification.

Ehreth & Basilico (1978), upon review of cost and operating data for nitrogen removal processes, point to the importance of lower cost alternatives, particularly those providing less expensive substitutes for methanol, the cost of which is tied to the rising price

Table 2. Mean concentration of nitrogen, phosphorus, BOD, and suspended solids in the secondary effluent at the Santee, California Treatment Facility (all values in mg l^{-1})

Total nitrogen (TN) = 18.0
Total inorganic nitrogen (TIN) = 17.4
Ammonia nitrogen = 0.1
Nitrate nitrogen = 17.3
Total phosphorus = 8.5
Ortho phosphorus = 8.1
BOD = 2.0
Suspended solids = 2.9

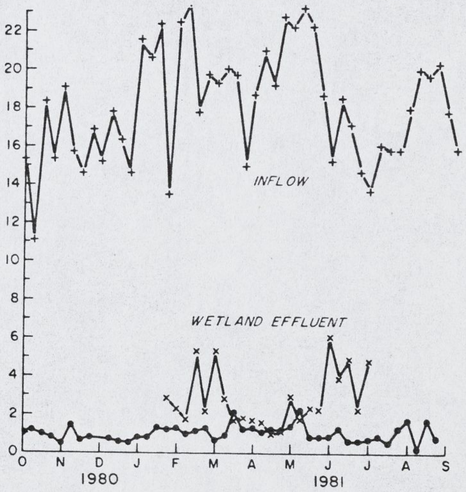

Fig. 2. Mean level of total nitrogen (TN) in the inflow to the artificial wetlands (+——+) as compared to the mean level of TN in the effluent of methanol-amended (●——●) and mulch-amended beds (×——×). Application rate for mulch-amended bed (plot 1E) was 8.4 cm day^{-1}. Application rate for methanol-amended beds (plots 1E and 2E) was 16.8 cm day^{-1}. Methanol:nitrate ratio was 6.8:1.

of fossil fuel. The artificial wetlands provide an ideal environment for both photosynthetic carbon fixation by higher aquatic plants and denitrification (dependent upon the availability of a carbon source). Therefore, we tested the efficacy of using plant biomass, mulched and applied to the overlying waters of the marsh beds, as a low-cost and renewable source of exogenous carbon which could, upon decomposition, satisfy the carbon demand of denitrification.

Engler & Patrick (1974) showed that the addition of organic matter (ground rice straw) to paddy soil samples decreased the thickness of the aerobic–anaerobic zone at the soil water interface, and increased the rate of nitrate reduction. In a summary of the investigations by the Interagency Agriculture Wastewater Treatment Center at Firebaugh, California, Brown (1975) cites studies on nitrogen removal in irrigation drainage canals to which straw (organic carbon) had been added. In spite of the fact that such a system was shown to reduce the influent concentration of NO_3–N from $14 \, mg \, l^{-1}$ to near zero at a detention time of 3 days, more intensive studies did not ensue.

Figure 2 also shows the results of our investigations in which the level of TN in the inflow to the artificial wetlands is compared to the level in the effluent of a wetland bed to which plant mulch has been added. At a wastewater application rate of $8.4 \, cm \, day^{-1}$, the mean removal efficiency for the mulch-amended bed was 87% ± 8 for TN and 91% ± 8 for TIN during the period 10 February–21 July 1981.

At the optimum M/N ratio of 4.5 observed in the artificial wetlands, the ratio of carbon to nitrate–N would be 1.7. Plant biomass (dry wt) is approx. 40% carbon; therefore, the calculated optimum carbon loading rate is $0.029 \, kg \, Cm^{-3}$ (assuming a mean value of $17 \, mg \, l^{-1}$ NO_3–N for the influent). The measured annual harvestable yield of biomass in the artificial wetlands was $5 \, g \, Cm^{-2} \, day^{-1}$. At a wastewater application rate of $8.4 \, cm \, day^{-1}$, wetland productivity amounts to approx. $0.060 \, kg \, Cm^{-3}$. These data indicate that if biomass carbon could be quantitatively converted to a form directly available to denitrifiers, it would supply more than twice the calculated optimum carbon loading requirement of $0.029 \, kg \, Cm^{-3}$. However, losses of carbon (as CO_2) can be significant when biomass carbon, applied as mulch to the marsh surface, is decomposed aerobically. Furthermore, the lignin fraction of plant biomass is relatively resistant to microbial degradation (Crawford, 1981). In order to assure an excess of carbon well above the optimum requirement for denitrification, the loading rate of carbon in the mulch-amended beds (Fig. 2) was adjusted to $0.17 \, kg \, Cm^{-3}$, a value nearly 6-fold the calculated optimum requirement of $0.029 \, kg \, Cm^{-3}$. Even at this relatively high biomass carbon loading rate, removal of nitrogen in the mulch-amended beds was not entirely complete (91% for TIN and 87% for TN), pointing to the fact that losses of biomass carbon were indeed high when the plant mulch was allowed to decompose on the marsh surface.

In spite of these losses of carbon, however, measurements of harvestable yield of wetland vegetation indicate that at the wastewater application rate of $8.4 \, cm \, day^{-1}$, endogenous productivity could supply $0.060 \, kg \, Cm^{-3}$, or 35% of the loading value of $0.17 \, kg \, Cm^{-3}$ at which there is an 87% reduction of TN. By using plant biomass as a substitute for methanol, the energy savings for a treatment facility serving a small community ($3785 \, m^3 \, day^{-1}$ or 1 mgd) would amount to the equivalent of $73 \, l \, day^{-1}$ of methanol, which is $1.22 \times 10^6 \, BTU \, day^{-1}$, or $4.45 \times 10^8 \, BTU \, yr^{-1}$ (at $16{,}704 \, BTU \, l^{-1}$ methanol).

In order to determine the net energy savings, the energy cost of harvesting and mulching the vegetation must be estimated. This was done in field trials using a tractor with a flail mower assembly, which cuts and mulches the aquatic plants in a single step. The annual energy cost of harvesting and mulching, using a 105 horsepower tractor at a rate of 0.2 hectares h^{-1}, was estimated to be $8.5 \times 10^6 \, BTU \, yr^{-1}$. This value amounts to only a small fraction of the total energy savings of $4.45 \times 10^8 \, BTU \, yr^{-1}$ associated with the use of wetland biomass as a substitute for part of the methanol demand of denitrification at a treatment facility (1 mgd).

A wetlands-overland flow sewage treatment system at the Disney World Resort Complex in Florida has shown very good total nitrogen removal efficiencies, nearly 82% of the total amount in the inflowing waters without carbon amendments (Kohl & McKim, 1980); however, the application rates were relatively low, $1.85 \, cm \, wk^{-1}$. Similarly, total N removals of 90% were obtained in a natural mixed-hardwood swamp near Wildwood, Florida, but application rates were only $0.25 \, cm \, wk^{-1}$ (0.15 mgd per 202 hectares of swamp) (Boyt *et al.*, 1977). In the studies described above no attempt was made to maximize hydraulic loading rates. However, in a rapid land infiltration study at the Flushing Meadows Project in Arizona, high hydraulic loading rates ($16.7 \, cm \, day^{-1}$) were attained with a 65% reduction of total nitrogen in secondary wastewater effluent containing 10–$20 \, mg \, l^{-1}$ BOD (Bouwer *et al.*, 1980).

Previous investigations using artificial wetlands as wastewater treatment systems have been reported (Spangler *et al.*, 1976; Seidel, 1976; de Jong, 1976) but none have focused upon maximizing the efficiency of both nitrogen removal processes and hydraulic loading (application) rates. Figure 3 shows the levels of TIN and TN in the inflow to the artificial wetlands as compared to the levels in the effluent of the mulch-amended wetland beds. At the relatively high application rate of 16.8 cm per day, the carbon loading is only $0.085 \, kg \, Cm^{-3}$, a value less than 3-fold the calculated optimum requirement. It is evident that at this low carbon loading factor complete denitrification was not attained, since the mean removal efficiencies were 60% ± 21 for TN and 66% ± 22 for TIN, for the mulch-amended beds during the period from October 1980 to September 1981.

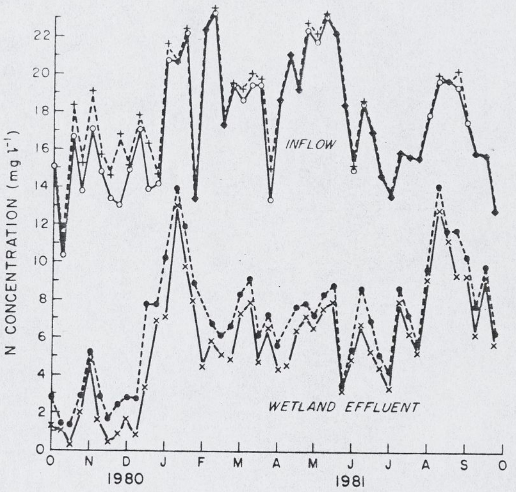

Fig. 3. Mean level of total nitrogen (+ --- +) and total inorganic nitrogen (○——○) in the inflow to the artificial wetlands, as compared to the mean level of total nitrogen (● --- ●) and total inorganic nitrogen (× —— ×) in the effluent of mulch-amended beds (plots 2W, 3W, 4W and 5W). Wastewater application rate was 16.8 cm day^{-1}.

Treatment efficiency was highest in the mulch-amended beds during the initial two months of the study in the fall of 1980, at which time the vegetative cover was still becoming established (Fig. 3). Since the density of plant cover is inversely related to the surface area available for decomposition of added plant mulch, the efficiency of nitrogen removal would tend to decrease somewhat as maximum vegetative cover becomes established. In the winter, removal efficiency is lowest due to the lower temperatures, and thereafter the efficiency remains at a relatively constant level (except for two dates in late summer). Our field trials have shown that cutting and mulching the marsh vegetation in place is the simplest method for returning the biomass carbon to the wetlands, thus avoiding the problem that arises when the density of plant cover interferes with adequate distribution of mulched biomass over the wetland surface.

Table 3 shows the levels of BOD, suspended solids, orthophosphorus and total phosphorus in the effluent from the mulched and the unmulched beds. The mean levels of all four parameters in the effluent were lower than in the inflowing waters for all of the beds. This indicates that the particulate matter and BOD added as mulch are efficiently degraded and that the mulching does not significantly increase the phosphorus pool.

Barth (1978) evaluated available nitrogen removal alternatives and found biological systems to prove clear overall superiority. Physico-chemical methods such as reverse osmosis and ion exchange are not selective for nitrate, are expensive to operate and generate hazardous waste products. The process appeal of biological denitrification is evident. It is based upon a simplicity of equipment and structures, is selective for nitrate with high removal efficiency (when sufficient carbon is available), and generates no environmentally detrimental waste products.

Middlebrooks *et al.* (1981) found that energy requirements of conventional treatment plus nitrogen removal (ion exchange) were 5-fold that of overland flow (flooding). These authors conclude that in an energy-conscious environment, whenever land is available at a reasonable cost, the lower energy requirements for land application systems will confer a distinct advantage. Ewel & Odum (1978), in a study of cypress swamps for nutrient removal and wastewater recycling, found that these swamps have a high ratio of solar energy inputs to dollar costs, and consequently disposal of wastewater into wetlands is a good energy conservation practice and is economically cost-effective.

As the cost of fossil fuel increases, energy cost will become the predominant factor in the selection of small (0.5–5 mgd) wastewater treatment systems (Middlebrooks *et al.*, 1981); however, in many cases where natural wetlands are either geographically unavailable or protected from wastewater discharge by environmental, legal or aesthetic restraints, artificial wetlands offer a viable alternative for energy-effective wastewater treatment.

Wetlands dominated by cattails and other emergent macrophytes are among the most productive biological systems in the temperate zone (Westlake, 1963),

Table 3. Removal of BOD, suspended solids, ortho phosphorus and total phosphorus in the artificial wetlands

	16 Dec. 1980–15 Sept. 1981		14 Dec. 1980–15 Sept. 1981	
	BOD	Suspended solids	Ortho P	Total P
Inflow	2.48 ± 2.43 (38)†	2.81 ± 2.31 (34)†	8.27 ± 0.73 (47)†	8.66 ± 1.0 (46)†
Non-mulched beds (vegetated)‡	0.93 ± 1.09 (106)	1.54 ± 2.01 (102)	7.82 ± 0.86 (150)	8.08 ± 1.05 (143)
Mulched beds (vegetated)‡	2.12 ± 3.31 (166)	1.70 ± 3.19 (144)	7.80 ± 1.23 (185)	8.00 ± 1.10 (174)
Unvegetated beds (non-mulched)	1.19 ± 2.09 (46)	1.52 ± 2.08 (46)	7.83 ± 1.03 (56)	7.98 ± 1.38 (55)

*Parameters sampled on a weekly basis throughout this period.
†Numbers in parentheses indicate the total number of data points.
‡Values for vegetated plots include pooled data for all three species of plant (*Scirpus*, *Typha* and *Phragmites*).

with total biomass often exceeding 40 tons per hectare (Andrews & Pratt, 1978). Although certain industrial waste products (whey, corn silage, spent sulfite liquor) have been shown to be suitable carbon sources in biological denitrification (Skrinde & Bhagat, 1982), these products are neither nationally distributed, nor are they typically produced near wastewater treatment facilities. Our studies have shown that artificial wetlands may be managed so as to fuel the process of denitrification by using carbon sources derived from biomass produced within the wetlands itself. Such a scheme would lead to a more rational and environmentally sound use of the increasingly precious resources—water, nutrients, and energy.

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Galat

From Grants' pt. view

ignore 81 stockers only emphasis no reproductn trout gone quality-sediment - but Grants' trout gone before Grants STP

- Emphasize survival, good growth of brown trout stocked 1981 -- proves water not toxic to trout, water qual. o.k. for trout survival - canary in mine - must be generally o.k.
- Need for in-situ bioassay (~~f~~ fish in boxes) for hard evidence --.

2 - Desperate need for water quality data to support what claimed in rept re. fishery. nutrient loading - etc - . Assume this being done

3 - Experience w/ Tribes - lack continuity & $ to get any kind sophisticated program going.
- Grants attack any plans showing great improvement over past - need for well documented plan

★ Gersberg R., & C.R. Goldman -- show fantastic N removal in arid areas by passing effluent thru marsh - cheap, biologically sound, creates great wildlife habitat.
- Water Res (?) recent -

Fishery in stream & lake < STP

After - Effects depletion sediment & STP
sort out impacts w/ w/o STP

current status.

stable level in Maryland or increased in Virginia waters during the past eight decades (Figure 1). Early reports by white explorers in Chesapeake Bay indicated the apparent existence of large finfish and shellfish resources (Arber, 1910; Meehan, 1897:320; Hall, et al, 1910; McAtee, 1918:9; Beatty and Croom, 1940:73-86; Mansueti and Kolb, 1953:64) but many such statements were exaggerated, biased, or based on isolated observations, depending on the observer and the incentive for the reports. Seafood resources then were probably not much more abundant than the level at peak production in the late 1800's. While the carrying capacity of the Bay has been reduced somewhat, man has offset this loss in small measure by adding to its natural fertility.

Chesapeake Bay's major features and productivity have been subjected to many influences of civilization, some catastrophic, others moderate but sustained, and some of a short-term minor nature. Odum (1961:1) described some of the background of man's use of estuaries. Indirect changes in the estuarine environment and its organisms have been produced by man, of which that by Indians were minor (Reynolds, 1889:252-6; Gay, 1892:151; Meehan, 1897:313-4; Maxwell, 1911:65, 95; Marye, 1938; Stearns, 1943:6, 9, 20-8; Weslager, 1950:39-41; Marye, 1955:139-40; and Odum and Odum, 1959:137-8). The early colonists exerted occasionally marked but local effects on the watershed and seafood resources in a few areas (Meehan, 1897:321, 328; Mansueti and Kolb, 1953:53, 64, 125, 143, 240). The most important, intensive and serious changes occurred simultaneously with the explosive population growth beginning in the mid-1800's (Pearl, 1925:14). At the same time as these indirect effects were manifested, man began to affect directly the estuarine fin and shellfisheries through use and abuse. Such long range river use as proposed by Wolman, et al (1961:1-10) is being challenged by Cumberland (1961:15-8). representing the generally new approach to such problems of great significence. The combined effects of the intensive topographic changes, water manipulation, and seafood exploitation, have been in some respects in competition with similar natural changes.

Density-Independent Effects

Deforestation and Sedimentation: The most extensive damage to the environment and its biota are traceable to density independent changes. That is, wholesale agricultural, industrial, and domestic use by man of the estuarine watersheds resulted in great changes in the topography, and the effects have in some cases been partially or totally destructive, regardless of the numbers of organisms. The processes operating in an estuarine ecosystem are complicated, and the environment in general is one of great productivity, instability, and wide ranges in salinity, temperature and oxygen (Ingle, 1954:64-7; Pritchard, 1951:365-9; Newell, 1959:61-5; Odum, 1961:1-4). Virtually all the virgin forest in the Chesapeake Bay watershed had been utilized before 1900, although it is now known that the area was not entirely wooded (Marye, 1955:141). Deforestation (Bond, 1959:17-9), freshets (United States Forest Service, 1943:12-3; Stearns, 1943:12), erosion (Cumberland, 1961:8-15), siltation, and sedimentation during the 1800's, which increased with each succeeding decade, began to have serious effects on the watershed and estuary (Brehmer, 1959:27; Bartsch, 1960:119). A conservative estimate suggests that roughly half of the former upper estuarine spawning areas for fish and shellfishery areas for oysters, *Crassostrea virginica,* (Beaven 1946:131), have been destroyed or shifted downstream by sedimentation in Chesapeake Bay. Many formerly well-known spawning areas for anadromous fishes are no longer suitable or greatly restricted in area. Sedimentation has had profound effects on the depths, contours, and quality of the estuarine bottoms (Gottschalk, 1944: 2-3; 1945:233-7; Weiss, 1950:39; Ratledge, 1959:14-5; Stephenson, 1959:13). Probably every part of the Chesapeake and its smaller estuaries has been so affected by the multiplicity of factors listed above, but the end point of sedimentation has had its greatest effects at the head of tidewater, and least effects in the deeper channels.

FRESHETS, DROUGHT, AND THERMAL CHANGES: Excessive precipitation or drought conditions, the extremes of which have been produced partly by man (Ashbaugh and Brancato, 1958:28), causes excessive dilution by fresh water in the estuary and destroys huge crops of moderately euryhaline oysters (Cumming, 1916:225; Beaven, 1946:131; Engle, 1946:136-7; Frey, 1946:14); or during long periods of no rainfall, increased salinity causes fish mortalities among euryhaline species (Truitt and Algire, 1930:58-9). Air temperatures have shown a slight upward trend in the last half century (Baum and Havens, 1956:445), and these have probably shifted spawning and activity time-wise for some organisms. Abnormally heated water in rivers by industrial power plants such as the Pepco (Potomac Electric Power Company) Plant in the Potomac River and one contemplated in the Patuxent River bring about marked local changes that affect the sedentary fauna and attract fishes during the colder periods (Elser, 1961B:1; Hynes, 1960:136-9). The effects can be subtle, and sudden temperature changes can exert serious changes among many estuarine forms (Brehmer, 1959:28).

CONTAMINANTS FROM MAN-MADE SOURCES: Industrial, domestic, agricultural, mining, and dredging activities have kept pace with human-population growth in the Chesapeake watershed (Cumberland, 1961:13-7), and a great variety of contaminants and other pollutants have been poured in the waterways. Pollution is a normal condition in a developing economy, and in spite of many safeguards, it has been intensive, highly localized, and destructive. Despite the magnitude of all types of pollution. Chesapeake Bay has been remarkably resilient. It has maintained a high ecological quality and has continued to produce seafood crops on a sustained or increased level, even though commercial fishing pressure has shown little increase.

INDUSTRIAL SOURCES: Industrial pollution is limited to larger metropolitan regions, and the effects are local and vitiated by the assimilative and flushing action of the estuary. This is true in the Patapsco River at its confluence with Chesapeake Bay (Olsen, et al, 1941:38-40; Davis, 1948; Garland, 1952:69-70, 77, 81), and in the Potomac River (Wolman, et al, 1957:386, 403). While chemical toxins and similar materials have produced biotic destruction on a local, temporary level, no long-range losses to economically important marine species in the whole Chesapeake area can be traced to it (Massmann, et al, 1952:1, 169; Weiss, 1952:180). The study by Galtsoff, et al, (1947:182-4) is a classic example of intensive contamination on oysters. Increased shipping activity has increased the burden of oil pollution in the Bay (Lincoln, 1936: 556-7), in spite of restrictive legislation, and the raw sewage load from these vessels is also increasing. In general, cooperation between interested people and strict regulations are bringing industrial pollution under control and possibly it will be completely managed in certain areas in the future.

AGRICULTURAL SOURCES: Agricultural pollution has produced beneficial and destructive effects; fertilizers have increased an uncontrollable type of productivity, some deleterious (Galtsoff, 1956:414; 1959:128-9; Wolman, et al, 1957:426), while poor farming practices have resulted in serious loss of habitat through erosion and sedimentation, and pesticide washings have produced serious mortalities among many estuarine organisms (Loosanoff, 1960: 89-92; United States Department of Health, Education, and Welfare, 1961:17; Barry, 1961:52-4). Many such mortalities go undetected, especially among sessile organisms, but the increasing incidence of fish kills, some of which can be traced to careless pesticide use, suggests that this problem will increase for all organisms. Highway and large-scale building construction has contributed heavily to the sedimentation rate, and it is competing importantly with poor farming practices as a major cause of landscape loss. The destructive effects of various forms of inert materials on aquatic life are well-known (Buck, 1956: 259; Wilson, 1960:269-71). Conservation groups are trying to minimize such massive sources of pollution by exercising controls on a large-scale watershed basis. The obstacles are great, but this approach holds the most promise, although little progress has been made in any part of the Chesapeake area except for the Potomac drainage.

DOMESTIC SOURCES: Domestic pollution has produced some public health hazards in Chesapeake Bay, but has locally, and sometimes abnormally, improved productivity and growth of estuarine organisms, especially among algae (Wolman, et al, 1957:428-9; Heukelekian, 1960:250) and filter-feeding organisms. The practice of certain watermen of "fattening" their oysters in tidal areas condemned as being sewage-laden (Cumberland, 1961:14-5), and then "cleaning" them in unpolluted waters, has been restricted greatly by enforcement authorities in recent years. The fact that soft-shelled clams, *Mya arenaria,* accumulate coliform organisms (Lear, 1960:39) precludes similar treatment for this species. Also, they cannot be eaten raw as are oysters and hardshell clams, *Mercenaria mercenaria,* which do not store pathogens. In general, sewer rivers are not being utilized well (Renn, 1956:71); control and balance of treated effluents can prove of great importance in estuarine production in the future. One of the most serious growing problems, as yet largely uncontrolled, is the increased introduction of detergents in the major waters of the Chesapeake watershed (Maryland Water Pollution Control Commission, 1961:1-11). Detergents are known to be extremely lethal to aquatic organisms and greatly modify the environment (Hynes, 1960:66-7, 75, 107, 120).

MINING AND DREDGING OPERATIONS: Mining pollution and major dredging operations are of variable importance in the Chesapeake watershed. Coal mining operations in the upper Susquehanna River have produced coal dust which occurs downstream to below Harrisburg (Reid, 1936:544-5). Although this material is being systematically removed, it still contributes to the unfavorable bottom conditions, so that it may be responsible for the failure of several attempts of stocked American shad, *Alosa sapidissima,* to spawn successfully above the various dams (Mansueti and Kolb, 1953:130-1; Whitney, 1961:4). Dredging of oyster reef shells (Bentley, 1960:24) may create serious changes on the bottom and increase sedimentation on adjoining areas with some loss to bottom organisms, although Hammer (1960:8) pointed out that operations to date have not seriously affected oysters. These shells, the origin of some of which have been described by Nelson (1960:220), are currently being mined in the upper bay and contemplated from the upper James River. Manning (1957:25) pointed out that hydraulic dredging operations for soft-shelled clams are destructive only on an extremely local basis, and that aquatic weeds destroyed are a small part of the total quantity available to wintering waterfowl in Chesapeake Bay. Baltimore harbor dredging operations, with its dumping operations in the Chesapeake Bay Channel off Kent Island, as well as other spots (Associated Press, 1961:B-2), has not been fully evaluated, but wintering populations of striped bass, *Roccus saxatilis,* may be immediately affected. In general, dumping of slag, garbage, trash, etc. into the bay destroys existing bottom communities, reduces the area of potential oyster bottom for future rehabilitation, but in turn it may be the basis for new communities of encrusting organisms.

UNDERWATER EXPLOSIVE EXPERIMENTS: Military agencies have used Chesapeake Bay as an experimental area for underwater explosives for the past two decades. Studies have shown that while such activities bring about local mortalities of fishes, blue crabs, *Callinectes sapidus,* and oysters, they have had no long range effects on the abundance of estuarine organisms either locally or bay-wide (Chesapeake Biological Laboratory Staff, 1948:35-42; Coker and Hollis, 1950:443-4; and Tiller and Coker, 1955:15-18). Naval authorities, however, have attempted to minimize such local kills by scheduling their firings in areas where fish are absent or scarce; i.e., virtually no explosives are set in deep-water areas containing overwintering congregations of fish.

RADIOACTIVE POLLUTION: Radioactive pollution in the bay is not presently a problem although natural radioactivity (Folsom and Harley, 1957:32) and fallout effects may exist at a low level. The construction of the Peach Bottom nuclear power-plant in the lower Susquehanna River, nine miles above Conowing Dam, and near the head of Chesapeake Bay poses many problems in industrial radioecology (Renn, 1957:26-7). The possibilities of accidents from atomic-powered vessels and structures, while remote, must be anticipated. The Associated Press (1959:36) reported the selection of three atomic-waste dumping sites off the mouth of Chesapeake Bay and two off the Maryland seaside. All of these could represent sources of contamination from migratory fish. Also, estuarine biologists should be further concerned because of the predilection of shellfish to accumulate radioactive substances (Boroughs, et al, 1957:82-3; Chipman, 1960:12).

CANALS, DAMS, AND OTHER MAJOR STRUCTURES: Major structures on or near estuaries have also had some effects. Three important canals—Chesapeake and Delaware Canal completed in 1829, Chesapeake and Ohio Canal completed in 1850, and the Susquehanna Tidewater Canal begun in 1822 and discontinued in 1906—have exerted little destructive effects on biota, but have increased water area and habitat for certain species of fish. The proposed Pocomoke-Chincoteague Canal (Jones, 1961:27) may raise salinity levels in the Chesapeake Bay tributary to such a point that the famed cypress swamp may be destroyed. The construction of Conowingo Dam cut off some anadromous fish from part of their spawning grounds in the lower Susquehanna River, while Triadelphia and Rocky Gorge dams have affected the upstream movements of river herrings, *Alosa pseudoharengus* and *A. aestivalis.* The newly created reservoirs and millponds, which also reduced access to minor spawning areas for fish on the Delmarva peninsula, created extensive new habitats for many native, introduced, and a few estuarine species. The fishway problem in several dams are intense, and in the case of Conowingo Dam, a recent study concluded that conditions upstream and the reaction of the introduced fish during the survey precluded the need for fish passage, except for the elvers of the American eel, *Anguilla rostrata,* (Whitney, 1961:2). Although a small fishway was installed in the dam at Little Falls, in the Potomac River, above Washington, D.C., the area has not attracted enough fish to be considered successful (Covell, 1961:E-4). Construction of bridges and tunnels have only temporarily affected a small part of bottom communities.

MARSH AND WETLAND RECLAMATIONS: Many areas in the Chesapeake Bay watershed have been reclaimed for many reasons: metropolitan expansion, mosquito control, additional land for agricultural, domestic, and industrial use, and as dumps for waste materials (Renn, 1956:470-1). The importance of such areas has been emphasized by many workers, and Odum (1961:1-4) has provided the most compelling description of their importance to the high productivity of estuaries. Adverse effects have been recorded for many wetland species, especially muskrats (Dozier, 1947:402-19; Harris, 1951:201). Losses in general have not been great, but great problems are contemplated in the near future when speculators and local agencies clamor for reclamation of the extensive wetlands on the Delmarva peninsula.

GENERAL EFFECTS OF DENSITY-INDEPENDENT FACTORS: Historical data indicates that habitat destruction, particularly through sedimentation, dam construction, and some pollution, was effective even before the 1800's; but that the major changes occurred after this time. Those changes brought about indirectly by man-made activities seem to be the most insidious and difficult to halt, since no one activity can be definitively controlled. Watershed management of deforestation, poor agricultural practices, and other major activities, hold the most promise of beneficial results. On the other hand, those conditions arising from industrial, domestic, or specific agricultural activities can be controlled under some conditions, and their management shows promise of alleviating many serious conditions of pollution. Man-made density-independent factors will continue to be the most important features of civilization on natural populations, no matter how well controlled.

Density-Dependent Effects

Man's primary motivation for harvesting estuarine seafood products, aside from their nutritive value, has been related to the abundance and ease in exploitation. Hence, his fishing efforts have been dependent on the density of the seafood resources. The direct influence of man's attempt to harvest fully the estuarine seafood resources, the industry of which has been considered of minor importance in Chesapeake Bay (Quittmeyer, 1957:1, 3-4), has had variable effects, some leading to no perceptible effects and others to depletion of certain species. Although Figure 1 shows that seafood harvests have been stable or increasing, important changes in the species composition and relative importance of different species have taken place. Even during the 1920's when fishing effort was less restrictive than today, catches overall were relatively stable (Hilderbrand and Schroeder, 1928:16).

EARLY FLUCTUATIONS IN SEAFOOD SUPPLY: Many species exhibited marked fluctuations in supply and availability throughout their range even before extensive exploitation or commercial fishing had begun. This was especially true for American shad, bluefish, *Pomatomus saltatrix,* and striped bass, *Roccus saxatilis,* (Ferguson, 1877:1-12; Brooks, 1905:213; Bigelow and Schroeder, 1953:386-7, 400-1). The principal reason sedentary oysters and clams, and migratory species such as shad, herring, and perches were exploited during colonial times was because shellfish could be conveniently harvested, or because the fish traversed estuaries to the river banks of communities in many inland areas. Even then, the available supplies were said to vary from year to year. These fluctuations emphasize the importance of meteorological and hydrographic conditions as factors affecting populations, rather than exploitation as a primary cause.

Effects of High Exploitation: Within the last century, especially between the Civil War and 1900 when seafood harvests reached their peak, exploitation was high, and wide fluctuations and important declines in landings were evident. These have been attributed to fishing effort, supply and demand, and natural fluctuations in abundance, conditions of which were so interwoven that they cannot now be separated. The socio-economic aspects continue to compete strongly with the biological features in the analysis of changes in the commercial fisheries of the Bay. Few important species have been over-fished. While many moderately valuable species are more or less being fully utilized, some important food and game species and presently non-commercial species are under-utilized. The American shad, the oyster, and the Atlantic sturgeon, *Acipenser oxyrhynchus,* are three important species that

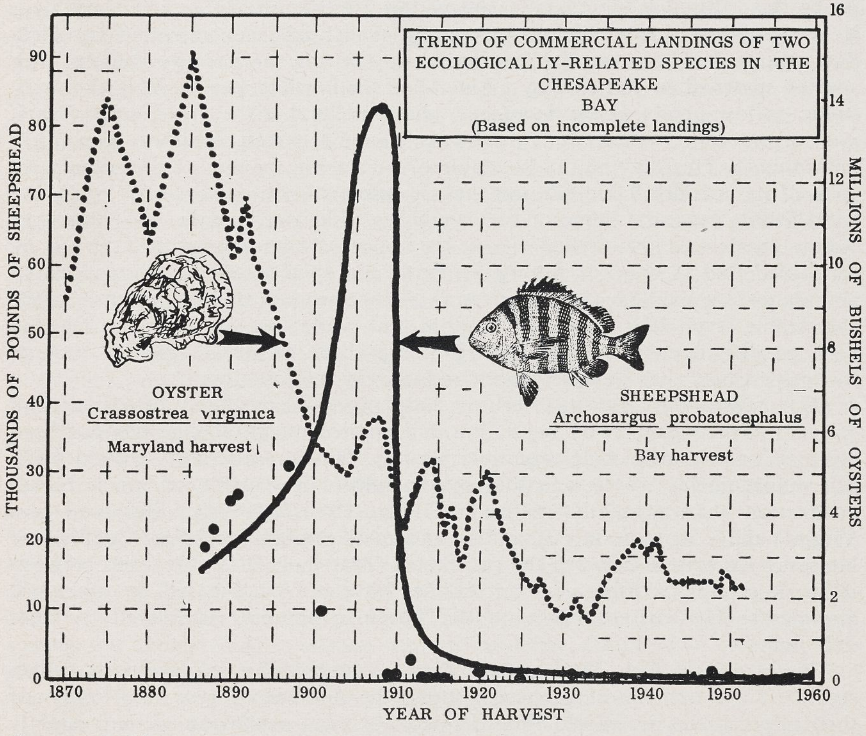


Figure 2. Trend of commercial landings of two ecologically related species in Chesapeake Bay to suggest the possible relationship in the decline of oyster environment with the apparent decline of sheepshead. Data based on catch records derived from official Maryland and Federal sources. The black dots represent recorded landings of sheepshead from which the black trend line was drawn.

have classicially been considered overexploited, but it is more probable that their low abundance is due primarily to their considerably reduced spawning and producing grounds and secondarily to exploitation in the past. These species have been unable to recover biologically in spite of their high biotic potentials, suggesting Allee's principle, that is, a species does not thrive unless the adult population density remains at a certain, presumably high, level (Odum and Odum, 1959:443-4). Figure 2, for example, shows the general trend of the oyster decline and its hypothetical relationship to the ecologically-related sheepshead, *Archosargus probatocephalus,* which has never been extensively exploited by man in Chesapeake Bay.

Declines in availability and/or violently fluctuating production of other important species (Atlantic croaker, *Micropogon undulatus;* spot, *Leiostomus xanthurus;* weakfish, *Cynoscion regalis;* menhaden, *Brevoortia tyrannus;* blue crab, *Callinectes sapidus;* bluefish, and striped bass) have occurred independently of man's exploitation, although his influence on the gross estuarine-marine environment may somehow be related to these population changes. With the exception of the blue crab and striped bass, all of these spawn outside Chesapeake Bay, although their larvae and young use the estuary as a nursery area. It is significant that stable or increasing availability, accompanied by some fluctuations, has occurred in Chesapeake Bay during the last two decades with species spawned in the estuary (American shad, white perch, *Roccus americanus;* yellow perch, *Perca flavescens;* chain pickerel, *Esox niger;* carp, *Cyprinus carpio;* white catfish, *Ictalurus catus;* channel catfish, *Ictalurus punctatus,* and others). This may be due to stable or increasing fertility of the estuary, in spite of its uncontrollable features and of sustained commercial and increasing sport fishing pressure. Some of these, such as white perch, carp, river herrings, yellow perch, and soft-shelled clams, are apparently under-exploited. It can be concluded that in spite of fishing activities and species-specific fluctuations in abundance, availability and commercial catches are still maintained at a relatively stable level. It is important to note that while the total biomass has not been greatly affected, the size and age composition of certain species, such as the striped bass, has definitely been reduced by exploitation.

MANAGEMENT BY REGULATION OF ESTUARINE RESOURCES: Man's attempt at seafood management by regulation and environmental change has not been optimal for primarily socio-economic reasons. This is particularly true in shellfish management, where scientific oyster culture is capable of much higher production than presently realized (Glude, 1951:399-402). Maryland and Virginia differ in seafood regulations and management emphasis. Conflicts of interest have existed between the two States (Marshall, 1949:431) and between different groups of fishermen, but clashes have not been based on biological arguments. The current furor on the Potomac compact is related to these differences.

The Maryland Fish Management Plan, a controlled-catch program, which stabilized the number of licensed netters, the amount of gear, and much of their effort at the pre-World War II level, has been accompanied by a slightly increasing trend in the commercial fin-fish harvest (Mansueti and Kolb, 1953: 221-25). Tiller (1945:7-8) claimed that the management plan had immediate beneficial effects in the form of more striped bass at larger size than obtained before the enactment of the Plan, while Walburg (1955:14-16) concluded that the increased yield of American shad was due to increased fishing effort, in spite of the stabilizing influence of the Plan. Muncy (1959:96) further indicated that the widespread replacement of nylon nets over linen contributed to increased catches beginning about 1950. There is evidence however, to indicate that catches were better in the early stages of the plan, but records were unfortunately incomplete to show this fact. Walburg further suggested that the effects of the Maryland plan on migratory stocks of fish were obscured by Virginia fishermen's effort and harvest, although Whitney (1961:19) and Mansueti (1961:20-9) showed from tagging that American shad and striped bass originating in Maryland waters were later harvested principally in Maryland, and virtually none in Virginia. In general, the Plan's effects are yet to be fully evaluated, but there are indications of benefit.

Many fishery regulations are biologically unsound; minimum length limits, for example, of 8 inches in the white perch probably results in important losses to natural mortality of three or four age groups up to this size (Mansueti, 1961:199-200). The maximum weight limits of 15 pounds in striped bass in Maryland have resulted in some waste to Maryland fishermen. The lack of any limit for anglers in Virginia and outside coastal waters where larger striped bass are known to migrate illustrates further the illogical aspects of Maryland's regulation. The striped bass is also the principal case in point in the commercial netter-sport fishermen controversy in Chesapeake Bay. The problem is based on a conflict of interests and the desire of relatively inefficient anglers, who spend substantial sums of money in pursuing the angling recreation, for exclusive franchise of fishing rights from the highly efficient netters. The small number of the latter group, it is argued, serve as hunters or agents for a large population of consumers who may or may not fish. Sport fishing interests were successful in closing two medium-sized estuaries (Magothy and Severn Rivers) to commercial netting in 1946. Since that time angling has been poor in the two rivers. Catch rates and harvests have been less than that recorded in other Chesapeake Bay tributaries where angling and netting coexist. The rationale behind the support of commercial harvests by management agencies is that from biological and conservation viewpoints, commercial fishing is a valuable activity (Russell, 1942:73, 95; Allen, 1954:159-60). The burgeoning increase in anglers and the economic importance of sport fishing in Chesapeake Bay, however, may dictate management from a strictly economic and political viewpoint sometime in the future.

Biological Management: Stocking of new species, except for certain game fishes, of eggs and young of resident or migratory species has not resulted in long-term beneficial effects (Muncy, 1959:10-12). Introduction of certain foreign species (carp; goldfish, *Carassius auratus;* water chestnut, *Trapa natans,* (Uhler, 1944:300-1; Beaven, 1955:1-2); watermilfoil, *Myriophyllum spicatum,* (Springer, et al, 1961:1-6) into the estuary has actually created serious problems of competition and habitat loss. The extensive list of introduced species, principally centrarchids, catfishes, and the walleye, *Stizostedion vitreum,* into tidal fresh and slightly brackish waters have been more or less beneficial, but the real effects of the introduction have yet to be assessed.

Manipulating populations and their environment seems a promising method of increasing production and rehabilitating stocks in low supply. Planted oyster bars, especially by private leasing, are socio-economically controversial, although scientifically sound (Brooks, 1905:218-24; Glude, 1951:400-2). Attempts at rehabilitating the long-depleted oyster bars by reef construction based on the mining of old buried oyster shells in upper Chesapeake Bay was begun in 1959, and they promise to have some long-term beneficial effects.

There are indications that if the oyster cannot be rehabilitated, then there will be a gradual transfer of effort toward partly replacing its low availability with the under-exploited soft-shelled clam. Fishing reefs, while in the untried experimental stage, may be valuable in increasing the carrying capacity of an area on a limited basis, but will best serve to concentrate fish, without increase in actual numbers. Arve (1960:58) found that fish catches were much greater over planted shell-bottom than over unplanted control bottoms, but Elser (1961A:10) found no difference, suggesting the need for extensive research on fishing reefs in general.

GENERAL EFFECTS OF DENSITY-DEPENDENT FACTORS: In general, fishing activities by man are influenced by the abundance or scarcity of a resource, Economic factors also exert important influence on his effort. Rarely has he reduced a species beyond the point of unprofitable return before another species could be utilized in its place. Estuarine organisms have been more affected by density-independent changes wrought by man on the environment than by exploitation; the former is greatly obscured and poorly supported with quantitative data; the latter ostensibly well-documented by catch records. The important effect of exploitation has been to alter greatly the size and age composition of a species, rather than to reduce the biomass. Thus, in Chesapeake Bay, with few exceptions, the great changes in the environment and population numbers of organisms cannot be attributed to fishing activities. Assuming that environmental conditions will remain stable or improve, then there is little danger that man's fishing activity at its present level of intensity can have any important effects on overall seafood production.

Relationship of Striped Bass Abundance to Fertilization in Estuaries

GENERAL COMMENTS ON FISH CROPS AND ARTIFICIAL NUTRIENTS: The purpose of this section is to suggest that the unusual increase in number and magnitude of dominant year-classes in the striped bass may be related to man-produced nutrients, especially from highly treated sewage. In spite of the vast quantities of artificial fertilizers entering North American estuaries, it is remarkable that none of the larger estuarine animals have been shown to benefit somehow from the long-term view. The striped bass's eggs and larvae are uniquely qualified to take advantage of these artificial effects, especially in the general spawning areas where brackish water meets tidal fresh water in the upper estuaries. This is an area of unusually rich plankton production, with specific hydrographic features, optimal light penetration, and reduced suspended materials.

Alterations by man in the Chesapeake Bay watershed have had adverse effects on many organisms; few examples can be given to show advantages. Changes in terrestrial habitats from forests to fields, for example, have benefitted certain game birds and mammals (Allen, 1954:63-5). The beneficial effects of organic pollution on certain organisms have been extensively documented by biologists and sanitary engineers. Thus, the population growth of bacteria, algae, certain tubificids, chironomids, and other invertebrates have served as classic examples (Wolman, et al, 1957:426-7; Odum and Odum, 1959:439; Hynes, 1959:27; Newell, 1959:62; Mohr, 1960:238). Although the beneficial effects of artificial fertilizers from the huge metropolitan areas on the coastal areas of North America have been alluded to by many writers, few people outside Europe have presented clear-cut examples.

Controlled introduction of modified sewage has been used by some investigators in the pond culture of carp (Schaeperclaus, 1933:172; Falck, 1934: 228), and this source of fertilizer elsewhere has a long history of use. Radebaugh and Agersborg (1934:448-9) demonstrated in an experimental lagoon that treated sewage effluents will support carp, catfishes, and other fish populations. They felt that this method of fertilization had great economic importance, as did Uhler (1956:457) who suggested that filter beds of sewage disposal plants be used to create new feeding and nesting grounds for waterfowl. Hardy (1956:66) pointed out that Graham (1938) showed that the abundant source of phosphates and nitrates in the southern North Sea opposite the opening of the Thames estuary was derived from the sewage of London. This region frequently developed a rich growth of phytoplankton that had marked effects on the fish production of the area. Hardy stated further that Carruthers (1954) recently summarized the work of K. Kalle of the Oceanographic Institute at Hamburg who also correlated the Thames drainage upon the fish populations

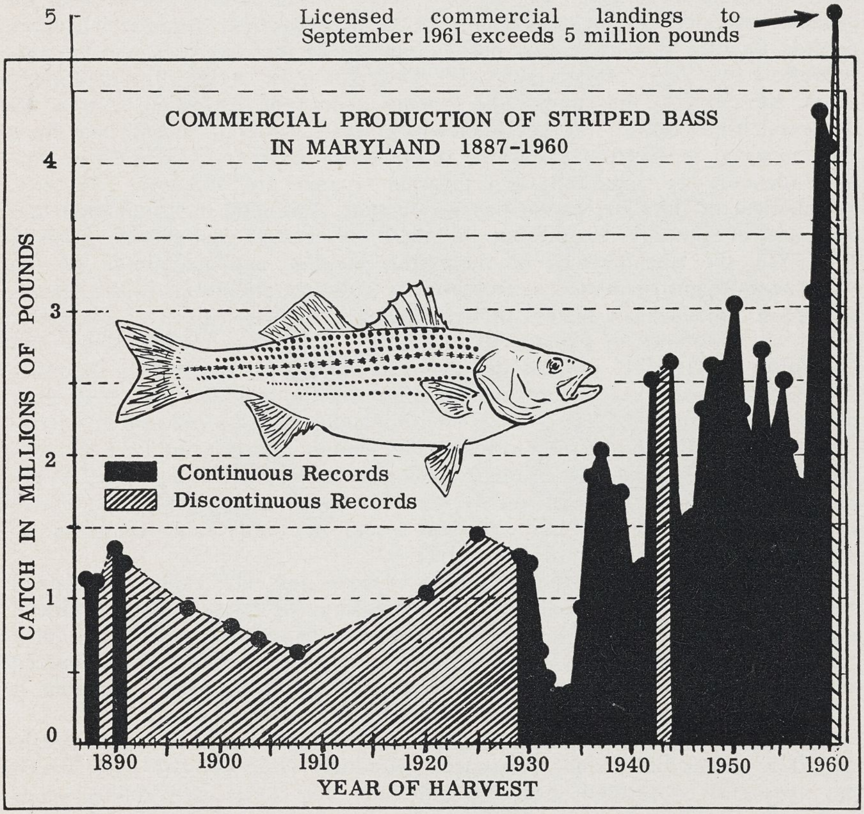


FIGURE 3. Trend of landings of striped bass, *Roccus saxatilis,* from Chesapeake Bay in Maryland to show the apparent increases in the frequency and magnitude of dominant year classes as reflected by peaks essentially two years after a hatch.

of the area. He showed that the catch of fish in this region is per unit area "about double the corresponding catch made in the rest of the North Sea, in the English channel and in the Kattegat/Skagerak region . . . and is about 25 times the catch reckoned for the Baltic Sea as a whole." Kalle believed that two-thirds of this higher average catch may be attributed to the rich supply of nutrients from the population of London. There is no comparable example for flowing systems for North America, although Langlois (1941:192) believed that roily, turbid waters benefitted catfish, carp, and sheepshead in inland waters. Fishery biologists have cited many isolated examples of fishes tolerant to conditions near sewage outfalls (Metcalf, 1942:196-7).

Dominant year-classes of striped bass have occurred in Chesapeake Bay during the last three decades during these years: 1934, 1940, 1942, 1943, 1946, 1948, 1950, 1954, 1956, 1958, and possibly 1961. Raney (1952:70) mentioned even earlier ones: 1896, 1898, 1904, and 1920. Figure 3 generally indicates the frequency and magnitude of the successful year-classes. They have occurred about every two or four years, where records occur, with no cyclical evidence. Preliminary examination of Maryland commercial catch records indicate that there has been a coincident increase in the catch-per-unit-effort two years after a successful hatch for most of the aforementioned years. Increases in the supply and catches cannot be explained entirely by increased fishing effort. Markedly successful year-classes of striped bass have also occurred in North Carolina in recent years (Sykes, 1961:personal correspondence), and apparently in California (Lyman and Woolner, 1961:40), independent of the Chesapeake Bay production. Assuming environmental factors are of primary importance in these successful year-classes (Raney, 1952:70), the phenomenon of increasing number and magnitude of the year-classes might be related to increasingly favorable conditions in the spawning areas. No clear-cut factors of hydrographic, meteorological, or biological origin are available to explain the increases. Trautman (1939:280-6) and Langlois (1941:193-4) pointed out that fish are highly selective in spawning and that man can have an unfavorable effect on the available spawning sites. Langlois also suggested (p. 190-2) environmental changes induced by civilization affected the dominant year-classes of certain species, and that successful hatches of saugers, for example, followed roily water conditions. In the case of striped bass, the eggs and larvae seem particularly adapted to survive abnormal hydrographic conditions that would be unfavorable or lethal to other species, due to their pelagic nature.

HYPOTHESIS: The following hypothesis is developed: civilization and striped bass populations are compatible, i.e., increasing fertilization from artificial and natural sources brought down to the estuary by run-off and freshets may be indirectly responsible for the dominant year-classes. It must be emphasized that at this time fertilization is uncontrolled and unpredictable, and that it can have deleterious as well as beneficial effects on striped bass.

The pelagic eggs and larvae of striped bass are preadapted to rapid, rough, silt-laden, and turbid waters. The species produces large buoyant eggs, which can apparently withstand extensive buffeting. The large perivitelline space may serve as an important breathing chamber (Mansueti, 1958B:7). Practically all other species spawning in tidal fresh and brackish waters in spring produce demersal or semi-demersal eggs. Striped bass eggs, however, float at or near the surface; they become semi-buoyant in slow-moving waters, such as at slack tide, and they then occur near the bottom. Observations and col-

FIGURE 4. Range and location of spawning areas of striped bass, *Roccus saxatilis,* in Chesapeake Bay, with illustrations of selected early developmental stages.

lections of eggs made in the Potomac River at Quantico in May, 1959, Patuxent River at Lower Marlboro in May, 1957, and in the Chesapeake and Delaware Canal near the Elk River at Chesapeake City in May, 1957, indicated that eggs were crowded toward the surface and were at the mercy of the prevailing current, tide, and wind-driven masses of water. For example, when observed in the Patuxent River at Lower Marlboro, several hundred thousand eggs were stranded in a window about two to three feet wide on the beach after surface waters were subjected to persistent west winds.

The spawning of striped bass occurs in tidal fresh and slightly brackish waters, and the location varies from year to year depending on a variety of hydrographic conditions (Figure 4). After the eggs are produced, they are transported at or near the surface by the net downstream flow of the estuary; those that sink during slack before flood tide will be carried upstream again by the net upstream movement of the more saline bottom water (Pritchard, 1951:375). By the time they hatch they are carried to the point where the increasing salinity neutralizes and precipitates the negatively-charged suspended particles (Nash, 1947:162). Here the turbidity is somewhat reduced, light penetration is optimal for the estuary, and photosynthesis by phytoplankton produces blooms which are grazed upon by increasing numbers of zooplankters. Figure 5 is a gross simplification of the interaction and sequence of all these factors in relation to spawning of fishes in tidal fresh water in a typical estuary in Chesapeake Bay. Additional nutrients provide for exceptional blooms and hence excellent grazing conditions for striped bass larvae. Brooks (1905:8-13), Nash (1947:167), and others, have described generally the dynamics of this food chain. Of all the fishes able to benefit from these conditions, the striped bass appears to be best adapted; although larvae and free-swimming young of other species also utilize the area. Extensive townet samples in the areas of lowest salinities in the Patuxent River indicate a predominance of early developmental stages of striped bass; eggs, larvae, and young of white perch, clupeids, percids, centrarchids, and cyprinids occur less abundantly.

Eggs and larvae of many of the species represented in the above-mentioned families are mostly restricted to the bottom and mid-water areas where light penetration is low, turbidity high, and sedimentation is accelerated (Nash, 1947:162). Although tidal changes and water movement keep many of them suspended, the majority of demersal and semi-demersal eggs and larvae without large oil globules are at a disadvantage in the bottom areas. After reaching the free-swimming stage, many of the survivors swim toward the surface, especially at night, and they actively compete in feeding with the striped bass young. Evidence suggests that this competition has little effect on the striped bass, not so much because the striped bass is an efficient grazer, but because the available zooplankton is generally very great in this enriched area.

PROBLEMS OF UNCONTROLLED ARTIFICIAL FERTILIZATION: The behavior of estuaries under future conditions of increasing fertilization, principally from highly treated mineralized sewage, is not now predictable, although some basic knowledge is available to achieve this end (Pritchard, 1960:25-7; Newell, 1959:64, 68-9). Figure 5 depicts provisionally in highly simplified terms the nature of the fertilization in relation to spawning of striped bass and the stratified nature of a typical estuary in Chesapeake Bay. It is based on data and concepts suggested by Hynes (1960:94), Nash (1947:162-4), Frey (1946:11-24, Massmann, et al (1952:113-31), Newell (1959:62-3), Wolman,

ASSESSMENT OF POTENTIAL FISHERY VALUES IN RELATION TO WATER QUALITY IN THE RIO SAN JOSE AND ACOMITA LAKE, ACOMA PUEBLO, NEW MEXICO

Robert J. Behnke

October, 1983

ABSTRACT

Fishery and recreational values possible with improved water quality can be greatly increased above previous levels. The present limitations on fisheries in the Rio San Jose and Acomita Lake are not irreversible nor irretrievable.

see. △ paper
PhD.
Walker report

OVERVIEW

From a review of literature compiled by BIA (Lt. Simpson's reconnaissance in New Mexico and Beale's account of U.S. Army's camel corps), it is clear that the Acoma and Laguana people were excellent stewards of their lands and waters and for hundreds of years they lived in harmony with nature. Under these precaucasian conditions there is no doubt that the Rio San Jose was an excellent trout stream that was not negatively impacted by pollution, erosion, or excessive flow depletion. For example, Lt. Simpson visited the Rio San Jose in September, 1849, in the vicinity of where McCarty's is now located, and found the stream to be ... "about 15 feet wide, lined with willows, and running swiftly over a gravelly bottom." He also noted that: "All along the valley (Laguna to Acoma) the land is cultivated in corn and melons, the luxuriance of their growth attesting the good quality of the soil. The cultivators of the soil are Pueblo Indians belonging to the villages of Laguna and Acoma."

E. E. Beale traveled the San Jose Valley in August, 1857, and wrote: "We find this valley, cultivated by the Indians, in far better condition than any part of New Mexico we have seen." Beale described the original condition of the Ojo del Gallo and its stream as: "A clear, sparkling stream with water as clear as crystal and very cool. It is quite deep, being in many places breast high." Beale and his men found the Rio San Jose and the stream from the Ojo del Gallo to be full of fish which they caught in makeshift nets made from gunny sacks. The fish were described as "trout" (Rio Grande cutthroat trout) and "mullet" (probably consisting of both Rio Grande chub and Rio Grande sucker).

Thus, we have an image of the precaucasian environment where although irrigated agriculture had been in existence for hundreds of years, the Rio San Jose ran clear and cold over clean gravel and contained an abundance of fish including the native cutthroat trout. It can also be assumed that the water flowing in the drainage basin was of good quality (low in dissolved salts). The luxuriant crops described would not have been possible from land suffering salt loading resulting from centuries of irrigation using water of high TDS.

The historical review in the Final Report of Aqua Science Inc., provides some insight into factors causing degregation of the Rio San Jose and the loss of trout spawning habitat. The headwater source, Bluewater Creek, was impounded in 1927, the water diverted for irrigation, and perennial flow from the headwaters ceased. Flow depletion increased from increased groundwater pumping and irrigation use. The Ojo del Gallo, which is estimated to have contributed a constant flow of 7 cfs of high quality water, ceased to flow in 1954. Surface flow from sewage discharge is reported to have first reached Horace Springs in the mid-1950's. It is estimated that the virgin flows in the Rio San Jose at the western boundary of Acoma lands was 19,710 acre feet per year (an average daily flow of about 27 cfs) and the present average annual flow is 5470 a.f. (average daily flow about 8 cfs), 30% of which comes from Grants sewer water. With reduced flows, and increased sediment and pollution loads, trout spawning habitat (clean gravel with clean, well oxygenated flows) probably disappeared in the 1940's and 50's. Perhaps the stream from the Ojo del Gallo was the last spawning habitat available and when this was lost, trout reproduction ceased. As will be discussed in more detail, this loss of spawning habitat is not irreversible nor irretrievable; the problem can be reversed when the sediment transport capacity of the steram exceeds the sediment load (degradation exceeds aggradation); but, I believe, until the problem of the suspended organic colloidal matter in the water is resolved, a "pollution blanket" would cause complete mortality of developing trout eggs.

-72%

1641AF

Stocked trout can survive in the Rio San Jose and grow well under present conditions, as described in Frank Halfmoon's report of November, 1981. Survival of the stocked trout was low (probably about 1% survived for 17 months), which makes it infeasible to attempt to maintain a trout fishery by stocking under present water quality conditions.

According to Mr. Halfmoon's report, the Rio San Jose traverses 13.8 miles of Acoma land (about 20 surface acres of stream) and its fishery potential could be a valuable recreational and economic asset to the Tribe if water quality improved.

The major economic benefits to the Tribe from recreational use of Rio San Jose water has been the fishery of Acomita Lake. Acomita Lake was put into operation in 1939. The information concerning the Acomita fishery available to me covers the period from 1962 to 1982.

is this high up or
lower on R. San Jose –
ie. is it an effective sediment
collector?

I don't quite understand this term. do you mean biological magnification ~~or actual~~ via Food chain or an actual ↑ in [nut]? The latter is difficult to prove, the former true but not necessarily negative -

Lakes act to magnify nutrients and the negative effects of organic matter (ammonia build-up and oxygen depletion). Due to cursory and sporadic bits of information and data and to differences in operational regimes of the lake, in annual precipitation and temperature patterns (amount of natural runoff into lake in relation to amount of Rio San Jose water), in different stocking programs, artificial fertilization of lake, effects of introduction of crawfish, etc., it is not possible to quantitatively partition the contribution to fishery problems of the influence of the Grants Sewage Treatment Plant, but a solid scenario can be developed emphasizing that the nutrient loading and organic matter input from the STP, above natural levels, led, through time, to a very predictable chronic problem of lake water quality that severely limited the fishery potential of the lake.

indicate its toxicity

it could be if $ and time were available | D. Porcella is well versed in this

In the past, although the lake was heavily used by anglers paying a fee, the Tribe realized only a small fraction of the income possible from the fishery. With improved water quality, imagination, expertise, and a more intensive and sophisticated fishery management and recreational program, the potential exists to tremendously increase tribal income from recreational use of its waters. This potential, however, cannot become a reality until the water quality in the Rio San Jose is significantly improved.

RIO SAN JOSE

See note 1 on attached

As discussed above, the Rio San Jose was originally a high quality stream inhabited by the native Rio Grande cutthroat trout. The native cutthroat trout is like the canary in the mine, it is extremely sensitive to environmental disturbances and is the first species to become extirpated in a changing environment (Behnke 1979). The cutthroat trout was probably replaced by brown trout and rainbow trout in the Rio San Jose many years ago. Brown and/or rainbow trout contributed to a fishery, probably into the 1950's. A New Mexico fishing map issued by the New Mexico Game and Fish Department (no date, but probably put together in the 1950's as no interstate highways occur on map) states that there is fishing in the Rio San Jose: " ... near lava beds and on Acoma Indian Reservation. 10 miles." Mr. Halfmoon's report mentions that Dr. Koster, Univ. New Mexico, collected brown trout in the Rio San Jose in 1940's. Brown trout are rarely stocked from hatcheries, thus it might be assumed that some natural reproduction was occurring in the 1940's. Prior to an experimental stocking of brown trout in 1980, the last stocking of trout (rainbow trout by USFWS) was in the 1960's.

~~The two~~ This suggests the possibility of competitive replacement rather than ↓ H_2O quality - a possible line of attack for those [illegible] to explain away R.G. cutthroat by a non-organic poll. cause see note on yellow paper.

In June, 1980, 3,500 brown trout fingerlings (3-inch size) were stocked into the Rio San Jose (Mr. Halfmoon's report does not give the locality of the stocking, but I assume it was below the irrigation diversion downstream from Horace Springs). In November, 1981, 7 sampling sites, covering 3,430 feet of stream were sampled by electrofishing (one site sampled with rotenone). A total of 12 trout, averaging 12.2 inches were recovered.

see note 1

~9"/yr growth

This experiment demonstrates that trout can survive in the Rio San Jose and exhibit good growth under present water quality conditions (there is an abundance of invertebrate organisms in this enriched stream). However, survival over the 17-month period appears to be very low. It is difficult to discuss survival in quantitative terms. Only 3,430 feet of stream were sampled, of 13.8 miles (72,864 feet) of stream on the Reservation. The collection of trout, however, was not randomly distributed. Ten of the 12 specimens recovered were found in the first three sites and the remaining two at a downstream site. Thus, it appears that surviving fish stayed relatively near their release point. If a significant number of trout did survive it should have been evident from numerous reports of seeing or catching trout by Tribal members. I would estimate that the 3,500 trout stocked in 1980 suffered greater than 95% mortality over the 17-month period -- the most intense mortality probably coming soon after stocking before full acclimation to degraded water quality was developed.

weak argument

the question is: what was cause of mortality? what are mortality rates of browns in other NM streams w/o organic poll?

All there to do is read on.

The question arises on the causes of this high mortality -- habitat or food limitations, predation, chronic or acute manifestation of water quality problems? My observations along the Rio San Jose revealed many sites with deep water and abundant cover, the invertebrates inhabiting the stream are low in diversity but high in numbers. Habitat and food limitations can be ruled out as a cause of the high mortality -- and this decision is validated by the good growth exhibited by the few surviving fish. Among the other fish species known to inhabit the Rio San Jose in the section stocked with trout, one species of sucker and **three** species of minnows, none are predators. The opaqueness of the water and areas of cover available to the stocked trout would have provided adequate protection against predation by birds and mammals. The most likely cause of the high mortality is the water quality parameters to which the fish were exposed. The presence of an abundance of other fish species surviving in this area indicates that a massive fish kill did not occur from a pollutant, but rather the extreme physiological sensitivity of trout species to low levels of toxicants indicates that chronic sublethal exposure resulted in increased susceptibility to secondary mortality factors such as disease.

OR

OK

exactly

not really - 12 fish / 3.4K of stream is a low density + even w/ limited food + cover one could argue: this growth might have occurred.

what are the toxicants? how high are [ ] - knowing this + using AFS red book would give you something more special.

the live boxes pg 14 won't resolve this effect only. acute toxicity ∴ the H_2O chemistry will be your best attack → EPA redbook

The Grants sewage effluent is highly chlorinated. This creates a "sterile" zone downstream from the outfall, free from bacteria that would digest organic matter. Thus, the typical septic zone of high BOD and recovery zone, characteristic of streams receiving organic wastes, is displaced downstream in the Rio San Jose. It was clear from my observations along the Rio San Jose downstream from the sewage plant outfall that considerable "undigested" organic matter is continually transported downstream. In areas of deposition along the streambanks, anaerobic sludge beds occur in abundance. Watersheds in this semiarid region mainly transport inorganic sediment in their stream channels. The source of such quantities of organic matter must be the sewer plant; there is no other logical explanation.

however not free from reoxygenation
conversion of
$NH_3 \rightarrow NH_4^+$
(toxic) (non toxic)
nitrification of
$NH_4^+ \rightarrow NO_3^-$

Good

Did you observe these - take photos, etc.

When organic and inorganic (P and N) enrichment occurs, two problems for trout survival may be expected. The enrichment will create zones of prolific algae growth. The rapidly photosynthesizing algae removes CO_2 from the water, raising the pH. The decomposition of organic matter releases ammonia. At higher pH values, a high proportion of ammonia is converted to the unionized form (NH_3) (toxicity increases by 200% from pH 7.4 to pH 8.0) which is extremely toxic to fish, especially trout. Most ammonia toxicity problems are transitory in nature and sublethal but cause increased susceptibility to other unfavorable conditions such as low oxygen levels and infection by disease organisms (Keup et al. 1967; Thurston et al. 1979; Tsai 1975). Alabaster J. Fish Biol has several 1979-1983 papers on NH_3 toxicity incld synergism w/ D.O, salinity - see TAFS 1983 vol 6 also

What are late afternoon pH's? there is

After sunset, the algae biomass ceases photosynthesis and begins respiration, depleting the dissolved oxygen in the water. The wild swings in diurnal O_2 values characteristic of enriched waters is exacerbated with organic enrichment because of its high biological oxygen demand. In the presence of extremely low levels of unionized ammonia, oxygen uptake is inhibited in the gill filaments of trout, magnifying the harmful effects of low oxygen. I believe this same phenomenon of the synergistic effect of sublethal unionized ammonia and low diurnal oxygen is responsible for the problems of the Acomita Lake fishery also. Until the nutrient loading attributable to the Grants STP is reduced, particularly a great reduction in suspended organic matter, a viable trout fishery is not possible in the Rio San Jose. - True if a) high NH_3 is observed, low morng DO, + high afternoon pH - otherwise your guess is as good as mine!

I would point out that for reduction of nutrients in sewage effluent, typically phosphorous (P) is emphasized, but in the case of the Rio San Jose, I doubt that even a considerable reduction in P will significantly

by weight total N vs total P or inorganic N vs ortho P?

Strongly Agree!

this is my battle in Reno.

recude aquatic plant production unless nitrogen (N) is also reduced proportionally. Typically, P becomes limiting to aquatic plant growth when its ratio to N is about 1:10. The N and P values I read for the Rio San Jose indicate the P to N values are only about 1:2-1:3. Thus, unless P were to be reduced by 4-5 times, there would still be a surplus available for plant growth. It is typical for western waters to have relatively high P values in relation to N. It is the nitrogen, not phosphorous that is currently the limiting nutrient.

I'm a firm supporter of the aridity-N limitation - terrestrial deserts are classic [illegible] N limited - so why not their streams? - See IBP text: Nitrogen in Desert Ecosystems in CSU Library.

If better water quality could be achieved, the Rio San Jose could become a viable trout fishery, but it would require additional effort to restore the stream to pre 1940(?) conditions.

Is it possible to develop a water use budget for the reservation? Most beneficial for fishery values would be a minimum flow bypass below the irrigation diversion below Horace Springs to supplement the flow of Anzac Spring and maintain some minimum flow through the Rio San Jose channel. With some constant flow (perhaps a minimum of 2-3 cfs) of clean water, silt and sediment would be continually removed from the stream channel, but only if sediment input were to be reduced. To reduce sediment input and greatly improve trout habitat, livestock should be fenced from the streambanks and all irrigated lands thoroughly checked to prevent spills of sediment laden return irrigation flows. Once erosion and sediment input are controleld and streambanks stabilized, stream improvement devices and trout spawning sites can be installed and created to establish a viable, self-reproducing trout population (Behnke and Raleigh 1979).

The Rio San Jose flows through 13.8 miles of Acoma lands and consists of about 20 surface acres. With clean water, adequate flows, and stream improvements, a yield of about 1,000 pounds of trout per year should be possible from natural reproduction, and supplementary stocking with hatchery raised trout can increase the catch as much as desired. A viable trout fishery would be a high value resource to the Tribe. Besides the recreation and food provided to Tribal members, one part of the stream could be opened to the public on a fee basis (the potential clientele for a wild trout fishery in a stream are willing to pay considerably more for this angling opportunity than are lake fishermen) and incorporated into the Tribal recreational enterprise.

Van Velson (1978) published a documented history of Otter Creek, Nebraska, a small stream that was changed from a silt laden water dominated by minnows and suckers, into a clear stream characterized by clean gravel ideal for trout reproduction. Within a few years trout became completely dominant in numbers and biomass over the minnows and suckers. This change resulted by fencing livestock from the stream which reduced sediment input, stabilized banks, restored riparian vegetation, and created improved habitat and clear water (I have a slide show of the Otter Creek Story).

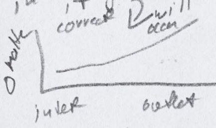
ACOMITA LAKE

Acomita Lake was filled in 1939. My information on the fishery were supplied by Mr. Frank Halfmoon and are for the period 1962-1982. The lake, when full, has a surface area of about 70 acres. The present storage volume is 710 acre feet, which is 24% less than the original volume. Examination of a map depicting 1937 and 1982 contour lines of the lake bottom (Acomita Lake Sedimentation Survey) indicates an interesting phenomenon concerning the filling of Acomita Lake. The filling has not proceeded from inlet to outlet, as would be expected if inorganic sediment was the main component of the fill material, but occurs from outlet (dam) to upper end of lake. This suggests that suspended organic matter, carried in from Rio San Jose water, is the major contribution to filling of the lake.

or else fine inorganics

it's easy to find this out run - C analysis on seds. in transect from inlet to outlet

if you are correct D will occur



also basin morph may have signif. effect here.

From the early reports in 1960's, it is apparent that Acomita Lake provided an environment conducive to rapid growth of trout. Two inch fingerling trout stocked one year would average 14 inches or more the following year. Growth continued during winter months, avaraging .5 inches per month and increased to 1.5 inches per month during late spring and summer. No nutrient data are available but it is obvious from notes on fish growth, food abundance, and vegetation problems that Acomita Lake waters were enriched. This can also be assumed on the basis of comparable lakes with relatively long retention time of inflow water that through biomagnification nutrient values (N and P) can be expected to double from values in inlet water. Despite this natural enrichment, Acomita Lake was artificially fertilized in 1964 and '65 with annual applications of about 17 pounds per surface acre of P and 21 pounds per acre of N. It is interesting to note, that despite the predictable increase in plant growth and rise in pH (to 9.9), no large-scale fish kill was reported.

this doesn't help your arguments for streams on pg 5!

this is very significant

Acomita Lake appears to have only weak and temporary stratification in the summer. During stratification, however, the large accumulation of benthic organic matter decomposes, creating anoxic conditions and hydrogen sulfide in deeper waters. Several references are made to the foul stench (H_2S) of the outlet water. Evidently wind action would break down the stratification and aerate the lake every week or two during the summer, preventing massive fish kills. The foul outlet water removed when the lake is stratified acts to remove nutrients concentrated in the hypolimnion and this may well have prolonged the life of the lake as trout habitat.

In the early 1960's, crawfish were stocked as a control of problem macrophyte vegetation. They flourished and did the job too well. In the early 1970's most rooted vegetation was gone and the water was often a brown color (from wind action stirring bare bottom soils and/or foraging action of crawfish) and fishermen complained that crawfish stole their bait. This indicates that channel catfish did not reproduce in Acomita Lake. Crawfish are a preferred item in the diet of channel catfish and I would assume that if catfish reproduction was successful, the catfish would have increased in response to the food supply and the resulting predator-prey interaction would have kept the crawfish population under control. In a 1982 report, Mr. Halfmoon commented on the problem of macrophyte vegetation choking the lake (similar to the early 1960's). What happened to the crawfish? No mention is made of their elimination.

interesting / since macrophytes do poorly in turbid water

It is evident from the 1960's that Acomita Lake was always in a precarious state during summer months when stratification occurred. The longer the lake was stratified the greater the volume of anoxic water and production of ammonia to be converted to toxic unionized ammonia by high pH. However, large scale fish kills were never observed and survival from one year to the next appeared to be good (based on number of larger, "holdover" trout in catch). In 1960's some rainbow trout must have survived for three years or more in the lake as some fish of 24-25 inches were reported. In the 1970's, it appears holdover survival was reduced and the maximum size of trout were 18-19 inches. In 1977 the first reports of channel catfish mortality were noted, which continued through 1982. Dead catfish were found to carry Aeromonas bacteria but this bacteris is ubiquitous and typically contributes to mortality as a secondary factor under stressful

conditions. I would suggest that the stress would come from the synergistic interaction of low O_2 and high unionized ammonia that would be expected to be localized in shallower water where macrophyte vegetation was dense (rapid daytime photosynthesis removes CO_2 and raises pH, increasing concentration of unionized ammonia, whereas nighttime and dim light respiration causes oxygen depletion and stress on fish). These impacts would be expected to be much less severe in the deeper open water of the lake inhabited by trout.

By the late 1970's long-term survival of both trout and catfish were reduced from earlier levels and the fishery had to be maintained by stocking catchable-sized trout and catfish. The valuable fish culture capacity of Acomita Lake -- the stocking of small fingerling fish and letting them grow to a large size on natural foods for two or three years -- had been lost. Although there are no limnological data available to me to document any trends of environmental conditions, the history of fishery problems resulting from nutrient loading follows a predictable pattern and is in agreement with case history studies of other lakes (Fisher and Ziebell 1980; Taylor and Hams 1981; Vigg 1983). Figure 1 illustrates the predicted problems resulting from nutrient loading of a lake through time and the maintenance of adequate salmonid habitat during summer stratification.

see Kock.

I would suggest that if Frank Halfmoon has addresses for Jack Dean and Terry Merkel (former USFWS biologists involved with management of Acomita Lake) he send them copies of this report and request their comments and any additional information they might provide.

The quality of the fishery of Acomita Lake and its proximity to Albuquerque made it a highly popular fishing site. Daily permits were sold for one dollar a day or three dollars per season in the 1960's. Use and income steadily increased to 1970 when the fishery received 17,000 person-days of angling (about 70,000 angling hours or 1,000 hours of angling per surface acre) and fees collected amounted to $16,861. In FWS annual reports by Jack Dean, it was recommended another lake be constructed to take advantage of the increasing demand.

dredging of Acomita? if P were shown to be the problem ([illegible]) - it may be if there are B-green algae blooms - then addition of alum could help - see 1983 issues of J. Freshwater Ecol - much success in Medical Lake, WA w/ this approach.

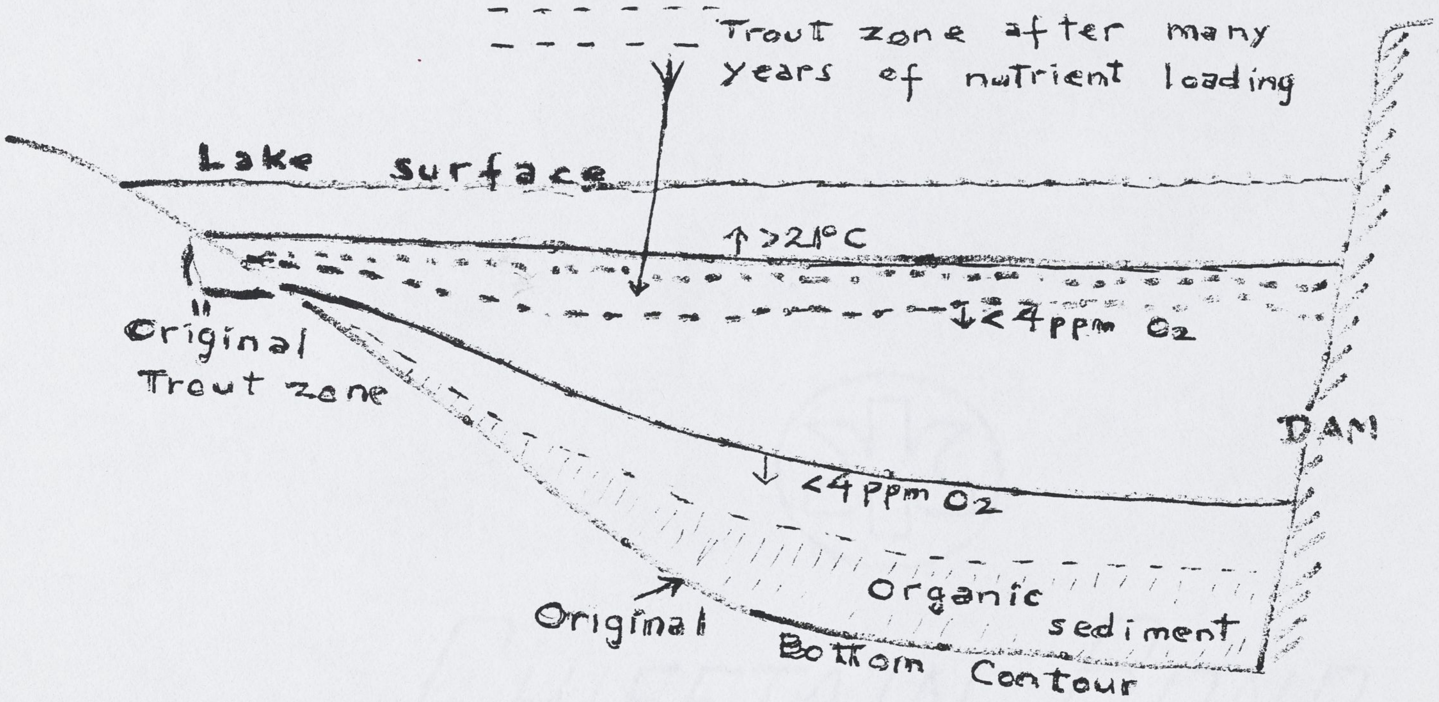


Figure 1. Illustrates a predictable course of fishery problems in an impoundment receiving waters enriched with inorganic and organic nutrients. After many years, organic sediment builds up reducing volume and depth of lake and binding nutrients that are released under anaerobic conditions. During summer stratification, the increasing BOD in the hypolimnion continually reduces the thermocline area that is inhabited by trout, defined by a combination of temperatures less than 21° C and dissolved oxygen of more than 4 ppm. Chronic problems of sporadic mortality and distressed fish may be expected for several years before a massive fish kill occurs.

whats an organic nutrient? N, P, C, Si are inorganic

actually much of hypo deoxy due to COD as well

<4?

most workers incld EPA use <5 cl prefer <6!

Walker lake is a classic example of this! See Fig in his report. I've enclosed.

Although somewhat beyond the scope of my report, I suggest that if improved water quality is available in the future in the Rio San Jose, then there are opportunities to greatly increase the economic returns from the fishery over previous levels. Until 1970 the Tribe received an average of only $1 per day of recreational use of their waters. The economic evaluation of a day's fishing can be figured in many ways, but a synthesis of all costs (fishing tackle, travel, food, lodging, license, permits, etc.) averaged about $25 per day's fishing (about 3 hours of actual angling) according to 1980 data compiled by the USFWS. A future goal should be to have the Tribe receive a significantly greater portion of the average daily cost of an angling day. A 1980 report of the Missouri Conservation Department to the Corps of Engineers documenting the value of the rainbow trout fishery in Lake Taneycomo to the local economy (based on income multiplier method), arrived at a figure of $9.9 million from 1.5 million hours of angling, or more than $6 per angler hour.

Good!

Clawson (1965) divided anglers into three basic groups for economic evaluations, casual, active, and purist. The "casual" angler chooses a recreation area because fishing is available, but the actual fishing experience and the catching of fish is not of primary importance. The "active" angler's primary concern is catching many fish and bringing home a limit. The "purist" angler's primary enjoyment concerns the angling experience of fishing for a favorite target species on artificial flies or lures, but not killing a "mess" of fish. Most of the catch of the purist is returned to the water. Both the casual and purist angler invest more, on average, for a day's fishing than does the "active" angler, and they have much less impact on the fish population. That is, each fish generates more dollars per hour of angling from the "casual" and "purist" group than it does from the "active" group. I suspect that the angler clientele of Acomita Lake has been overwhelmingly from the "active" group in the past.

Increasing the fishery valuation of Acomita Lake would require more intensive management and investment.

For the lake fishery, besides domesticated rainbow trout and channel catfish I would recommend the use of the more thermally adapted and high pH adapted redband trout (Behnke 1979) currently propagated at the Ennis, Montana National Fish Hatchery. The redband trout along with brown trout and Snake River cutthroat trout could be stocked as fingerlings and

allowed to grow in the lake. This management strategy, if successful, would greatly increase total trout production by interspecific ecological segregation (Trojnar and Behnke 1974) and provide long-lived trout that could be expected to live for several years in the lake and reach trophy sizes (trophy trout that would generate publicity for the lake's fishery and attract the "purist" group of anglers). To be maximally effective, domesticated catchable size rainbow trout could be regularly stocked from April-July for the "casual" and "active" groups of anglers. The "wild" trout, stocked as fingerlings, would be expected to have distinctly different feeding and behavior patterns and should not be excessively harvested by anglers fishing for the hatchery rainbow trout. Early, and late in the season (for example, October 1 to April 15). A special regulation trophy fishery could be instituted, for example, a bag limit of one or two trout with a minimum size limit of 18 inches, and artificial flies and lures only. This season would attract mainly the purist group. The vegetation problem that has consistently plagued Acomita Lake was controlled when crawfish were very abundant, but the lack of vegetation and excessive crawfish abundance caused other problems. The solution to this problem would be to establish balanced predator-prey interactions between fish-crawfish-vegetation. If successful, crawfish would maintain an abundance sufficient to control nuisance vegetation but when "too much" vegetation is eliminated the crawfish would be exposed to intensive predation by fish.

In the past, channel catfish and brown trout were the only species in the lake that would be expected to be effective predators on crawfish, but they did not occur at sufficient density to be effective control agents. In addition to the channel catfish, I would recommend smallmouth bass, an extremely effective crawfish predator, be stocked. Smallmouth bass would probably need protective regulations (for example, release all bass between 10-16 inches) to maintain adequate predation pressure on crawfish. The goal would be to make the crawfish an asset by being both a weed control agent and a food supply for valuable fish. Crawfish are an ideal food for fishes because they are efficient assimilators of energy from diverse trophic levels and in turn supply a large food item that favors feeding segregation between small and large trout (zooplankton feeders and "large item" feeders on crawfish and fish). I would point out that the redband trout is a specialized predator on chubs of the genus Gila.

I would also suggest the possibility of introducing a few (10-15) grass carp into the lake as a weed control agent. I have no doubt that they would survive in the lake and actively consume macrophyte vegetation. They would not reproduce and they could not reach the Rio Grande if they escaped from the lake.

With an excellent fishery with an appeal to a wide spectrum of anglers, fees and support facilities should be planned to maximize income. A parking fee could be instituted, RV and camping facilities and simple cabins could be constructed for those desiring to spend more than one day at the lake, and this would also be attractive to travelers on the interstate highway. With other services, a goal might be to average $8 to $10 return per recreational day with an annual use of 25,000 recreational days for Acomita Lake (and more if a trout fishery were to be established in the Rio San Jose).

The point is that realization of potential fishery value is dependent on better water quality (significant improvement of Grants STP). The potential gains possible with better water quality from a more intensively managed fishery and recreational enterprise (and conversely the potential loss suffered by continued poor water quality) is $100,000's annually.

RECOMMENDATIONS

A fishery-recreational enterprise plan should be developed along the lines indicated above. Such a plan, contingent on improved water quality, would demonstrate that future options foregone by continued water quality degradation, are worth $100,000's annually to the Tribe, not simply the $10,000-$20,000 range of fishing fees formerly collected at Acomita Lake.

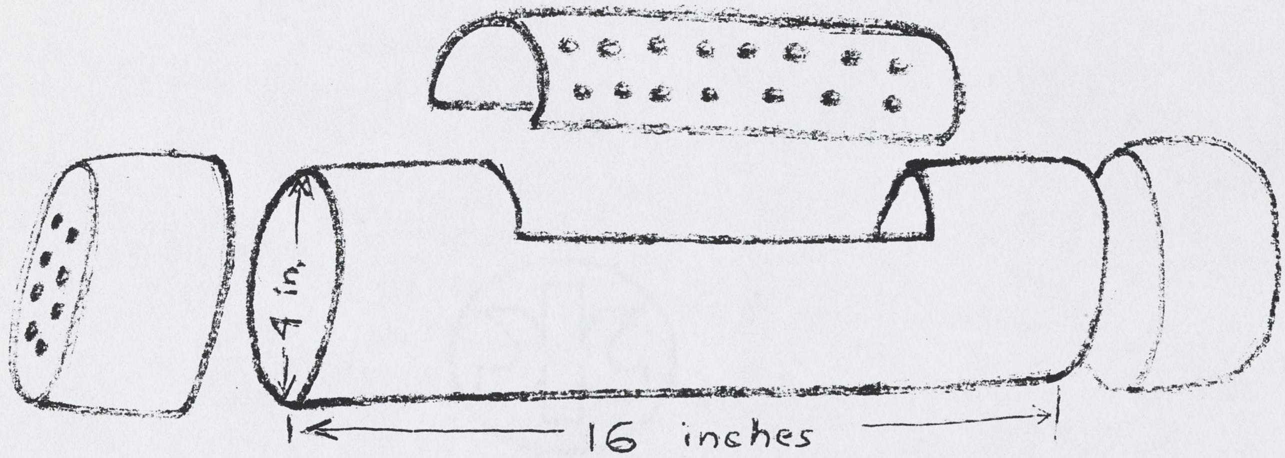
The plan should detail what measures might be instituted by the Tribe to greatly improve the fishery potential, such as development of a water budget recognizing fishery values by minimum flows in Rio San Jose, operation of Acomita Lake storage to increase both inflow and hypolimnetic outflow during periods of summer stagnation and a strategy to maintain certain annual levels in the lake designed to benefit the fish and fishermen. The creation of habitat improvement structures in the Rio San Jose, livestock fencing and irrigation management to reverse erosion and sediment input.

A more sophisticated stocking and management strategy for Acomita Lake that would maximize production of valuable species by utilizing interspecific niche diversity in concordance with trophic diversity and habitat diversity of the lake ecosystem. A strategy designed to appeal to a wider spectrum of anglers with a goal of greatly increasing the return to the Tribe of daily fishing expenditures. Discussion of expanding facilities to include RV and camping areas, simple cabins, etc. and the possibility of construction of a new lake after a certain level of use is attained (for example, 15,000-20,000 person days of use).

In view of the fact that water quality problems such as drastic diurnal fluctuations of O_2, pH, and uionized ammonia, that can be lethal to fish, are transitory in nature and likely to be undetected by intermittent water quality sampling, I recommend that live fish be used for continuous monitoring. Typically, fathead minnows are used for this type of monitoring, but any readily available species can be used as long as the same species or species combinations are placed in each of the live boxes. The information that can be documented by such a monitoring program includes: the distance below the sewage outfall with lethal conditions (chlorine alone will likely kill fish within 6-12 hours for a mile or more below the outlet, and the zone of lethal oxygen levels can be expected to change with the season). The frequency of lethal conditions at various downstream points through time (my observations above Horace Springs indicate that occasional fish kills occur at some regular interval); and a valuable documentation lending itself to simple charts and graphs that could be impressive evidence in court.

excellent approach — simple, + it would prove the point well. I would recc: using Fish species that are stocked there rather than Fatheads — This is such a simple, useful approach that I'll suggest it for summer hypolimnion in these lakes.

Live boxes can be of various sizes, shapes, and materials. Figure 2 illustrates a live box for 10 fathead minnows used by Dr. G. Fred Lee for monitoring below sewage outfalls. Typically stations are set up with an upstream or downstream station outside the limits of sewage impact to act as a control. The site downstream from the sewage outfall that is lethal to all fish in 24 hours can be first determined by setting live boxes out in a regular downstream pattern, about .5 miles apart and checking the following day. When this point is established (lethality here would be from chlorine), regular stations could be established, perhaps at the



Body is 16 in. section of 4 in. diameter PVC pipe. Ends are 4 in. end caps of PVC and cover is split PVC pipe with 1/8 in. holes.

Figure 2. Type of fish container used by G. Fred Lee (adapted from: Application of the hazard assessment approach for establishing water quality classification for Fountain Creek and appropriate water quality standards for this classification. G. F. Lee, 1980). A series of these containers, each with 10 fathead minnows, were placed below sewage outfall (one box above the outfall was control) about .5 - 1.0 mile apart to delineate lethal zone.

same sites as water quality sampling stations, fish set out and checked with frequency needed to document such aspects as sites with 50% survival for 24, 96 hours, and one week. Thereafter boxes could be checked each week (new fish added as necessary) to monitor for sporadic lethal conditions that might be missed by water quality sampling. Accurate records must be maintained from all observations and dead fish should be labeled as to site and date and frozen for possible use as evidence.

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OVERVIEW

From a review of literature compiled by BIA (Lt. Simpson's reconnaissance in New Mexico and Beale's account of U.S. Army's camel corps), it is clear that the Acoma and Laguana people were excellent stewards of their lands and waters and for hundreds of years they lived in harmony with nature. Under these precaucasian conditions there is no doubt that the Rio San Jose was an excellent trout stream that was not negatively impacted by pollution, erosion, or excessive flow depletion. For example, Lt. Simpson visited the Rio San Jose in September, 1849, in the vicinity of where McCarty's is now located, and found the stream to be ... "about 15 feet wide, lined with willows, and running swiftly over a gravelly bottom." He also noted that: "All along the valley (Laguna to Acoma) the land is cultivated in corn and melons, the luxuriance of their growth attesting the good quality of the soil. The cultivators of the soil are Pueblo Indians belonging to the villages of Laguna and Acoma."

E. E. Beale traveled the San Jose Valley in August, 1857, and wrote: "We find this valley, cultivated by the Indians, in far better condition than any part of New Mexico we have seen." Beale described the original condition of the Ojo del Gallo and its stream as: "A clear, sparkling stream with water as clear as crystal and very cool. It is quite deep, being in many places breast high." Beale and his men found the Rio San Jose and the stream from the Ojo del Gallo to be full of fish which they caught in makeshift nets made from gunny sacks. The fish were described as "trout" (Rio Grande cutthroat trout) and "mullet" (probably consisting of both Rio Grande chub and Rio Grande sucker).

Thus, we have an image of the precaucasian environment where although irrigated agriculture had been in existence for hundreds of years, the Rio San Jose ran clear and cold over clean gravel and contained an abundance of fish including the native cutthroat trout. It can also be assumed that the water flowing in the drainage basin was of good quality (low in dissolved salts). The luxuriant crops described would not have been possible from land suffering salt loading resulting from centuries of irrigation using water of high TDS.

The historical review in the Final Report of Aqua Science Inc., provides some insight into factors causing degregation of the Rio San Jose and the loss of trout spawning habitat. The headwater source, Bluewater Creek, was impounded in 1927, the water diverted for irrigation, and perennial flow from the headwaters ceased. Flow depletion increased from increased groundwater pumping and irrigation use. The Ojo del Gallo, which is estimated to have contributed a constant flow of 7 cfs of high quality water, ceased to flow in 1954. Surface flow from sewage discharge is reported to have first reached Horace Springs in the mid-1950's. It is estimated that the virgin flows in the Rio San Jose at the western boundary of Acoma lands was 19,710 acre feet per year (an average daily flow of about 27 cfs) and the present average annual flow is 5470 a.f. (average daily flow about 8 cfs), 30% of which comes from Grants sewer water. With reduced flows, and increased sediment and pollution loads, trout spawning habitat (clean gravel with clean, well oxygenated flows) probably disappeared in the 1940's and 50's. Perhaps the stream from the Ojo del Gallo was the last spawning habitat available and when this was lost, trout reproduction ceased. As will be discussed in more detail, this loss of spawning habitat is not irreversible nor irretrievable; the problem can be reversed when the sediment transport capacity of the steram exceeds the sediment load (degradation exceeds aggradation); but, I believe, until the problem of the suspended organic colloidal matter in the water is resolved, a "pollution blanket" would cause complete mortality of developing trout eggs.

Stocked trout can survive in the Rio San Jose and grow well under present conditions, as described in Frank Halfmoon's report of November, 1981. Survival of the stocked trout was low (probably about 1% survived for 17 months), which makes it infeasible to attempt to maintain a trout fishery by stocking under present water quality conditions.

According to Mr. Halfmoon's report, the Rio San Jose traverses 13.8 miles of Acoma land (about 20 surface acres of stream) and its fishery potential could be a valuable recreational and economic asset to the Tribe if water quality improved.

The major economic benefits to the Tribe from recreational use of Rio San Jose water has been the fishery of Acomita Lake. Acomita Lake was put into operation in 1939. The information concerning the Acomita fishery available to me covers the period from 1962 to 1982.

Lakes act to magnify nutrients and the negative effects of organic matter (ammonia build-up and oxygen depletion). Due to cursory and sporadic bits of information and data and to differences in operational regimes of the lake, in annual precipitation and temperature patterns (amount of natural runoff into lake in relation to amount of Rio San Jose water), in different stocking programs, artificial fertilization of lake, effects of introduction of crawfish, etc., it is not possible to quantitatively partition the contribution to fishery problems of the influence of the Grants Sewage Treatment Plant, but a solid scenario can be developed emphasizing that the nutrient loading and organic matter input from the STP, above natural levels, led, through time, to a very predictable chronic problem of lake water quality that severely limited the fishery potential of the lake.

In the past, although the lake was heavily used by anglers paying a fee, the Tribe realized only a small fraction of the income possible from the fishery. With improved water quality, imagination, expertise, and a more intensive and sophisticated fishery management and recreational program, the potential exists to tremendously increase tribal income from recreational use of its waters. This potential, however, cannot become a reality until the water quality in the Rio San Jose is significantly improved.

RIO SAN JOSE

As discussed above, the Rio San Jose was originally a high quality stream inhabited by the native Rio Grande cutthroat trout. The native cutthroat trout is like the canary in the mine, it is extremely sensitive to environmental disturbances and is the first species to become extirpated in a changing environment (Behnke 1979). The cutthroat trout was probably replaced by brown trout and rainbow trout in the Rio San Jose many years ago. Brown and/or rainbow trout contributed to a fishery, probably into the 1950's. A New Mexico fishing map issued by the New Mexico Game and Fish Department (no date, but probably put together in the 1950's as no interstate highways occur on map) states that there is fishing in the Rio San Jose: " ... near lava beds and on Acoma Indian Reservation. 10 miles." Mr. Halfmoon's report mentions that Dr. Koster, Univ. New Mexico, collected brown trout in the Rio San Jose in 1940's. Brown trout are rarely stocked from hatcheries, thus it might be assumed that some natural reproduction was occurring in the 1940's. Prior to an experimental stocking of brown trout in 1980, the last stocking of trout (rainbow trout by USFWS) was in the 1960's.

In June, 1980, 3,500 brown trout fingerlings (3-inch size) were stocked into the Rio San Jose (Mr. Halfmoon's report does not give the locality of the stocking, but I assume it was below the irrigation diversion downstream from Horace Springs). In November, 1981, 7 sampling sites, covering 3,430 feet of stream were sampled by electrofishing (one site sampled with rotenone). A total of 12 trout, averaging 12.2 inches were recovered.

This experiment demonstrates that trout can survive in the Rio San Jose and exhibit good growth under present water quality conditions (there is an abundance of invertebrate organisms in this enriched stream). However, survival over the 17-month period appears to be very low. It is difficult to discuss survival in quantitative terms. Only 3,430 feet of stream were sampled, of 13.8 miles (72,864 feet) of stream on the Reservation. The collection of trout, however, was not randomly distributed. Ten of the 12 specimens recovered were found in the first three sites and the remaining two at a downstream site. Thus, it appears that surviving fish stayed relatively near their release point. If a significant number of trout did survive it should have been evident from numerous reports of seeing or catching trout by Tribal members. I would estimate that the 3,500 trout stocked in 1980 suffered greater than 95% mortality over the 17-month period -- the most intense mortality probably coming soon after stocking before full acclimation to degraded water quality was developed.

The question arises on the causes of this high mortality -- habitat or food limitations, predation, chronic or acute manifestation of water quality problems? My observations along the Rio San Jose revealed many sites with deep water and abundant cover, the invertebrates inhabiting the stream are low in diversity but high in numbers. Habitat and food limitations can be ruled out as a cause of the high mortality -- and this decision is validated by the good growth exhibited by the few surviving fish. Among the other fish species known to inhabit the Rio San Jose in the section stocked with trout, one species of sucker and three species of minnows, none are predators. The opaqueness of the water and areas of cover available to the stocked trout would have provided adequate protection against predation by birds and mammals. The most likely cause of the high mortality is the water quality parameters to which the fish were exposed. The presence of an abundance of other fish species surviving in this area indicates that a massive fish kill did not occur from a pollutant, but rather the extreme physiological sensitivity of trout species to low levels of toxicants indicates that chronic sublethal exposure resulted in increased susceptibility to secondary mortality factors such as disease.

The Grants sewage effluent is highly chlorinated. This creates a "sterile" zone downstream from the outfall, free from bacteria that would digest organic matter. Thus, the typical septic zone of high BOD and recovery zone, characteristic of streams receiving organic wastes, is displaced downstream in the Rio San Jose. It was clear from my observations along the Rio San Jose downstream from the sewage plant outfall that considerable "undigested" organic matter is continually transported downstream. In areas of deposition along the streambanks, anaerobic sludge beds occur in abundance. Watersheds in this semiarid region mainly transport inorganic sediment in their stream channels. The source of such quantities of organic matter must be the sewer plant; there is no other logical explanation.

When organic and inorganic (P and N) enrichment occurs, two problems for trout survival may be expected. The enrichment will create zones of prolific algae growth. The rapidly photosynthesizing algae removes CO_2 from the water, raising the pH. The decomposition of organic matter releases ammonia. At higher pH values, a high proportion of ammonia is converted to the unionized form (NH_3) (toxicity increases by 200% from pH 7.4 to pH 8.0) which is extremely toxic to fish, especially trout. Most ammonia toxicity problems are transitory in nature and sublethal but cause increased susceptibility to other unfavorable conditions such as low oxygen levels and infection by disease organisms (Keup et al. 1967; Thurston et al. 1979; Tsai 1975).

After sunset, the algae biomass ceases photosynthesis and begins respiration, depleting the dissolved oxygen in the water. The wild swings in diurnal O_2 values characteristic of enriched waters is exacerbated with organic enrichment because of its high biological oxygen demand. In the presence of extremely low levels of unionized ammonia, oxygen uptake is inhibited in the gill filaments of trout, magnifying the harmful effects of low oxygen. I believe this same phenomenon of the synergistic effect of sublethal unionized ammonia and low diurnal oxygen is responsible for the problems of the Acomita Lake fishery also. Until the nutrient loading attributable to the Grants STP is reduced, particularly a great reduction in suspended organic matter, a viable trout fishery is not possible in the Rio San Jose.

I would point out that for reduction of nutrients in sewage effluent, typically phosphorous (P) is emphasized, but in the case of the Rio San Jose, I doubt that even a considerable reduction in P will significantly

recude aquatic plant production unless nitrogen (N) is also reduced proportionally. Typically, P becomes limiting to aquatic plant growth when its ratio to N is about 1:10. The N and P values I read for the Rio San Jose indicate the P to N values are only about 1:2-1:3. Thus, unless P were to be reduced by 4-5 times, there would still be a surplus available for plant growth. It is typical for western waters to have relatively high P values in relation to N. It is the nitrogen, not phosphorous that is the limiting nutrient.

[redacted]

If better water quality could be achieved, the Rio San Jose could become a viable trout fishery, but it would require additional effort to restore the stream to pre 1940(?) conditions.

Is it possible to develop a water use budget for the reservation? Most beneficial for fishery values would be a minimum flow bypass below the irrigation diversion below Horace Springs to supplement the flow of Anzac Spring and maintain some minimum flow through the Rio San Jose channel. With some constant flow (perhaps a minimum of 2-3 cfs) of clean water, silt and sediment would be continually removed from the stream channel, but only if sediment input were to be reduced. To reduce sediment input and greatly improve trout habitat, livestock should be fenced from the streambanks and all irrigated lands thoroughly checked to prevent spills of sediment laden return irrigation flows. Once erosion and sediment input are controleld and streambanks stabilized, stream improvement devices and trout spawning sites can be installed and created to establish a viable, self-reproducing trout population (Behnke and Raleigh 1979).

The Rio San Jose flows through 13.8 miles of Acoma lands and consists of about 20 surface acres. With clean water, adequate flows, and stream improvements, a yield of about 1,000 pounds of trout per year should be possible from natural reproduction, and supplementary stocking with hatchery raised trout can increase the catch as much as desired. A viable trout fishery would be a high value resource to the Tribe. Besides the recreation and food provided to Tribal members, one part of the stream could be opened to the public on a fee basis (the potential clientele for a wild trout fishery in a stream are willing to pay considerably more for this angling opportunity than are lake fishermen) and incorporated into the Tribal recreational enterprise.

Van Velson (1978) published a documented history of Otter Creek, Nebraska, a small stream that was changed from a silt laden water dominated by minnows and suckers, into a clear stream characterized by clean gravel ideal for trout reproduction. Within a few years trout became completely dominant in numbers and biomass over the minnows and suckers. This change resulted by fencing livestock from the stream which reduced sediment input, stabilized banks, restored riparian vegetation, and created improved habitat and clear water (I have a slide show of the Otter Creek Story).

ACOMITA LAKE

Acomita Lake was filled in 1939. My information on the fishery were supplied by Mr. Frank Halfmoon and are for the period 1962-1982. The lake, when full, has a surface area of about 70 acres. The present storage volume is 710 acre feet, which is 24% less than the original volume. Examination of a map depicting 1937 and 1982 contour lines of the lake bottom (Acomita Lake Sedimentation Survey) indicates an interesting phenomenon concerning the filling of Acomita Lake. The filling has not proceeded from inlet to outlet, as would be expected if inorganic sediment was the main component of the fill material, but occurs from outlet (dam) to upper end of lake. This suggests that suspended organic matter, carried in from Rio San Jose water, is the major contribution to filling of the lake.

From the early reports in 1960's, it is apparent that Acomita Lake provided an environment conducive to rapid growth of trout. Two inch fingerling trout stocked one year would average 14 inches or more the following year. Growth continued during winter months, avaraging .5 inches per month and increased to 1.5 inches per month during late spring and summer. No nutrient data are available but it is obvious from notes on fish growth, food abundance, and vegetation problems that Acomita Lake waters were enriched. This can also be assumed on the basis of comparable lakes with relatively long retention time of inflow water that through biomagnification nutrient values (N and P) can be expected to double from values in inlet water. Despite this natural enrichment, Acomita Lake was artificially fertilized in 1964 and '65 with annual applications of about 17 pounds per surface acre of P and 21 pounds per acre of N. It is interesting to note, that despite the predictable increase in plant growth and rise in pH (to 9.9), no large-scale fish kill was reported.

Acomita Lake appears to have only weak and temporary stratification in the summer. During stratification, however, the large accumulation of benthic organic matter decomposes, creating anoxic conditions and hydrogen sulfide in deeper waters. Several references are made to the foul stench (H_2S) of the outlet water. Evidently wind action would break down the stratification and aerate the lake every week or two during the summer, preventing massive fish kills. The foul outlet water removed when the lake is stratified acts to remove nutrients concentrated in the hypolimnion and this may well have prolonged the life of the lake as trout habitat.

In the early 1960's, crawfish were stocked as a control of problem macrophyte vegetation. They flourished and did the job too well. In the early 1970's most rooted vegetation was gone and the water was often a brown color (from wind action stirring bare bottom soils and/or foraging action of crawfish) and fishermen complained that crawfish stole their bait. This indicates that channel catfish did not reproduce in Acomita Lake. Crawfish are a preferred item in the diet of channel catfish and I would assume that if catfish reproduction was successful, the catfish would have increased in response to the food supply and the resulting predator-prey interaction would have kept the crawfish population under control. In a 1982 report, Mr. Halfmoon commented on the problem of macrophyte vegetation choking the lake (similar to the early 1960's). What happened to the crawfish? No mention is made of their elimination.

It is evident from the 1960's that Acomita Lake was always in a precarious state during summer months when stratification occurred. The longer the lake was stratified the greater the volume of anoxic water and production of ammonia to be converted to toxic unionized ammonia by high pH. However, large scale fish kills were never observed and survival from one year to the next appeared to be good (based on number of larger, "holdover" trout in catch). In 1960's some rainbow trout must have survived for three years or more in the lake as some fish of 24-25 inches were reported. In the 1970's, it appears holdover survival was reduced and the maximum size of trout were 18-19 inches. In 1977 the first reports of channel catfish mortality were noted, which continued through 1982. Dead catfish were found to carry <u>Aeromonas</u> bacteria but this bacteris is ubiquitous and typically contributes to mortality as a secondary factor under stressful

conditions. I would suggest that the stress would come from the synergistic interaction of low O_2 and high unionized ammonia that would be expected to be localized in shallower water where macrophyte vegetation was dense (rapid daytime photosynthesis removes CO_2 and raises pH, increasing concentration of unionized ammonia, whereas nighttime and dim light respiration causes oxygen depletion and stress on fish). These impacts would be expected to be much less severe in the deeper open water of the lake inhabited by trout.

By the late 1970's long-term survival of both trout and catfish were reduced from earlier levels and the fishery had to be maintained by stocking catchable-sized trout and catfish. The valuable fish culture capacity of Acomita Lake -- the stocking of small fingerling fish and letting them grow to a large size on natural foods for two or three years -- had been lost. Although there are no limnological data available to me to document any trends of environmental conditions, the history of fishery problems resulting from nutrient loading follows a predictable pattern and is in agreement with case history studies of other lakes (Fisher and Ziebell 1980; Taylor and Hams 1981; Vigg 1983). Figure 1 illustrates the predicted problems resulting from nutrient loading of a lake through time and the maintenance of adequate salmonid habitat during summer stratification.

I would suggest that if Frank Halfmoon has addresses for Jack Dean and Terry Merkel (former USFWS biologists involved with management of Acomita Lake) he send them copies of this report and request their comments and any additional information they might provide.

The quality of the fishery of Acomita Lake and its proximity to Albuquerque made it a highly popular fishing site. Daily permits were sold for one dollar a day or three dollars per season in the 1960's. Use and income steadily increased to 1970 when the fishery received 17,000 person-days of angling (about 70,000 angling hours or 1,000 hours of angling per surface acre) and fees collected amounted to $16,861. In FWS annual reports by Jack Dean, it was recommended another lake be constructed to take advantage of the increasing demand.

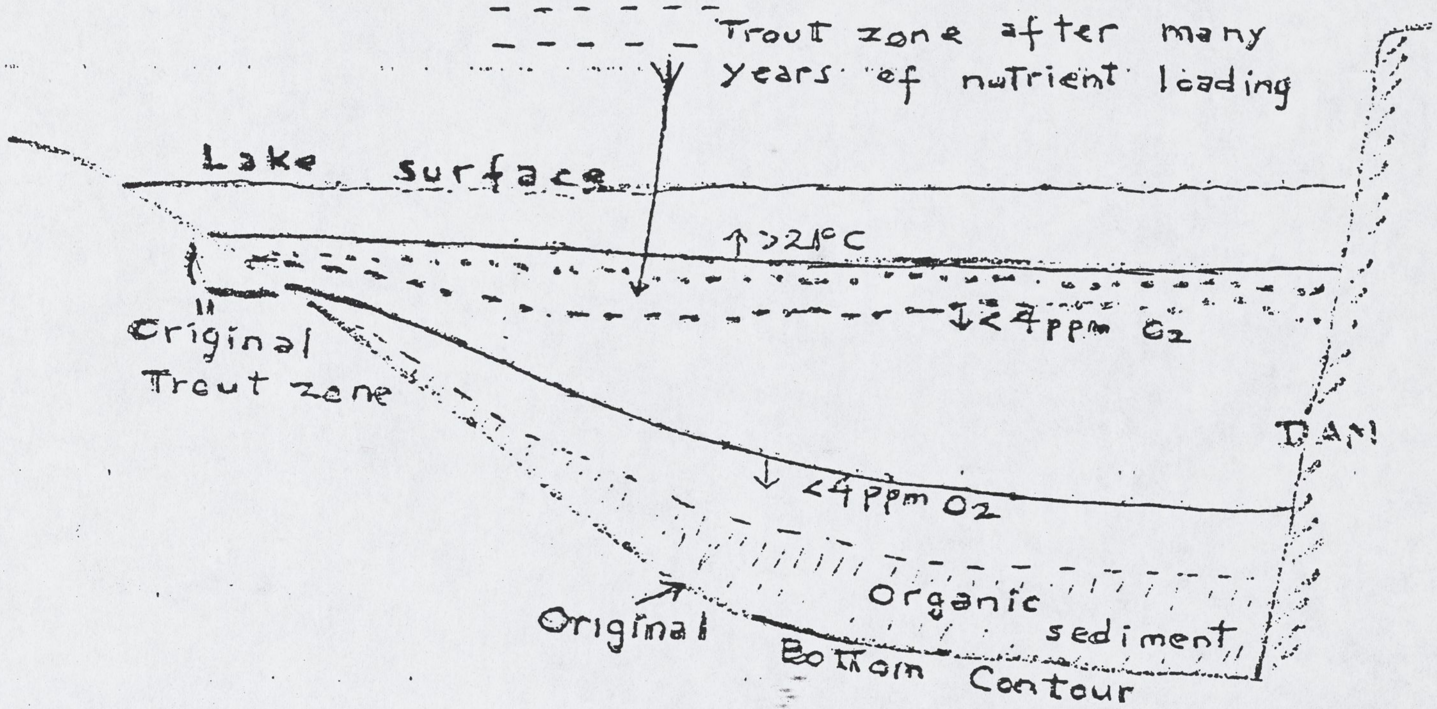


Figure 1. Illustrates a predictable course of fishery problems in an impoundment receiving waters enriched with inorganic and organic nutrients. After many years, organic sediment builds up reducing volume and depth of lake and binding nutrients that are released under anaerobic conditions. During summer stratification, the increasing BOD in the hypolimnion continually reduces the thermocline area that is inhabited by trout, defined by a combination of temperatures less than 21° C and dissolved oxygen of more than 4 ppm. Chronic problems of sporadic mortality and distressed fish may be expected for several years before a massive fish kill occurs.

Although somewhat beyond the scope of my report, I suggest that if improved water quality is available in the future in the Rio San Jose, then there are opportunities to greatly increase the economic returns from the fishery over previous levels. Until 1970 the Tribe received an average of only $1 per day of recreational use of their waters. The economic evaluation of a day's fishing can be figured in many ways, but a synthesis of all costs (fishing tackle, travel, food, lodging, license, permits, etc.) averaged about $25 per day's fishing (about 3 hours of actual angling) according to 1980 data compiled by the USFWS. A future goal should be to have the Tribe receive a significantly greater portion of the average daily cost of an angling day. A 1980 report of the Missouri Conservation Department to the Corps of Engineers documenting the value of the rainbow trout fishery in Lake Taneycomo to the local economy (based on income multiplier method), arrived at a figure of $9.9 million from 1.5 million hours of angling, or more than $6 per angler hour.

Clawson (1965) divided anglers into three basic groups for economic evaluations, casual, active, and purist. The "casual" angler chooses a recreation area because fishing is available, but the actual fishing experience and the catching of fish is not of primary importance. The "active" angler's primary concern is catching many fish and bringing home a limit. The "purist" angler's primary enjoyment concerns the angling experience of fishing for a favorite target species on artificial flies or lures, but not killing a "mess" of fish. Most of the catch of the purist is returned to the water. Both the casual and purist angler invest more, on average, for a day's fishing than does the "active" angler, and they have much less impact on the fish population. That is, each fish generates more dollars per hour of angling from the "casual" and "purist" group than it does from the "active" group. I suspect that the angler clientele of Acomita Lake has been overwhelmingly from the "active" group in the past.

Increasing the fishery valuation of Acomita Lake would require more intensive management and investment.

For the lake fishery, besides domesticated rainbow trout and channel catfish I would recommend the use of the more thermally adapted and high pH adapted redband trout (Behnke 1979) currently propagated at the Ennis, Montana National Fish Hatchery. The redband trout along with brown trout and Snake River cutthroat trout could be stocked as fingerlings and

allowed to grow in the lake. This management strategy, if successful, would greatly increase total trout production by interspecific ecological segregation (Trojnar and Behnke 1974) and provide long-lived trout that could be expected to live for several years in the lake and reach trophy sizes (trophy trout that would generate publicity for the lake's fishery and attract the "purist" group of anglers). To be maximally effective, domesticated catchable size rainbow trout could be regularly stocked from April-July for the "casual" and "active" groups of anglers. The "wild" trout, stocked as fingerlings, would be expected to have distinctly different feeding and behavior patterns and should not be excessively harvested by anglers fishing for the hatchery rainbow trout. Early, and late in the season (for example, October 1 to April 15). A special regulation trophy fishery could be instituted, for example, a bag limit of one or two trout with a minimum size limit of 18 inches, and artificial flies and lures only. This season would attract mainly the purist group. The vegetation problem that has consistently plagued Acomita Lake was controlled when crawfish were very abundant, but the lack of vegetation and excessive crawfish abundance caused other problems. The solution to this problem would be to establish balanced predator-prey interactions between fish-crawfish-vegetation. If successful, crawfish would maintain an abundance sufficient to control nuisance vegetation but when "too much" vegetation is eliminated the crawfish would be exposed to intensive predation by fish.

In the past, channel catfish and brown trout were the only species in the lake that would be expected to be effective predators on crawfish, but they did not occur at sufficient density to be effective control agents. In addition to the channel catfish, I would recommend smallmouth bass, an extremely effective crawfish predator, be stocked. Smallmouth bass would probably need protective regulations (for example, release all bass between 10-16 inches) to maintain adequate predation pressure on crawfish. The goal would be to make the crawfish an asset by being both a weed control agent and a food supply for valuable fish. Crawfish are an ideal food for fishes because they are efficient assimilators of energy from diverse trophic levels and in turn supply a large food item that favors feeding segregation between small and large trout (zooplankton feeders and "large item" feeders on crawfish and fish). I would point out that the redband trout is a specialized predator on chubs of the genus Gila.

I would also suggest the possibility of introducing a few (10-15) grass carp into the lake as a weed control agent. I have no doubt that they would survive in the lake and actively consume macrophyte vegetation. They would not reproduce and they could not reach the Rio Grande if they escaped from the lake.

With an excellent fishery with an appeal to a wide spectrum of anglers, fees and support facilities should be planned to maximize income. A parking fee could be instituted, RV and camping facilities and simple cabins could be constructed for those desiring to spend more than one day at the lake, and this would also be attractive to travelers on the interstate highway. With other services, a goal might be to average $8 to $10 return per recreational day with an annual use of 25,000 recreational days for Acomita Lake (and more if a trout fishery were to be established in the Rio San Jose).

The point is that realization of potential fishery value is dependent on better water quality (significant improvement of Grants STP). The potential gains possible with better water quality from a more intensively managed fishery and recreational enterprise (and conversely the potential loss suffered by continued poor water quality) is $100,000's annually.

RECOMMENDATIONS

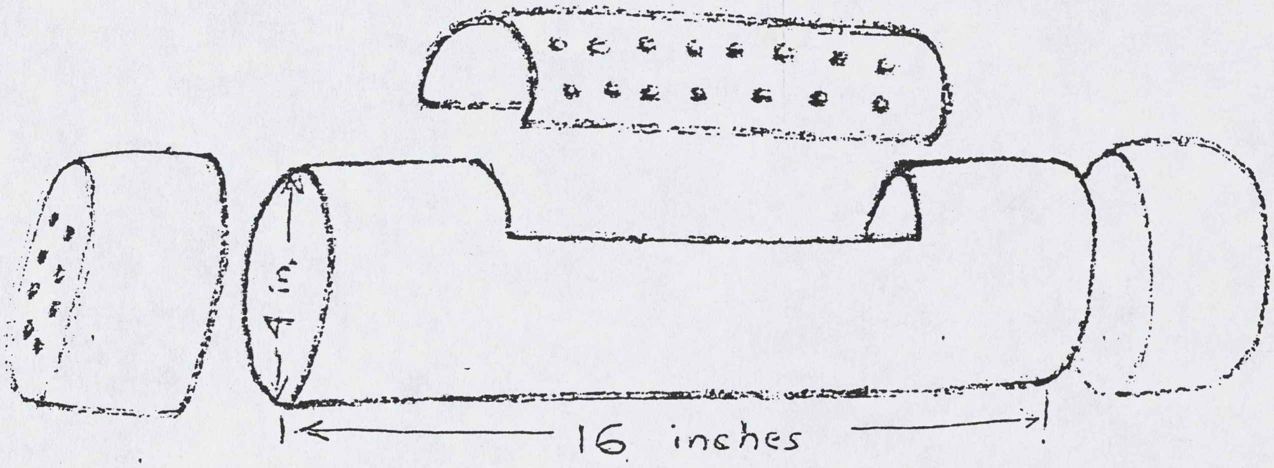
A fishery-recreational enterprise plan should be developed along the lines indicated above. Such a plan, contingent on improved water quality, would demonstrate that future options foregone by continued water quality degradation, are worth $100,000's annually to the Tribe, not simply the $10,000-$20,000 range of fishing fees formerly collected at Acomita Lake.

The plan should detail what measures might be instituted by the Tribe to greatly improve the fishery potential, such as development of a water budget recognizing fishery values by minimum flows in Rio San Jose, operation of Acomita Lake storage to increase both inflow and hypolimnetic outflow during periods of summer stagnation and a strategy to maintain certain annual levels in the lake designed to benefit the fish and fishermen. The creation of habitat improvement structures in the Rio San Jose, livestock fencing and irrigation management to reverse erosion and sediment input.

A more sophisticated stocking and management strategy for Acomita Lake that would maximize production of valuable species by utilizing interspecific niche diversity in concordance with trophic diversity and habitat diversity of the lake ecosystem. A strategy designed to appeal to a wider spectrum of anglers with a goal of greatly increasing the return to the Tribe of daily fishing expenditures. Discussion of expanding facilities to include RV and camping areas, simple cabins, etc. and the possibility of construction of a new lake after a certain level of use is attained (for example, 15,000-20,000 person days of use).

In view of the fact that water quality problems such as drastic diurnal fluctuations of O_2, pH, and uionized ammonia, that can be lethal to fish, are transitory in nature and likely to be undetected by intermittent water quality sampling, I recommend that live fish be used for continuous monitoring. Typically, fathead minnows are used for this type of monitoring, but any readily available species can be used as long as the same species or species combinations are placed in each of the live boxes. The information that can be documented by such a monitoring program includes: the distance below the sewage outfall with lethal conditions (chlorine alone will likely kill fish within 6-12 hours for a mile or more below the outlet, and the zone of lethal oxygen levels can be expected to change with the season). The frequency of lethal conditions at various downstream points through time (my observations above Horace Springs indicate that occasional fish kills occur at some regular interval); and a valuable documentation lending itself to simple charts and graphs that could be impressive evidence in court.

Live boxes can be of various sizes, shapes, and materials. Figure 2 illustrates a live box for 10 fathead minnows used by Dr. G. Fred Lee for monitoring below sewage outfalls. Typically stations are set up with an upstream or downstream station outside the limits of sewage impact to act as a control. The site downstream from the sewage outfall that is lethal to all fish in 24 hours can be first determined by setting live boxes out in a regular downstream pattern, about .5 miles apart and checking the following day. When this point is established (lethality here would be from chlorine), regular stations could be established, perhaps at the



Body is 16 in. section of 4 in. diameter PVC pipe. Ends are 4 in. end caps of PVC and cover is split PVC pipe with 1/8 in. holes.

Figure 2. Type of fish container used by G. Fred Lee (adapted from: Application of the hazard assessment approach for establishing water quality classification for Fountain Creek and appropriate water quality standards for this classification. G. F. Lee, 1980). A series of these containers, each with 10 fathead minnows, were placed below sewage outfall (one box above the outfall was control) about .5 - 1.0 mile apart to delineate lethal zone.

same sites as water quality sampling stations, fish set out and checked with frequency needed to document such aspects as sites with 50% survival for 24, 96 hours, and one week. Thereafter boxes could be checked each week (new fish added as necessary) to monitor for sporadic lethal conditions that might be missed by water quality sampling. Accurate records must be maintained from all observations and dead fish should be labeled as to site and date and frozen for possible use as evidence.

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IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF NEW MEXICO

THE PUEBLO OF ACOMA, and **THE PUEBLO OF LAGUNA,** each on its own behalf and each on behalf of its respective members,

Plaintiffs,

vs. No. CIV 82-1540 M

THE CITY OF GRANTS, et al.,

Defendants.

NOTICE OF DEPOSITION DUCES TECUM

TO: ALL COUNSEL OF RECORD

PLEASE TAKE NOTICE that the State Defendants will take the deposition upon oral examination of Robert Behnke Ronald Benkhe on September 9, 1986 at 9:00 a.m., before a certified court reporter of Boverie, Jackson & Associates, located at 210 Clayton Street, Suite 3, Denver, Colorado, 80206.

Mr. Benkhe is requested to bring with him to his deposition the following items:

Any and all supporting data, notes or other documentation relied upon, referred to, or generated by the witness or by those working under this control or supervision in preparation for trial in this matter, or in analyzing fish or biological conditions on the Rio San Jose, or on Acoma or Laguna Pueblos.

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ATTORNEYS FOR STATE DEFENDANTS

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF NEW MEXICO

THE PUEBLO OF ACOMA
and the PUEBLO OF LAGUNA,

Plaintiffs,

v. CIV 82 1540 M

CITY OF GRANTS, et. al.,

Defendants.

Bob, 1/8/84

Enclosed interrogatories are for your info. Please be thinking about the fisheries-related items. I'll be calling you in the next month concerning future strategy on the project. Let me know if you need more info. Thanks.

Walt

DEFENDANT CITY OF GRANTS'
FIRST SET OF INTERROGATORIES
TO PLAINTIFF, THE PUEBLO OF ACOMA

COMES NOW Defendant, City of Grants, a municipal corporation, [illegible] by and through its attorneys, Poole, Tinnin & Martin, a Professional Corporation, pursuant to Rule 33 of the Federal Rules of Civil Procedure, and propounds the following interrogatories to Plaintiff, the Pueblo of Acoma on behalf of itself and its members, which shall be answered fully under oath and in writing within thirty (30) days after service hereof.

Definitions

The following definitions apply to each of the interrogatories and are deemed to be incorporated therein:

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF NEW MEXICO

THE PUEBLO OF ACOMA
and the PUEBLO OF LAGUNA,

Plaintiffs,

v. CIV 82 1540 M

CITY OF GRANTS, et. al.,

Defendants.

DEFENDANT CITY OF GRANTS' FIRST SET OF INTERROGATORIES TO PLAINTIFF, THE PUEBLO OF ACOMA

COMES NOW Defendant City of Grants, a municipal corporation, ("Grants"), by and through its attorneys, Poole, Tinnin & Martin, a Professional Corporation, pursuant to Rule 33 of the Federal Rules of Civil Procedure, and propounds the following interrogatories to Plaintiff, the Pueblo of Acoma on behalf of itself and its members, which shall be answered fully under oath and in writing within thirty (30) days after service hereof.

Definitions

The following definitions apply to each of the interrogatories and are deemed to be incorporated therein:

1. "You" or "your" refers to Plaintiff the Pueblo of Acoma and its members, individually and collectively, and any person or entity acting as an agent, representative, consultant, attorney or employee of the Pueblo and its members.

2. "WQCC" means the New Mexico Water Quality Control Commission; "Grants STP" means the Grants sewage treatment plant.

3. "Document" means any tangible thing, recording or reproduction made in any manner, any visual or auditory data in your possession, custody or control, including without limiting the generality of its meaning, correspondence, memoranda, pleadings, briefs, transcripts, photographs, stenographic or handwritten notes, studies, evaluations, analyses, reports, reviews, working papers, books, charts, telegrams, pamphlets, pictures, video or audio tapes, voice recordings, computer tapes, printouts or cards, microfilming, microfiche, and any papers on which words have been written, printed, typed or otherwise affixed, and shall mean a copy where the original is not in the possession, custody or control of the Pueblo of Acoma and/or its members, and shall mean every copy of every document where any such copy is not an identical copy of any original. Designated documents shall be taken to include all attachments and enclosures.

4. "Identify", or "identity of", when used in reference to a natural person, means to state his or her full name, present or last known address and present or last known employment or business affiliation.

"Identify", or "identity of", when used in reference to a document, means to state the name of the author or signer, the addressee(s) of the document and to whom the document, in original form or copies, was distributed, the type of document (i.e., letter, memorandum, book, photograph, etc.), the date of the document, its title or other means of identification, its present location and the document's current custodian. In lieu of a description, the document may be produced, provided that the document produced is marked with the number of the interrogatory to which it is responsive. If any document was but is no longer in your possession or subject to your control, state what disposition was made of it and when such disposition was made. If any claim of privilege is made with respect to any document, describe the document by author, date, type, addressee(s) (including distribution addressee(s)) and subject matter sufficient to allow identification, and state the grounds of privilege claimed.

"Identify", or "identity of", when used in reference to a firm, partnership, corporation or other organization, means to state its full name and present or last known address.

"Identify", when used in reference to a communication, means to identify every person participating in the communication, to state the type of the communication (e.g. telephone call, face-to-face meeting, letter, etc.), the date and place of the communication and to summarize the substance and content of the communication. If any claim of privilege is made with respect to any communication, identify all persons participating in the communication, state the type of the communication, the date and place of the communication, and state the subject matter sufficient to allow identification and the privilege claimed.

5. "State in detail the complete and specific factual basis", when referring to a claim or statement, means to describe in detail all facts known to you or believed by you to be true upon which the claim or statement is based, and to identify every person, firm, partnership, corporation or other organization whose acts, omissions or statements constitute any of such facts.

6. All paragraph (¶) references in the following interrogatories are to paragraphs in the Complaint in this action, filed by Plaintiffs on December 30, 1982.

DEFENDANT CITY OF GRANTS' FIRST SET OF INTERROGATORIES TO PLAINTIFF, THE PUEBLO OF ACOMA

1. Please state the name(s) and identify the person(s) providing information used in answering these interrogatories, and identify the interrogatories for which each person provided information.

ANSWER:

2. With respect to the allegation in ¶2(a) of the Complaint (all subsequent references to paragraphs (¶____) are to those in the Complaint, <u>see</u> Definition No. 6) that you assign to various members "certain tracts of land," please identify each tract of land for which you claim damages in this action, and include a description of its size, location, and date of assignment, and identify each document which constitutes, describes, or refers to each assignment.

<u>ANSWER</u>:

3. Please state in detail the complete and specific factual basis for the allegation in ¶ 3(a) that your lands and waters were protected and reserved for your use and benefit by Spain, Mexico, and the United States; identify each tract of land protected and reserved, and for each such tract identify the grantor, grantee, conveyance, decree, statute, treaty, judgment and any other document constituting, translating, or interpreting said protection and reservation.

ANSWER:

4. Please state in detail the complete and specific factual basis of the allegation in ¶ 4(a)(i) that you are "being deprived of" your rights and privileges, liberty and established water uses "by actions taken under the color of state law".

<u>ANSWER</u>:

5. For each of the pollution alleged in ¶¶ 5(c), 5(f), 5(g), 5(i), 5(j), ¶ 1(f) of your Second Cause of Action and ¶ 1(a) of your Third Cause of Action, respectively, please describe the kind and quality of each alleged pollution and identify the source(s) of each alleged pollution; state the date(s) when each of the alleged pollution began, and

a. whether each alleged pollution has changed in source, quantity and/or quality from the time it began to the present. If so, describe with particularity the change in the source, quantity or quality of the pollution alleged; identify all documents and persons with knowledge and/or information concerning the changes.

ANSWER:

6. Please state in detail the complete and specific factual basis for the allegation in ¶ 5(f) that the effluent from the Grants STP "seriously pollutes" the water of the Rio San Jose, "destroying the ecology and environment" of the stream, "damaging Indian lands and seriously interfering with the long established uses" of the water by the Pueblos and their members, and include:

a. the identity of the "notice" to Grants alleged in ¶ 5(f);

b. a description of the quality and quantity of the alleged pollution from the time it began to the present; identify the chemicals, compounds and substances constituting the polluting agents; state the complete factual basis of your claim that the source of the pollution is the Grants STP;

c. for the period from 1940 to the present, a detailed description of the ecology and the environment of the stream; state in detail the complete and specific factual basis of their alleged destruction from the Grants STP effluent; identify the location of the stream and the environment allegedly damaged; and

d. a detailed description of all alleged damages to Indian lands, in whole or in part, from the Grants effluent, including the location of each parcel of land allegedly damaged, the date(s) of the alleged damage(s), and a complete description of the condition of the land before and after the alleged damage(s).

<u>ANSWER</u>:

7. Please state in detail the complete and specific factual basis of your allegation in ¶ 5(i), that the "agricultural capacity" of your lands have been damaged by the effluent from the Grants STP; and for the period from 1940 to the present,

a. identify each type of crop allegedly damaged;

b. for each type of crop, please state its expected and actual net annual yield; identify all documents which describe or refer to your crop yield(s);

c. for each type of crop, please state its expected and actual annual gross and net cash value; identify all documents which describe or refer to cash value;

d. for each type of crop, identify the lands upon which it is grown and the persons or organizations who own(ed) the crop(s) at each location;

e. identify any and all organic, inorganic, chemical, and any other substances applied to each type of crop for fertilization, insect and disease control, or for any other purpose; and identify all documents which describe or refer to the use and application of such substances.

ANSWER:

8. Please state in detail the complete and specific factual basis of your allegation in ¶ 5(i) that the Grants STP effluent has "destroyed the fishery" in the Rio San Jose; identify each species of fish allegedly destroyed, and with respect to each species, for the period from 1940 to the present, state:

a. its annual yield;

b. the annual gross and net revenue and/or cash value of the harvest or catch of each species;

c. the season(s) in which each species of fish was caught or harvested, and the location(s) of the catch or harvest; and in addition, please state,

d. whether the alleged decline or destruction of your fishery is due in part to a decline in the quantity of the water in the Rio San Jose? If so, please state in detail the complete and specific factual basis of your answer, including the cause(s) of the diminuition in quantity and its effect on the fishery;

e. the damages you claim as a result of the alleged destruction of the fishery, assigning a dollar value to each item of damage you claim; and

f. identify all documents which describe or refer to the alleged decline or destruction of your fishery, and all documents which are the basis of your response(s) to subsections (a) to (e) of this interrogatory.

ANSWER:

9. Please state in detail the complete and specific factual basis of your allegation in ¶ 5(i) that the Grants STP effluent has "prevented the established use" of the water for:

a. domestic purposes;

b. religious uses;

c. recreational uses; and

for each use above, give a detailed description of its historical basis; and, for the period from 1960 to the present, describe in detail the frequency of each use, the location of each use and the quantity and quality of water used; describe in detail the damages you claim as a result of the alleged prevention of each use, assigning a dollar value to each item of damage you claim; and identify all documents which describe or refer to each of the above uses and its alleged prevention by the Grants STP effluent.

<u>ANSWER</u>:

10. Please state in detail the complete and specific factual basis of your allegation in ¶ 5(j) that the pollution "has caused great inconvenience, discomfort and annoyance to the Pueblos and their members"; specify the exact nature of the alleged "inconvenience," "discomfort" and "annoyance"; identify the persons thus affected, describe in detail the damages you claim as a result of the alleged inconvenience, discomfort and annoyance, assigning a dollar value to each item of damages; and identify all documents which describe or refer to your claim of damages.

ANSWER:

11. Are there any sources or users of the waters of the Rio San Jose, other than the Grants STP, which contribute, directly or indirectly, to the alleged pollution? If so, please identify each source or user, describe with particularity the quality and quantity of the pollution from each source or user, and identify all documents which describe or refer to each source or user.

ANSWER:

12. State in detail the complete and specific factual basis for your allegation in ¶ 5(b) that your "possessory interests in the lands and in the quality of the water" and the interests of your members in their "established uses" of that water and in "the preservation of the ecology" of the stream are the subject of the "trust responsibility of the United States".

<u>ANSWER</u>:

13. Please state in detail the complete and specific factual basis of the allegation in ¶ 1(c) of your Second Cause of Action that you and your members have "certain property rights and liberty rights" that are secured by the Treaty of Guadalupe Hidalgo (herein the "Treaty"), and

a. state whether you claim that you and your members, in your status as Indian tribes and Indians, have a right different in kind or in quality from those of non-Indian beneficiaries of the terms of the Treaty. If so, please state in detail the complete and specific factual basis of your claim.

<u>ANSWER</u>:

14. State in detail the complete and specific factual basis of your claim in ¶ 1(c) of the Second Cause of Action that you and your members have certain rights secured under the Fourteenth Amendment of the Constitution, and

a. state whether you claim that you and your members, in your status as Indian tribes and Indians, have a liberty and property right different in kind or in quality from those secured by the Fourteenth Amendment of the Constitution to non-Indian citizens. If so, please state in detail the complete and specific factual basis of your claim.

<u>ANSWER</u>:

15. Please state in detail the complete and specific factual basis of your claim in ¶ 1(c) of the Second Cause of Action that you have a right to the "environmental integrity" of your land, the water and your established uses of the Rio San Jose.

ANSWER:

16. State in detail the complete and specific factual basis of your claim in ¶¶ 1(f) and 1(g), respectively, of the Second Cause of Action that the WQCC's policies and interpretations of state law allow the alleged pollution to exist, and are the "legal cause" of the harm of which you complain.

<u>ANSWER</u>:

17. State in detail the complete and specific factual basis of your allegation in ¶ 1(h) of the Second Cause of Action that you have been damaged by the policy of the WQCC and the alleged violation of your rights and civil rights; itemize each element of the damages claimed, and assign a dollar value to each element of damage.

ANSWER:

18. State in detail the complete and specific factual basis of your claim in ¶ 1(a) of your Third Cause of Action that the alleged failure by Grants to prevent and abate the pollution of the Rio San Jose constitutes a nuisance; describe with particularity the nature of the nuisance alleged; identify the land, water, environs, or any other persons or property affected by the alleged nuisance; itemize each element of damage you claim as a result of the alleged nuisance, assigning a dollar value to each element of damage; and identify all document(s) and person(s) with knowledge and/or information concerning the alleged nuisance.

ANSWER:

19. State in detail the complete and specific factual basis of your claim for damages in ¶ 1(d) of the Third Cause of Action; itemize each element of the damages claimed and assign a dollar value to each element of the alleged damages.

ANSWER:

20. State in detail the complete and specific factual basis of your claim in ¶ 1(e) of the Third Cause of Action that "after notice" Grants "persistently failed" to operate its sewage treatment plant to reduce the pollution and failed to meet the standards "in the current NPDES permit, in the various water quality acts and in the stream standards . . . thus increasing the damage" to you; identify the alleged "notice" to Grants; state in detail the complete and specific factual basis of your claim for increased damages, and assign a dollar value to each item of the alleged increased damages.

<u>ANSWER</u>:

21. Do you or your members operate or maintain any sewage treatment facilities, septic tanks and/or other waste disposal systems or dumps downstream from the Grants' STP in the Rio San Jose drainage? If so, describe with particularity each facility, septic tank and/or system or dump, its location and treatment capacity; identify all person(s) who operate, maintain or supervise each facility, tank, system or dump; and identify all document(s) which describe or refer to each facility, tank, system or dump.

ANSWER:

22. Do livestock, horses, or any other domestic or wild animals come into primary contact with or roam near the waters of the Rio San Jose, as it flows through your reservations? If so, for the period from 1960 to the present: identify the animals and their owners; describe in detail the location and frequency of such contact in or near the water and identify all documents which describe or refer to such contact.

<u>ANSWER</u>:

23. Describe in detail the plants and vegetation from the Rio San Jose which are used in your religious rites; for each variety of plant or vegetation state whether it has increased or decreased in abundance from 1940 to the present; identify all documents which are the basis of your response to this interrogatory and which describe or refer to the plants and vegetation used in your religious rites.

ANSWER:

24. State the name of and identify the experts you expect to call as a witnesses at trial; state the subject matter and the substance of the facts and opinions to which each expert is expected to testify, and provide a summary of the grounds for each opinion.

ANSWER:

POOLE, TINNIN & MARTIN, a
Professional Corporation

By /s/ Gregory D. Huffaker, Jr.
Robert C. Poole
Gregory D. Huffaker, Jr.
Linda Yen-Elerath
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Attorneys for Defendant
City of Grants

Western Outdoors

Jan. 1987

– article "Western Indians welcome anglers"

+ p. 57 – White R. Apache Res.
Christmas Tree L. $15/day fee
to fish for native Apache trout

Required Text: Bailey, J.A. 198
John Wiley & Sons

Grading:

Two mid term exams
Two short quizzes
Final exam (compreh

Normally: 93+% = A 8

Paper presented at the First National Symposium on Social Science in Resource Management, Oregon State University, Corvallis. May 14, 1986. To be published by Westview Press, Boulder, 1987.

VALUE OF ALTERNATIVE FISHERY MANAGEMENT PRACTICES

Donn M. Johnson and Richard G. Walsh*

ABSTRACT

Understanding the value of alternative fishery management practices can help managers improve the effectiveness of programs. This paper provides preliminary results on the value of alternative practices to distinct user groups. We apply the contingent valuation method, recommended by the U.S. Water Resources Council, in a pilot study of recreation users of the cold water fishery in parks and forests of the Rocky Mountains, Colorado. Empirical willingness to pay functions are presented for the number and size of fish caught. These and related values are shown to vary by skill level of fishermen.

INTRODUCTION

That the quality of fishing contributes to the value of the recreation experience is well known. The pioneering economic work on the subject was by Stevens (1966). Managers increasingly face important problems of evaluating fishing opportunities in a way that will allow comparisons with their economic costs. The problem is especially acute at many parks and forest recreation sites, where it is not enough to know how many users value fishing. It is necessary to determine how much various user groups value specific levels of fishing quality in order to make managerial decisions relating values to costs of alternative fishery management practices.

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The contingent valuation method is by far the most important tool that we have to decide these questions. The approach was recently recommended as providing an acceptable measure of the economic value of recreation opportunities and resources. The U. S. Water Resources Council (1979 and 1983) authorized use of the contingent valuation method and established procedures for its application to recreation and environmental quality problems. In this approach, a sample of the affected population is asked to report their maximum willingness to pay, contingent on hypothetical changes in recreation opportunities or resources. The approach has been successfully applied to a number of recreation valuation problems since its initial proposal by Davis (1963).

The purpose of this study is to apply the contingent valuation method to measure the effect of fishing quality on willingness to pay for the experience. The primary objective is to develop empirical value functions for the number and size of fish caught. These and related values are shown to vary with the skill level of fishermen.

STUDY DESIGN

The basic data used in this pilot study were obtained from on-site interviews with a sample of 32 cold-water fishermen at rivers and lakes in the northern front range of the Rocky Mountains, Colorado. Interviews were conducted on random days throughout the summer of 1985. Interviewing was initiated at the beginning of the day with the first person encountered at the study sites. Subsequent interviews were conducted with persons randomly selected throughout the day. The interviewer was identified as an employee of the University to establish the legitimate scientific purpose of the study. Less than 5 percent of those approached refused to participate in the survey (thus response bias should be insignificant).

The value questions were designed to be as realistic and credible as possible. Respondents were first asked to report the direct costs of their current trip. Then, they were asked to estimate the maximum amount they would be willing to pay rather than forego the recreation experience. Direct trip costs represent a generally accepted method of paying for recreation trips. This relatively neutral measure of value was selected over alternatives such as an entrance fee or tax in an effort to avoid emotional reaction and protest against the method of valuing fishing quality. As a result, protest responses, which were removed from the analysis, represented less than 7.0 percent of the sample, well within the Council's standard of 15.0 percent.

An iterative bidding technique, recommended by the Council, was used to encourage fishermen to report maximum values, representing the point of indifference between having the amount of income reported or the specific change in quality of the resource. The respondents were asked to react to a series of dollar values posed by the interviewer. Respondents answered "yes" or "no" to whether they were willing to pay the stated amount of money to obtain the increment in recreation opportunity or resource. The interviewer increased the dollar value by random amounts until the highest amount the respondent was willing to pay was identified.

The Council recommends net willingness to pay (consumer surplus) as an acceptable economic measure of the benefits of public recreation programs. These net benefits are measured as the area below a demand curve and above direct cost or price. We asked fishermen to report their maximum willingness to pay for the current or marginal trip. The response represents a direct estimate of one point on a demand curve in which change in willingness to pay is related to the change in number of trips. Integrating under this marginal benefit function provided an estimate of total benefit. Subtracting direct travel costs from total benefits and dividing by number of days resulted in consumer surplus of $12.20 per day, with average catch of 6.1 fish, 9.4 inches in length.

From this starting point, respondents then were asked to report changes in net willingness to pay contingent on changes in the quality of fishing. Values were obtained from each individual for several changes in the number and size of fish caught. These observations trace out the representative individual fisherman's marginal benefit function for quality of the resource.

PRELIMINARY RESULTS

Following the usual procedure in the study of recreation values, least-squares statistical methods were used to estimate the relationship between willingness to pay and fishing quality.

Number of Fish

$$\underset{}{WTP = 0.193 + \underset{(0.293)}{0.989Q} + \underset{(0.073)}{0.0206Q^2}} \qquad R^2 = 0.189$$

Size of Fish

$$WTP = -0.467 + \underset{(0.716)}{1.563S} + \underset{(0.298)}{0.460S^2} \qquad R^2 = 0.235$$

Where WTP = change in willingness to pay per day; Q = change in number of fish caught; and S = change in size of fish caught (length in inches). Standard errors are shown in parentheses below the coefficients.

The number of observations was sufficient for statistically significant analysis of the relationship between value and change in the number and size of fish caught. The coefficients of determination, R^2, adjusted for degrees of freedom, indicates that 19 to 24 percent of the variation in willingness to pay was explained by the number and size of fish caught. This is considered a satisfactory level of explanation with data from a cross-sectional survey of individual consumers. The regression coefficients for the number and size of fish were significantly different from zero at the 0.05 level, as indicated by the standard errors for the linear terms in the equations. Alternative forms of the equations were evaluated including linear, quadratic, semi-, and double logarithmic models. The quadratic form seems to provide the best fit of the relationship; although the squared terms for the number and size of fish caught are not statistically significant.

Figures 1 and 2 illustrate the shape of these willingness to pay functions. Figure 1 shows that willingness to pay for fishing increased by more than $1 per additional fish caught. It decreased by slightly more than $1 with each fewer fish. Figure 2 shows that willingness to pay for fishing increased by nearly $2 with a 1-inch increase in the size of fish caught. Apparently, willingness to pay is an increasing function of fish size. With a 4-inch increase in size, willingness to pay rose by more than $3 per inch to about $25, or more than double the average willingness to pay of $12.20 for 9.4 inch trout. This approaches the maximum increase in size possible given the biological constraints of the study sites.

Table 1 illustrates how fishing value functions may shift with participant skill level -- low, medium, and high. This classification was based on reviews of preference data from several fishing studies (Bergersen, et al., 1982; and Driver, et al., 1984). They suggest that skill level may be a reasonable proxy for the type of fishing opportunities produced by fishery management programs. Respondent reported skill levels were adjusted by the interviewer after observing their fishing practices.

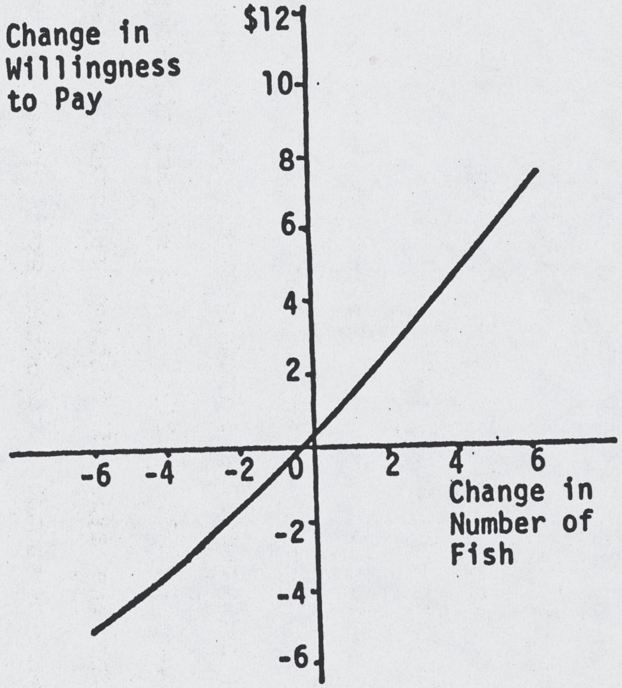

Figure 1. Effect of Change in the Number of Fish Caught on Willingness to Pay

Zero Point = 6.1 Fish
= $12.20 WTP

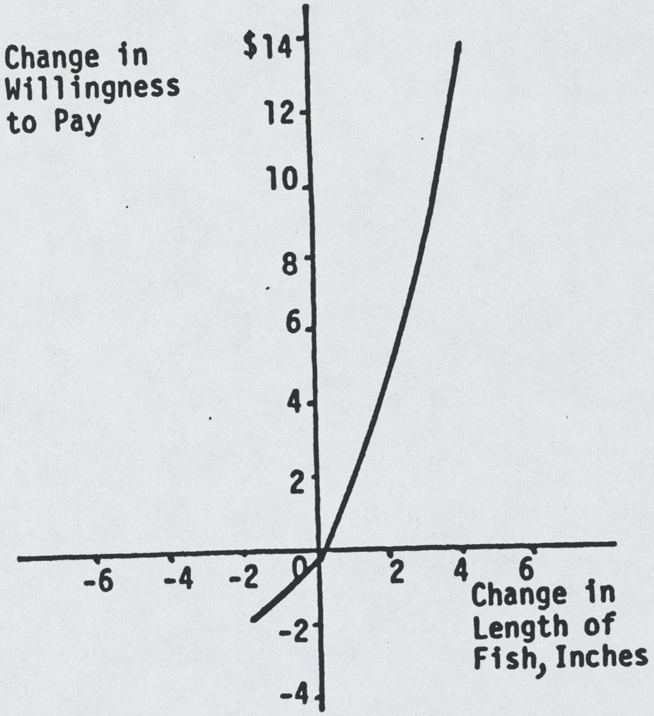

Figure 2. Effect of Change in the Size of Fish Caught on Willingness to Pay

Zero Point = 9.4 Inches
= $12.20 WTP

Table 1. Participant Skill Level and Fishing Values

Variable	Skill Level Low	 Medium	 High	 Total
Number of Cases	8	13	11	32
Annual days fished per year	15.50	18.15	34.27	23.03
Consumer surplus per day	$10.44	$10.78	$18.08	$12.20
Number of fish caught per day	1.88	4.85	10.64	6.09
Added days fished per added fish caught	0.54	0.70	0.28	0.48
Consumer surplus per added fish caught	$1.25	$1.40	$0.44	$0.93
Average size fish caught, inches in length	8.40	7.70	9.90	9.40
Added days fished per added inch	0.67	0.79	1.23	0.94
Consumer surplus per added inch	$1.25	$1.78	$2.02	$1.75
Added days with wild fish	0.25	0.69	1.55	0.88
Added consumer surplus per day with wild fish	$2.13	$2.62	$3.46	$2.78
Importance of method (1=Low, 5=High)	1.88	2.54	3.09	2.56
Percent of time:				
Bait fishing	42.50	47.54	15.91	35.41
Lure fishing	7.75	21.39	25.64	19.44
Fly fishing	49.75	31.46	58.46	45.32
Investment in equipment	$338.75	$440.00	$2219.09	$1026.25
Income	$37,500	$53,077	$26,364	$40,000

The relationships are suggestive of the possible true variation in values. Owing to the smallness of the pretest sample (32 cases), the differences in the cross-sectional mean values were in general not statistically significant. However, the results of this pilot study are suggestive of variations that are likely to prove significant with a larger sample. An additional 300 fishermen will be interviewed in the summer of 1986.

Table 1 shows that those with higher skill fished about twice as many days per year as those of lesser skill. Apparently, those with higher skill caught a larger number and size of fish and had more consumer surplus per day. High skill anglers placed greater value on: (1) size as compared to number of fish; (2) wild trout; and (3) had a greater preference for artificial lures and flies.

Fishermen of less skill often did not catch any fish and rarely caught very many. Thus, it should not be surprising that those with lower skill were more responsive to changes in the number of fish caught than those of higher skill. Those with less skill were more concerned with catching fish than the method; more used live bait. Also, they were less interested in catching wild trout.

COMPARATIVE STUDIES

Few previous studies have measured the effect of the number and size of fish caught on the value of fishing. Harris (1983) reported the data were not sufficient to estimate the effect of number of fish caught on the benefits of fishing in Colorado. Adamowicz and Phillips (1983) surveyed 272 resident fishermen in Alberta, Canada. The authors reported the marginal value of an additional fish ranged from $1.69 to $2.69 in 1976 Canadian dollars.

Sorg, et al. (1985) summarized the results of a telephone survey of resident and nonresident fishermen in Idaho. They caught an average of 5 fish on primary purpose trips and 7.4 fish on non-primary-purpose trips of 1.6 days. The authors reported an incremental value of $1.60 per each additional fish for primary purpose trips and $2.20 for non-primary-purpose trips. Benefits per trip increased by about $2 to $4 per added inch in length, holding number of fish constant.

Compared to these results, our study indicates that the value of catching additional fish may be somewhat less, particularly for participants with high skill who are already catching large numbers of fish. However, with regard to the value of catching larger fish, our results are consistent with the Idaho study, and we show that it increases with the level of skill.

CONCLUSIONS

The results of this pilot study should be viewed as tentative and a first approximation subject to improvement with further work. Much more research is needed before we will understand all of the relevant economic and noneconomic questions concerning the value of fishery management services in parks and forests of the United States. We estimated the empirical nature of willingness to pay functions for the number and size of fish caught, and explored the effect of participant skill levels. The results suggest that research on the value of fishing quality in the future should include participant skill as an independent variable in willingness to pay functions. Then the effects of participant skill can be held constant to develop value functions for management units with programs for a particular type of fishing experience.

There is a need for further research on the social costs of fishery management programs for different types of fishing experience. This would allow managers to compare the benefits and costs of alternatives such as catch and release regulations, stocking catchable size fish, and habitat improvement measures.

The contingent valuation approach to the problem illustrated here appears to be sufficiently promising to indicate that it could be used to analyze the value of service in other types of outdoor recreation activities. We recommend further research to test its general application.

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Marine Biology Update

VOLUME 1 NUMBER 1

NOVEMBER 1986

This and subsequent issues of the Marine Biology Update will bring you notice of new Wiley publications and highlight reviews of books in your specialty. All of these publications are available on 15-day free trial.

FRESHWATER FISH DISTRIBUTION IN N.A. CATALOGED AND INTERPRETED

Sub-dividing the North American continent into a series of novel ichthyfaunal "provinces" a new monograph charts the distribution of freshwater fishes through historical drainage alterations, plate tectonics, and Pleistoscene glaciation. Each province is examined by a leading authority in **THE ZOOGEOGRAPHY OF NORTH AMERICAN FRESHWATER FISHES**, edited by Charles H. Hocutt of the University of Maryland and Edward O. Wiley of the University of Kansas (1986. 866 pp. $89.95). Special interest chapters cover the history of ichthyology in North America, fossil fishes, and exotic species. Distribution trends are also explained by computer simulation. (#1 on reply card)

FIRST COMPLETE FIELD GUIDE TO A SUB-TROPICAL MARINE ECOSYSTEM

As a demonstration of the application of the concepts of systematic marine biology, few works can rival the new, **MARINE FAUNA AND FLORA OF BERMUDA: A Systematic Guide to the Identification of Marine Organisms**, edited by Wolfgang Sterrer of the Bermuda Biological Station in cooperation with Christine Schoepher-Sterrer and 63 contributors.

More than 2,600 black-and-white illustrations and 212 color photographs help the reader make identifications from the taxonomic descriptions. The book is very useful also for field identifications throughout the Caribbean, where most Bermudan species are found. (1986. 742 pp. $99.95) (#2 on reply card)

"WHAT (JOHN GULLAND) SEES AS IMPORTANT, IS IMPORTANT, BY DEFINITION"

observed the Transactions of the American Fisheries Society in their review of the latest version of the work by "one of the leading fishery biologists of our time" -- **FISH STOCK ASSESSMENT: Manual of Basic Methods** (1983. 223 pp. $48.95).

The manual provides techniques for assessing fish stocks, evaluating the effect of fishing on the stocks, and the likely impact of different policies for developing and managing fisheries. Nature suggested it "will be of great value to assessment biologists with responsibility for giving advice each year to the managers." (#3 on reply card)

NEW ENDORSEMENT FOR SPOTTE'S CLASSIC MARINE AQUARIUM GUIDE

This year, Zoo Biology echoed what many fisheries experts and aquarium keepers have learned first hand about Stephen Spotte's book, **SEAWATER AQUARIUMS: The Captive Environment** (1979. 413 pp. $37.50). The reviewer noted that "it is a superior, original compilation of diverse information that would be beyond the ability of most workers in this field to acquire independently." Spotte covers all the factors for protecting water quality and fish stocks from filtration to aeration, from nutrients and culture media to toxicity and buffering. He also supplies information on analytical methods supported by formulas, charts, tables, and diagrams. (#4 on reply card)

For those concerned with fresh and brackish water cultures as well as seawater environments, Spotte offers a full range of guidance in his widely-used volume, **FISH AND INVERTEBRATE CULTURE: Water Management In Closed Systems, 2nd Ed.** (1979. 179 pp. $23.50). He spells out both biological and mechanical filtration methods along with techniques for reducing the level of dissolved organic carbon and methods of disinfection and disease prevention. (#5 on reply card).

"HANDS ON" APPROACH TO MASTERING MODELING SKILLS

Until this year, there has been no practical guide to modeling skills as they apply to fisheries science. Filling this void is **SYSTEMS ANALYSIS AND SIMULATION IN WILDLIFE AND FISHERIES SCIENCES** by William E. Grant of Texas A & M University (1986. 338 pp. $47.50). It supplies step-by-step guidance and demonstrates general principles through fully worked-out examples. One detailed example is developed and carried through each chapter to give readers the opportunity to participate in the entire modeling process. (#6 on reply card)

EXPANDED EDITION OF NELSON'S WIDELY-USED CLASSIFICATION MANUAL

The accelerating pace of icthyological research is reflected in the major classification revisions found in the second edition of **FISHES OF THE WORLD** by Joseph S. Nelson (1984 523 pp $44.95). It references recent systematic works...lists more genera under the families...enlarges many family descriptions...and synthesizes differing conclusions of leading workers in the field. In all, the current edition covers 445 families in which 21,700 species of living fishes are recognized. Over 450 drawings and 45 revised distribution maps round out what Sea Frontiers calls "an excellent reference book," and one that Nature recommends "should be in every library where fisheries are studied." (#7 on reply card)

WORKSHOP PROCEEDINGS ON TOXICANTS PRAISED BY REVIEWERS

To find new avenues of research for monitoring contaminant effects on individual fish and populations, the Great Lakes Fisheries Commission hosted an international workshop. Presentations from this meeting were then brought together in **CONTAMINANT EFFECTS ON FISHERIES**, edited by Victor W. Cairns, Peter V. Hodson, and Jerome O. Nriagu (1984. 333 pp. $74.00).

A recent review in Marine Pollution found: "This stimulating book can be highly recommended to all research workers concerned with the effects of chemicals on aquatic animals." The International Journal of Environmental Studies said it "contains a wealth of good ideas and subject reviews," and the reviewer for Fisheries "would encourage any person concerned with the effects of contaminants on fishes to acquire a copy." (#8 on reply card)

FULL SCALE REFERENCE/TEXT ON TROPICAL FRESHWATER ENVIRONMENTS

Author of numerous aquaculture, fisheries, and environmental impact studies in tropical countries on several continents, Dr. A. I. Payne of Coventry Polytechnic has crystallized his experience in **THE ECOLOGY OF TROPICAL LAKES AND RIVERS** (1986. 301 pp. $54.95). Payne draws together the diverse threads of freshwater ecology throughout the tropics including environmental, structural, and functional aspects of tropical freshwater communities. His singular work examines environments as diverse as the cold lakes of the Andes, the deep lakes of the East African Rift Valley, the almost demineralized streams and rivers of the equatorial rainforest, and the turbid rivers of the savanna. Important coverage is also given to the use and abuse of water in these regions. (#9 on reply card)

UPDATE OF LEADING AQUATIC MICROBIOLOGY TEXT/AND REFERENCE

Building on an approach that has made his book the top introduction to the field (in both English and German) G. Rheinheimer of the University of Kiel has concentrated on keeping his work abreast of the latest research findings in the Third Edition of **AQUATIC MICROBIOLOGY** (1986. 571 pp. $32.95).

New material is particularly evident in the chapters on the distribution of micro-organisms, their role in the cycling of elements, their functions in aquatics systems (inland waters, estuaries, and oceans) and their importance for water pollution studies. The volume remains, as Aquatic Botany said of the previous edition "...a very useful book, particularly because of the logical and systematic arrangements of the subjects." (#10 on reply card)

"MUST READING" FOR ALL COMMUNITY ECOLOGISTS

Judging by recent reviews, Dr. E. C. Pielou has made the methods used to clarify and interpret large, unwieldy masses of multivariate field data highly accessible in her book: **THE INTERPRETATION OF ECOLOGICAL DATA: A Primer on Classification and Ordination** (1984. 263 pp. $32.50). Bioscience found "the self instruction exercises...very good and...helpful to anyone attempting to master the subject," and applauded the "simple alternatives for calculations."

The Quarterly Review of Biology called Pielou's book "must reading" in pointing out that this is not just "another statistics cookbook," and praised the "good discussions of the advantages and disadvantages of various methods as well as (the) practical advice on their interpretations." For class use, R. F. Sutton in Forestry Chronicle concluded, "This is by far the best text on the subject I have seen." (#11 on reply card)

A NEW KEY TO MORE PRODUCTIVE FISHERIES MANAGEMENT

Highly accurate and easily applied methods for balancing fishing fleet capacity with the supply and production of fish are outlined in the recent guide, **BIOECONOMIC MODELLING AND FISHERIES MANAGEMENT**, by Colin W. Clark of the University of British Columbia (1985. 291 pp. $44.95). Simple mathematical models provide the basis for understanding the complex dynamic interactions between the biology of fish populations and the economics of the fishing industry. Critical of traditional management approaches, this guide is unique in supplying practical methods for controlling overcapacity, improving economic performance, and developing a dynamic investment strategy. (#12 on reply card)

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FISHERY ASSESSMENT REPORT

ON

ACOMA PUEBLO FISHERY

ACOMA PUEBLO

PREPARED BY

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FISHERIES ASSISTANCE OFFICE
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GALLUP, NEW MEXICO

NOVEMBER 1983

ABSTRACT

When the Acoma fishery started to include recreational fishing in the 1950's, it was a put-grow-and-take management of rainbow trout in the Rio San Jose only. That fishery was limited because not all of the 13-mile tribal segment was accessible. In the period prior to when the Grants sewage treatment plant came on line, There was little or no documentation found that related to the fish species or their habitat in the Rio San Jose. Very early on when non-Indian settlers arrived, they reported the stream to have trout.

Lake Acomita, an impoundment built in 1937 to provide irrigation water to Acoma tribal members, was included into the tribal fishery in 1961 The Fish and Wildlife Service (FWS) provided rainbow, brown and cutthroat trout as well as channel catfish at an average rate of about 45,000 fish weighing 10,000 lbs. per year. The lake has a diversion on the Rio San Jose which is used to fill the lake during winter months. During irrigation season the lake will draw down to a level that depends on stream discharge and run-off from the lake drainage. Eutrophication of the lake has progressed steadily. When aquatic vegetation reached such abundance as to impact the fishery, the tribe exercised some physical cleaning of the lake by drawdown and removal of accumulated enriched silt build-up and vegetation. This was done four times since 1961.

The angler use was around 500 man-days per year when Rio San Jose was the only water. Subsequent to the addition of Lake Acomita, the fishing pressure reached 10,000 man-days per year in 1963. The average since then is about 12,000 man-days per year, ranging from 3,000 to 19,000. Fishing is open to the public generally from April to November. In spring and fall, the angler's catch is rainbow, brown and cutthroat trout. In summer, channel catfish are the main species in the creel. The rate of 0.5 fish/hr (a FWS standard) was exceeded in 8 of the first 9 years of data, but has been on the decline since.

Revenues generated by the recreational fishing program started at $230/year in 1961 reached around $37,000/year in 1981. This represents fishing permit sales to both tribal members and non-tribal members.

The nutrient loading of the Rio San Jose system has not complied to ~~been above~~ EPA standards for nitrate nitrogen and phosphorus. These two constituents are essential to aquatic vegetation and algae growth. There has been a flourishing phytoplankton community in Rio San Jose and Lake Acomita that could not have otherwise developed but for the enriched waters of the Rio San Jose. The submergent aquatic vegetation reduces fish habitat and can be part of the mechanism in fish kills. When sunlight hits the plant it produces oxygen in the photsynthetic process, increasing the dissolved oxygen levels in the water. When sunlight is not available the photosythesis process reverses and the plant becomes an oxygen consumer thus reducing dissolved oxygen. Photsynthesis also effects similar changes in pH levels. Both factors of low dissolved oxygen and high pH values have been attributed to induce summer kill and winter kill.

The net effect of the eutrophication has been a negative impact on the angler success. The angler use and on fish habitat of the Acoma fishery. The harvest rate or fish catch per stocked fish has also declined. Permit sales had an upward trend that indicates more people availed themselves to the fishing opportunities of the Acoma fishery. Without a fishery no revenues are generated via the recreational fishery. A value of $146,000 has been placed on the fishery, using 1981 creel census data. This represents monies that are spent on license fees, bait, tackle, and expenses associated with the angler getting to and from the fishery. The expenses involved in cleaning up the lake were not analyzed, but they are very high.

INTRODUCTION

This report is prepared by the Fish and Wildlife Service, Fisheries Assistance Office, Gallup, New Mexico at the request of the Bureau of Indian Affairs, Albuquerque, New Mexico. The intent of this document is to evaluate the Acoma Pueblo fishery, what impact it has experienced from the discharges of the Grants Wastewater Treatment Plant, and establish the consequent fish loss in Lake Acomita.

BACKGROUND

The Rio San Jose flows into the Rio Grande River, intersecting the main stem about 25 miles north of Socorro, New Mexico. Bluewater Creek, a perennial stream originating in the Zuni Mountains, is one of the main feeders to Rio San Jose. Another major contributor to the river is the discharge from the City of Grants Treatment Plant. It discharges its effluent into the Rio San Jose above Horace Springs. These springs are the last of the major stream feeders, the other minor source for stream water is surface runoff. Horace Springs is located above and to the west of Acoma Indian Reservation boundary, further downstream and to the east is the Laguna Indian Reservation (see map Fig. 1). Both tribes have historical and cultural use of the stream since time immemorial.

The Acoma fishery, prior to the early 1950's when Grants sewage treatment plant (STP) came on line, has little or no FWS documentation as to its stocking, recruitment or catch. The Rio San Jose comprised the entire fishery until 1961, when Lake Acomita was first stocked.

Lake Acomita was built in 1937 to irrigate tribal lands for agricultural purposes. Since 1961 it had also been managed to include fishing. Trout were first stocked in Acomita in 1961 by the FWS, when some 24,000 rainbow fingerling were released into the 58 acre impoundment (see Table 1). The tribe has emptied the lake four times: October 1961, December 1971, December 1974 and again in May 1983, to clean the lake and or remove enrichments from the lake bottom. These cleanup procedures usually involved de-watering to dry out the lake bottom, and where necessary removing the debris and accumulated enrichments to a location away from the drainage basin of the lake.

The 1962 FAO report stated that "Acomita Lake irrigation management filled the lake in fall (from October to April). Aquatic weeds in the lake grow and multiply in the spring of the year, such that by June the lake was almost choked, especially up to depths of 12 ft. As irrigation withdrawal lowered the lake level it also permitted this aquatic vegetation additional habitat." The end result was prolific growth of aquatic vegetation. To correct this, the lake was subsequently treated with fertilizer to promote algae blooms, which would in turn deny sunlight to submergent plants. These treatments were to be carried out annually at the rate of 3 or 4 times per year. It was found that by just adding Rio San Jose stream water to the lake in spring instead of fertilizer the algae blooms would still occur because the stream was so enriched. No further fertilization treatments were recommended.

Fishing pressure for the tribal fishery was effectively transferred from the Rio San Jose to Acomita Lake, by implementing a put-grow-and-take trout stocking program. However, by 1969 the fishery was changed and became a put-and-take program. The main reasons for the changed management practices were that fingerling returns on stocking were poor, and the angling pressure was increasing such that catchables had to be stocked to insure adequate angler catches. The anglers now had improved access to the fishery through the lake rather than through the stream. Additional water provided via Lake Acomita and more fish stocked, provided more angler use on the reservation. Permit sales rose from less than $250/year in 1960 to some $9,000/year in 1964. By 1981 annual permit sales were in excess of $35,000 (see Figure 2).

The Rio San Jose was surveyed from Horace Springs to the Acomita Diversion in 1980 and 1981 by FWS personnel from Gallup, NM. The purpose of these stream surveys was to evaluate water quality and to determine the current status of the Rio San Jose fishery. Water quality was evaluated by using six of the eleven chemical parameters for New Mexico Water Quality Control Commission (WQCC) standards. (Medlin) The five parameters for which no comparative data were available include: ammonia nitrogen, unionized ammonia, total chlorine (residual), total organic carbon and turbidity. Three of the remaining six parameters: conductivity, nitrate nitrogen and total phosphorus were found to be in excess of WQCC stream standards set forth for a high quality cold water fishery. The high conductivity levels are common to many streams in New Mexico and are believed to be directly related to the edaphic characters of Southwestern streams. (Medlin) The high levels of nitrate nitrogen (see Fig. 6) were attributed mainly to STP discharges and the consequent enrichment of the stream substrate. In watersheds producing alfalfa or other legumes, nodules are formed by the legumes that undergo biochemical reactions that produce increased levels of both nitrate and nitrite nitrogen in the run-off that occurs with irrigation or precipitation. The process is facilitated by nematodes in the soil. Total phosporus levels were also high. Phosphorus loading is almost entirely man-induced, whereas nitrogen can have some natural origins (see Fig. 7).

Suitability of the Rio San Jose for trout was found, in the second survey, to be adequate in terms of flow according to criteria developed by the Instream Flow Group (Bovee). Some segments of the stream were identified by the FWS second survey as potential salmonid spawning areas because of their gravels and flows. Temperature also appeared favorable for trout reproduction and propagation, (less than 20°). However, before trout could successfully reproduce in the Rio San Jose some corrective measures would be required: 1. Clear the spawning gravels of silt as well as to insure their availability and utility for future spawners; 2. Reduce the nutrient loading of nitrogen and phosphorus to comply with EPA standards. The fish species composition on both surveys appeared to favor a minnow-sucker complex. Recent introductions of brown trout subcatchables (see stocking Table 1) have been more successful than have rainbow trout plantings. Brown trout exhibit more tolerances for less-than-ideal conditions than do rainbow trout. In fact, during the 1981 survey no rainbow survivors of the 1980 plant were found.

Angler accesses to the stream are limited. The build-up of aquatic vegetation have encroached on and reduced both angler access and trout habitat.

On December 3, 1981 the New Mexico WQCC heard federal and tribal testimony on behalf of upgrading the classification of Rio San Jose from "cold water fishery" to "High Quality Cold Water Fishery". (Clayton) Before the

Commission amended the classification in 1980, Rio San Jose was classified as a "High Quality Cold Water Fishery". The recent hearing did not reclassify the stream to its higher classification, but left that option open for future consideration.

RIO SAN JOSE WATER QUALITY

PHYTOPLANKTON

Water in the Rio San Jose has a luxuriant growth of aquatic vegetation. Diatoma are represented by cocconeis, cyclotella and navicula genera. The Blue-green algae are represented by chroococcaceae and oscillatoriaccae and the euglenid trachelomonas is also present. (U.S. Geological Survey) The presence of these diatoms and algae indicate an enriched water system.

TEMPERATURE

Bluewater Creek, a perennial stream, was recorded by USGS in the water year of 1980 as averaging 14.4°C at the west boundary of the Acoma reservation. Horace Springs at the same time period has a mean temperature of 13.10°C. It would appear that water temperatures in Rio San Jose are well within the range required for trout survival, growth and reproduction.

NUTRIENTS

The phosphorus loading of the Rio San Jose currently ranges between 0.013 and 0.018 lbs/capita/day by the Grants wastewater treatment plant. This compares to 0.015 lbs/capita/day in Albuquerque. (Aquascience) Phosphorus levels at the west boundary of the Acoma Indian Reservation were found to be 2.55 mg/l in 20 observations by Bureau of Indian Affairs, U.S. Geological Survey, Environmental Improvement Division (State of New Mexico), Environmental

Protection Agency and Aqua Science, Inc. (Dickerson) The stream discharge at the Acoma west boundary downstream from Horace Springs was approximately 19,710 AF/yr. under natural conditions. (BIA 1981 Statement to WQCC) It is now 5470 AF/year. Various diversions by upstream users have impacted the quantity and quality of water that reaches the Acoma Pueblo, e.g., the natural total dissolved solids (TDS) were estimated to be 434 mg/l below Horace Springs when flows were 19,710 AF/yr. but the present level is 852 mg/l (see Fig. 7 Phosphorus levels).

The graph in Fig. 7 shows that phosphorus levels have been consistently above the WQCC standard of 0.1 mg/l since 1967. Phosphorus pollution is almost always man-made.

Nitrate nitrogen samples were graphed to show their concentration since 1967 (see Fig. 6). The Aquascience data indicates that WQCC standards of 0.8 mg/l were exceeded nine of the fourteen years during the period 1967-1980.

It is believed that phosphorus and nitrogen are primarily responsible for the proliferation of algae blooms and aquatic vegetation in the Rio San Jose as it enters the Acoma reservation. Lake Acomita submergent vegetation reached such density in the spring of 1982 that available fish habitat was reduced by approximately 50 percent. Fish kills, both summer and winter, were associated with the aquatic vegetation abundance. FAO investigated fish dieoffs by collecting moribund fish when possible or having tribal personnel and freeze any suspect fish during the dieoff. Causative agents were by themselves not likely to induce mortality e.g., *Aeromonas salmoncida*, a bacteria endemic to the system, was isolated on mortality. (Majors) The bacteria plus stress resultant from reduced habitat were diagnosed by FWS as the cause for the dieoff in most cases. No estimates were made of numbers of fish lost in any summer kill or winter kill. Then were insufficient data with which to work.

ACOMA FISHERY

RIO SAN JOSE

Before Lake Acomita was developed to include recreational fishing, the angling pressure was estimated to be less than 500 man-days per year (see Fig. 3). The stream provided the only fishing opportunities available on the reservation and accesses to the stream were limited. Recent angling pressure for the entire reservation averages about 12,000 man-days per year. (Fig. 3) This is due primarily to Lake Acomita providing a ten month per year fishery.

Since the lake has been added to the fishery, fishing pressure on the stream has been reduced. Present angling pressure on the stream is limited primarily to tribal members who live adjacent to the Rio San Jose. Brown trout stocked in the river as fingerling (2.5") in 1980 had grown to catchables (10") in 1981. None of the 8" rainbow stocked in 1981 were recovered in the 1983 survey. Present fish populations in the Rio San Jose are dominantly non-game species: Rio Grande chub (*Gila nigrescens*), Rio Grande sucker (*Catostomus plebius*), fathead minnow (*Pimephales promelas*), mosquitofish (*Gambusia affinis*) and brown trout (*Salmo trutta*).

There are stream segments which have good flow and good cover where trout could have adequate year round habitat. However, spawning gravels are now covered preventing their use for trout spawning. As indicated previously, the greatest adverse impact on the stream comes from enriched waters.

Seven Springs State Hatchery stocked Rio San Jose with 3,370 6" rainbow in FY 1955 and 1,800 2" rainbow fry in FY 1956. Rainbow were the mainstay of the put-grow-and-take fishery. Good growth and carryover allowed anglers to catch large fish in the late 50's and early 60's. Narrowleaf pondweed and filamentous algae provided habitat for freshwater shrimp, which in turn converted to good fish growth. Stocking of the Rio San Jose after 1961 was irregular. In 1980 both rainbow and brown trout were released at fingerling size. The 1981 FWS survey could not find any rainbow survivors in the stream. Brown trout were present and exhibited good growth. Rainbow are less tolerant to adverse conditions than brown trout.

LAKE ACOMITA

The lake was formed in 1937, when a dam was constructed to impound diverted Rio San Jose water mainly for irrigation use. Most of the water needed to fill the lake, 710.6 acre-feet, comes from the Rio San Jose and is provided during the winter filling period. Surface runoff from the 17.24 square miles of watershed augments the lake volume during the whole year. At an annual water yield of 0.5 inches, this calculates to 460 acre-feet per year. (Monahan) The Rio San Jose watershed is about 1200 square miles and has a mean annual discharge of 4850 acre-feet. In recent years, water volume has not been a problem in Acomita. Maximum water depth in this 58 acre lake was 23 feet just prior to de-watering in 1983. Its average depth was 9 ft. during a recent survey conducted in 1983.

Since 1961, the tribe has managed the water of Lake Acomita to include fisheries and irrigation. There have been four drawdowns during that period, October 1961, December 1971, fall of 1974, and May 1983. The 1983 drawdown was to clean the lake of its excessive vegetation and silt build-up. Soils Conservation Service conducted a sediment study before drawdown and found silt deposits ranging from 2 ft. to 8 ft. (Monahan) The deepest deposits are near the dam. As of this writing no silt removal has occurred.

Enriched via the Rio San Jose and a relatively slow turnover rate of 1.5 turns per year allow ample opportunity for the abundant aquatic vegetation to flourish. The hard water of the lake also favors plant growth.

Before the lake was recently de-watered, fish habitat appeared marginably suitable for both warm water and cold water species, the stocking schedule included both. Trout during the winter, channel catfish during the summer. Fishing is provided throughout most of the year. No fish disease were found in fish examined by the FWS pathologist just prior to the time the lake was drained. (Majors) During winter, ice forms on the lake's surface, but of insufficient depth to support ice fishermen. In summer the surface water temperatures frequently reach the high 70's and low 80's. Sometimes a major kill occurs, as in January of 1972, but most are partial kills. Too much aquatic vegetation in the lake has been a factor that allowed oxygen depletion and high levels of pH to occur. Such conditions cause stress that often culminate in the death of the fish.

Fish species in the lake include those found in Rio San Jose plus: rainbow trout (*Salmo gairdneri*), Snake River cutthroat (*Salmo clarki*), and channel catfish (*Ictalurus punctatus*).

Lake Acomita was first stocked in 1961 with 24,000 fingerling sized rainbow (see Table 1 Stocking). The fingerling stocking continued until 1969 when increased fishing pressure led to the stocking of 8" trout. Since then catchable sized rainbow have been the mainstay of the program. Annual plants of catchables trout have varied from 24,000 to 74,000 per year since 1969. Growth of fingerling early on, was about 1 1/2 inches per month. This allowed October releases to be catchable-sized by the following June, and April releases to be legal size by September. Several factors prompted the change from fingerling to catchables: Increased angler usage; fathead minnow populations plus other non-game species endemic to the system provided too much competition for available food reducing fingerling trout growth; high levels of pH occurred, especially between June and October; high surface temperatures of Lake Acomita added to the problem. Fish survival is better when the released fish are larger.

Management of irrigation releases also allowed the aquatic vegetation to proliferate. In those years when the lake was filled to spillway levels, prior to the irrigation season, fish habitat was not nearly so impacted as when low lake levels prevailed.

Fishing in Lake Acomita has experienced a drawdown trend since the late 60's until the early 80's (see Fig. 8). Catch rate - the time an angler needs to catch a fish - has peaked in 1966 and generally declined to a point where it takes an angler 3.85 hours to catch one trout! The harvest rate - percentage of stocked fish that are caught has also declined in a similar fashion. Ideally, the FWS would like to see at least 80% of stocked catchables land in the anglers creel.

The cost benefit analyses in Figures 10 and 11 were made with 1981 data, because 1982 was missing at the time the analyses were made. The methodology was developed by Fred Everest, Corvallis, Oregon. In terms of 1983 dollars the Acoma Pueblo fishery had a net value of $145,000. Fish condition data from FAO files were analyzed by the month to generate monthly means.

Rainbow fish condition (see Fig. 9a) appears to be less than robust during most of the year. The channel catfish (Fig. 9b) appears better suited to Lake Acomita. Brown trout (Fig. 9c) do not have as wide a sampling range but when sampled these trout were always above their standard. These graphs were compiled from the catch data during the period of 1962-1981 (Table 6). Statistical data in Table 7 (also compiled for the same period) indicate a wide range of growth rates (see slopes Table 7). Slope values are based on length-weight data which over various lengths and weights provide a line slope. The smaller the number the less the rate of growth, the larger value is interpreted accordingly. Rainbow ranged from .0358 (1975) to .2113 (1979). Brown trout ranged from .1340 (1978) to .4013 (1979). Catfish growth rates were consistently high - ranging from .2198 (1978) to .4445 (1980).

SUMMARY

There are a multitude of forces that have acted on fish populations in Lake Acomita. Each has impacted the fishery individually and in unison with other forces. These forces include irrigators, anglers, natural predators, sedimentation, aquatic vegetation, STP discharges and changes in D.O. and pH. Impacts on rainbow trout have been the most apparent.

Irrigators use water during the growing season - the main reason for the impoundment. The fluctuation in water level allows aquatic weeds to expand their range. A typical zone of aquatic growth extends to depths of about 12 feet within the lake. Fluctuating water levels brought about by irrigation have extended this aquatic vegetation zone to greater depths within the lake. The net result is fish have less area available to them.

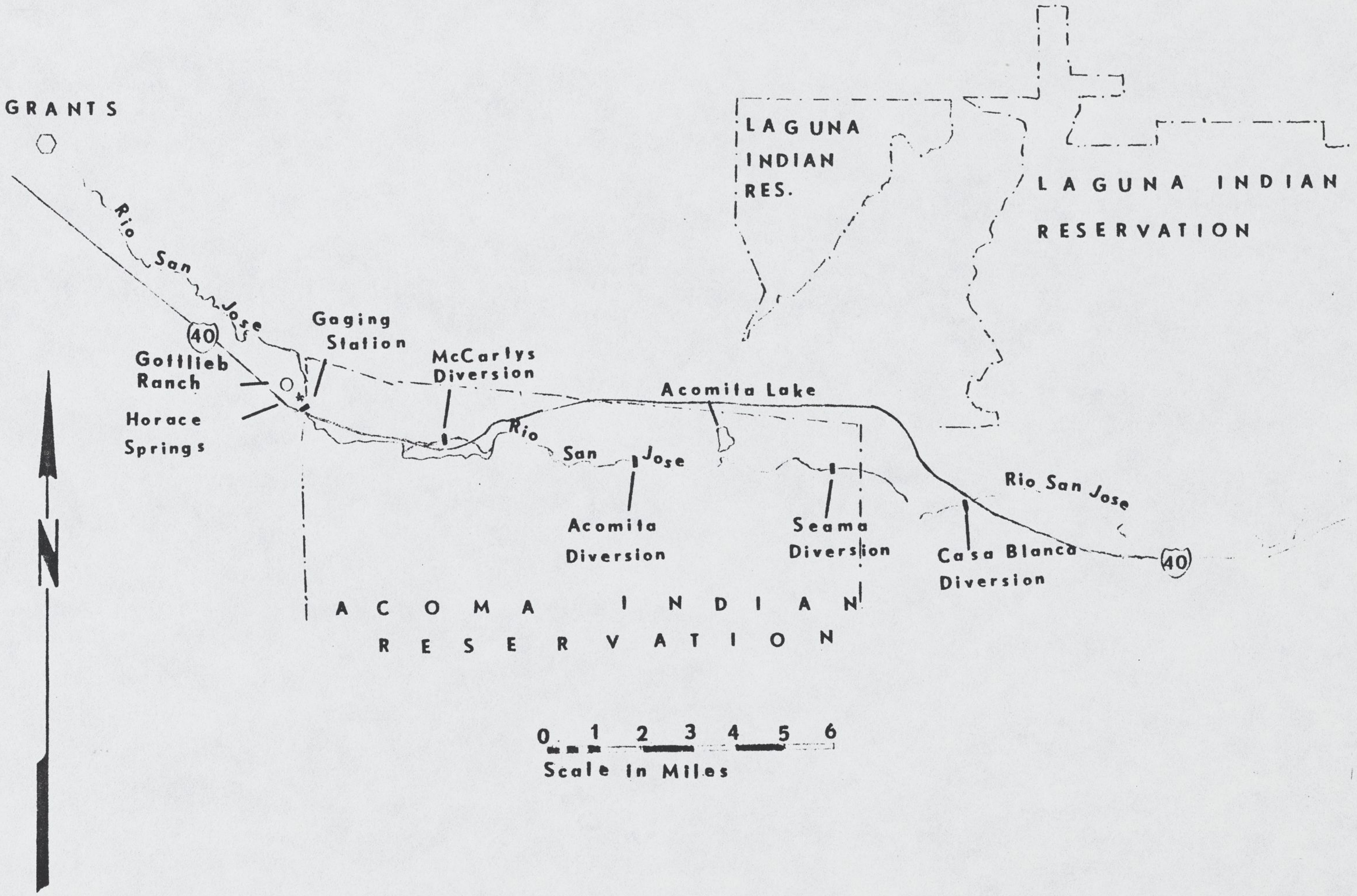
Vegetation is also an effective barrier to bank fishermen desiring to fish open water beyond the vegetation. Fishermen success rate has declined gradually, in part due to the increased vegetation. Plant growth had a more direct impact on fish populations in Lake Acomita. Excessive algal and submerged plant growth has caused wide varriations in oxygen and pH content and in some instances caused fish kills.

Predators, birds, and other fish, were not enumerated. During the period of evaluation, it did not appear that predators were a limiting factor on the fishery.

Sedimentation, limited benthic production and reduced trout carrying capacity in the lake. During the past several years, trout growth had been less than usual. The data indicated that rainbow trout were not as robust, especially during the summer months. However, in the mid to late 70's some rainbow did attain 20 inches or more. In subsequent years, the carryover, measured by angler success and net surveys, revealed fewer large fish. Rainbow trout appeared to be losing their niche in the system to catfish and brown trout; both of which appeared to be better suited to the enriched environment.

It would appear that, discharges from the Grants Treatment Plant have contributed to rainbow trout habitat loss in Lake Acomita and the Rio San Jose stream. The stream system appears to be loaded to, or near, it's carrying capacity with nutrients. If nutrient levels are controlled in the stream, then I estimate that the lake will require about two years to free itself of excessive nutrient. Lake Acomita did reach a point which required corrective and remedial action. De-watering was the method selected and the lake was drained. All fish were lost in the process and the lake closed to fishermen.

FIGURE 1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Gottlieb Ranch
Horace Springs
Gaging Station
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LAGUNA INDIAN RES.
LAGUNA INDIAN RESERVATION
Acomita Lake
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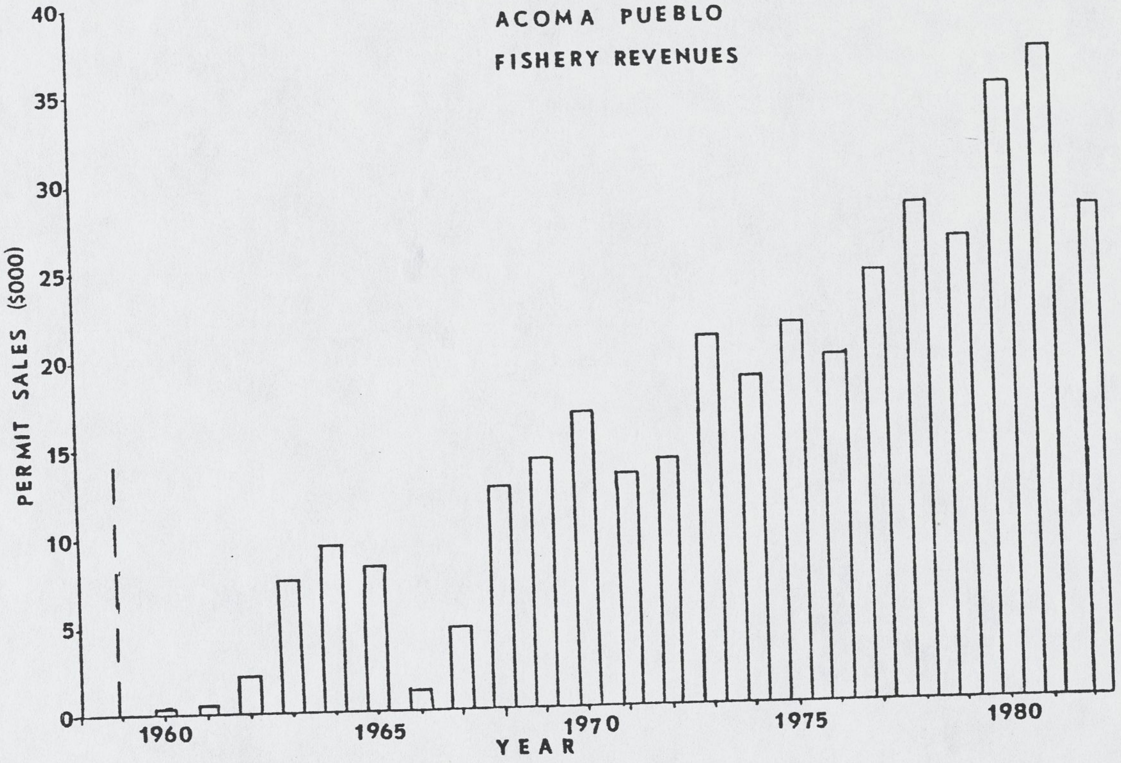

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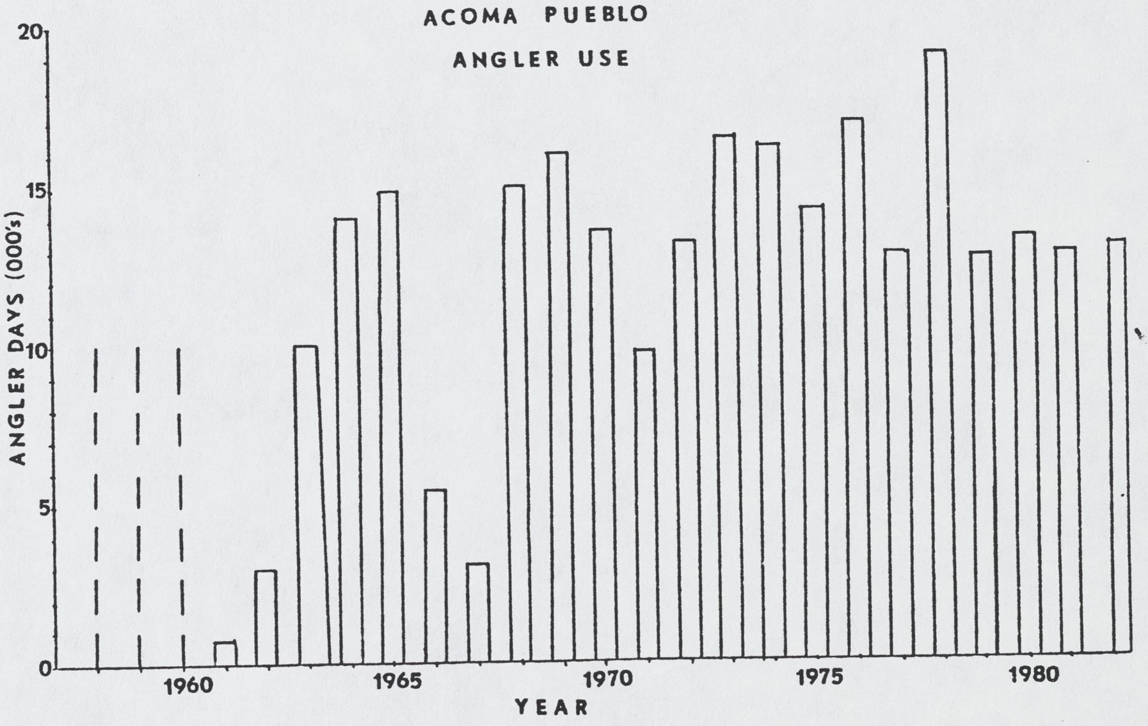

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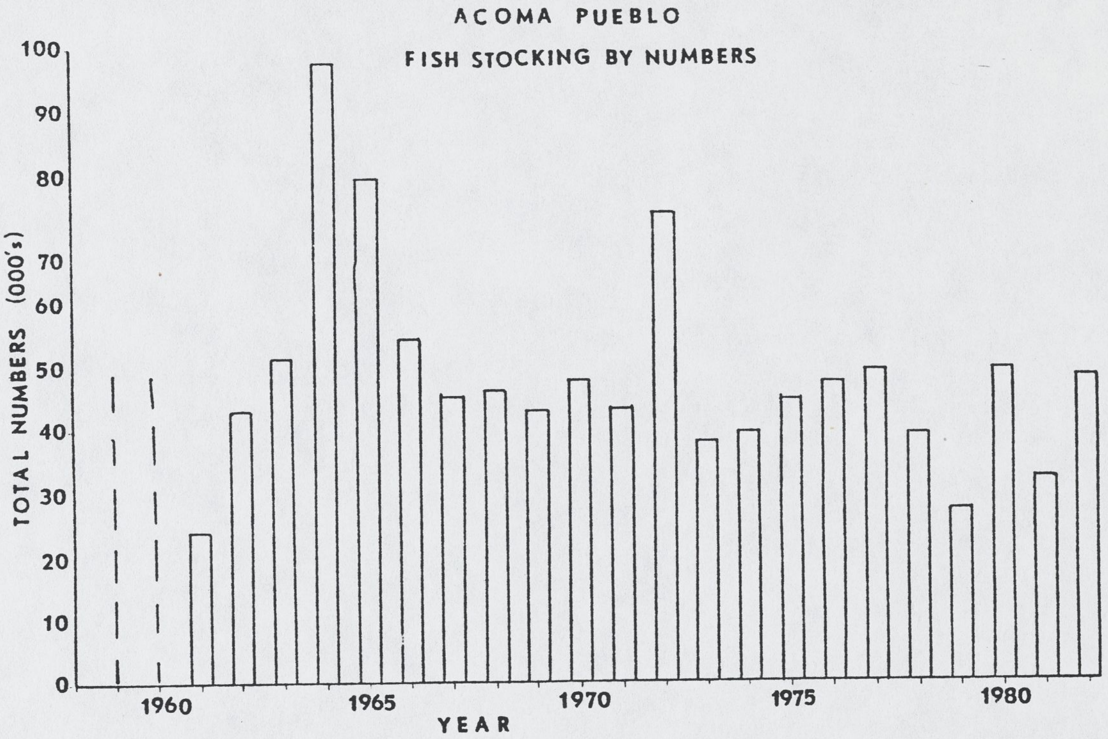

ACOMA PUEBLO
FISH STOCKING BY NUMBERS

Figure 4

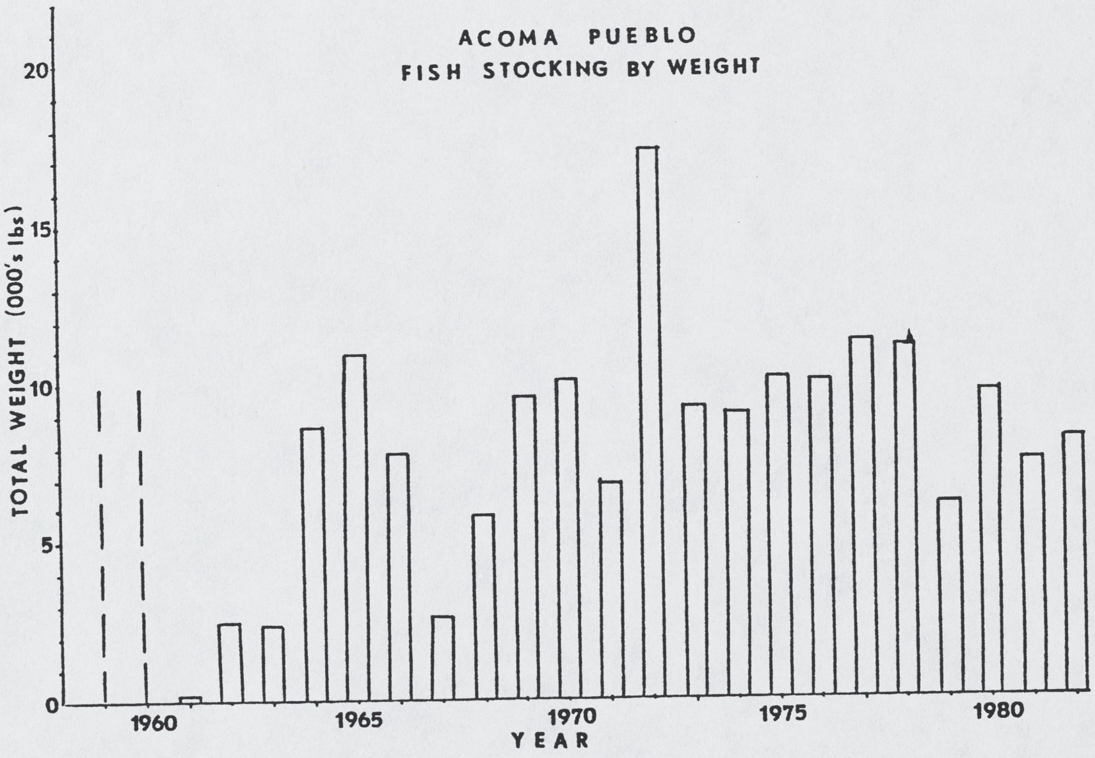

ACOMA PUEBLO
FISH STOCKING BY WEIGHT

Figure 5

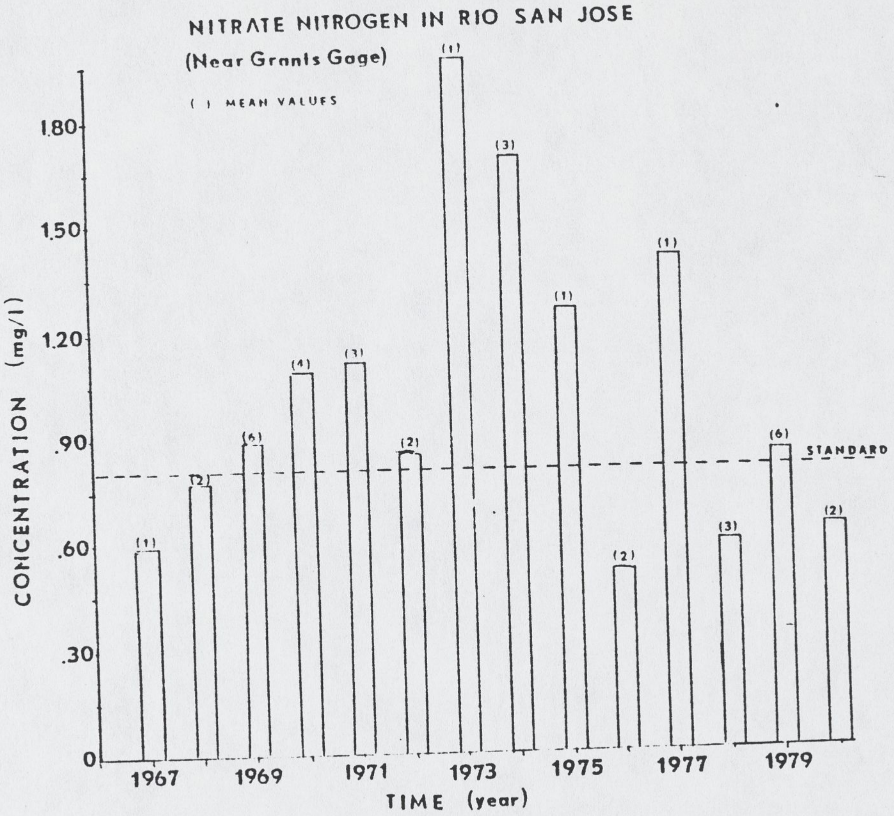


Figure 6

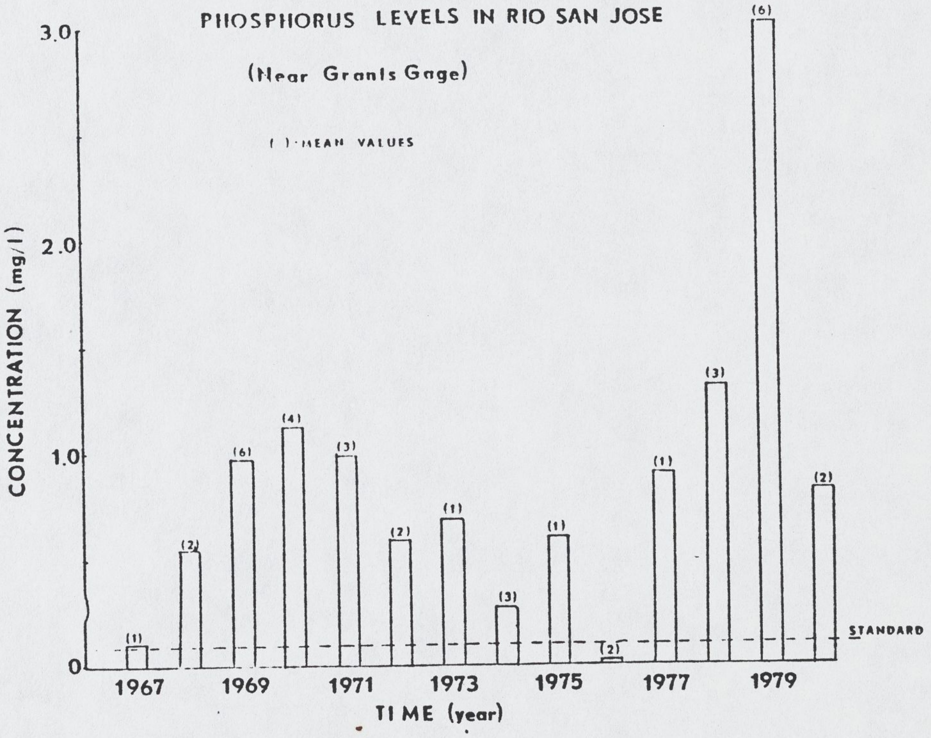


Figure 7

Table 1

ACOMA PUEBLO FISH STOCKING

	TOTALS		AVERAGE SIZE (F/lb.)			
YEAR	NUMBER	WEIGHT	RBT	CCF	BNT	CUT
1960	NO DATA	NO DATA	-	-	-	-
1961	23,744	212	112	-	-	-
1962	43,000	2,531	15.2	200	-	-
1963	50,760	2,378	21.3	-	-	-
1964	97,652	8,699	11.2	-	-	-
1965	79,541	10,990	6.9	40.8	-	-
1966	54,400	7,841	6.9	-	-	-
1967	45,000	2,703	16.6	-	-	-
1968	46,000	5,865	6.5	-	285.7	-
1969	43,000	9,625	4.5	-	-	-
1970	47,577	10,010	4.8	3.7	-	-
1971	26,622	6,862	3.9	-	-	-
1972	73,981	17,381	4.3	-	-	-
1973	38,000	9,315	4.1	-	-	-
1974	39,500	9,037	4.4	-	-	-
1975	44,700	10,170	4.2	28.6	1.9	-
1976	47,100	10,041	4.6	3.0	16.6	-
1977	48,976	11,312	4.6	3.0	-	-
1978	39,276	11,126	3.5	-	-	-
1979	27,000	6,195	4.4	-	-	-
1980	48,935	9,680	4.5	2.8	144.1	-
1981	32,075	7,548	4.4	3.5	-	-
1982	48,008	8,278	4.1	3.2	166.7	10.5

CATCHABLES (8"+ trout, 10"+ catfish) = 4.5 F/lb or less
FINGERLINGS (less than 8" trout, 10" catfish) = 4.5 F/lb or larger
FRY (less than 1") = 2400 F/lb or larger
e.g. RBT @ 112 F/lb are fingerlings of 2.8"
RBT @ 3.5 F/lb are catchables of 8.9"
CCF @ 38 F/lb are fingerlings of 4"
CCF @ 2.2 F/lb are catchables of 11"

Table 2.

	NON-TRIBAL			TRIBAL				
Year	Adult Non-Tribal Daily Permit	Child Non-Tribal Daily Permit (12 yrs.)	Non-Tribal Season	Adult Tribal Daily Permit	Child Tribal Daily Permit (12 yrs.)	Tribal Season Permit	Other Fishing Permits Sold	Total Permits Sold/Season
1960	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
1961	"	"	"	"	"	"	"	"
1962	"	"	"	"	"	"	"	"
1963	"	"	"	"	"	"	"	"
1964	"	"	"	"	"	"	"	"
1965	"	"	"	"	"	"	"	"
1966	"	"	"	"	"	"	"	"
1967	"	"	"	"	"	"	"	"
1968	"	"	"	"	"	"	"	"
1969	"	"	"	"	"	"	"	"
1970	7,648	778	678	No Data	No Data	135	23	9,626
1971	5,648	671	619	162	No Data	No Data	No Data	7,231
1972	7,076	936	355	42	28	71	6	8,514
1973	9,857	1,061	645	No Data	No Data	228	No Data	11,791
1974	8,651	942	495	200	No Data	202	15	10,505
1975	9,749	914	631	167	15	205	23	11,704
1976	8,598	769	614	176	5	171	11	10,344
1977	8,799	975	617	No Data	No Data	1	16	10,408
1978	8,819	900	880	No Data	No Data	341	5	10,945
1979	6,538	1,128	200	212	156	No Data	No Data	8,234
1980*	No Data*	No Data*	No Data*	No Data*	No Data*	No Data*	No Data*	9,359
1981	"	"	"	"	"	"	"	9,039
1982	"	"	"	"	"	"	"	9,893

*No data as of this writing on angler breakdown.

Table 3.

Year	No. Camping Permits Sold	Total Camping Permits Revenue	Total Permit Sales Revenue	Angler Days Generated/Season	No. Fish Stocked	Total Weight of Fish (lbs.)
1960	No Data	No Data	$ 230.00	No Data	No Data	No Data
1961	"	"	333.00	700	RBT 23,744	212
1962	"	"	1,960.00	3,000	RBT 38,000 CCF 5,000 43,000	2,506 25 2,531
1963	"	"	7,500.00	10,000	RBT 50,750	2,378
1964	"	"	9,105.00	14,028	RBT 97,652	8,699
1965	"	"	7,960.50	14,900	RBT 75,541 CCF 4,000 79,541	10,392 98 10,990
1966	"	"	1,020.00	5,430	RBT 54,400	7,841
1967	"	"	4,478.00	3,078	RBT 45,000	2.703
1968	"	"	12,401.75	15,000	RBT 38,000 BNT 8,000 46,000	5,837 28 5,865
1969	"	"	13,938.05	16,000	RBT 43,000	9.625
1970	97	$156.50	16,375.00	13,626	RBT 44,577 CCF 3.000 47,577	9,207 303 10,010
1971	"	159.50	13,585.75	9,707	RBT 26,622	6,862
1972	"	150.00	13,959.40	13,194	RBT 73,981	17,381
1973	242	407.50	20,969.25	16,423	RBT 38,000	9,315
1974	No Data	574.00	18,499.50	16,158	RBT 39,500	9,037
1975	336	581.50	21,387.00	14,272	RBT 36,200 BNT 2,500 CCF 6,000 44,700	8,627 1,333 210 10,170
1976	278	485.00	19,299.00	16,939	RBT 37,100 BNT 5,000 CCF 5,000 47,100	8,074 301 1,666 10,041
1977	206	482.00	24,161.00	12,859	RBT 43,976 CCF 5,000 48,976	9,645 1,667 11,312
1978	156	364.00	27,993.00	19,042	RBT 39,276	11,126
1979	62	188.00	25,955.92	12,706	RBT 27,000	6,195
1980	No Data	No Data	34,522.50	13,302	RBT 36,000 BNT 8,500 CCF 4,435 48,935	8,037 59 1.584 9,680
1981	"	"	37,089.58	12.349	RBT 27,000 CCF 5,075 32,075	6,098 1,450 7,548
1982	No Data	No Data	No Data	No Data	RBT 24,000 CUT 9,000 CCF 5,008 BNT 10.000 48,000	5,794 859 1,565 60 8,278

TABLE 4

CREEL CENSUS DATA
ACOMITA LAKE

YEAR	NO. OF ANGLERS INTERVIEWED	TOTAL HOURS	TOTAL FISH CAUGHT	AVERAGE ANGLER DAY(HRS)	CATCH RATE (F/HR)	NO. OF PERMITS SOLD	ANGLER DAYS	PERCENT INTER-VIEWED	SEASON TOTAL HOURS	SEASON TOTAL CATCH	TOTAL NO. OF FISH STOCKED	HARVEST RATE
1964	13,921	57,516.0	26,076	4.13	0.45	-	14,028	-	57,935	26,276	97,752	.27
1965	10,220	38,028.0	23,973	3.72	0.63	-	14,900	-	55,428	34,920	79,541	.44
1966	1,435	4,549.5	6,355	3.24	1.37	NO DATA	5,430	-	17,213	23,582	54,400	.44
1967	3,824	18,913.0	19,460	4.95	1.03	NO DATA	3,078	-	15,236	15,693	45,000	.35
1968	2,443	13,842.5	8,331	5.67	0.61	NO DATA	15,500	-	85,050	51,881	46,000	1.13
1969	2,292	15,248.0	10,825	6.65	0.71	NO DATA	16,000	-	106,400	75,544	43,000	1.76
1970	3,813	12,392.0	10,569	3.25	0.85	9,262	13,626	41	44,285	37,642	47,577	.79
1971	-	-	-	-	-	7,231	9,707	-	-	-	26,622	-
1972	4,430	11,254.0	7,109	2.54	0.63	8,514	13,194	52	33,513	21,113	73,981	.29
1973	5,891	17,968.0	9,049	3.05	0.50	11,791	16,423	50	50,090	25,045	38,000	.65
1974	4,479	14,991.5	9,887	3.35	0.66	10,505	16,158	43	54,129	35,725	39,500	.90
1975	2,732	11,846.5	4,246	4.34	0.36	11,704	14,272	23	61,940	22,298	44,700	.50
1976	3,046	13,937.0	3,898	4.57	0.28	10,344	16,939	29	77,411	21,675	47,100	.46
1977	15,075	39,546.5	19,342	2.62	0.49	10,408	12,859	145	33,690	16,508	48,976	.34
1978	10,528	36,136.5	13,049	3.43	0.36	10,945	19,042	96	65,314	23,513	39,276	.60
1979	4,863	9,260.5	5,058	1.90	0.55	8,234	12,706	59	24,141	13,278	27,000	.49
1980	11,263	40,122.5	15,205	3.56	0.38	9,359	13,302	120	47,355	17,995	48,935	.37
1981	7,833	26,767.0	8,626	3.41	0.32	9,039	12,849	87	43,815	14,021	32,075	.44
1982	5,492	19,513.5	5,039	3.55	0.26	9,893	13,040	59	46,292	12,036	48,008	.25
MEAN	6310	22,324	11,450	3.77	0.58	9,746*	13,307	56*	51,122*	27,181	46,681	.58
STD. DEV.	4167.408	14,165.401	6758.941	1.148	0.283	1353.642	3789.989	37.4	23,263.457	15,766.332	19,984.955	.3734

*Since 1970

Figure 8

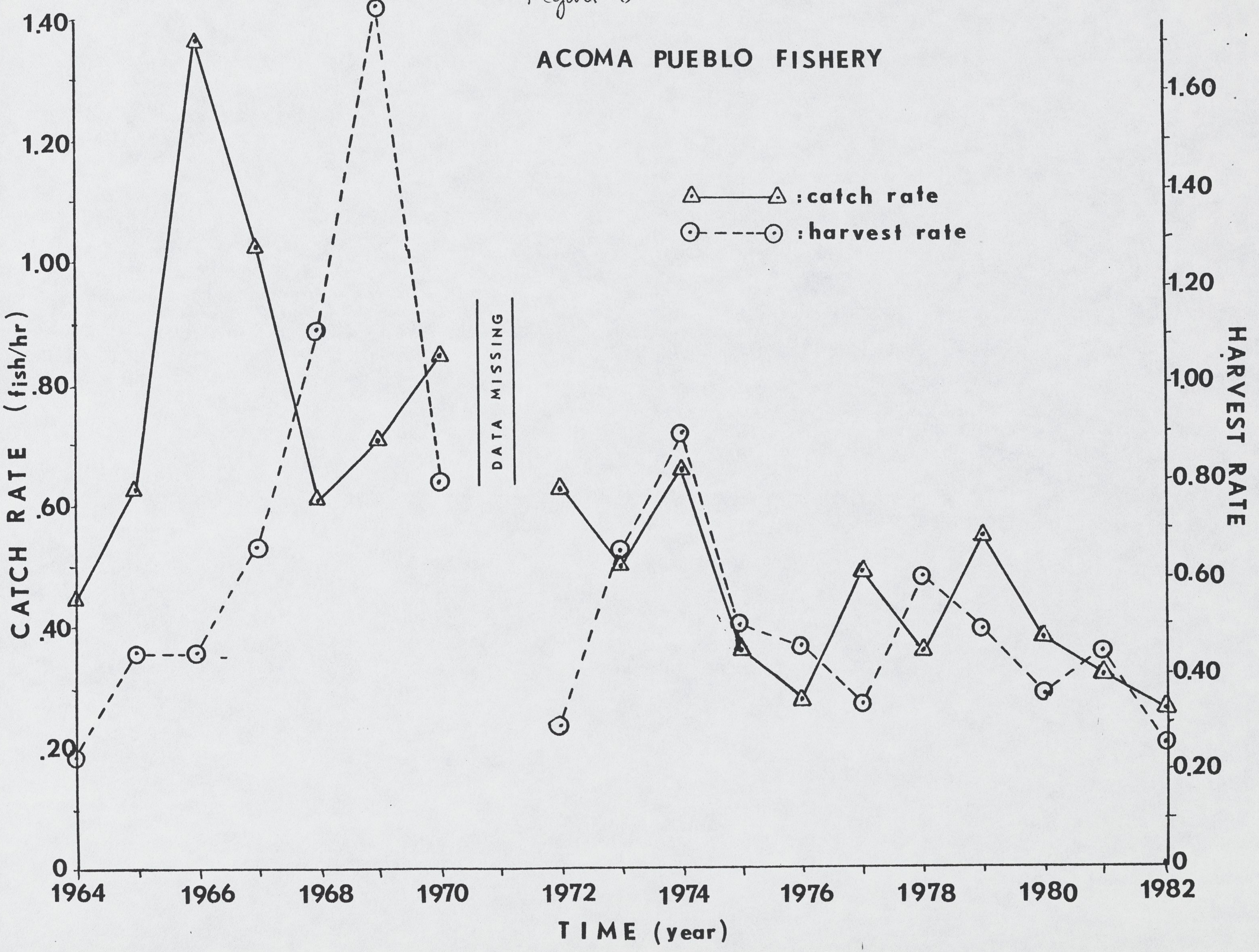

ACOMA PUEBLO FISHERY
:catch rate
:harvest rate
DATA MISSING
CATCH RATE (fish/hr)
HARVEST RATE
TIME (year)
1.40
1.20
1.00
.80
.60
.40
.20
0
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982

Table 5.

STATISTICAL DATA DEVELOPED FROM ACOMITA CREEL CENSUS

YEAR	EXPLOITATION RATE E	INSTANTANEOUS MORTALITY RATE M	INSTANTANEOUS FISHING MORTALITY RATE F	TOTAL ANNUAL MORTALITY RATE A	INSTANTANEOUS ANNUAL MORTALITY RATE Z	SURVIVAL RATE S	COEFFICIENT OF CATCHABILITY (1 * 10^{-6}) q
1964	.27	.22	.31	.41	.5276	.59	22
1965	.44	.11	.57	.49	.6733	.51	39
1966	.44	.11	.57	.49	.6733	.51	106
1967	.35	.11	.43	.42	.5447	.58	140
1968	-	-	-	-	-	-	132
1969	-	-	-	-	-	-	17
1970	.79	.10	1.56	.19	.2107	.81	114
1971	-	-	-	-	-	-	-
1972	.29	.22	.34	.43	.5621	.57	26
1973	.65	.11	1.08	.70	1.2040	.30	64
1974	.90	.11	.92	.64	1.0217	.36	143
1975	.50	.11	.69	.55	.7985	.45	49
1976	.46	.11	.62	.52	.7340	.48	36
1977	.34	.11	.42	.41	.5276	.59	32
1978	.60	.11	.92	.64	1.0217	.36	48
1979	.49	.11	.67	.54	.7765	.46	53
1980	.37	.11	.46	.43	.5621	.57	35
1981	.44	.16	.60	.53	.7550	.47	45
1982	.26	.22	.30	.40	.5108	.60	23
n	16	16	16	16	16	16	18
MEAN	.47	.13	.65	.49	.6939	.51	61.3
STD. DEV.	.1822	.0449	.3315	.1212	.24198	.1213	44.5843

FIGURE 9a

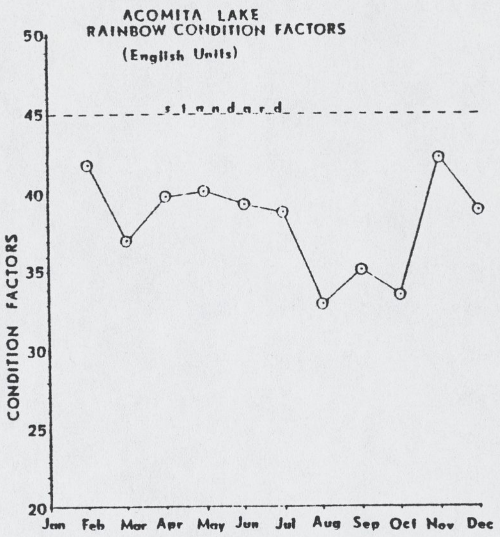


FIGURE 9b

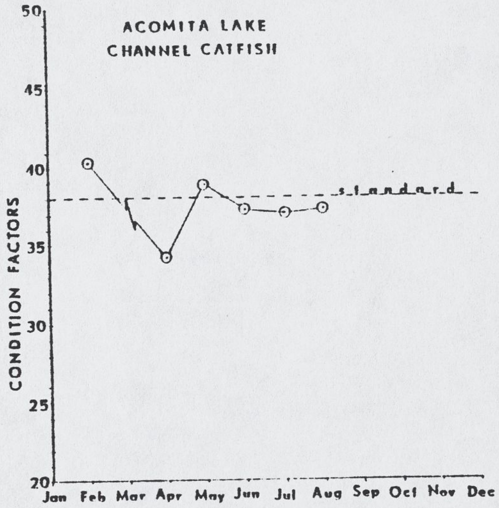
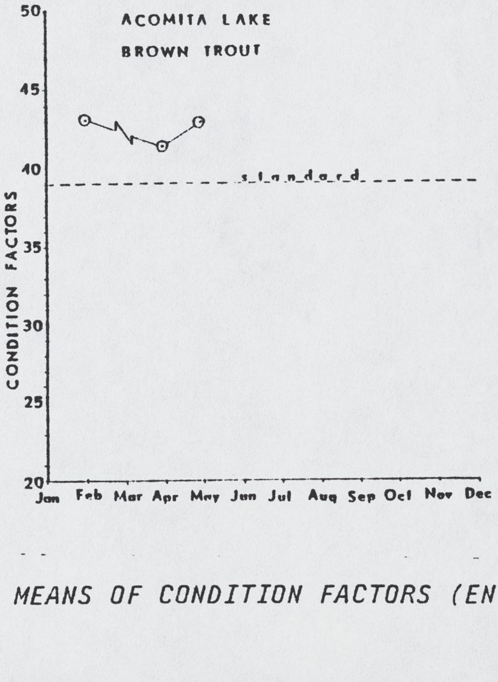


FIGURE 9c



MONTHLY MEANS OF CONDITION FACTORS (ENGLISH UNITS)

Figure ~~8~~ 10

ACOMA PUEBLO 1981 FISHERY
COST BENEFIT ANALYSIS

	NON-INDIAN	INDIAN	DATA SOURCE
ANGLERS	8,734 1/	305 2/	Permit Sales
ANGLER DAYS	12,416	433	FAO Estimates
AVAILABLE WATER	58 ac	58 ac 4 ac of stream 62	FAO Records
% OF TOTAL	94	100	
NUMBER OF FISH STOCKED	32,075		FAO Records
WEIGHT OF FISH STOCKED	7,548		FAO Records
COST OF FISH 3/	$15,095		FAO Records
ANNUAL NET VALUE			
1981 (CPI DEC 281.5)	$93,454	$3,264	
1983 (CPI JUNE 298.1)	$98,965	$3,456	
COST: BENEFIT RATIO:	1:6	1:0.23	

1/ Season, daily and free permits

2/ Estimate of anglers based on previous years use. Less than 10% of tribal members living on the reservation are estimated to be anglers.

3/ $2.00/lb. average cost of NFH trout production in 1981.

4/ $10.70/angler day. (1980 National Survey of Fishing, Hunting & Wildlife Associated Recreation, USFWS and Bureau of Census).

Figure ~~10~~ 11

ACOMA PUEBLO FISHERY
1981

TOTAL CATCH		14,021
	multiplied by	
ANGLER DAY/FISH		0.9164[1]
	equals	
TOTAL A~~L~~NGLER DAYS		12,849
	multiplied by	
VALUE OF ANGLER DAY		$10.70[2]
	equals	
ANNUAL NET VALUE 1981 (CPI DEC 1981: 281.5)		$137.484
ADJUSTED ANNUAL NET VALUE 1983 (CPI JUNE 1983: 298.1)		$145,591

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[1] Creel data reports 1 angler day = 3.41 hours and a catch rate of 0.32 f/hr.

[2] 1980 National Survey of Fishing, Hunting and Wildlife Associated Recreation, Fish & Wildlife Service and Bureau of Census.

TABLE 6
CONDITION FACTORS OF ACOMITA FISH

YEAR	SPECIES	NUMBER	"C" FACTOR	SIZE RANGE (inches)	METHOD OF CATCH PERCENTAGE	
					GILLNET	ANGLER
1962	RBT	24	43.6	5.2-12.1	100	0
1963	RBT	39	39.7	7.0-14.9	21	79
1964	RBT	27	40.0	7.2-12.0	0	100
1965	RBT	40	37.6	8.0-12.1	0	100
1966	RBT	59	33.3	6-7-12.5	83	17
	CCF	12	37.3	10.7-15.0	0	100
1967	RBT	53	37.6	7.6-12.3	0	100
1968	RBT	30	40.3	8.4-13.4	0	100
1969	RBT	19	32.9	8.0-11.5	0	100
1970	RBT	4	40.3	13.1-15.0	0	100
1971	NO DATA					
1972	NO DATA					
1973	RBT	62	36.8	8.4-23.9	0	100
1974	RBT	35	41.8	8.3-14.1	0	100
1975	RBT	54	40.5	10.3-15.3	0	100
1976	RBT	29	42.0	9.5-19.8	0	100
1977	RBT	66	32.7	8.0-19.9	56	44
1978	RBT	284	40.3	7.7-21.8	0	100
	BNT	17	40.8	11.8-16.1	0	100
	CCF	22	37.7	12.7-20.8	0	100
1979	RBT	62	40.8	9.3-18.3	50	50
	BNT	4	39.1	15.7-16.2	100	0
	CCF	9	37.4	15.0-18.2	0	100
1980	RBT	189	40.4	7.6-18.5	47	53
	BNT	4	45.9	15.0-19.2	100	0
	CCF	16	39.3	14.8-26.5	13	87
1981	RBT	113	41.0	7.1-14.9	100	0
	CCF	2	35.3	17.2-18.2	100	0
1983	RBT	5	42.0	13.9-14.8	100	0
	CCF	110	36.4	10.2-24.2	100	0

TABLE 7
STATISTICAL DATA
ACOMITA LAKE

	n	$\bar{x}_w$	$\bar{x}_L$	s_w	s_L	s_w^2	s_L^2	a	b	r
04-27-62	9	.14	6.7	.0999	1.2849	.0089	1.4677	-.3834	.0773	.99
07-31-62	15	.30	8.1	.2338	2.5159	.0510	5.9078	-.4507	.0921	.99
05-22-63	11	.70	11.6	-	-	-	-	-	-	-
06-03-63	12	.26	8.3	-	-	-	-	-	-	-
07-16-63	8	.84	12.9	-	-	-	-	-	-	-
09-10-63	8	-	10.6	-	-	-	-	-	-	-
04-01-64	8	.65	11.2	-	-	-	-	-	-	-
06-24-64	6	.45	10.3	-	-	-	-	-	-	-
07-08-64	6	.37	9.9	-	-	-	-	-	-	-
12-30-64	7	.35	9.4	-	-	-	-	-	-	-
04-01-65	19	.52	10.9	.1443	1.0740	.0197	1.0929	-.8759	.1273	.95
04-16-65	15	.47	10.7	.2139	1.7492	.0427	2.8558	-.8125	.1198	.98
04-29-65	6	.26	8.8	-	-	-	-	-	-	-
04-15-66	10	.31	9.7	-	-	-	-	-	-	-
08-19-66	49	.31	9.5	-	-	-	-	-	-	-
" (CCF)	12	.73	12.2	-	-	-	-	-	-	-
05-18-67	12	.25	9.1	-	-	-	-	-	-	-
06-06-67	14	.21	8.3	.0336	.6450	.0010	.3863	-.2239	.0520	.99
07-18-67	11	.23	8.6	.0522	.7058	.0025	.4529	-.3976	.0730	.98
09-30-67	5	.46	10.5	.1309	1.1127	.0137	.9904	-.7419	.1137	.97
10-11-67	4	.48	10.6	.1053	.8921	.0083	.5969	-.7632	.1178	.99
11-30-67	7	.69	11.8	.0534	.4231	.0024	.1535	-.6266	.1119	.89
03-22-68	7	.44	9.9	-	-	-	-	-	-	-
04-01-68	10	.57	11.0	-	-	-	-	-	-	-
06-06-68	6	.58	11.5	-	-	-	-	-	-	-
07-22-68	4	.37	9.3	.1825	1.4899	.0250	1.6650	-.7530	.1210	.99
08-20-69	6	.26	9.3	.0356	.3371	.0011	.0947	-.6000	.0927	.88
09-09-69	8	.33	10.1	.1145	.9884	.0115	.8548	-.4602	.0788	.68
09-25-69	5	.38	10.2	.1278	1.0963	.0131	.9616	-.7566	.1116	.96
06-4/6-70	4	1.05	13.8	.2084	.8737	.0326	.5725	-1.7425	.2033	.85
04-01-73	51	.97	12.3	1.0630	4.4702	1.1079	19.5908	-1.7571	.2220	.93
10-03-73	11	.38	10.6	.1132	.8414	.0117	.6436	-.9139	.1219	.91
04-01-74	35	.59	11.1	.2005	1.2039	.0391	1.4078	-1.1983	.1613	.97
04-01-75	54	.73	11.6	.1972	2.6536	.0381	6.9110	.3205	.0358	.48
03-06-76	29	.78	11.8	.4655	2.7900	.2092	7.5156	-.6602	.1224	.73

04-01-78	64	.90	12.1	.5421	3.3510	.2893	10.9493	-.6118	.1243	.76
" (BNT)	6	1.06	13.4	.3902	1.2549	.1269	1.3122	-2.9915	.3014	.97
05-09-78	27	.58	10.4	.2792	3.3516	.0751	10.8173	-.0339	.0591	.71
" (BNT)	6	1.18	14.2	.0741	.3834	.0046	.1225	-.7180	.1340	.69
" (CCF)	3	1.58	15.6	.9232	2.9000	.5683	5.6057	-3.3152	.3138	.99
05-13-78	39	.63	10.5	.4097	2.4663	.1635	5.9270	-6.9969	.1228	.74
" (BNT)	4	1.41	14.6	.3649	1.1117	.0999	.9267	-1.6397	.2087	.64
" (CCF)	4	1.50	15.5	.4102	1.078	.1262	.8719	-3.7111	.3353	.88
06-03-78	44	.47	9.9	.1834	2.8657	.0329	8.0257	.0626	.0414	.65
06-10-78	14	.70	11.6	.3888	2.1409	.1404	4.2560	-1.3421	.1767	.97
07-18-78	63	.56	11.0	.2038	1.8703	.0409	3.4424	-.3412	.0820	.75
07-19-78	11	.51	10.6	.1880	1.2186	.0322	1.3499	-1.0861	.1508	.98
" (CCF)	3	2.50	18.0	1.540	4.4238	1.5820	13.0467	-3.6631	.3422	.98
07-25-78	21	.51	10.3	.1519	2.4034	.0220	5.5011	.0958	.0400	.63
" (CCF)	5	.97	13.8	.3035	1.3755	.0737	1.5136	-2.0692	.2198	.99
07-26-78	3	2.23	17.4	1.1491	2.7099	.8803	4.8956	-5.1531	.4237	.99
02-27-79	31	.75	11.7	.5232	2.4364	.2649	5.7444	-1.7287	.2113	.98
" (BNT)	3	1.70	16.2	.2021	.5033	.0272	.1689	-4.8180	.4013	.99
04-01-79	19	.70	11.8	.2364	1.2766	.0529	1.5440	-1.4349	.1802	.97
06-03-79	12	.75	12.1	.3512	1.9490	.1131	3.4822	-1.4036	.1777	.99
" (CCF)	5	1.82	17.0	.4405	1.2736	.1552	1.2976	-3.6233	.3208	.93
02-16-80	20	.67	11.8	.3262	2.0387	.1011	3.9485	-1.1811	.1565	.98
02-17-80	69	.50	9.6	.4426	2.8025	.1931	7.7402	-5.7901	.1118	.71
" (BNT)	4	2.55	17.6	.7059	1.8110	.3737	2.4600	-4.1394	.3801	.98
" (CCF)	13	3.14	19.6	1.2179	2.4571	1.3692	5.5729	-5.5859	.4445	.90
04-13-80	100	.45	10.1	.2123	2.1118	.0446	4.4152	-.3019	.0746	.75
04-04-81	113	.44	9.9	.2351	1.6539	.0548	2.7113	-.6988	.1150	.81

KEY

n = Number
$\bar{x}_w$ = Mean weight
$\bar{x}_L$ = Mean length
s_w = Standard deviation weight
s_L = Standard deviation legnth

s_w^2 = Variance weight

s_L^2 = Variance length

a = y-intercept
b = Slope
r = Correlation coefficient
RBT = Rainbow trout
BNT = Brown trout
CCF = Channel catfish

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