UNIVERSITY

[Publications \(WR\)](https://digitalscholarship.unlv.edu/water_pubs) Notifiable Resources and Mater Resources and Mater Resources

1979

Potential use of hydroelectric facilities for manipulating the fertility of Lake Mead

Larry J. Paulson University of Nevada, Las Vegas

John R. Baker University of Nevada, Las Vegas

James E. Deacon University of Nevada, Las Vegas

Follow this and additional works at: [https://digitalscholarship.unlv.edu/water_pubs](https://digitalscholarship.unlv.edu/water_pubs?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages)

Part of the [Aquaculture and Fisheries Commons](https://network.bepress.com/hgg/discipline/78?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages), [Biochemistry Commons,](https://network.bepress.com/hgg/discipline/2?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages) [Biology Commons](https://network.bepress.com/hgg/discipline/41?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages), [Environmental Health and Protection Commons](https://network.bepress.com/hgg/discipline/172?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages), [Environmental Indicators and Impact Assessment](https://network.bepress.com/hgg/discipline/1015?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages) [Commons](https://network.bepress.com/hgg/discipline/1015?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages), [Environmental Monitoring Commons,](https://network.bepress.com/hgg/discipline/931?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages) [Fresh Water Studies Commons](https://network.bepress.com/hgg/discipline/189?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages), [Natural Resources](https://network.bepress.com/hgg/discipline/170?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages) [Management and Policy Commons,](https://network.bepress.com/hgg/discipline/170?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages) and the [Sustainability Commons](https://network.bepress.com/hgg/discipline/1031?utm_source=digitalscholarship.unlv.edu%2Fwater_pubs%2F60&utm_medium=PDF&utm_campaign=PDFCoverPages)

Repository Citation

Paulson, L. J., Baker, J. R., Deacon, J. E. (1979). Potential use of hydroelectric facilities for manipulating the fertility of Lake Mead.

Available at: https://digitalscholarship.unlv.edu/water_pubs/60

This Presentation is protected by copyright and/or related rights. It has been brought to you by Digital Scholarship@UNLV with permission from the rights-holder(s). You are free to use this Presentation in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Presentation has been accepted for inclusion in Publications (WR) by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact [digitalscholarship@unlv.edu.](mailto:digitalscholarship@unlv.edu)

 1070 The Mitigation Symposium: A National Workshop on Mitigating Losses of \overline{L} Wildlife Mitigation Symposium: A National Workshop on Mitigating Losses of Fis Wildlife Habitats. Rocky Mountain Forest and Range Experiment Station General

Potential Use of Hydroelectric Facilities for Manipulating the Fertility of LaCellitie Manipulating the Fertility of Lake Mead¹

John R. BakerJ

John R. Baker³

L. JAMES F. LaBOUNTY

James E. Deacon⁴

Abstract.—Analysis of historical nutrient data for Lake

Mead in the fertility of the reservoir has decreased in the contract of the fertility mead indicates that the fertility of the recently in the largewhich may be the cause for a corresponding deal. which may be the cause for a corresponding decline in the large-
mouth bass population. However, it appears that fertility can be manipulated by altering the operation of the dam. The depletion of nutrients in the euphoric zone by the daw. In subsequent accumulation in the hypolitection during 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 patterns compli can possi

INTRODUCTION

Reservoirs are usually highly productive aquatic systems during initial impoundment since nutrients derived from the basin pro vide adoquate fertility from the basin growth (Neel 1967). He phytoplankt growth (Neel 1967). However, in deep-discharge reservoirs, nutrients that accumulate in the hypolimnion during thermal stratifica-
tion are removed via the discharge. This progressive loss of the discharge. This pr fertility of the nutrients tends to reduce t fertility of the reservoir and may explain why
the productivity of deep reservoirs often decreases with time (Wright, 1967).

Paper presented at Tha Mitigation Sympo sium, Colorado Sympation Colorado Sympation Colorado Sympation Colorado, J.J., 16-20, 1979. Colorado, July 16-20, 1979.
²Director, Lake Mead Limnological Re-

search Center, University Limnological Re-

 $3R_{\text{B}}$ and $4R_{\text{B}}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ 3Research Associate, Department of Bio-
logical Sciences, University of Nevada, Las V_{202} ^{4}C hairman, Department of Biological of Biological of Biological of Biological of Biological order order order order order order order ord

Sciences, University of Nevada, Las Vegas.

Analysis of historical nutrient data for Take Mood Anders with hardfullent data fo fertility of this large reservoir has decreased
since 1956. Over this same period, the large- $\frac{1}{2}$ farrility of the same periodic limit cannot the largemouth has μ and μ and μ and μ are mouth has μ has undergone a significant decline (Espinosa, Deacon and Simmons 1970, Allan and Romero 1975), has undergraphy control Samuolues) population Dossibly due to relative the relationship and Romer In this paper accrease in fertility, hetween formilier of Transace the relationship tion of Hoover Dam, and suggest some mechanisms
whereby the fertility could possibly be manip- $\frac{1}{2}$ fion of Hoorem possible possibl ulated to enhance productivity in the reservoir.

DESCRIPTION OF LAKE MEAD

Due to limitations imposed on length of papers for this symposium, the reader is re f arred to η_{eff} of η_{eff} , the reader is rereserve in the secret of the Mead. However, per-
tinent morphometric characteristics of the tailed dogentatic characteristic characteristics of the theorem reservoir are given in Table 1.

A PARTICIPAL AND A PARTICULAR COMPANY OF CONTRACTOR

STAR SHARES AND STARTED

DATA SOURCES DATA SOURCES

Nitrate data collected at the Hoover Dam

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 The average nitrate concentration i 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 $\mu g \cdot 1^{-1}$. 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 con-"entration in the mid-1950's and early 1960's Wis caused by increased runoff and high titrate 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 Heading from the Colorado River (Paulson and Waker 1979). Subsequent to each increase in

⁵J.E. Deacon unpublished data.

loading from the Colorado River, the nitrate concentration in Lake Mead had decreased vithin 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 Dan.

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

Nitrate Concentration in Lake Mead 1946-1976

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 hypolimnice 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 hypolimnioa loading. However, displacement of nitrogen from the epilimnion to the hypolimnion via sinking phytoplankton cells seems to be the principal mechanism of nitrate accumulation principal meet

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 $20 \mu g \cdot 1^{-1}$ 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 in fluence the nutrient status of a reservoir (Paulson and Baker 1979). If water is dis charged 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 pre dicted by our model have been observed in experiments conducted on Kortowskia 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 rutrient status and productivity of these systems.

Alterations in the seasonal pattern of discharge from hydroelectric facilities can also influence the nutrient status of a reser voir, if seasonal nutrient gradients develop near the depth of discharge. In Lake Mead, nitrate concentration in the hypolimion 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

Nitrate and Phosphate Profiles in Lake Mead **in** 1975

 \mathbf{u} **g** \mathbf{I}^{-1}

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

Hischarge during the late summer and fall (Paulson and Baker 1979). Annual nitrate loss was 15.0% higher during the year when discharged was high. Thus, it appears that the fertil 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 manage-

n the discharg e dept

h can

Alterations i

TA KANADARA BUTAN TARA KANADA

Alterations in the discharge depth can influence other physical and chemical ractor Reservoirs with epilimnion discharge tend to dissipate heat, whereas those with hypolimni discharge store heat (Wright 1967, Martin Arneson 1978). Oxygen concentration in the epilimnion does not vary appreciably with discharge depth, but oxygen in the hypolimn 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 limpion discharge (Neel 1967). The upper reaches of Lake Mohave, located immediate downstream from Hoover Dam, are extremely nroductive due to enrichment from the hypoitration of Lake Mead. Depending on the pi scribed use of the downstream environments, it might not be possible to alter discharge regimes for purposes of nutrient manipulat: of a reservoir. However, alterations in the discharge of an upstream reservoir might 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 charge for environmental management of this series of reservoirs.

Angler use on Lake Mead has increased significantly in recent years (Espinosa et a 1970), However, the total catch of largeme bass has decreased from about 800,000 in 1963 to the current level of 125,000 (NDFG 197 The decline in the bass population has been the subject of much local concern and i gation, Arizona and Nevada Fish and Game Departments are currently investigating sever al possible causes for the decline in fishery, but it appears that it could be related to decreased fertility of the rese Prier to the high nitrate loading in the mi 1950 's, Jonez and Sumner (1954) suggested th line hass fishery could be improved by ing Lake Mead. This has never been done directly, although sewage input from L has increased phosphorus input to Boulder
Basin of Lake Mead. However, the Colorado

River provides most (80-90%) of the inorganic niver provides most (or yon) to the most nicrogen (noz) to have nearly the these compara-1979). Without an additional nitroge n input, t_{total} , whence annot be used efficiently by phytoplankton. However, it appears that more phytopiauston. Nowthere we have reservoil puttogen court be received on the pattern of by altering the depth of stations (prove for gischarge. This might prove the wead. Increasing the groundering.... proce fibir yield to crossely from McConnel 1963 Hrbace k 1969, Melac k 1976), the largemout h nivates 1909; include 2000/9 2000 pass population could be experienced. It more untrreated were received and

:| i{' '(•

if

SUMMARY

The physical, chemical and biological processes the processes that conceate in receptoirs creat vertical and seasonal nutrient gradients from yercrear and seasonds necessary of the draw fo mich water of varying continues, in the department of discharge in the contrary In the depth of seasonds present at the dam represent potential means manipurating the returns of limiting by increasing the recenter of the productivit nutrients in the reservoir, and the state of the state which, in turn could be expected to merical would sustain insuration process. prove effective as a fisheries management tool prove effective as a frontier man of

LITERATURE CITE D

- Allan, R.C. and J. Romero. 1975. Underwater allan, a.v. and v. homorever where spawni and survival distribution of the Mead. p. 104-112. $\frac{R}{L}$ Bass Biology and Management. National pass biology and management. plands change the Centrarchid Basses. Sport Fishing The Central City Dassoo.
- $E = \frac{1}{2}$ πA , πB Descons and A. Simmons. L spinosa, $F(n)$, o.g. D choticalistic 1970, An economic due presente analysis of the part age. Entry of Nev. Spec. Public St
- μ Bohan, D.A. and A.R. Jonez. 1973. La Mea Mead a case history. p. 220-233. In: $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ B. Worthw.C. ACKELBARD, OUT mess and The ington (eds.) Man-made lakes: Their
problems and environmental effects. Geopropress and environmental series 84
- metal in the some problems between some $HTPACEK$, $J. IJOJ. REEQZOPE = 100$ environmental parameters and the model $Y = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$ $v_{\rm e}$
- Jonez, A.R. and R.C. Sumner. 1954. Lake Mead and Lake Mohave investigations. Nev. Fish and Game Comm. Final Rept., D-J Project F-1-R. $186p.$
- Lara, J.M. and J.I. Sanders. 1970. The 1963-64 Lake Mead Survey. U.S. Bur. Rec. Rept. No. REC-OCE-70-21. 172p.
- Martin, D.B. and R.D. Arneson. 1978. Comparative limnology of a deep-discharge reservoir and surface-discharge lake on \mathbf{B} \mathbf{B} \mathbf{B} \mathbf{B} \mathbf{B} \mathbf{B} \mathbf{B} M_{\odot} 1963. Primary productivity pro
- Biol. 8:32-42.
McConnel, W.J. 1963. Primary productivity and fish harvest in a small desert impoundment. Trans. Amer. Fish. Soc. 92:1-12.
- Melack, J.W. 1976. Primary productivity and fish yields in tropical lakes. Trans. Amer. Fish. Soc. 105:575-580.
- Mientki, C. and I. Mlynska. 1977. Balance of nutrients in Kortowskie Lake waters during the experiments on its restoration. Pol. Arch. Hydrobiol. 24:49-59.
- Nevada Department of Fish and Game. 1977. Lake Mead Job Progress Report for 1977. State of Nevada Project No. F-20-14.

Neel, J.K. 1967. Reservoir eutrophication and discrement in the dynamic impoundment. and dystrophication formals Fisherie p. 322-332. In: Reservoir Fisheries Resources Symposium. Am. Fish. Soc.,
Wash. D.C. 569p.

 1.11

- Paulson, L.J. and J.R. Baker. 1979. Possible causes for long-term changes in the nitrate budget and concentration in Lake Mead, Arizona-Nevada. Am. Soc. Lake nead, At Long Network Ten. $L1$ mnol. U Ceanogr., T_{cav} 2.5 , 1979 (Abstr.) Christi, Texas. Jan. 2-5, 1979 (Abstr.)
Stroud, R.H. and R.G. Martin. 1973.
- Influence of reservoir discharge location Influence of reservoir exercise on the water quality; where of restors. fisheries of reservoirs and tailwaters.
p. 540-548. In: W.C. Ackermann, G.F. White and E.B. Worthington (eds.) Man- Made Lakes, Their Problems and Environ- Made Lakes, incl. From the Monography mental Effects. Se
- $V = \frac{1}{2}$ and $\frac{1}{2}$ in $\frac{1}{2}$ if $\frac{1}{2}$ is $\frac{1}{2}$ if $\frac{1}{2}$ if $\frac{1}{2}$ is $\frac{1}{2}$ if $\frac{1}{2}$ \arg{nt} , $\lim_{n \to \infty}$ $\lim_{n \to \infty}$ and heat on productivity, water chemistry and heat
budgets of rivers. p. 188-199. In: Reservoir Fisheries Resources Symposium. Am. Fish. Soc., Wash. D.C. 569p.

5408

JAMES F. LaBOUNTY

Potential Use of Hydroelectric Facilities for Manipulating the Fertility of Lake Mead¹

 γ

John R. Baker³

James E. Deacon⁴

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 large mouth bass population. However, it appears that fertility can be manipulated by altering the operation of the dam. The de pletion 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 pro vide adequate fertility for phytoplankton growth (Keel 1967). However, in deep-dis charge reservoirs, nutrients that accumulate in the hypolimnion during thermal stratifica tion are removed via the discharge. This pro gressive loss of nutrients tends to reduce the fertility of the reservoir and may explain why the productivity of deep reservoirs often de creases with time (Wright, 1967).

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 large mouth bass (Micropterus salmoidcs) 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 opera tion of Hoover Dam, and suggest some mechanisms whereby the fertility could possibly be manip ulated to enhance productivity in the reservoir.

DESCRIPTION OF LAKE MEAD

Due to limitations imposed on length of papers for this symposium, the reader is re ferred to Hoffman and Jonez (1973) for a de tailed description of Lake Mead. However, per tinent morphometric characteristics of the reservoir are given in Table 1.

¹Paper presented at The Mitigation Symposium, Colorado State University, Fort Collins, Colorado, July 16-20, 1979.

[^]Director, Lake Mend Limnological Re search Center, University of Nevada, Las Vegas.

³Research Associate, Department of Biological Sciences, University of Nevada, Las Vegas.

^{&#}x27;Chairman, Department of Biological Sciences, University of Nevada, Las Vegas.

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

DATA SOURCES

Nitrate data collected at the Hoover Dam intake towers were obtained from the U.S. Geo logical 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 Qual ify 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 Pro gram. 5

HTSTOR1CAL 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 Dan intake towers. Nitrate concentration in the epilimnion ranged from $200 - 350 \text{ µg} \cdot 1^{-1}$ during 1946-1952 but increased to 600 μ g.1⁻¹ in the mid-1950's. (Fig. 1). Nitrate then decreased sharply in 1957 but increased again ..r>>i;: ; ! '060. After Lake Powell was formed in 1963, nitrate concentration in the epilimnion increased slightly but decreased again after 1969. The increase in nitrate con centration in the mld-1950's and early 1960's was caused by increased runoff and high \mathbf{r} : \mathbf{r} at \mathbf{r} leading 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

 $M.E.$ Deacon unpublished data.

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,

jlU:

كالألف والمتأر فأشهو ليواددنا الموالح الحالا والأقطاط الحالجة والمساحات

The average nitrate concentration in the hypolJmnion during thermal stratification al ways 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 accumula tion that occurs either due to hypolimnion loading from the Colorado River or decomposi tion 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 μ g·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 \cdot 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 in fluence the nutrient status of a reservoir (Paulson and Bal;er 1979). If water is dis charged 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

また、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、このことは、こ

fertility of the reservoir. The trends pre dicted 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 epiliranion 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 reser voir, 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

Nitrate and Phosphate Profiles in Lake Mead in 1975

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 manage ment purposes.

Alterations in the discharge depth can influence olher physical and chemical factors. Reservoirs with epilimnion discharge tend to dissipate heat, whereas those with hypolimnion Jischarge store heat (Wright 1967, Martin and Arneson 1978) . Oxygen concentration in the epilimaion does not vary appreciably with discharze depth, but oxygen in the hypolinnion is typically lower with epilimnion discharge (Stroud and Martin 1973). Altering the dis charge depth can also have an immediate Impact on limnological conditions of the river and reservoirs downstream. Enrichment of down stream 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 hypo limnion 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 i'f 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 dis charge 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 hass 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 "'e subject of much local concern and investi- \cdots \cdots . Arizona and Nevada Fish and Game • '• ••partraents are currently investigating sever- ⁴¹ possible causes for the decline in the bass fishery, but it appears that it could be related to decreased fertility of the reservoir. firier to the high nitrate loading in the mid- $\mathbb{P}^{1} \cup \mathbb{P}^{1}$ s, Jonez and Sumner (1954) suggested that the bass fishery could be improved by fertiliz- $\lim_{n \to \infty} L$ ake Mead. This has never been done lirectly, although sewage input from Las Vegas has increased phosphorus input to Boulder bisin of Lake Mead. However, the Colorado

'••"*""»•»".."

River provides most (80-90%) of the Inorganic nitrogen ($NO₃$) 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 wore nutrients were retained in the reser voir .

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.

LITERATURE CITED

- Allan, R.C. and J. Ronero. 1975. Underwater observations of largemouth bass spawning and survival in Lake Mead. p. 104-112. In: R.H. Stroud and H. Clepper (eds.), Black Bass Biology and Management. National Symposium on the Biology and Management of the Centrarchid Basses. Sport Fishing Institute. Wash D.C. 534p.
- Espjnosa, F.A., J.E. Deacon and A. Simmons. 1970. An economic and biostatistical analysis of the bait fish industry in the lower Colorado River. Univ. of Nev. Spec. Pub. 87p.
- Hoffman, D.A. and A.R. Jonez. 1973. Lake Mead a case history, p. 220-233. In: VI.C. Ackermann, G.F. White and E.B. Worth- Ington (eds.) Man-made lakes: Their problems and environmental effects. Geophysical Monograph Series No. 17. 847p.
- Hrbacek, J. 1969. Relations between some environmental parameters and the fish yield as a basis for a predictive model. Verh. Intcrnat. Verein. Limnol. 17:1069- 1081.
- Jonez, A.R. and R.C. Sumner. 1954. Lake Mead and Lake Mohavc Investigations. Nev. Fish and Game Comm. Final Rept., D-J Project F-l-R. 186p.
- Lara, J.M. and J.I. Sanders. 1970. The 1963-64 Lake Mead Survey. U.S. Bur. Rec. Rcpt. No. REC--OCE-70-21. 172p.
- Martin, D.B. and R.D. Arneson. 1978. Comparative limnology of a deep-discharge reservoir and surface-discharge lake on the Madison River, Montana. Freshwater Biol. 8:32-42.
- McConnel, W.J. 1963. Primary productivity and fish harvest in a small desert impoundment. Trans. Amer. Fish. Soc. 92:1-12.
- Melack, J.W. 1976. Primary productivity and fish yields in tropical lakes. Trans.
- Amer. Fish. Soc. 105:575-580.
- Mientki, C. and I. Mlynska. 1977. Balance of nutrients in Kortowskie Lake waters during the experiments on its restoration. Pol. Arch. Hydrobiol. 24:49-59.
- Nevada Department of Fish and Game. 1977. Lake Mead Job Progress Report for 1977. State of Nevada Project No. F-20-14.
- Neel, J.K. 1967. Reservoir eutrophication and dystrophication following impoundment. p. 322-332. In; Reservoir Fisheries Resources Symposium. Am. Fish. Soc., Wash. D.C. 569p.
- Paulson, L.J. and J.R. Baker. 1979. Possible causes for long-term changes in the nitrate budget and concentration in Lake Mead, Arizona-Mevada. An. Soc. Limnol. Oceanogr., Winter Meeting, Corpus Christi, Texas. Jan. 2-5, 1979 (Abstr.)
- Stroud, R.ll. and R.G. Martin. 1973. Influence of reservoir discharge location on the water quality, biology and sports fisheries of reservoirs and tailwaters. p. 540-548. In: W.C. Ackermann, G.F. White and E.B. Worthington (eds.) Man-Made Lakes, Their Problems and Environ mental Effects. Geophysical Monograph Series No. 17. 847p.
- Wright, J.C. 1967. Effect of impoundments on productivity, water chemistry and heat budgets of rivers, p. 188-199. In: Reservoir Fisheries Resources Symposium. Am. Fish. Soc., Wash. D.C. 569p.

300