Candlewood Lake: A Tentative Plant Nutrient Budget

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As a part of our analysis of plant nutrient inputs to various lakes in Connecticut, a study of several impoundments in the Housatonic River basin was begun in August 1968. Although the study is not yet complete, local interest in possible changes in the fertility of Candlewood Lake since its impoundment in 1923 prompted the present attempt to derive a nutrient budget for the lake.

Candlewood Lake is the largest impoundment in Connecticut, covering 5,420 acres in Fairfield and Litchfield counties. It is fed by the runoff from a watershed of 25,860 acres and by water pumped up from the Housatonic River by the Connecticut Light and Power Company. The lake serves as a pump-storage reservoir for power generation and is also used extensively for recreation. According to the State Board of Fisheries and Game (1), the waters are average in fertility and in production of plankton and bottom fauna.

Automatic water samplers (2) collected weekly composite samples at nine different stations along the river and its major tributaries for a period of 52 weeks. The samples were analyzed according to Standard Methods (3) for nitrate nitrogen, organic nitrogen, chloride, total phosphorus and volatile, fixed and total solids (4). Flow in the river was obtained from U.S. Geological Survey gaging stations and Connecticut Light and Power Company records. Samples of the bottom sediments in Lakes Candlewood, Zoar, and Lillinonah were obtained with an Ekman dredge and their chemical and mineralogical properties determined as described elsewhere (5).

In order to derive a nutrient budget, it is essential that we first establish a water budget, so that we can compare the inputs from the watershed with those from the Housatonic River. The accompanying budget has been derived from data supplied by the Connecticut Light and Power Company and the U.S. Geological Survey, as well as from climatological data from the U.S. Department of Commerce.

According to records of the Connecticut Light and Power Company, the lake has a usable volume of 6,210 million cubic feet (ft^3) of water, and a total volume of 7,500 million ft^3. During the period 1928-1968, the average amount of water used for power generation per annum was 2,770 million ft^3, while 1,400 million ft^3 was pumped up from the Housatonic River. The difference, or 1,370 million ft^3, was presumably supplied by runoff from the watershed. According to measurements of reservoir height during this period, the mean net runoff from the watershed was 1,410 million ft^3. This difference of 1,410 to 1,370 is only about

0.4% of the volume of the lake, so that the agreement is quite good. Since the measured net runoff is the difference between rainfall and evaporation, and evaporation differs between the open lake and the watershed, this item in the water budget must be examined further.

According to Visher (6), the average annual rainfall for Connecticut is 45 inches, of which about 23 inches are lost by evaporation, leaving 22 inches to run off the watershed. Evaporation from open bodies of water is greater, amounting to about 30 inches of water per annum. Using these figures, the annual input to the lake from the watershed and by direct rainfall on the lake should be 2,050 + 880 or 2,930 million ft^3. Losses by evaporation from the lake should be 590 million ft^3, so that net runoff should be 2,930 − 590 or 2,340 million ft^3. As previously noted, records of Connecticut Light and Power Company indicate that the mean net runoff was 1,410 million ft^3. Although this discrepancy amounts to only about 12% of the 7,500 million ft^3 volume of the lake, the discrepancy is large in terms of power generation and apparent runoff from the watershed and indicates one of two possibilities: a leaky lake or watershed, or errors in the measurement of the area of the watershed. Geological maps of the watershed and lake reveal large numbers of fractures, some nearly vertical, in the granitic bedrock. In addition, a porous limestone stratum underlies the nearby Still River and may extend beneath the lake. These two geological peculiarities indicate that both the watershed and the lake may indeed leak significant quantities of water. Thus, for the present purpose it is assumed that the lake has a leak equivalent to about 12% of its volume per annum.

A tentative water budget for the lake for the period August 1968 through July 1969 is shown in Table 1. For this purpose, the actual volumes of water pumped up from the river and used for power generation are shown. Slightly less water was pumped and more was used

Table 1
Water budget for Candlewood Lake, August 1968 - July 1969

	Million ft^3
INPUTS	
Pumped up from Housatonic	1,100
Runoff from watershed	2,050
Direct rainfall on lake	880
Total	4,030
OUTPUTS	
Used for power generation	3,000
Evaporation from lake	590
Total	3,590
DIFFERENCE (million ft^3)	440
DIFFERENCE % of lake volume	6%

for generation than the 40-year average; hence the apparent excess runoff is somewhat less than for the 40-year average. It might also be noted here that Candlewood Lake is not operated strictly as a pump-storage reservoir; more water is used for generation than is pumped, and, due to low flow in the river, no water was pumped during the period August 1968 through October 1968.

Within the limitations of the accuracy of our water budget, a nutrient budget showing the annual inputs and outputs of the plant nutrients nitrogen and phosphorus is shown in Table 2. The inputs from the Housatonic River and the outputs in the water used for generation were obtained from the water budget in Table 1 and the measured concentrations of nitrogen and phosphorus in the water during the sampling period August 1968 through July 1969. During this period, the mean nutrient concentrations in the Housatonic River were: phosphorus, 0.066 parts per million (ppm) and nitrogen 0.550 ppm. The water leaving Candlewood Lake used for power generation contained fewer nutrients: the mean concentrations were 0.017 ppm phosphorus and 0.347 nitrogen.

The inputs from the watershed were estimated in two ways. A previous study (7) of Bantam Lake had shown a mean annual input from the watershed of 3.0 lbs of nitrogen per acre per year, and 0.21 lbs of phosphorus. Assuming the watersheds to be similar, the 25,860 acre watershed would provide the amounts shown in Table 2 under "Bantam Lake estimates."

Another approach was to assume that the major sources of nutrients were from septic tanks serving homes in the watershed. Mulligan (8) estimated that between 3,800 and 4,500 dwellings are located in the watershed of Candlewood Lake. A recent report by Polta (9) indicates

Table 2
Nutrient Budget for Candlewood Lake, August 1968 - July 1969

	Lbs per annum	
INPUTS	*Nitrogen*	*Phosphorus*
Housatonic River	37,890	4,550
Watershed Runoff		
Bantam Lake estimates	77,570	5,430
Septic tank leakage	60,750	2,250
Direct rainfall on lake	16,260	
TOTAL IN	131,720*	9,980
OUTPUT		
Power generation	64,960	3,180
NET RETAINED	66,760	6,800
PERCENT RETAINED	51%	68%

* Using Bantam Lake estimates

that septic tank effluent from a family of five represents approximately 5 lbs of phosphorus and 27 lbs of nitrogen applied to the soil per year. Not all of this will reach the lake, since phosphorus is readily fixed by soils and much nitrogen may be lost by volatilization to the atmosphere. It is reasonable to assume, for example, that 90% of the phosphorus is retained by the soil, and that 50% of the nitrogen may be lost by volatilization. If we do so, the 4,500 dwellings could contribute the amounts shown in Table 2 under "Septic tank leakage." These estimates seem reasonable by comparison with those from the Bantam Lake study, especially since they do not include any allowance for losses from fertilizer spread on lawns (10). Thus, we probably should use the higher of the two estimates. Direct rainfall on the lake also contributes nitrogen, in amounts of about 3 lbs per acre per year. Since the lake is relatively large compared to the watershed, this is also a significant source of supply as shown in Table 2.

With these various estimates of nutrient gains and losses, we arrive at the nutrient budget shown in Table 2. This of course does not answer the question as to possible changes in the fertility of Candlewood Lake, but it does allow us to make some inferences. First, it is evident that nutrients entering from the watershed are at least equal to those pumped up from the Housatonic River. Second, and of equal importance, the lake is presently retaining about 50% of the nitrogen and nearly 70% of the phosphorus entering from all sources. This is in distinct contrast to our observations on Lakes Zoar and Lillinonah: presently, Lake Zoar appears to be retaining about 30% of the incoming nitrogen and 40% of the phosphorus, while Lillinonah is actually losing nitrogen and retaining only about 10% of the incoming phosphorus (11, and unpublished data).

These observations imply that the sediments in Candlewood Lake serve a useful function by adsorbing incoming nutrients and maintaining low concentrations in the overlying water. However, at some point this adsorption capacity may be exceeded and nutrient concentrations in the water may increase. The point at which this may happen cannot be predicted from our present knowledge of lake sediment chemistry.

By comparing the annual nutrient load into various lakes, however, it is possible to make some comparisons of rates of eutrophication. Estimates of the total annual input into several Connecticut lakes are shown in Table 3. These are expressed as pounds of nitrogen and phosphorus per acre of lake surface per annum. There are clearly very large differences in loading rates and we might speculate that these are reflected in the differences in nutrient status of the lakes. Lake Zoar, built in 1919, and Lake Lillinonah, built in 1955, became eutrophic shortly after impoundment, while Bantam Lake has existed for 10,000 years. We do not know, of course, how long it has been eutrophic, but the depth of sediment in the lake implies that it has not been 10,000 years. Accordingly, the outlook for Candlewood Lake, with the lowest calculated nutrient loading rate, appears fairly bright.

Table 3
Estimated annual nutrient load entering Connecticut lakes

LAKE	Lbs per acre per annum	
	Nitrogen	*Phosphorus*
Candlewood	24	2
Bantam	78	5
Lillinonah	1290	180
Zoar	3380	330

It is also important to attempt to determine whether nitrogen or phosphorus are limiting the growth of algae in the Housatonic River and in Candlewood Lake. The accompanying graph, Figure 1, compares the nitrogen and phosphorus in the water entering and leaving Candlewood Lake. This graph includes data for the period August 1968 through October 1968 when no water was pumped into Candlewood Lake, but this has little effect on the present use of the graph. Two conclusions are evident from Figure 1. First, the phosphorus concentration in the water leaving Candlewood Lake is reduced to a much greater extent than is the nitrogen concentration, confirming the calculated retentions in Table 2. Second, extrapolation of the graph to zero phosphorus concentration in the water intersects the nitrogen axis at about 0.3 ppm. This indicates that if phosphorus is being removed from the water by growing algae, nitrogen still remains when phosphorus is depleted. This implies that phosphorus is the element in shortest supply and is limiting the growth of algae.

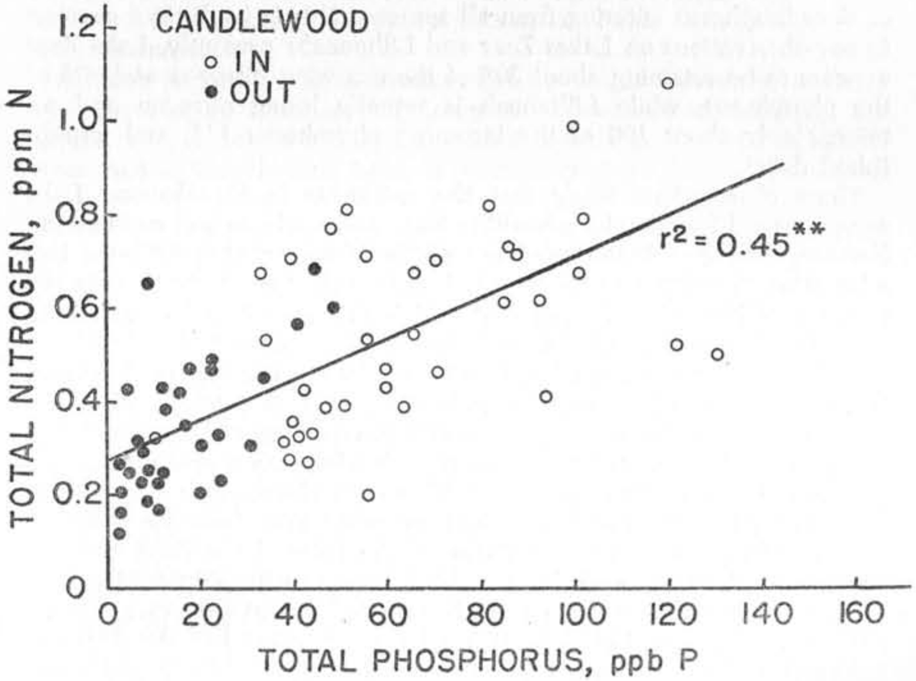

Figure 1. Comparison of nitrogen and phosphorus in water entering (IN) and leaving (OUT) Candlewood Lake

The conclusions of this analysis may be stated very briefly. There are no measurements of fertility or algal productivity in Candlewood Lake that permit us to determine whether changes have occurred since the lake was impounded in 1923. However, the present data indicate that nutrient sources in the watershed slightly exceed those in the water pumped up from the Housatonic River and nutrients are being accumulated in the lake sediments. Fortunately, the sediments appear to be acting as a nutrient sink, maintaining low concentrations in the overlying water. Their sorption capacity may ultimately be exceeded; however, our present knowledge of sediment chemistry does not permit us to predict when this may occur. Phosphorus, rather than nitrogen appears to be the element most likely to be limiting algal growth.

ACKNOWLEDGEMENT

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