CENTRAL PACIFIC RIVER BASINS PROJECT

LIMNOLOGICAL ASPECTS OF CLEAR LAKE, CALIFORNIA, WITH SPECIAL REFERENCE TO THE PROPOSED DIVERSION OF EEL RIVER WATER THROUGH THE LAKE.

BY
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U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Southwest Region

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REPORT TO

U. S. DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

SOUTHWEST REGION

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April, 1968

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INSTITUTE OF ECOLOGY • DAVIS, CALIFORNIA 95616

April 23, 1968

Mr. Richard C. Bain
Central Pacific River Basins Comprehensive Water
Pollution Control Project
Bldg. 2G
620 Central Ave.
Alameda, California 94501

Dear Dick:

Attached is the report on limnological aspects of Clear Lake, Lake County, California, with special emphasis on possible diversion of Eel River.

The work continues here on the problem and I hope to begin a more extensive research program on nutrient regeneration, from the sediments in the near future. In this area we badly need more information and my report could be a good deal more authoritative if we had it. I have appended a research proposal for this work which will be submitted to a funding agency in the very near future.

I have reviewed three drafts of your report and am in substantial agreement with their conclusions and recommendation. I would like to stress the importance of a total watershed approach to the problem and some concern as to the water quality of the Clear Lake out flow. If I can be of further assistance please feel free to contact me.

Sincerely,

Charles R. Goldman

Charles R. Goldman, director

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encl. 25pp

CONTENTS

INTRODUCTION

The natural process of lake eutrophication has been discussed in the limnological literature for many years. Since the turn of the century there has been increased interest in cultural influences which are, with paleolimnological techniques, traceable back to Roman antiquity (Cowgill and Hutchinson 1964). The speed with which a lake can pass from oligotrophic through mesotrophic to a eutrophic state was well documented by the transition of Lake Erie in North America and Lake Zurich in Switzerland in a half century of domestic pollution. Attention to domestic pollution was first directed to obvious public health problems such as typhoid epidimics. Gradually, with the advent of better sewage treatment plants there developed a concern for the destruction of aesthetic qualities of lakes and streams. Although good secondary sewage treatment could produce an effluent of near drinking water quality the content of such important nutrients for plant growth as nitrogen and phosphorus accelerate the growth of algae in waters receiving plant discharge.

The problem of lake eutrophication has been extensively discussed and debated for years. It often has been reduced to a consideration of the importance of nitrogen and phosphorus in accelerating the eutrophication of the lakes. Sawyer's recent analysis of eutrophication is very useful but must by necessity be considered an oversimplification which is almost impossible to avoid in any general discussion of lakes. Both phosphorus and nitrogen metabolism by algae are influenced by a host of environmental and nutrient factors. In a lake receiving treated sewage severe trace element limitations are not likely, but a careful analysis may prove useful. Clear Lake is an extremely productive lake in a rather advanced state of eutrophication (Goldman and Wetzel 1963). The question of the relative importance of nitrogen and phosphorus in the lake at this point in its history are rather academic since there is obviously enough to sustain a nearly continuous bloom. In contrast, Lake Tahoe, which has received increasing attention during the last five years, shows severe nitrogen deficiency and added phosphorus is ineffective without additional nitrogen (Goldman and Carter 1965). The proposed diversion of Eel River water through Clear Lake would not greatly alter the ratio of nitrogen and phosphorus but would dilute both. Let us therefore first consider a widely accepted generality. Most algae require about twenty times as much nitrogen as they do phosphorus and are able to extract it from the media against a tremendous gradient. Further, they are able to store it against "hard times". The overall importance of the nitrogen fixing ability of some of the bluegreen algae in compensating for a deficiency of fixed nitrogen has really never been determined. We know that where phosphorus levels are high the nitrogen fixers have an easier time, but in a lake like Crater Lake, Oregon, where there is both high P and low nitrogen bloom conditions have not resulted despite the presence of nitrogen fixing bluegreen algae (Hutchinson 1957, p. 847). In Brooks Lake, Alaska, where phosphorus levels were very low, bioassays showed nitrogen to be by far the most limiting nutrient. Only in late summer did response to phosphorus develop when the environmental levels had dropped well below the limit of our detection at the .001 ppm level (Goldman, 1960).

Unlike many lakes which show a spring and fall bloom of algae, Clear Lake undergoes what even the casual observer must admit is a sustained phytoplankton bloom. Obviously phosphorus and nitrogen levels, as well as the spectrum of trace elements, remain high enough to support this condition. Any diversion of lower nutrient water through the Clear Lake basin will reduce these levels, but it is more likely that the reduction in nitrogen will be most significant in lowering the rate of algal production in the lake. Our own nitrate nitrogen analysis of Clear Lake and Eel River water with the sensitive and reliable cadmium reduction method indicate that Eel River water contained only one fourth as much nitrate as Clear Lake (See Section III). Bioassays of the natural Clear Lake phytoplankton population in September have shown higher growth response with nitrogen addition than was achieved with phosphorus addition. In July the best growth was obtained with sulfate and nitrate in combination (Goldman and Wetzel 1963).

Although Clear Lake is extremely turbid, its productivity can scarcely be considered seriously light limited. Similar lakes in African Rift Valley that have been studied by the author are even more turbid and productive than Clear Lake, California. They are also characterized by the lack of anything more than temporary stratification and have sufficient wind mixing to keep re-exposing the phytoplankton population to the narrow euphotic zone. In a later section likely benefits to be derived from upsetting this regime are discussed.

The current eutrophication problem in Clear Lake can be summarized as a high rate of nutrient supply and regeneration in relation to nutrients lost from the ecosystem by harvest of plants and animals as well as those lost through sedimentation and outflow. Altering this nutrient budget can be achieved in various ways. Diversion of lower nutrient Eel River water into Clear Lake is one useful approach, but to really solve the problem of the lake's accelerated eutrophication will require in addition, a concerted effort to reduce the nutrient inflow from all sources on the Clear Lake watershed.

<u>Some Laboratory Experiments on the Dilution of Clear Lake Cultures with Eel River Water</u>

Bioassay experiments utilizing 14 Carbon as sodium carbonate to measure growth were conducted during the fall of 1967. In these experiments fresh Clear Lake water was collected offshore at Lakeport and diluted with Eel River water collected at the same time. The general bioassay proceedure was that reported by Goldman, 1963, where the entire culture was labeled with 14 Carbon and subsamples of the algae were collected on Millipore[R] filters. There have been a number of sophisticated experiments to demonstrate the equivalence of 14 C uptake and increase in particulate organic carbon (Antia <u>et al</u>. 1963, Ryther and Menzel 1965). Because pigments may vary diurnally and cells may divide by simply splitting their organic material the 14 Carbon method of measuring growth has much to recommend it.

In the first experiment (Figure 1) additions of Eel River water covered the low range of .001% to 1% dilution of Clear Lake cultures. In all cases there was slight stimulation to carbon assimilation until 60 hours when the growth rate fell off below the 0.11% dilution level. Possible implications of the slight (probably well below the level of detection of any method except 14 Carbon uptake) stimulation is discussed in Section III in relation to copper toxicity.

The second culture experiment extended the dilution to 50%. The results for a short term experiment (Figure 2) are in general agreement with the first experiment and show the overall decrease in growth to be expected with a 50% dilution. These short term growth experiments support the results of batch experiments at the FWPCA laboratory in Alameda. The lower nutrient content of Eel River water reduces the algal growth potential of Clear Lake water.

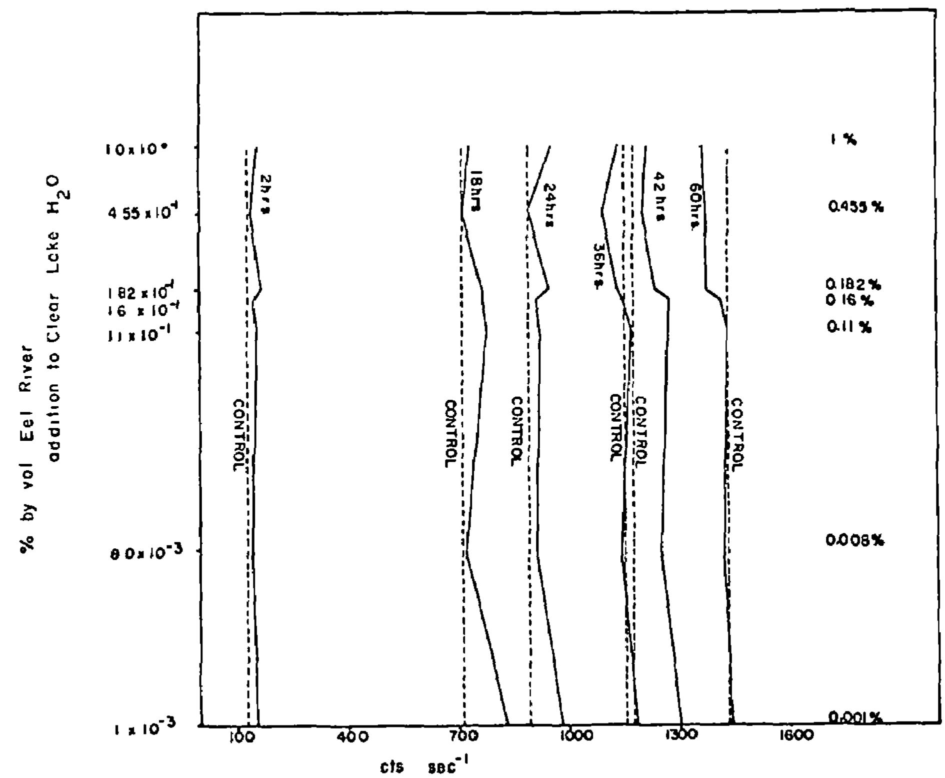

Figure 1. Cultures of Clear Lake water with various percentage by volume dilutions with Eel River water.

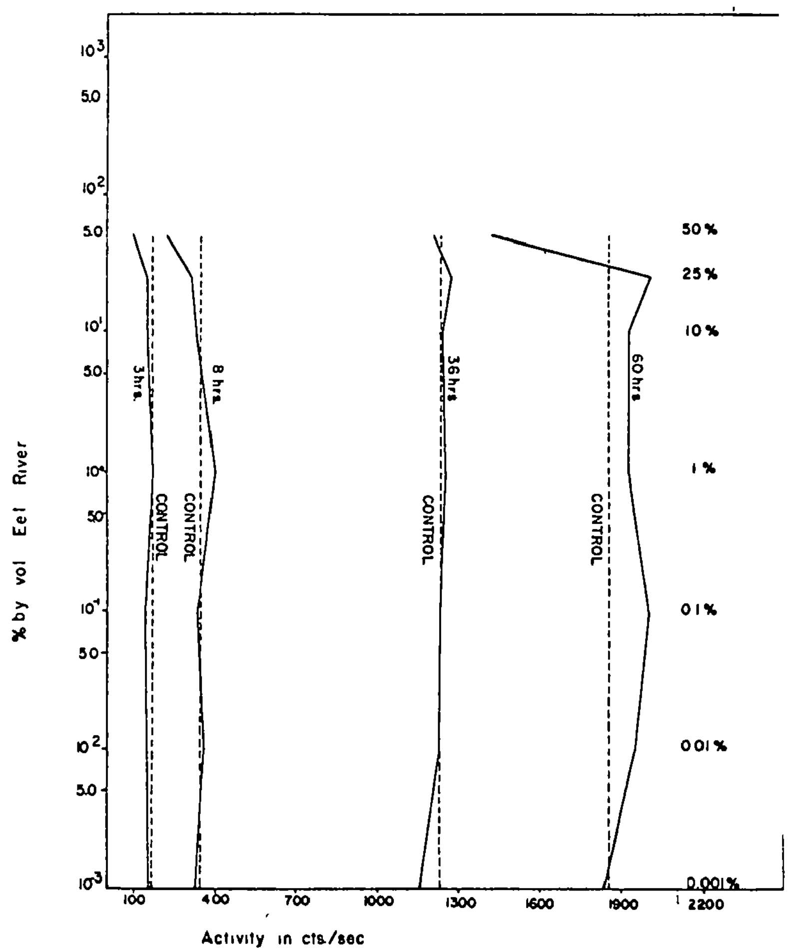

Figure 2. Cultures of Clear Lake water with various percentage by volume dilutions with Eel River water.

Some Aspects of the Water Chemistry of Clear Lake in Comparison with the Eel River with Special Reference to Copper

On 6 October a comparative analysis of Clear Lake and Eel River water was made at the limnological laboratory in the Institute of Ecology (Table 1). Clear Lake was found to have significantly higher levels of all elements measured except iron and calcium. There are four times as much nitrate nitrogen in the Clear Lake water and over twelve times as much copper. It is probable that mining activities and the extensive use of copper as a dormant spray in the orchards surrounding the lake are responsible for the high environmental levels. The extremely high copper level in the sample was surprising and a laboratory culture experiment utilizing the natural Clear Lake phytoplankton population was established on 2 Nov. 1967. The object of the experiment was to determine how close the copper is to inhibiting levels in Clear Lake at the present time (Figure 3).

Copper was added at 1.25, 1.50 and 1.75 times the natural Ca level. All additions were inhibiting to photosynthesis of the natural phytoplankton population over a sixty hour period with 110 parts per billion essentially stopping growth. In one culture container a copper specific chelator was added which, after initially depressing photosynthesis slightly, increased photosynthesis slightly over the control after thirty-six hours. It is obvious that algal control with copper sulfate might be less expensive in areas of Clear Lake than in other environments and that addition of Eel River water will be expected to lower the copper levels. This experiment is more suggestive of additional work on the algal growth in the lake than conclusive of present copper toxicity. There may be considerable variation in the copper levels at various points in the lake. It may well be related to the Clear Lake

10/6/67 COMPARATIVE ANALYSIS OF CLEAR LAKE AND EEL RIVER COLLECTED ON 6 OCTOBER 1967

ELEMENT	CLEAR LAKE	EEL RIVER	METHOD
Mn	27 ppb	20 ppb	Atomic Absorption
Fe	360 ppb	270 ppb	Atomic Absorption
Ca	21.4 ppm	22.0 ppm	Atomic Absorption
Mg	13.8 ppm	6.4 ppm	Atomic Absorption
NO_3-N	20.8 ppb	4.9 ppb	Cadmium Reduction
Na	65 ppm	40 ppm	Flame Emission
Cu	62.9 ppb	5 ppb	Atomic Absorption
Mo	0.76 ppb	0.52 ppb	Dithiol
Ca/Mg	1.55	3.44	
Particulate Matter	4	1	Relative Volume to Obstruct HA Filter

Table 1. A comparison of the water chemistry of Clear Lake and the Eel River on 6 October 1967. Analyses were performed in the limnology laboratory of the Institute of Ecology.

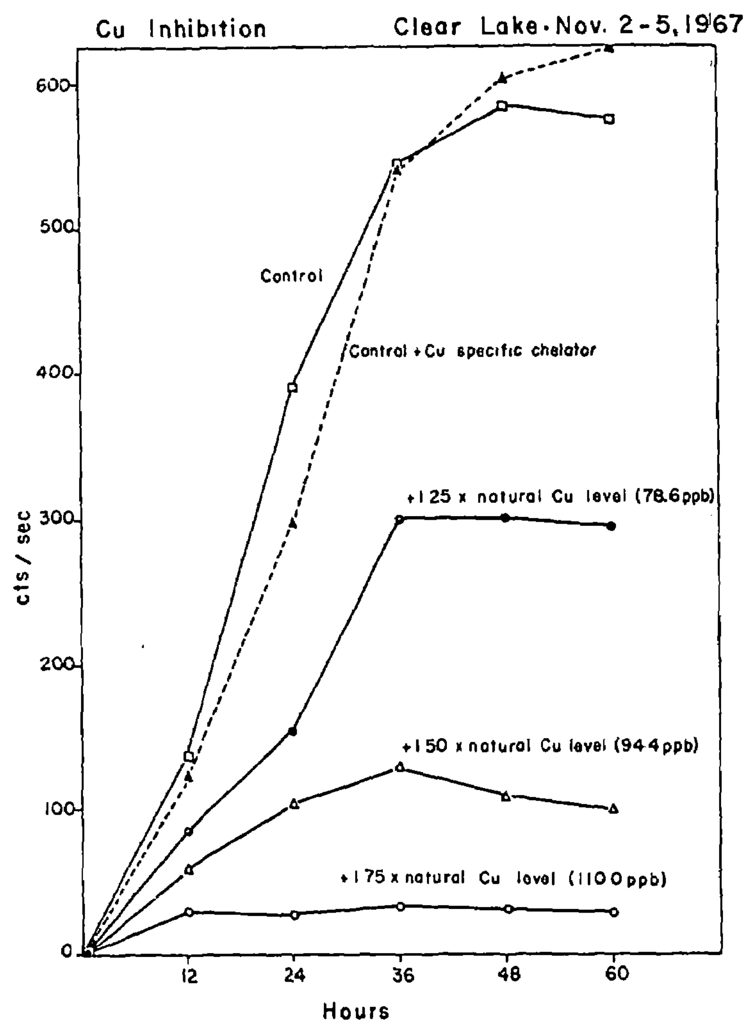

Figure 3. Inhibition of photosynthesis with copper additions to Clear Lake phytoplankton.

dilution experiments discussed in the previous section (II) in explaining the initial stimulation to photosynthesis below the 50% dilution level. Additional work is needed over a long period of time to resolve this interesting consideration, eventually including large *in situ* test vessels of the type described by Goldman, 1962, and Goldman and Carter, 1965.

Nutrient Regeneration from the Clear Lake Sediment and a Recommendation for Altering the Regime

In evaluating the question of whether or not diversion of Eel River water through Clear Lake would improve the water quality of Clear Lake, one of the most important and least documented areas of consideration is nutrient regeneration from the lake sediments. Clear Lake neither freezes in the winter nor stratifies permanently in the summer. In this respect it is very similar to some of the shallow, highly productive lakes of the Rift Valleys in East Africa. Although light penetration is severely limited by turbidity the whole system is mixed by the wind so that individual organisms are constantly returned to the light zone. Actual measured rates of primary productivity in bottles give values which are lower than the actual rates since the bottles are not rotated through the light zone in the manner that wind constantly returns algae to the illuminated surface (Goldman and Wetzel 1963). The lake actually functions like a giant stabilization (oxidation) pond with only brief periods of oxygen depletion near the bottom on windless days.

It is clear that in this wind mixed system the biggest obtacle to reaching a precise prediction about the effect of Eel River diversion on Clear Lake is the lack of quantitative information about the present and potential contribution of nutrients from the sediments. Clear Lake, as a biological system, is more than an isolated body of water. At the very least it must be viewed as a water-sediment system. Implicit in this view is the notion that nutrient concentrations in the water and in the sediments are in equilibrium. Flushing of the Lake with low nutrient water would upset such an equilibrium condition and increase the rate of regeneration of nutrients from the sediments. If low nutrient water were introduced at a rate that was low relative to the rate at which nutrients were released from the sediment the rate of decrease in lake waters nutrient concentrations would also be low. Intuition and experience with other lakes suggest that the proposed rate of delivery of English Ridge project water alone without control of nutrient inflows may be small when compared with the possible capacity of Clear Lake sediment to release nutrients.

As noted above, a relevant characteristic of Clear Lake is that the water within it circulates continuously. Constant circulation increases sediment-water contact by agitating the sediment surface; it brings heat from above to the sediment surface increasing the rate and extent of mineralization of dead algae; it carries dissolved nutrients from the sediment surface into the photic zone where they may be utilized for algal growth. Unremitting circulation also increases the turbidity of the water.

Constant circulation is not characteristic of all lakes. Many lakes which are deeper or less exposed to strong winds become thermally stratified during the warmer months. One result of thermal stratification is a lens of cold stagnant water in contact with the sediments. This lower layer or hypolimnion isolates the sediments from the upper lighted water where algal growth occurs. As long as stratification persists the hypolimnion serves as an effective nutrient trap. Once an algal cell sinks into the hypolimnion the material of which it is composed is effectively removed from the productive part of the lake as long as stratification persists. If Clear Lake were deep enough to stratify and based on studies made on Lake Berryessa (Goldman, unpublished) Clear Lake would be expected to stratify from late May to mid-September or throughout the period when algal growth is most intense and recreation use is highest. Thus a hypolimnion in Clear Lake would be expected to have a beneficial effect on the quality of the surface water during the summer. It would act as a sink into which nutrients would drain throughout the growing season with a concomitant increase in water clarity.

During the winter months stratification would disappear and all of the lakes dissolved nutrients would again be uniformly distributed throughout the water mass. However, natural light intensities are low during the winter and there is much less algal growth potential regardless of the nutrient concentration. In short, stratifying Clear Lake would certainly reduce its primary productivity and probably lower the intensity of algal blooms.

How to stratify Clear Lake in the most economical manner would require an intensive analysis of existing data and collection of at least a years supplementary information on air and water temperature and eensity, and wind velocity. With the availability of colder Eel River water it might well be possible to inject a cold hypolimnion beneath the warmer Clear Lake water thus producing a strong temperature and density gradient without the necessity of greatly deepening the basin. If disposal sites were available the Army Engineers could probably be encouraged to undertake dredging the main shallow basin of the lake. The high nutrient sediment would be valuable as fill or top soil and its removal from the lake basin would eliminate the last half century of high nutrient accumulation as well as increasing the depth for thermal stratification of the lake's water.

Conclusions

In general this writer is in agreement with the recommendations of the FWPCA report of March 1968. The lower nutrient water, if introduced into the lake in sufficient volume would reduce the present concentration of algal nutrients, particularly nitrogen, and probably begin to flush out some of the nutrients stored in the lake's sediments.

Because of the possibility of stratifying Clear Lake as suggested in Section IV, multi-level outlets will be essential in the reservoirs tapped. Proper manipulation of the Clear Lake thermal regime may have numerous beneficial side effects such as nutrient trapping in a hypolimnion during summer with a greater contribution to the sediments. There is even the possibility of destroying the ideal habitat now provided by the lake for Clear Lake gnat (*Chaoborus astictopus*).

The serious lack of information on regeneration of nutrients from the lake sediment should be rectified by research. Without this information our ability to predict with a high degree of certainty the influence of Eel River water on the algal production is admittedly reduced.

With the projected population increase on the Clear Lake watershed drastic pollution control measures must be established if the lake is to be maintained even at its present, less than satisfactory, condition. Further, if water quality is to be improved in the lake for recreational benefits by diversion of Eel River water, concommitant steps must be taken to reduce the nutrient input. Unless this is done the steady increase in pollution which, unabated, will follow the population rise on the watershed, will tend to diminsh any benefits of Eel River diversion as well as degrading the quality of the water leaving Clear Lake. A complete sewage and irrigation run-off bipass system would seem the best solution.

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