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Abstract.--Analysis of historical nutrient data for Lake Mead indicates that the fertility of the reservoir has decreased which may be the cause for a corresponding decline in the largemouth bass population. However, it appears that fertility can be manipulated by altering the operation of the dam. The depletion of nutrients in the euphotic zone by phytoplankton and subsequent accumulation in the hypolimnion during summer and fall provide a natural nutrient gradient from which water of varying fertility can be drawn for discharge. This combined with alterations in the depth or seasonal pattern of discharge can possibly be used to enhance fertility and bass production in Lake Mead.

INTRODUCTION

Reservoirs are usually highly productive aquatic systems during initial impoundment since nutrients derived from the basin provide adequate fertility for phytoplankton growth (Neel 1967). However, in deep-discharge reservoirs, nutrients that accumulate in the hypolimnion during thermal stratification are removed via the discharge. This progressive loss of nutrients tends to reduce the fertility of the reservoir and may explain why the productivity of deep reservoirs often decreases with time (Wright, 1967).

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Analysis of historical nutrient data for Lake Mead, Arizona-Nevada indicates that the fertility of this large reservoir has decreased since 1956. Over this same period, the largemouth bass (Micropterus salmoides) population has undergone a significant decline (Espinosa, Deacon and Simmons 1970, Allan and Romero 1975), possibly due to this decrease in fertility. In this paper, we evaluate the relationship between fertility of Lake Mead and the operation of Hoover Dam, and suggest some mechanisms whereby the fertility could possibly be manipulated to enhance productivity in the reservoir.

DESCRIPTION OF LAKE MEAD

Due to limitations imposed on length of papers for this symposium, the reader is referred to Hoffman and Jonez (1973) for a detailed description of Lake Mead. However, pertinent morphometric characteristics of the reservoir are given in Table 1.

Table 1.--Morphometric characteristics of Lake Mead (derived from Lara and Sanders (1970), Hoffman and Jonez (1973))

Parameter	Lake Mead
Maximum operating level (m)	374.0
Maximum depth (m)	180.0
Mean depth (m)	55.0
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Maximum width (km)	28.0
Shoreline development	9.7
Discharge depth (m)	83.0
Annual discharge (1977) ($m^3 \times 10^9$)	9.3
Storage ratio at maximum operating level (years)	3.9

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Nitrate data collected at the Hoover Dam intake towers were obtained from the U.S. Geological Survey "Quality of Surface Waters in the U.S.," Water Supply Papers 1946-1963 and from "Water Resources Data for Arizona" or "Water Resources Data for Nevada," Water Quality Records 1964-1976 prepared jointly by the U.S. Geological Survey and state agencies. Recent nitrate and phosphate data were also obtained from the Lake Mead Monitoring Program.[5]

HISTORICAL CHANGES IN FERTILITY OF LAKE MEAD

The average nitrate concentration in the epilimnion and hypolimnion during thermal stratification (May to October) was computed from monthly measurements made at the Hoover Dam intake towers. Nitrate concentration in the epilimnion ranged from 200 - 350 $\mu g \cdot l^{-1}$ during 1946-1952 but increased to 600 $\mu g \cdot l^{-1}$ in the mid-1950's. (Fig. 1). Nitrate then decreased sharply in 1957 but increased again around 1960. After Lake Powell was formed in 1963, nitrate concentration in the epilimnion increased slightly but decreased again after 1969. The increase in nitrate concentration in the mid-1950's and early 1960's was caused by increased runoff and high nitrate loading from the Colorado River (Paulson and Baker 1979). Nitrate loading also increased during 1965-1969, but this was caused by loss from Lake Powell rather than flooding from the Colorado River (Paulson and Baker 1979). Subsequent to each increase in loading from the Colorado River, the nitrate concentration in Lake Mead had decreased within a few years. We are currently investigating the cause(s) for the decline in nitrate, but available data indicate that it is most related to the hypolimnion discharge at Hoover Dam.

[5]J.E. Deacon unpublished data.

The average nitrate concentration in the hypolimnion during thermal stratification always exceeds that in the epilimnion (Fig. 1).

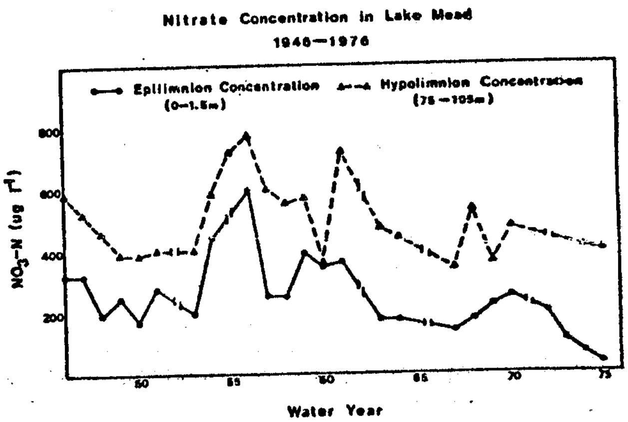

Figure 1.--Average nitrate concentration in the epilimnion and hypolimnion at the Hoover Dam intake towers during thermal stratification (May-October) 1946-1975. (USGS data).

This reflects the degree of nitrate accumulation that occurs either due to hypolimnion loading from the Colorado River or decomposition of morbid phytoplankton cells settling from the epilimnion. Periodic increases in hypolimnetic nitrate concentration (e.g. 1962, 1967) are apparently caused by hypolimnion loading. However, displacement of nitrogen from the epilimnion to the hypolimnion via sinking phytoplankton cells seems to be the principal mechanism of nitrate accumulation in the hypolimnion.

The concentrations of nitrate and phosphate in Boulder Basin of Lake Mead are essentially uniform with depth during the winter (Fig. 2). Epilimnetic nitrate, and to a lesser degree, phosphate, become depleted during the spring and early summer following periods of high phytoplankton productivity. By summer, nitrate has been reduced to less than 20 $\mu g \cdot l^{-1}$ in the euphotic zone with a corresponding accumulation of nitrate in the hypolimnion. Phosphate also accumulates somewhat but not to the degree observed for nitrate. As the lake mixes in the fall, the concentration of nitrate and phosphate becomes uniform and remains so through winter.

The uptake of nutrients by phytoplankton in the euphotic zone and subsequent release and accumulation in the hypolimnion during the summer provide vertical and seasonal nutrient gradients from which water of varying fertility can be drawn for discharge. This combined with alterations in the depth or seasonal pattern of discharge represent potential mechanisms for manipulating the fertility of Lake Mead.

MECHANISMS FOR MANIPULATING FERTILITY

We have developed a simple model to illustrate how moving the discharge depth could influence the nutrient status of a reservoir (Paulson and Baker 1979). If water is discharged from the nutrient-poor epilimnion in the summer, the reservoir will accumulate nutrients, much like occurs in natural lakes. However, if water is discharged from the nutrient-rich hypolimnion, the reservoir will progressively lose nutrients. In a few years, this can have a significant impact on the fertility of the reservoir. The trends predicted by our model have been observed in experiments conducted on Kortowskie Lake, Poland under different discharge regimes (Mientki and Mlynska 1977). Annual nitrogen and phosphorus retention was 28% and -10%, respectively, for hypolimnion discharge but increased to 37% and 57%, respectively, for epilimnion discharge. Similarly, Martin and Arneson's (1978) limnological comparison of a surface-discharge lake and deep-discharge reservoir on the Madison River indicates that discharge depth can influence the nutrient status and productivity of these systems.

Alterations in the seasonal pattern of discharge from hydroelectric facilities can also influence the nutrient status of a reservoir, if seasonal nutrient gradients develop near the depth of discharge. In Lake Mead, nitrate concentration in the hypolimnion reaches a maximum in the late summer and fall. We have compared nitrate output from Hoover Dam from one year of relatively high seasonal discharge against a year of relatively low

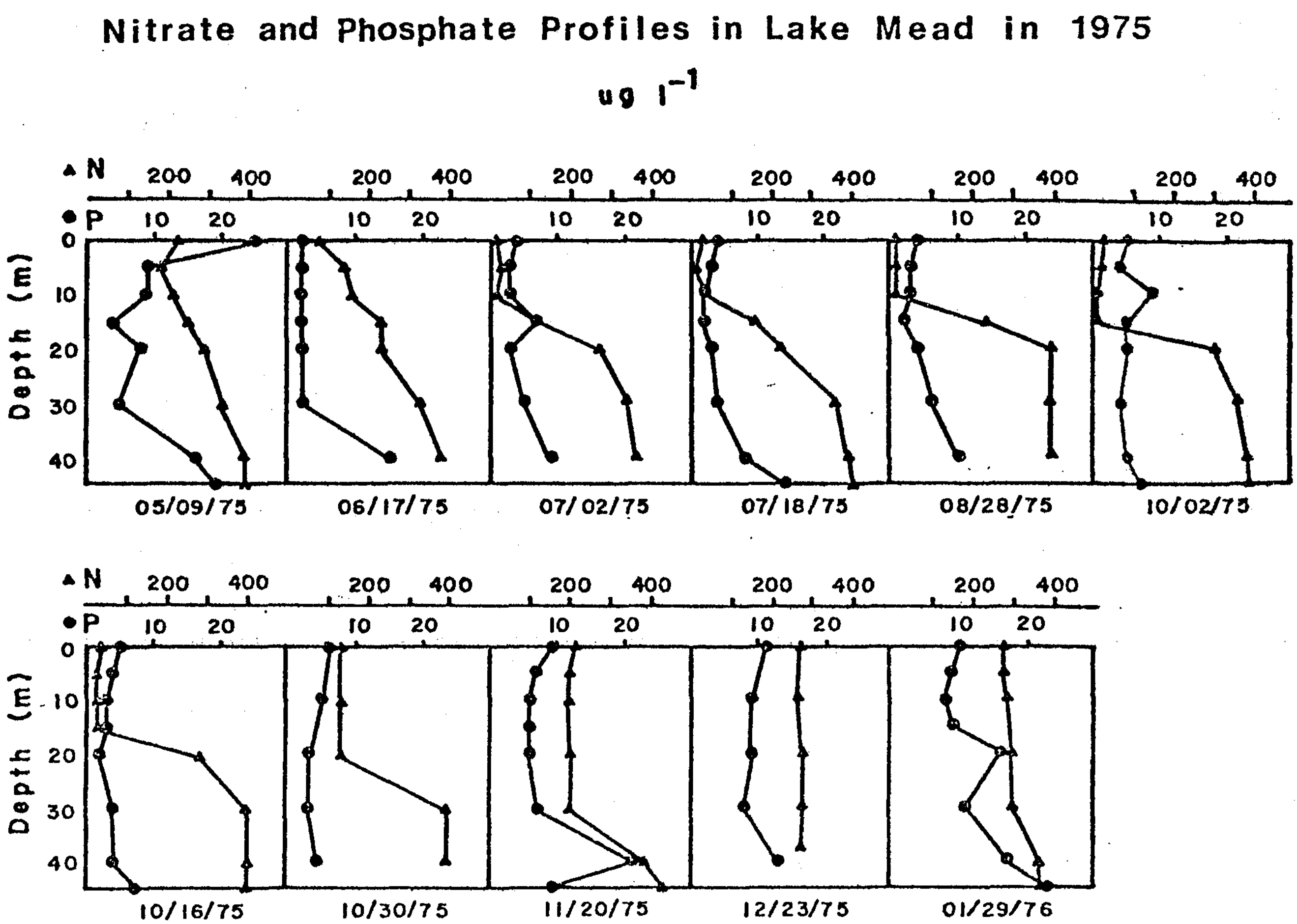

Figure 2.--Nutrient profiles in Boulder Basin, Lake Mead from May, 1975 to January, 1976 (Lake Mead Monitoring Program).

discharge during the late summer and fall (Paulson and Baker 1979). Annual nitrate loss was 15.0% higher during the year when discharge was high. Thus, it appears that the fertility of Lake Mead can be manipulated by altering the discharge regime at hydroelectric facilities. However, there are other factors that must be investigated before this can be used for management purposes.

Alterations in the discharge depth can influence other physical and chemical factors. Reservoirs with epilimnion discharge tend to dissipate heat, whereas those with hypolimnion discharge store heat (Wright 1967, Martin and Arneson 1978). Oxygen concentration in the epilimnion does not vary appreciably with discharge depth, but oxygen in the hypolimnion is typically lower with epilimnion discharge (Stroud and Martin 1973). Altering the discharge depth can also have an immediate impact on limnological conditions of the river and reservoirs downstream. Enrichment of downstream reservoirs is fairly common with hypolimnion discharge (Neel 1967). The upper reaches of Lake Mohave, located immediately downstream from Hoover Dam, are extremely productive due to enrichment from the hypolimnion of Lake Mead. Depending on the prescribed use of the downstream environments, it might not be possible to alter discharge regimes for purposes of nutrient manipulation of a reservoir. However, alterations in the discharge of an upstream reservoir might prove as effective for managing the downstream environment as the reservoir itself. We have identified several such possibilities on the Colorado River system and are planning to further investigate the potential use of discharge for environmental management of this series of reservoirs.

SIGNIFICANCE TO THE LARGEMOUTH BASS FISHING

Angler use on Lake Mead has increased significantly in recent years (Espinosa et al. 1970). However, the total catch of largemouth bass has decreased from about 800,000 in 1963 to the current level of 125,000 (NDFG 1977). The decline in the bass population has been the subject of much local concern and investigation. Arizona and Nevada Fish and Game Departments are currently investigating several possible causes for the decline in the bass fishery, but it appears that it could be related to decreased fertility of the reservoir. Prior to the high nitrate loading in the mid-1950's, Jonez and Sumner (1954) suggested that the bass fishery could be improved by fertilizing Lake Mead. This has never been done directly, although sewage input from Las Vegas has increased phosphorus input to Boulder Basin of Lake Mead. However, the Colorado River provides most (80-90%) of the inorganic nitrogen (NO_3) to Lake Mead, and this has decreased in recent years (Paulson and Baker 1979). Without an additional nitrogen input, the phosphorus cannot be used efficiently by phytoplankton. However, it appears that more nitrogen could be retained in the reservoir by altering the depth or seasonal pattern of discharge. This might prove effective for increasing the productivity of Lake Mead. Since fish yield is closely related to plankton productivity and standing crop (McConnel 1963, Hrbacek 1969, Melack 1976), the largemouth bass population could be expected to increase if more nutrients were retained in the reservoir.

SUMMARY

The physical, chemical and biological processes that operate in reservoirs create vertical and seasonal nutrient gradients from which water of varying fertility can be drawn for discharge. This combined with alterations in the depth or seasonal pattern of discharge at the dam represent potential mechanisms for manipulating the fertility of the reservoir. By increasing the retention of limiting nutrients in the reservoir, the productivity could be expected to increase which, in turn, would sustain higher fish production. Thus, the operation of hydroelectric facilities may prove effective as a fisheries management tool in Lake Mead and other large reservoirs.

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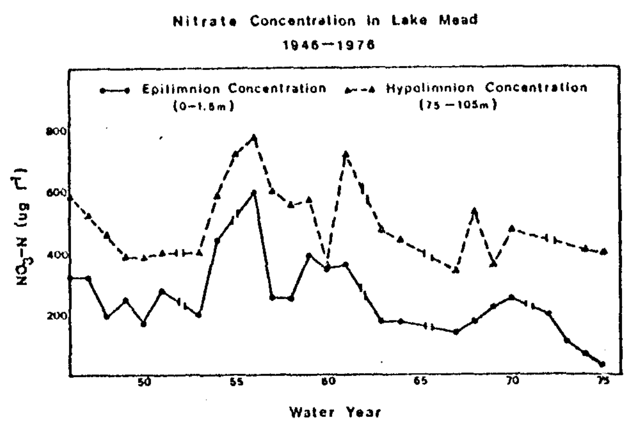

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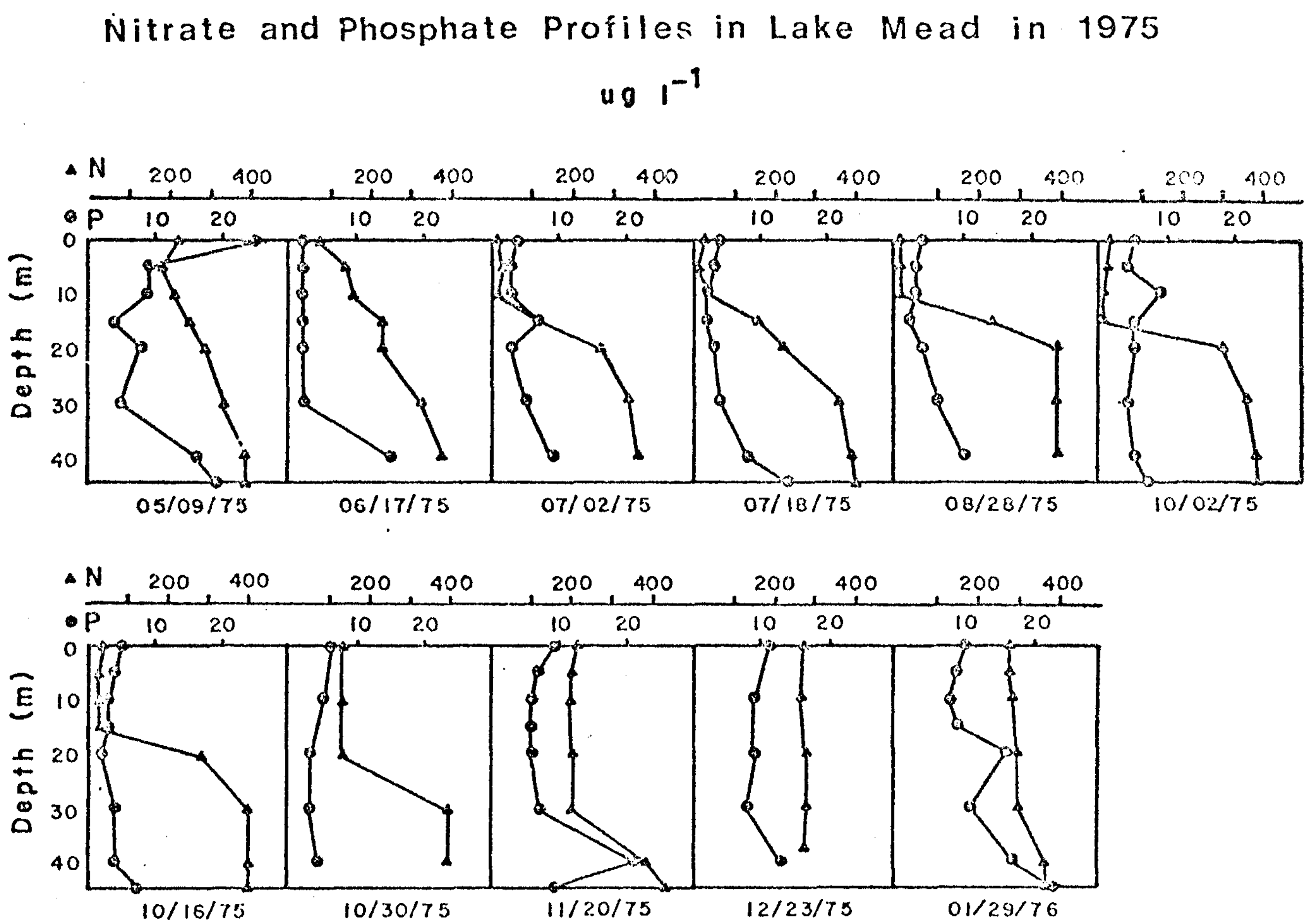

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