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A Proposal to fertilize the Overton Arm and Gregg Basin areas of Lake Mead

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Limnological Conditions in Lake Mead

Several limnological studies have been conducted in Lake Mead during the past decade (Deacon and Tew 1973; Deacon 1975, 1976, 1977; Baker et al. 1977, Paulson et al. 1980; Brown and Caldwell 1982; Paulson and Baker 1983a, 1983b). The recent studies clearly show that most of Lake Mead is deficient in nutrients, especially phosphorus, and very low in productivity. The reservoir-wide average total phosphorus concentration for 1981 - 1982 was only 9 mg/m^3 (Table 1). This is below levels found in most oligotrophic lakes and reservoirs. Algal biomass, as measured by chlorophyll-*a*, averaged only 1.5 mg/m^3. That also places Lake Mead in the oligotrophic range. Transparency, as measured by a Secchi disc, averaged 9.5 m in Lake Mead during 1981-1982. That far exceeds levels found in most oligotrophic lakes and reservoirs. Lake Mead is oligotrophic based on every trophic state criteria used to classify lakes and reservoirs.

The phosphorus deficiency in Lake Mead began to develop in 1963 when Glen Canyon Dam was formed 286 miles upstream. As that reservoir slowly filled, it cut off the phosphorus supply in the Colorado River inflow to Lake Mead (Evans and Paulson 1983). Algal productivity in the upper basin of Lake Mead decreased considerably after 1963 (Prentki et al. 1981). Phosphorus concentrations and productivity in Virgin Basin have been extremely low since monitoring began in 1977 (Figs. 1, 2). The Overton Arm, upstream of Fish Island, and Iceberg Canyon/Grand Wash are the only areas left in the upper basin where phosphorus levels are sufficient to sustain higher productivity (Paulson et al. 1980; Paulson and Baker 1983a, 1983b).

Wastewater inflows from Las Vegas Wash provided enough phosphorus

Table 1. Trophic state of Lake Mead during 1981 and 1982 based on classification criteria proposed for lakes and reservoirs in previous studies. (Data for Lake Mead based on area weighted averages for monthly sampling at several stations. All references cited from Forsberg and Ryding 1980.)

	Total Phosphorus (mg/m^3)			Chlorophyll-a (mg/m^3)			Transparency (m)		
Authors	Oligo	Meso	Eutro.	Oligo	Meso	Eutro.	Oligo	Meso	Eutro.
USEPA 1974	<10	10-20	>20	<7.0	7.0-12.0	>12.0	3.7	2.0-3.7	<2.0
Carson 1977	<12	12-24	>24	<2.5	2.5- 6.5	> 6.5	>4.0	2.0-4.0	<2.0
Ahl & Wiederholm 1977	<12.5	12.5-25	>25						
Rast and Lee 1978	<10	10-20	>20	<2.0	2.0-6.0	>6.0	>4.6	2.7-4.6	<2.7
Forsberg & Ryding 1980	<15	15-25	>25	<3.0	3.0-7.0	>7.0	>4.0	2.5-4.0	<2.5
Lake Mead 1981-82	9			1.5			9.5		

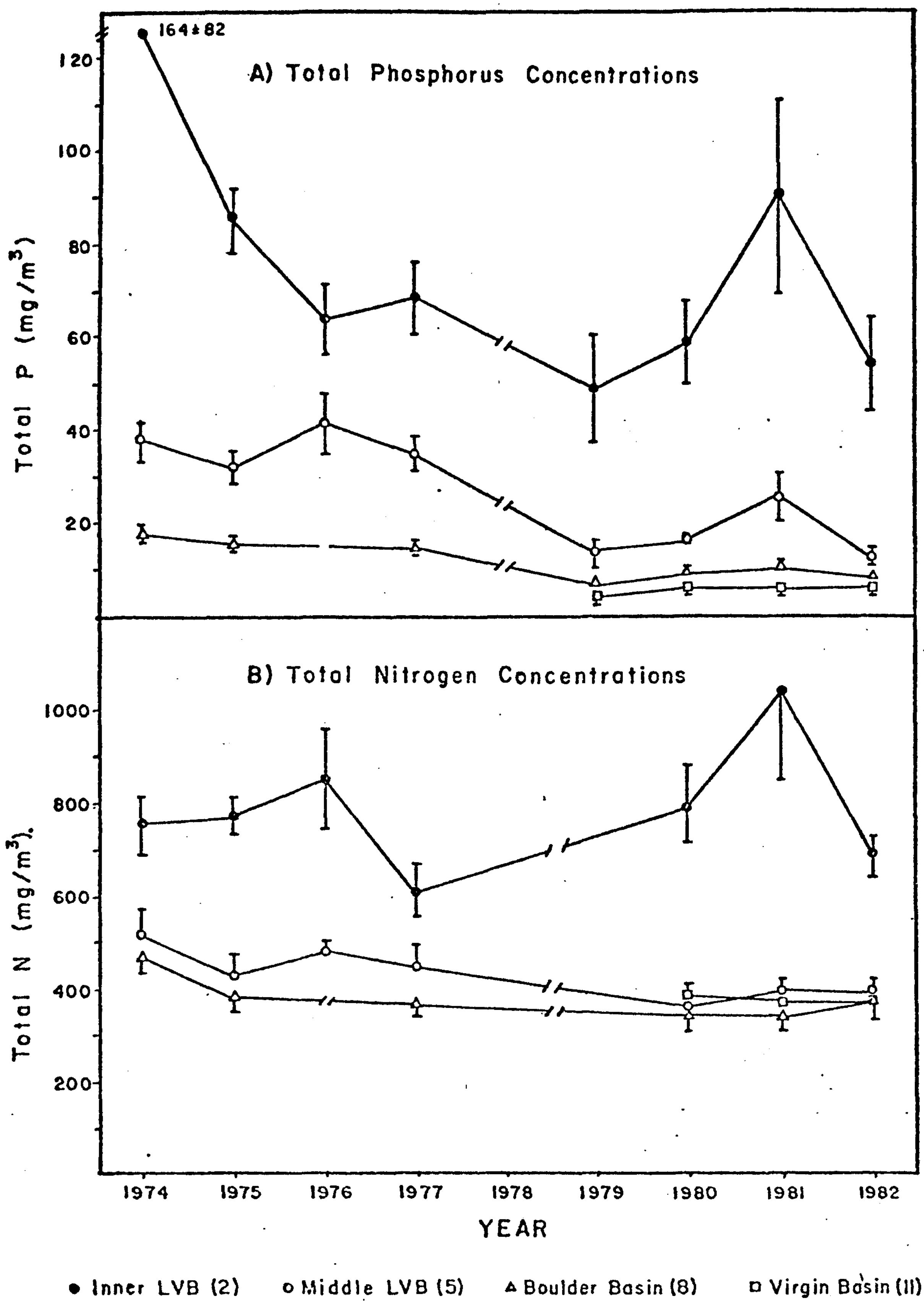

Figure 1. Annual average total phosphorus (1a) and total nitrogen (1b) concentrations at select locations in Lake Mead during 1974-1982 (±SE).

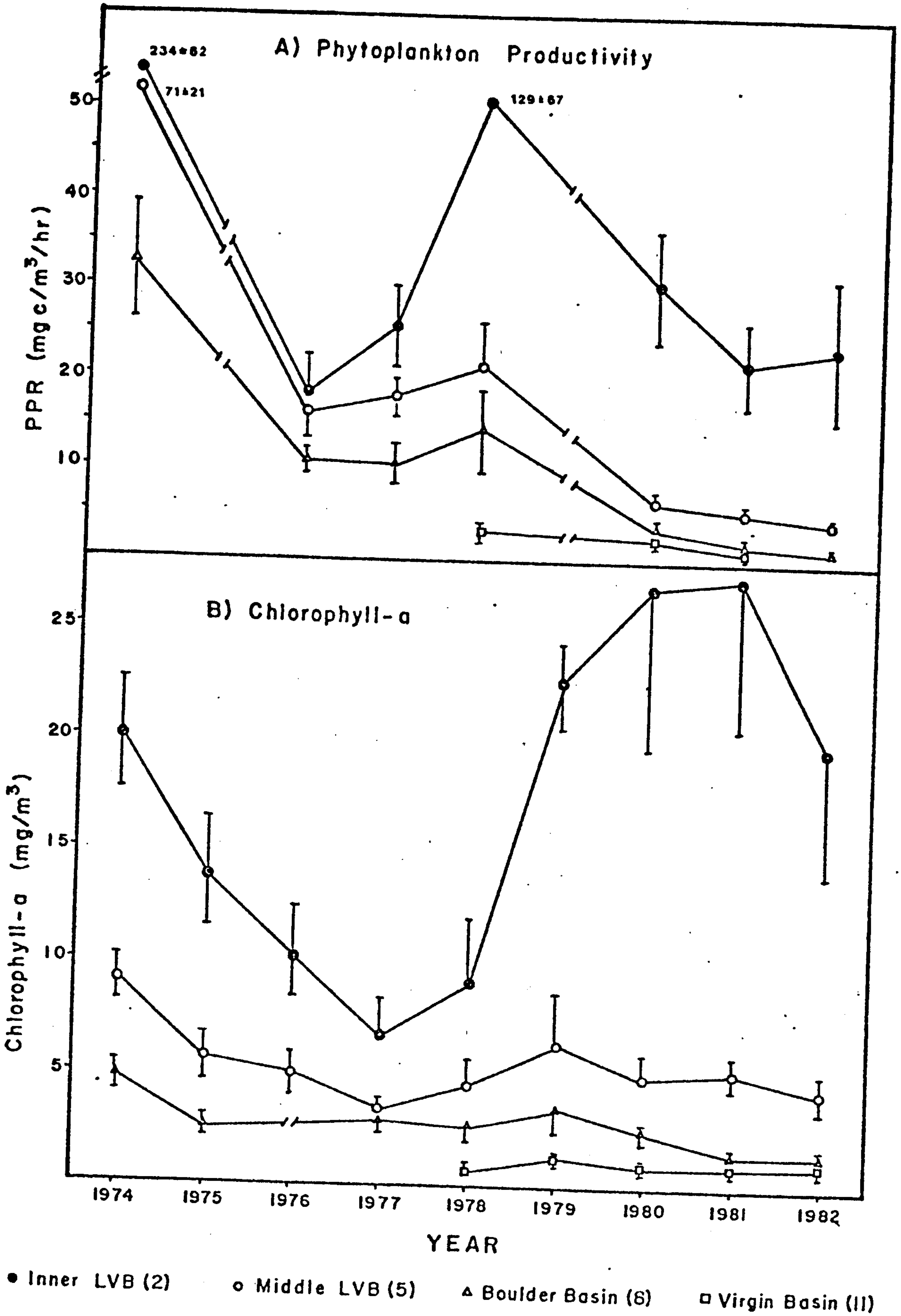

Figure 2. Annual average phytoplankton productivity (2a) and chlorophyll-a (2b) at select locations in Lake Mead during 1974-1982 (± SE).

to sustain higher algal productivity in the lower basin during the early and mid-1970's (Figs. 1, 2). The effects of wastewater inflows began to decrease in the late 1970's when reservoir elevations increased (Fig. 3b) and phosphorus loading decreased (Fig. 3a). Clark County began removing some phosphorus at its secondary plant in the late 1970's. The county began full-scale phosphorus removal at the Advanced Wastewater Treatment (AWT) plant in 1981. The city of Las Vegas refused to hook up to the AWT plant but has been removing phosphorus, to the same level as the county, at its secondary plant. Phosphorus loading from Las Vegas Wash is now about five times lower than it was during the early 1970's.

Total phosphorus, chlorophyll-a and phytoplankton productivity in Boulder Basin have decreased steadily since 1974 (Figs. 1, 2). There has also been a decline in zooplankton densities (Fig. 4) and in the relative abundance of fish (Fig. 5a). Fish sampling conducted in the early 1970's showed that most of the fish in open waters of Las Vegas Bay and Boulder Basin were threadfin shad (Paulson and Espinosa 1975, Allan and Roden 1978).

Total phosphorus, chlorophyll-a and productivity have also declined somewhat in the middle Las Vegas Bay since 1974 (Figs. 1, 2). Zooplankton data for the middle Las Vegas Bay are not available prior to 1977. There has been some decrease in zooplankton densities since that time in the midle bay (Fig. 4). Fish are still fairly numerous in the middle Las Vegas Bay, but densities are lower than in 1974 and 1975 (Fig. 5b).

Nutrient concentrations, chlorophyll-a and productivity are still very high in the inner Las Vegas Bay (Figs. 1, 2). Chlorophyll-a concentrations have actually increased and remained high in recent years

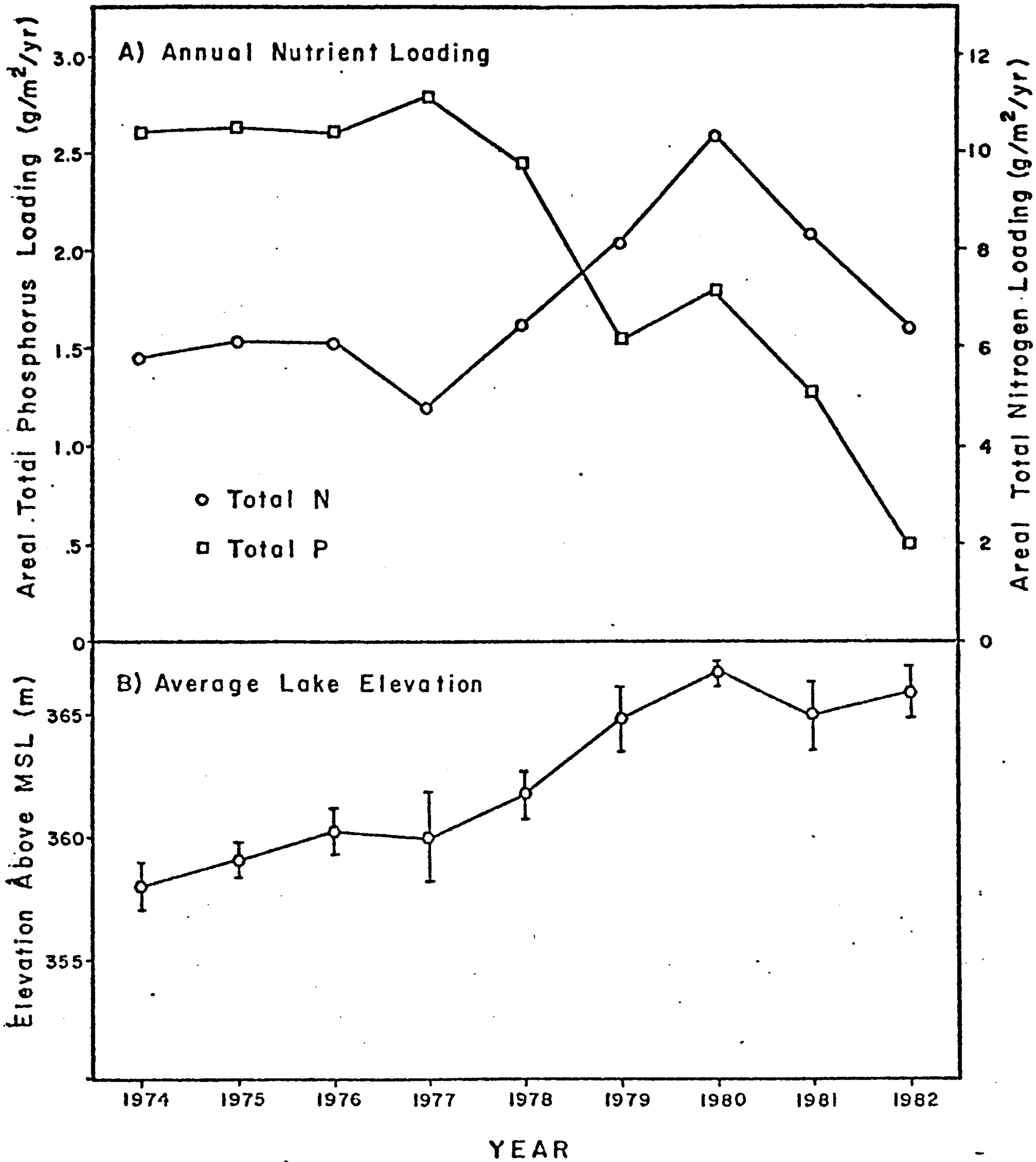

Figure 3. Annual nutrient loading from Las Vegas Wash (3a) and average lake elevations in Lake Mead during 1974–1982 (± SE).

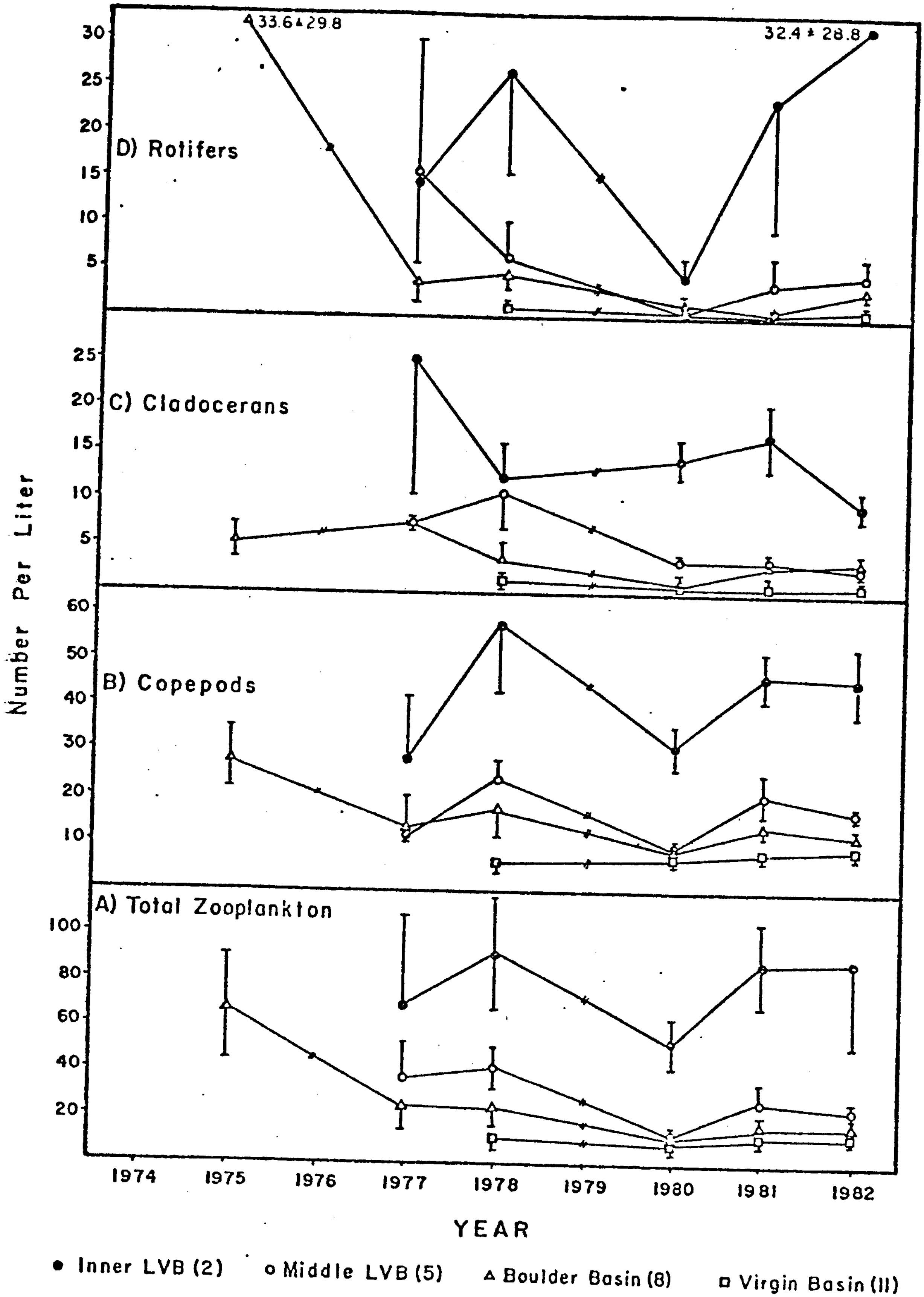

Figure 4. Average zooplankton densities at select locations in Lake Mead during Jan-May 1975-1982 (± SE) (Data for 1975 from Baker et al. 1977).

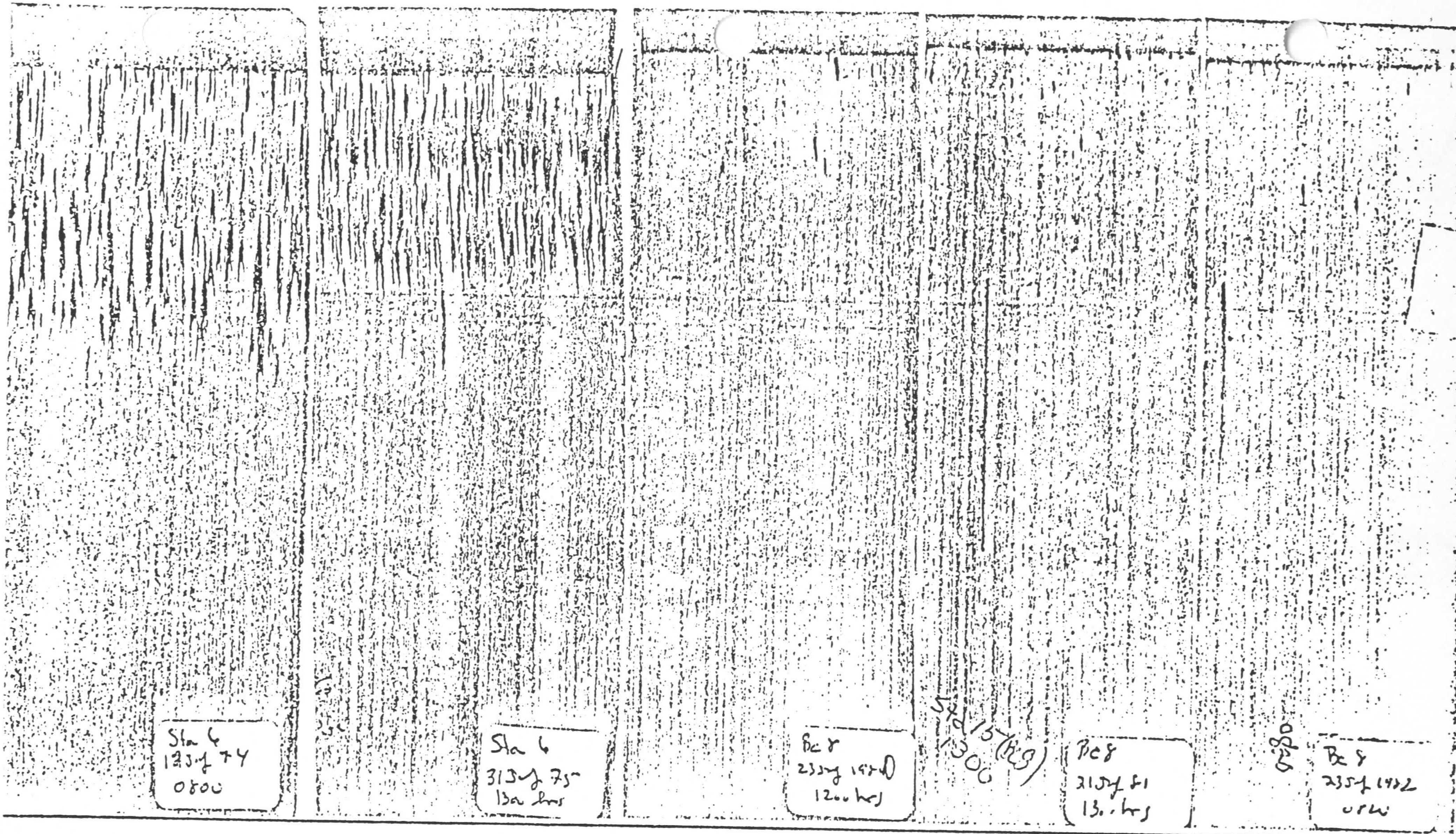

Figure 5a. Relative abundances of fish in Boulder Basin of Lake Mead during 1974, 1975, and 1980-1982.

despite cutbacks in phosphorus loading from Las Vegas Wash. This area of the the lake is nitrogen limited (Brown and Caldwell 1982), and chlorophyll-a generally tracks nitrogen loading from Las Vegas Wash (Figs. 1b, 3a). Zooplankton densities (Fig. 4) and relative abundances of fish in the inner Las Vegas Bay (Fig. 5c) have not changed appreciably since monitoring began.

Effects on the Fisheries

The changes in limnological conditions in Boulder Basin and parts of Las Vegas Bay have had a major impact on the fisheries. Adult shad (Age I and II) were prevalent in littoral areas during late winter and spring, and large numbers of juveniles dispersed to limnetic areas during summer (Deacon et al. 1972). Juvenile shad comprised most of the limnetic population (Paulson and Espinosa 1975), although adults were also frequently captured in mid-water trawls (Allan and Roden 1978). Shad occurred primarily in the epilimnion and metalimnion to depths of 15-20 m (Paulson and Espinosa 1975). They dispersed to deeper waters at the onset of fall mixing, and large schools overwintered in the deep basins (Allan and Roden 1978). Shad moved back into shallow waters to spawn during spring and early summer (Deacon et al. 1972).

The abundance of threadfin shad in deep, open basin areas was ideal for trout and adult striped bass. Trout in Lake Mead occupied depths between 30-40 m at temperatures of 13-15 C during summer (Allen and Roden 1978). Trout captured at these depths had shad in the stomachs. This indicates shad were present at these depths or that trout were briefly ascending into warmer overlying waters to forage. The latter is the most probably foraging strategy because echo sounding shows that few shad occurred in the hypolimnion, even when they were abundant.

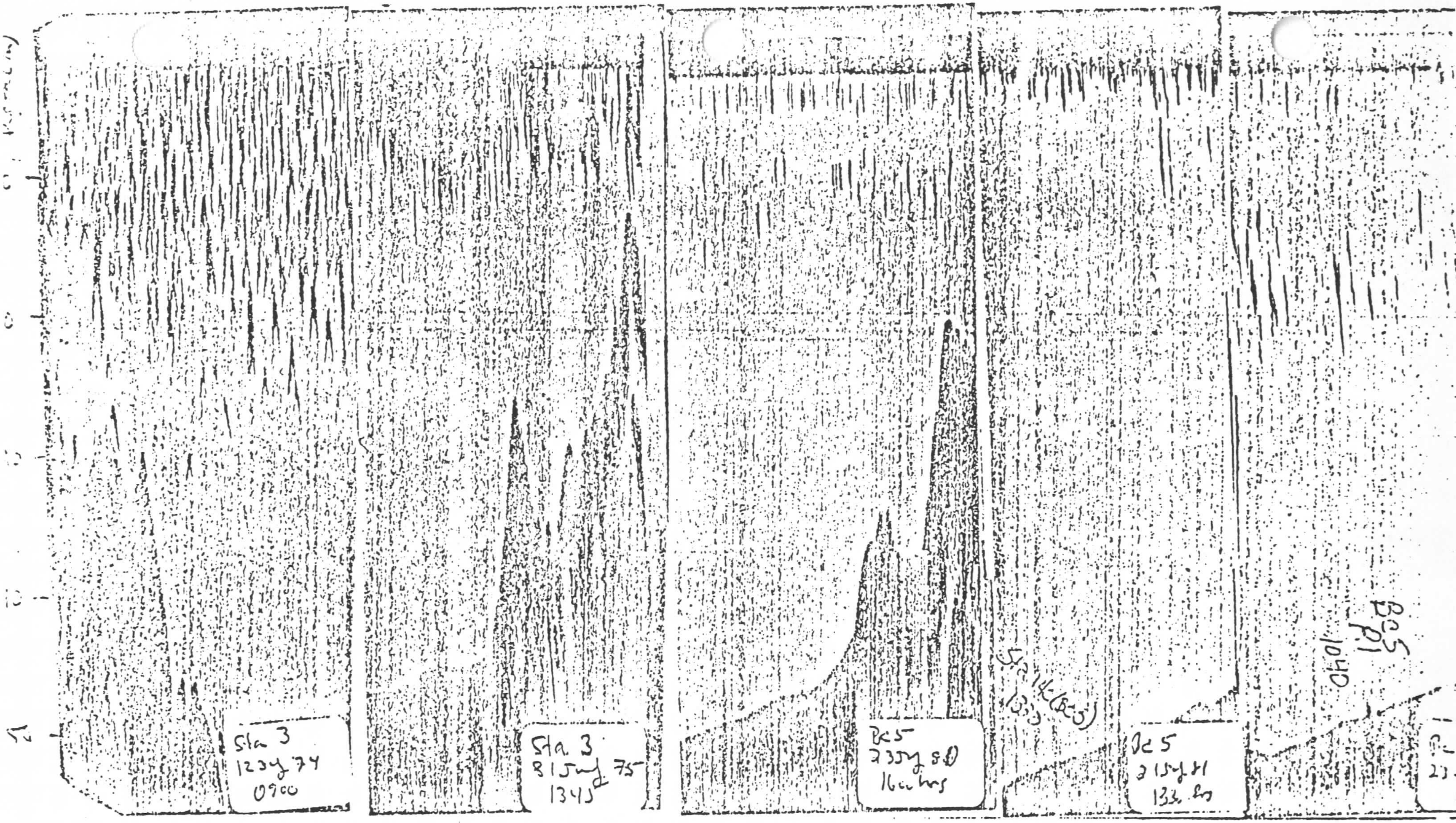

Figure 5b. Relative abundances of fish in middle Las Vegas Bay of Lake Mead during 1974, 1975, and 1980-1982.

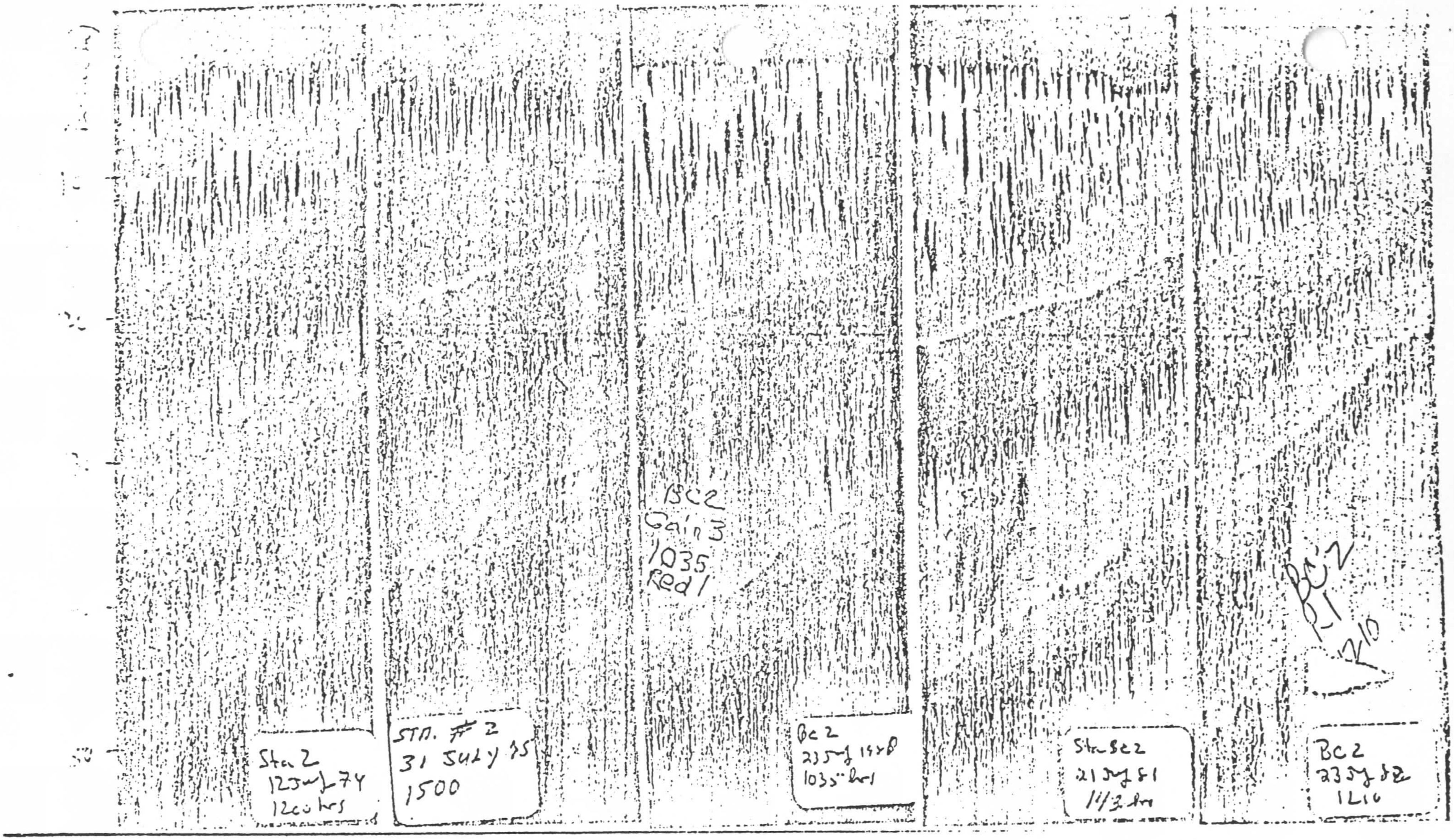

Figure 5c. Relative abundances of fish in inner Las Vegas Bay of Lake Mead during 1974, 1975, and 1980-1982.

The trout fishery collapsed in 1976. Some felt this was due to predation. Trout frequently occurred in diets of large striped bass (Allan and Roden 1978). Predation probably was a factor, but it is unlikely that it was the sole cause for the decline in trout fishery. The shad population declined sometime between 1975 and 1980 (Baker and Paulson 1983). As the population declined, it seems trout were forced to spend more and more time foraging for shad at depths where temperatures exceeded their thermal tolerance. Mortality from predation, disease and outright starvation must have increased as limnetic shad densities decreased. The breaking point for trout was apparently reached in the late 1970's. There is little chance for survival of trout in Lake Mead now that limnetic areas are virtually devoid of shad.

Summer dieoffs of adult striped bass were also common in Lake Mead in the late 1970's. Similar dieoffs have been observed in other reservoirs and appear to be caused by low oxygen concentrations in the thermal refuges of adults (Coutant 1984). Adult striped bass prefer temperatures of 18-22 C (Cox and Coutant 1981). In order to satisfy those requirements in Lake Mead, adults would have to occupy depths of 15-25 m in limnetic areas during summer. A negative heterograde oxygen curve develops in Lake Mead during summer months (Paulson et al. 1980). Oxygen minima generally occur at thermocline (10-15 m), but concentrations rarely drop below 4 mg/l (Paulson and Baker 1983).

There is no shortage of oxygenated thermal habitat in Lake Mead. Suitable habitat for adult striped bass exists in most of the reservoir. The problem is that forage is scarce in all but a few areas. The middle Las Vegas Bay is the only area in the lower basin were the thermal and forage requirements of adult striped bass currently come close to being met.

Temperatures in the inner Las Vegas Bay range between 24 and 28 C during the summer (Paulson and Baker 1983a). This exceeds the thermal tolerance of adult striped bass. Subadult stripers prefer temperatures between 20-24 C (Coutant and Carroll 1980) and can tolerate temperatures as high as 28-30 C (Cox and Coutant 1980). Subadults can thus forage in the warm, productive inflow areas all summer. Although this results in tremendous pressure on the remaining shad population, production is nonetheless sufficient to sustain predation. However, the shad population is maintained at critically low levels because the productive areas comprise such a small percentage of surface area in Lake Mead.

It also appears that the largemouth bass population in Lake Mead has been affected by the decline in the shad population. The importance of shad to largemouth bass was clearly reflected in growth rates of Age 0 and Age I bass before and after shad introductions into Lake Mead (Minckley 1972). Age 0 largemouth bass averaged 136 mm (TL) before shad compared to 240 mm (TL) after shad introductions. Age I bass increased from an average of 261 mm (TL) to 316 (TL) over the same period. There are no data available on survival for comparable periods.

Recent studies show the first-year survival of largemouth bass in Lake Mead is lower than other reservoirs due to high overwinter mortality (Morgensen 1983). The lack of suitable size forage during transition to a fish diet is thought to be the main cause for low survival. Aggus and Elliott (1975) noted that year class strength of largemouth bass in Bull Shoals Reservoir was related to availability of optimum sized prey. They believed that bass which could not shift to a fish diet suffered high mortality during winter. The work of Shelton et al. (1979) and Timmons and Shelton (1980) indicate that growth and survival of largemouth are closely linked to prey availability.

Largemouth bass in Lake Mead begin to utilize fish when they reach 40 mm (TL) and by 60-70 mm (TL) fish are prevalent in their diet (Allan and Roden 1978). They usually reach this size during early summer. The sooner bass switch to a fish diet, the faster they grow which may increase survival (Moyle and Holzhauser 1978). Threadfin shad in lake Mead spawn during late May and early June (Deacon et al. 1972). Young-of-the-year threadfin shad were very abundant during summer in the early 1970's. Shad were heavily utilized by largemouth during the summer and fall (Deacon et al. 1972). Threadfin shad densities are now low in most of Lake Mead during the summer and fall months. Bass are forced to stay on zooplankton or insect diets. Neither of these food sources is abundant enough to sustain good growth and survival of first year bass.

The decline in the shad population has had a major impact on the sport fisheries. This clearly tracks the decrease in productivity that occurred with cutbacks in phosphorus loading. The potential food chain effects were not even considered where strict phosphorus standards (0.5 mg/l) were established for Las Vegas Wash in 1973. There was nationwide concern at that time over eutrophication of lakes and reservoirs. Standards were established hastily on the basis of limited studies in order to comply with federal legislation. The inner Las Vegas Bay was the only area of Lake Mead which was eutrophic. Ironically, chlorophyll-*a* concentrations in the inner Las Vegas Bay have increased and remained high as phosphorus loading decreased. The area was nitrogen deficient and has responded to recent changes in nitrogen loading from Las Vegas Wash. Chlorophyll-*a* concentrations in the middle Las Vegas Bay and Boulder Basin have decreased. There were no serious water quality problems in these areas to start with. The moderate levels of productivity were beneficial in sustaining a food base for the fisheries. It will be necessary to restore the productivity to significantly improve the fisheries in Lake Mead.

Experimental Fertilization

Artificial fertilization is the only way that nutrient levels can be restored in the upper basin of Lake Mead. I propose that fertilization experiments be done in the Overton Arm and Gregg Basin area. These areas are shown as sections 8 and 4, respectively, in Figure 6. The volume and surface areas in each areas proposed for fertilization is summarized in Table 2.

Liquid ammonia phosphate $(NH_4)_2HPO_4$ will be broadcast in the Overton Arm from a diffuser towed behind a boat or barge. Fertilizer will be applied in late spring or early summer when the reservoir begins to thermally stratify. This greatly decreases the amount of fertilizer required because it can be added directly to the epilimnion.

The epilimnion in Lake Mead is about 10 m (30 ft.) deep during early summer. The epilimnion volume at lake elevation 1200 ft. is 798,745 acre-feet ($.985 \times 10^9 m^3$). It will take about 40 t of ammonia phosphate to increase phosphorus concentrations to about 20-25 μg/l (assuming a background of 10 μg/l). That increase in phosphorus would increase productivity into the mesotrophic range.

The Gregg Basin area is much smaller than the Overton Arm. The epilimnion volume at 1200 ft elevation is 310,138 acre-feet (.383 x

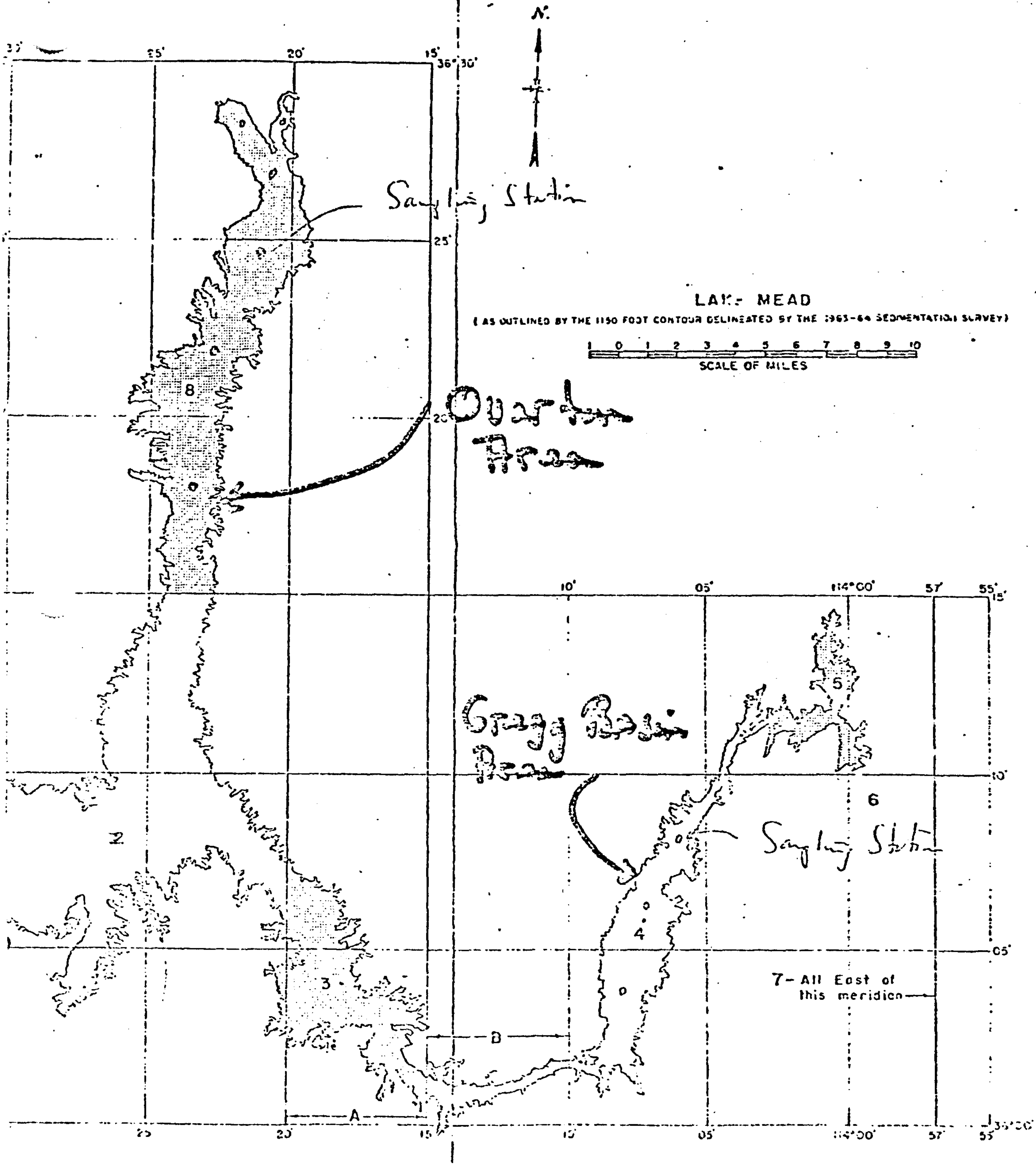

Figure 6. Map of Overton Arm and Gregg Basin areas proposed for fertilization.

Table 2. Volume and surface area of epilimnion (upper 30 ft) at elevation 1200 ft. for Overton Arm and Gregg Basin (From Lara and Saunders 1970).

	Volume		Surface Area	
Location	Acre-feet	M^3	Acres	Hectares
Overton Arm	798,749	$.985 \times 10^9$	29,842	12,076
Gregg Basin	310,138	$.383 \times 10^9$	10,739	4,346

$10^9 m^3$). It will take about 16t of ammonia phosphate to increase phosphorus concentrations to 20-25 µg/l in the area. It may be possible to apply fertilizer in this area by diffusing it into the Colorado River. The river forms an overflow for a brief period during spring (Paulson et al. 1980). Stratification sets in shortly thereafter. If sufficient fertilizer can be added to the river during the overflow, it may be possible to elevate phosphorus concentrations to desired levels. If not, fertilizer will have to be applied by boat or barge.

It is unknown how many fertilizer applications will have to be made to either area to sustain phosphorus concentrations at desired levels. That will have to be determined by monitoring. The study will be conducted over a three year period. In the first year, one or possibly two fertilizer applications will be made. The results from that year will be used to determine application rates in year 2 and year 3 of the study. It is anticipated that two or three applications will be made in the last two years of the study.

Limnological monitoring will be conducted at both sites during the study. An initial survey will be made just prior to the first fertilizer application to establish background conditions. Sampling will be conducted weekly during fertilizer applications and bi-weekly thereafter through the summer. One survey will also be made in fall or winter. Sampling will be conducted at six stations in the Overton Arm and four stations in Gregg Basin (Fig. 6).

Water samples will be collected from a 0-5 m depth integrated samples at each station. The samples will be analyzed for total nitrogen, ammonia, nitrate and nitrite, total phosphorus, orthophosphorus and chlorophyll-a. Phytoplankton productivity (^{14}C

method) will be measured at 0, 1, 3, 5, 7, 10, 15, 20 and 25 m at three stations in the Overton Arm and two stations in Gregg Basin. Zooplankton tows will be taken from 0-40 m at deep stations on 0 - bottom at shallow stations. Relative abundances of fish will be measured at each station with an echosounder. Temperature, oxygen, pH and conductivity will be measured at each station by 1 m intervals in the epilimnion and 5 m intervals in the hypolimnion. Transparency will be measured with an underwater light meter and Secchi disc. All methods are described in Paulson and Baker 1983b.

Additional sampling will be conducted at several coves lateral to the main-lake stations at least twice during the summer. These samples will be analyzed for nutrients and chlorophyll-a . Zooplankton and relative fish abundances will also be measured. Secchi depth and physical measurements will be also done at these stations.

The fish sampling will be done by Nevada Department of Wildlife in the Overton Arm and Arizona Game and Fish Department in Gregg Basin.

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Budget (Approximate)

	Year I	Year II	Year III
Fertilizer (Ammonia phosphate)			
Gregg Basin	$4,800.	$9,600.	$14,400.
Overton Arm	12,240.	24,480.	36,720.
	17,040.	34,080.	51,120.
Application/Limnological Monitoring (Manpower, overhead)	100,000.	125,000.	150,000.
Total	$117,040	$159,080.	$201,120.
		$477,240.	