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Alaska Department of Fish and Game

POLICY AND GUIDELINES FOR LAKE FERTILIZATION

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June 30, 1979

July 3, 1979

"LAKE FERTILIZATION GUIDELINES"
Alaska Department of Fish and Game

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INTRODUCTION

This booklet is a first cut at providing structure and direction for lake enrichment programs for Alaskan lakes.

Program participants, possibly representing State, Federal and local agencies, as well as private corporations, promise to be widely varied in experience, expertise, support, and even program objectives. Thus there is much to be accomplished in terms of the way in which lake fertilization programs will be administered across the state. We encourage your comments on this booklet, and your cooperation and comments on ways and means of implementing this promising area of fisheries rehabilitation and enhancement.

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June 30, 1980

Contribution to the common property fishery, as well as other evaluation, will take place during the post-treatment period.

A lake fertilization technical team will review all enrichment proposals and forward recommendations to the Chief of Technology and Development, F.R.E.D. Division. The team will consist of Mike Kaill, Jeff Koenings, (Co-Chairmen), Mike Haddix, Paul Novak, John Clark and Larry Engel. The team will function to serve as a "clearing house" to avoid inter-agency duplication of effort. It is understood that lake fertilization projects, by their nature, are long term. For example, fertilization of sockeye systems would probably entail a 5-10 year project period. Approved projects will be reviewed on an annual basis to assure conformity in meeting performance standards.

Details on format, methodology and standards are available in the lake enrichment guidelines.

CLARIFYING STATEMENT

Pre- and post-treatment evaluation is critical in view of the inherent variability within and between lake systems. Such evaluation is mandatory in order to properly evaluate the success and/or failure of nutrient enrichment. Without an evaluation program, scientific and monetary benefits from lake enrichment projects may not be clearly identified, nor will benefits likely reach the maximum potential.

It is important to identify that portion of the salmonid life cycle where increased production takes place. Otherwise, results from treatment will not be distinguishable from natural fluctuations. Increased fish production resulting from lake treatment must then be correlated with indices of primary and secondary production to provide an understanding of the ecological pathways that provide such production.

Adequate chemical and biological assessment must take place prior to, during and after lake enrichment to detect undesirable changes occurring in a lake's food web. Such changes may result from nutrient imbalances imposed upon the lake system after addition of fertilizer.

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Introduction

The addition of nutrients to a lake system, with the end result being to increase the standing stock of salmon, impacts on all aspects of a lake ecosystem. Since few biological processes are determined by independently operating factors, such large scale ecosystem manipulation becomes very complex and produces many changes within the lake.

The productive capacity of different lake systems is determined by edaphic, morphometric and climatic factors, but within a lake is intimately linked to the cycling of carbon, nitrogen, phosphorus and silica (plus other trace elements). Without a thorough knowledge of the cycling of the above nutrients it is impossible to understand the patterns of production, and to control (through lake fertilization) the productive capacity of lakes. By combining the knowledge of nutrient cycling within lake systems with selective nutrient addition, the entire food chain can be enhanced. In such enhancement, it is important to distinguish between rates of change in an ecosystem and biomass standing crop within that system. Essentially, the rate of change is productivity, while standing crop represents the situation at an "instant" in time, or a part of that productivity. A graphic representation of a functioning lake system, showing parts (standing crop), and linkages (rates of change) is presented in Figure 1. The combination of standing crop and linkages between them can be thought of as a "finger print" of a particular system. Treatment appropriate to a particular lake may very well be unique to that system.

The role of nutrient enhancement is to supply the lake, at critical periods and locations, with the necessary nutrients so that the rates of change are increased, leading to the production of more fish food. The goal is not necessarily to increase all the standing stocks within the lake system, rather it is to increase the rates of transfer through the food chain. That is, as fish stocks are the end result of most freshwater food chains, they will ultimately respond to an increase in nutrient levels, and will show a corresponding increase in numbers. Enhancement has to be accomplished in this manner to maintain the quality of the phyto- and the zooplankton present and to safeguard existing water quality.

Guidelines*

The following guidelines serve both as a general outline for the fertilization of lakes in the State of Alaska, and as a detailed accounting of the overall objectives of the various phases of nutrient enhancement discussed above. It provides details on format, methodology and standards that must be met in order to insure the adequate appraisal of the fertilization project.

*Sockeye salmon are emphasized in these guidelines because of the current program emphasis in F.R.E.D. Division. Similarly, clear-water lakes are emphasized because the bulk of our experience is in those systems. As experience is gained with respect to other species and systems, these guidelines will expand to specifically include other salmon species trout and glacial systems.

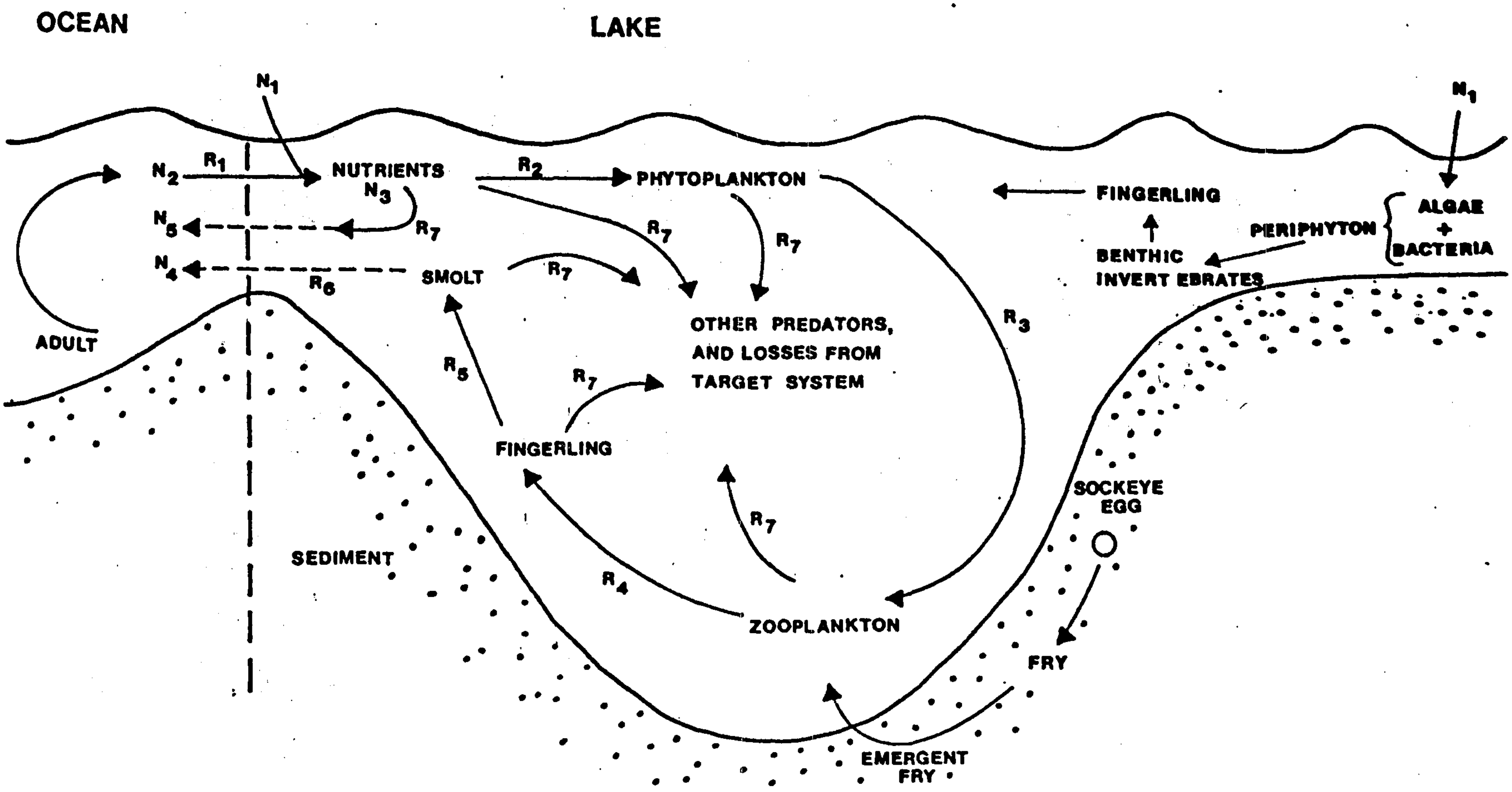

Figure 1. Generalized schematic of a lake ecosystem showing the major pathways of nutrient and energy transfer (R_{1-7}), and major links (e.g., phytoplankton) involved in the salmonid food chain.

Legend for Figure 1.

This greatly simplified diagram shows the interacting elements, linkages between those elements, and rates of change, in a lake system.

N_1: Nutrients supply from atmosphere, land runoff, lake sediment, and stream tributaries.

N_2: Nutrients provided by returning anadromous fish.

N_3: Existing supply of available nutrients in the euphotic zone.

N_4: Nutrients lost to the system by outmigrant anadromous fish.

N_5: Nutrients lost to the system in the river outflow.

Phyto: Standing crop of primary producers - phytoplankton.

Zoopl: Standing crop of secondary producers - zooplankton. Note that this element in the food chain is instrumental in the linkage between emergent fry and fingerling. If artificial nutrients are applied, they must be introduced at N_1, so that the precise zooplankton populations (species, timing, and location) are available at "zoopl". If this is not done properly, food chains might be stimulated that may have a detrimental effect on target salmon or trout production.

Other Predators:
Includes non-target species that may be competing for food organisms. Examples are stickleback, white fish, etc.; this category may also include littoral communities (also in competition for food supplies) utilizing lake nutrient supplies (N_3).

For example, N_3 ----------) periphyton ---------) snail.

Fingerling:
Standing crop of rearing target fish species (Sockeye life cycle is depicted. Modifications can be made for other species.)

Smolt:
Production from the lake, represented in outmigrant target species of fish. This could be thought of as a "final product" of a lake fertilization project, as this is the stage that passes beyond our control. However, recent work suggests that such an approach is not desirable. For example, a system may respond to a strategy of "few large smolt" while another system may respond to the strategy of "many, smaller smolts".

Adult:
The standing crop of biomass taking place outside of the system. Increase in this standing crop is done by way of energy and nutrient sources outside the system. Returning adults (spawners) may be an important source of nutrients for the lake system.

R_1: Rate of nutrient input to the lake system. Includes atmospheri and watershed inputs as well as nutrients supplied by returning adult salmon.

R_2: Rate of nutrient uptake from dissolved, available form in the w column, to biomass as primary producers. This uptake rate is measured in minutes, and is reflected as bio-mass of primary pr biomass for 4 or 5 days.

R_3: Rate of change from primary to secondary producer. This linkag the food chain is the energy source for production of rearing f biomass. It must be proper species composition, in the proper location at the appropriate time. Interacting factors necessar achieve this may be critical.

R_4: Rate of change of biomass for rearing phase of lake populations salmonids. Acceptable growth of rearing fish populations depen upon a continuous supply of food organisms. Again, for biomass appear as the desired salmonid linkage, proper species and loca must be accomplished, through judicious application of fertiliz at the N_1 phase.

R_5, R_6:
Rate of change to smolt outmigrant biomass is a result of conti cropping by the rearing salmonid population. Outmigrant smolts represent a temporary loss of that linkage biomass to the syste

R_7: Rate of change of biomass to non-target elements within the lak food web. For example, phytoplankton can be cropped by zooplan that are not appropriate as salmon food; competitor or predator species of fish can crop zooplankton or rearing salmonids, nutr can be channeled and bound into macrophytes.

Such "side channels" from the desired food chain can produce se losses to lake fertilization programs, and have reduced the B/C ratio in some projects to below feasibility levels.

Summary:
Energy and nutrient flow in a lake is a product of nutrient sup and the factors of sunlight, temperature and the nature of the basin. Successful production of target species will be enhance minimizing biomass "side channels" (R_7) such as large littoral communities and large populations of predator/competitor specie Needs of the target species, such as spawning area, should be considered.

A successfully managed lake fertilization project will have low standing crop levels and high rates of change, moving the bioma rapidly to growth of target fish populations. Little or no cha should be detectable in the other elements within the lake's ec

I. Lake Selection Criteria and Feasibility Studies

There are lakes within the State of Alaska whose fish stocks would benefit immensely from a fertilization program. However, there are some lakes whose stocks would not. It is necessary to know as much as possible about the physical, chemical and biological charateristics of candidate lakes so that selection criteria can be applied to determine which lake systems could benefit from nutrient enrichment, and the nature of the treatment to be used for each lake.

This first phase is designed to allow the sampling of a large number of potential lakes, of which only a portion will be considered for the nutrient enhancement program. The criteria are detailed to provide the reader with the particular lake characteristics which would maximize the cost effectiveness of nutrient enrichment. That is, they would minimize the losses from the target system (R_7) in Figure 1.

Since this is a feasibility-study stage designed to investigate several lake systems, sampling is limited in time and involves only those parameters of critical importance. It is to be emphasized that such a study does not necessarily preempt a lake from the more extensive pre-fertilization phase study of one year. It merely provides baseline information necessary to intelligently determine suitability of a lake for a nutrient enrichment program.

A. Lake Selection Criteria

1. Food supply (zooplankton and/or benthic invertebrates) must limit salmonid growth and/or numbers during a critical period in their life history by limiting nutrient supply for some significant part of the growing season.

2. For added nutrients to be available to the phytoplankton, the following should apply:
   a. Mean depth of the lake should be greater than the depth of the euphotic zone.
   b. Epilimnion should be less than twice the depth of the euphotic zone.
   c. Flushing rate of the epilimnion should be low enough so that the turnover time is greater than one year.
   d. Shoreline should be steep with very little littoral zone periphytic and macrophytic vegetation.
   e. Light penetration should not limit primary production, and turbidity should be low.

3. Nutrient enhancement is compatible with pre-existing water usage, whether for domestic consumption, hatchery operations, and/or for areas classified under the Federal Wilderness program.

4. The ability to evaluate, monitor and manage adult salmon returns to the commercial, sport, and/or subsistence fishery must exist.

5. Initial salmon populations of 300 to 400 fry per lake-surface-hectare, or the potential for stocking to that density, should be present. A lower density would increase costs and mean a longer period of time to realize the benefits.

6. Spawning or rearing area should be sufficient for increased numbers of returning adults or of an area which would not limit salmonid production.

7. Predators and/or competitor populations should be of a size which would not limit salmonid production.

B. Feasibility Sampling

1. Physical parameters

a. The determination of water flow should be made by either direct measurement (U.S.G.S. methods) on streams and/or rivers, by indirect means such as watershed area, or by other approved methods (e.g., Thornwaite projections for Southeast Alaska).

b. Lake mapping for depth contours and volume estimates should be done either directly, using a fathometer, or indirectly, using pre-existing U.S.G.S., ADF&G, and Federal agency maps.

c. Light penetration should ideally be measured using a submarine photometer {preferably measuring only the photosynthetically available radiation (PAR)}; however, a secchi disk (22-cm dia) can be used to <u>estimate</u> the depth of the euphotic zone.

d. Parameters to be determined (in metric units) include:
   1. Morphometric features (maps, streamflow, lake mean depth, lake volume, lake surface area, and watershed area).
   2. Watershed development (edaphic factors).
   3. Temperature regimes, turbidity, light penetration (PAR), and/or secchi disk depth.

2. Chemical parameters

a. Water sampling should be done at least once a month, emphasizing the spring and fall overturn periods and the summer production period. Size and morphometric characteristics such as major lake basins and/or bays will dictate the number of sampling sites. However, one carefully selected station per lake is a minimum requirement.

b. Sampling is to be done at the 1.0-m depth or in the middle of the epilimnion, and in the middle of the hypolimnion or at 75 percent of the lake depth.

c. All samples should be placed in rigorously cleaned poly-bottles (phosphate-free detergent followed by a rinse with 10 percent HCL and three distilled water rinses) filtered onsite (if appropriate) and preserved.

d. Parameters to be sampled include:

Alkalinity* (mg/l as $CaCO_3$)	Ammonium**+(μg/l as N)
pH*	Nitrate**+(μg/l as N)
Specific conductance (μmhos/cm)	Nitrite**+(μg/l as N)
Dissolved solids*(mg/l)	Reactive phosphorus**+ (μg/l as P)
Dissolved oxygen (mg/l)	Total phosphorus**(μg/l as P)
Metals***(μg/l)	Reactive silica**+ (mg/l as SiO_2)

*Stored at 4°C in a full container in the dark.
**Stored frozen in the dark.
***Preserved with acid (3 ml of 1:1 HNO_3 per liter of sample to a pH < 2.
+Filtered (GFF glass fiber filter).

3. Biological parameters

a. Primary production

1. Sampling for phytoplankton production should be done once a month, emphasizing the ice-free period. Size of the lake and morphometric characteristics such as major basins and/or bays will dictate the number of sampling sites. However, one carefully selected station per lake is a minimum requirement.
2. Sampling should be done at the 1.0-m depth or in the middle of the epilimnion, and should consist of Chlorophyll a (Chl a) measurements, a species list and either directly or indirectly calculated wet and dry weights.

b. Secondary production

1. Zooplankton sampling should be done once a month, emphasizing the ice-free period. The size of the lake and morphometric features such as major basins and/or bays will dictate the number of sampling sites. However, one carefully selected station per lake is a minimum requirement.

2. Sampling should be done with a ½-meter diameter 130-μ-mesh zooplankton net using 50-m vertical hauls at stations greater than 50 meters deep and bottom-to-surface hauls at stations less than 50 meters deep.

3. Zooplankton are to be counted, identified and wet and dry weights determined. Subsampling can be done as long as at least 60 individuals of each taxa are counted.

c. Tertiary production

1. Salmonid adult escapement and the number of potential predator and/or competitor species are to be estimated.

2. Beach spawning areas are to be identified and an estimate made of the total number of potential beach spawning sites within the lake.

II. Pre-fertilization Phase

This second phase is designed to document the premise that low nutrient levels may limit the amount of fish food the lake produces and, therefore, cause low levels of fish production. In addition, the pre-fertilization phase (lasting a minimum of one year but may last for additional time - resulting in better information for evaluation) involves the detailed monitoring of the chemical, biological and physical factors of a candidate lake. Remembering the complexity of aquatic systems, great care should be exercised in the evaluation of treated versus control or reference responses. The before condition serves as a control to be compared with the condition of the lake after nutrients have been used. Sufficient knowledge of how the system operates before treatemnt permits the conclusion that results obtained after treatment were due to the nutrient additions. Thus, background information from candidate lakes is needed not only to determine those lakes which could potentially benefit from fertilization but, perhaps more importantly, to provide the researcher with the data base from which to evaluate the success (or failure) of a fertilization program.

A. Physical parameters

1. The determination of water flow should be made every three weeks during the ice-free period, either directly according to U.S.G.S. methods on major rivers and streams, by indirect means such as watershed comparisons with gauged systems in the same geographic area or by other approved methods (e.g., Thornwaite, projections for Southeast Alaska).

2. Lake mapping for depth contours and volume estimates should be done either directly, using a fathometer, or indirectly, using pre-existing U.S.G.S., ADF&G and Federal agency maps that were constructed from direct measurements.

3. Light penetration is to be measured every three weeks using a submarine photometer {measuring only the photosynthetically available radiation (PAR)}; and with a secchi disk (22-cm dia).

4. Parameters to be determined (in metric units) include:
   a. Morphometric features (maps, streamflow, lake mean depth, lake volume, lake surface area, and watershed area).
   b. Watershed development (edaphic factors).
   c. Temperature regimes, turbidity, light penetration (PAR), and secchi disk depth.
   d. Ambient light levels, air temperature, length of ice cover and other pertinent climatic indicators such as degree days. Extrapolation can be made to set sites that exhibit the same weather conditions within the same geographical location.

B. Chemical parameters

1. Water sampling should be done every three weeks during the ice-free period. Size of the lake and/or morphometric

characteristics such as major lake basins and/or bays will dictate the number of sampling sites.

2. Sampling is to be done using an at-depth sampler (e.g., Kemmerer, vanDorn bottles) at the 1.0-m depth, the top of the thermocline and in the middle of the hypolimnion or at 75 percent of the lake depth.

3. All samples should be placed in rigorously cleaned poly-bottles (phosphate-free detergent followed by a rinse with 10-percent HCL and three distilled water rinses), filtered on site (if appropriate) and preserved. See figure 2 for a suggested sampling scheme.

4. Parameters to be sampled include:

   - Alkalinity*(mg/l as $CaCO_3$)
   - pH*
   - Specific conductance (µmhos/cm)
   - Dissolved solids*(mg/l)
   - Dissolved oxygen (mg/l)
   - Metals*** (µg/l)
   - Ammonium**+ (µg/l as N)
   - Nitrate**+ (µg/l as N)
   - Particulate nitrogen++ (µg/l as N)
   - Nitrite**+(µg/l as N)
   - Reactive phosphorus**+ (µg/l as P)
   - Reactive silica**+ (mg/l as SiO_2)
   - Total phosphorus**(µg/l as P)
   - Keljdahl nitrogen** (µg/l as N)
   - Particulate phosphorus++ (µg/l as P)

*Stored at 4^oC in a full container in the dark.
**Stored frozen in the dark.
***Preserved with acid (3 ml of 1:1 HNO_3 per liter of sample) to a pH < 2.
+Filtered (GFF glass fiber filter).
++Stored frozen in GFF glass fiber filters.

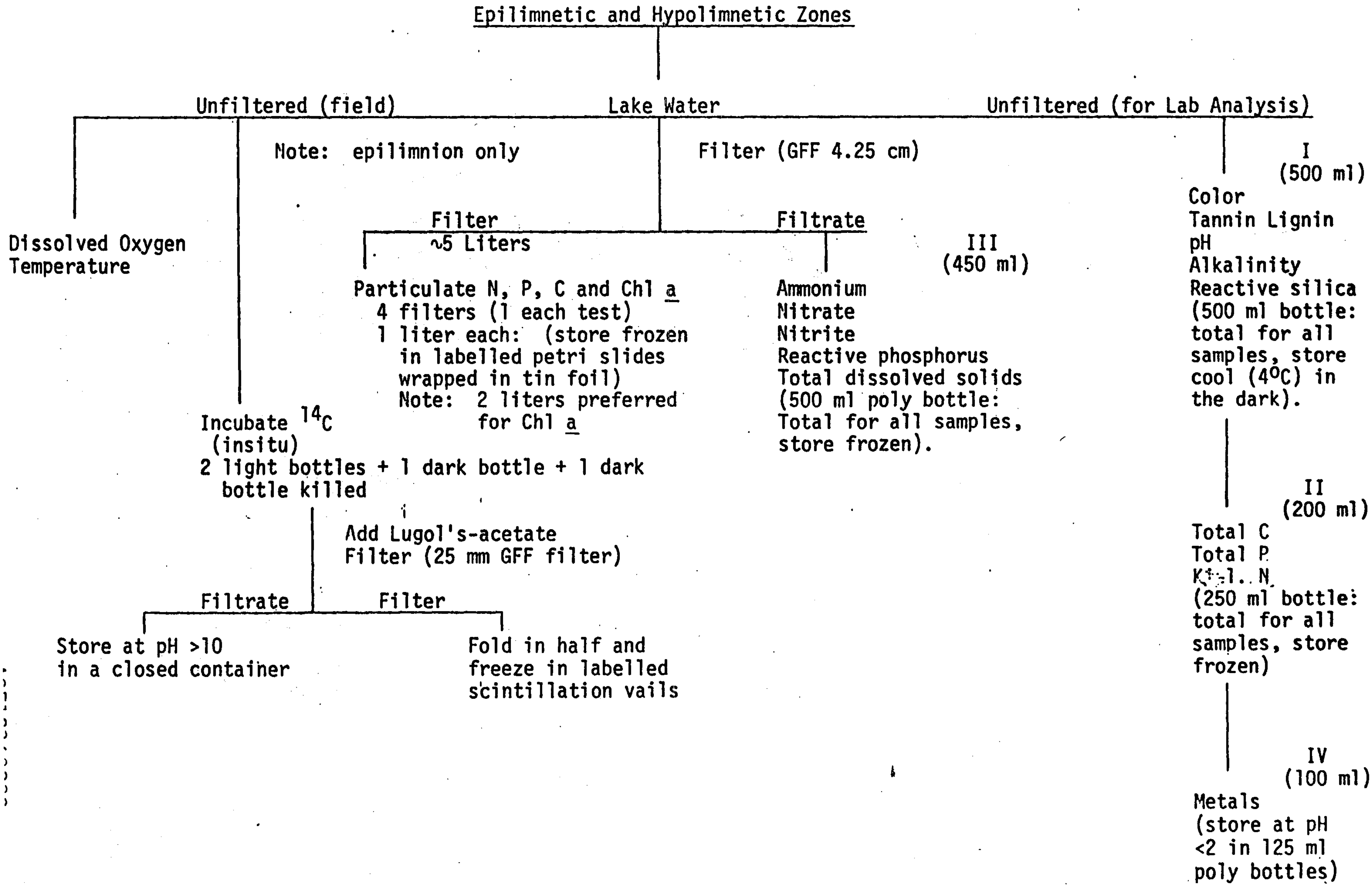

Figure 2. A suggested sampling protocol for nutrient and primary productivity measurements.

C. Biological parameters

1. Primary production

a. Sampling for phytoplankton production <u>and</u> productivity should be done every three weeks, emphasizing the ice-free period. During the ice-cover period, sampling should be on a monthly to six-week basis. Lake size and morphometric characteristics such as major basins and/or bays will dictate the number of sampling sites.

b. Sampling for algal pigments and carbon uptake rates within the pelagic area should include several strata within the euphotic zone. Strata should include the surface (1.0 m), middle of the euphotic zone, and/or the top of the thermocline. In addition, samples should be taken within and outside the fertilized zone when a lake is only partially fertilized.

c. Periphyton growth rates and biomass estimation within the littoral zone are made using artificial plexiglass substrates. Three sites should be located in the lake system with two sites located both within and outside the fertilized zone when a lake is only partially fertilized.

d. Parameters to be measured include those that differentiate between the rate of production and standing crop estimates which are:

1) Pelagic zone (phytoplankton)

a) Chlorophyl a and phaeophyton (production) in µg/l.

b) 14 carbon uptake (productivity) in mg C/l/hour.

c) Wet and dry weights (mg/l).

2) Littoral zone (periphyton)

a) Chlorophyl a and phaeophyton (production) in µg/l.

b) Growth rate measurements (productivity) in $mg/m^2/d$.

c) Wet and dry weights (mg/l).

2. Secondary production

a. Zooplankton sampling should be done every three weeks, emphasizing the ice-free period. The size of the lake and morphometric features such as major basins and/or bays will dictate the number of sampling sites. Sampling will be done within and outside fertilized zones if a lake is only partially fertilized.

b. A 50-meter vertical haul should be taken at each sampling date within the pelagic zone at depths greater than 50 meters, and bottom-to-surface hauls at stations less than 50 meters deep.

c. Sampling should be done with a ½-meter diameter 130-µ-mesh zooplankton net. Zooplankton are to be identified, counted, and wet and dry weights determined.

If sub-sampling is employed, at least 60 individuals of each taxa are to be counted, and reported as number/liter of water strained and as mg/l, respectively.

d. Littoral zone benthic invertebrates are to be sampled every three weeks using artificial substrates (e.g., Hester-Dendy). Three substrates are to be sampled per lake with samplers located within and outside fertilized zones if a lake is only partially fertilized.

e. Invertebrates should be counted, identified, and wet and dry weights determined. Results are to be reported as numbers/m^2 and as mg/m^2, respectively.

3. Tertiary production

a. Salmonid smolt and adult enumeration should be made by appropriate acoustic means, a weir arrangement located at the lake outlet and/or by tower counts.

b. Enumeration of smolt and juvenile salmonids, either by tow-netting or acoustic means, should be developed and implemented in each lake system studied.

c. Salmonid viral and bacterial diseases should be monitored.

d. Determination of the following factors should be made:

1) Smolt and adult salmonid enumeration including age, weight and length determinations.

	Adult	Smolt
Length:	nearest cm:mid-eye to fork	nearest mm:snout to fork
Weight:	nearest 0.5 kg	nearest 0.1 gms

2) Lake spawning (beach spawning) and rearing areas should be estimated.

3) Stomach samples of juvenile salmonids need to be collected to determine food preferences and location of feeding at critical life stages.

4) Information necessary to determine fecundity and potential egg-to-fry (spring), egg-to-juvenile (fall), and egg-to-smolt (following spring) survival is to be collected.

5) The enumeration of potential predator and/or competitor species and their population response to fertilization should be documented.

e. Specific methods of data collection will be standardized to meet procedures.

f. Planning of specific fertilization projects should include appropriate statistical design to ensure adequate data analysis. The lake sampling scheme should be reviewed by Alaska Department of Fish and Game biometricians.

g. The estimation of appropriate cost-benefit ratios must be made in any lake fertilization project.

h. It is very important that adequate consideration be given to public awareness of lake fertilization projects in view of increased public concern over water quality.

i. Data collected will be compiled and analyzed by the lake fertilization team for lake selection approval, and then disseminated to appropriate personnel.

III. Fertilization Phase

The fertilization phase should be carried out in a manner which permits some insight into how the nutrient enrichment effected the observed response. Careful observations of what is taking place along the entire food chain may lead to a fuller explanation of the processes involved. It is important that careful consideration be given to the design and execution of the fertilization project in order to maximize the chances of unequivocal results and to ensure efficient expenditure of time and effort.

To this end, sufficient monitoring must be maintained to detect detrimental and/or nondetrimental changes occurring within the lake system and to acquire the data necessary to further the understanding of the causes of the changes. In addition, the monitoring serves to document the extent to which the nutrient enrichment program has enhanced the entire food chain up to the target stock, i.e., salmon smolts.

Guidelines for the second phase are designed for the addition of fertilizer and for the monitoring of the effects of that addition.

A. Fertilizer application

1. Nutrients in the form of inorganic fertilizer will be added to the epilimnion of the lake at a N:P atomic ratio of 15:1, and at an inorganic phosphate concentration that matches that of the spring turnover period.

2. Fertilization should commence as soon as possible after stratification and should be applied every two weeks during the spring-summer growing period in a liquid form at a temperature equivalent to the surface water.

3. Depending on lake size and basin configuration, the entire lake or portions thereof will be fertilized. Nutrient addition will be of sufficient quantity to maintain the phosphorus concentration of the spring overturn period.

B. Monitoring during the fertilization phase

1. Monitoring the physical, chemical and biological parameters will be discussed under Section II, 1, 2, and 3 of the guidelines, and will be done on a schedule of every three weeks (when appropriate) during fertilizer addition and monthly where possible thereafter.

2. Specific methods of data collection will be standardized to meet procedures.

3. Such monitoring will be done as necessary to alter nutrient ratios and quantity of fertilizer subsequently added so as to minimize any alteration of existing water quality of plankton communities present in the lake.

4. Public awareness and involvement in the fertilization phase is deemed important as is interagency coordination of the fertilization project. This is critical especially in regard to the management of increased numbers of returning adult fish.

IV. Post-fertilization Phase

This last phase is intended to serve as a check both on any undesirable changes occurring in the lake's phytoplankton, zooplankton, and fish communities, and on any apparent decrease in fertilization efficiency associated with long-term nutrient enrichment. This is achieved by a cessation of fertilization for a period sufficient to reduce the observed changes to conditions existing at the pre-fertilization phase. In addition, it serves to document that few permanent changes have occurred in the lake due to the fertilization program and that any undesirable effects may be alleviated over time.

During all phases of the fertilization project, the public should be kept aware of the progress of the project so as to preclude any adverse reactions and undue expectations. Such participation greatly expands the public awareness of the lake enrichment and promotes a feeling of cooperation with the management agencies.

A. Cessation of fertilization

1. Application of fertilizer will be stopped if adverse changes are found to be occurring in water quality, phytoplankton and/or zooplankton community structure.

2. In this event, fertilization will be stopped until at least one year of post-fertilization fish have returned, in all aspects, to those conditions existing during the pre-fertilization phase.

B. Monitoring during the post-fertilization phase

1. Monitoring the physical, chemical and biological parameters as discussed under Section II, 1, 2, and 3 of the guidelines will be done on a schedule of every three weeks during the ice-free period and monthly thereafter.

2. Specific methods of data collection will be standardized to meet procedures.

3. Public awareness and involvement in the post-fertilization phase is deemed a necessity to avoid adverse public reaction to any anticipated decrease in the return of adult fish.

4. Data review and dissemination is deemed a necessity to update future fertilization projects. To this end, process models should be developed so that adverse results may be avoided, and predictions of the effect of fertilization on different systems should be made.

V. Remarks

The reader should realize that proper management of large-scale nutrient additions to lake systems is dependent upon the quality of chemical and biological sampling. To insure quality, the program must be a coordinated effort undertaken by qualified personnel.

It should be added at this point that the fertilization of lakes is still an experimental salmon enhancement technique. Because of this, the guidelines outlined above are just that, and will be updated and expanded to include particular changes in techniques when applied to different salmon stocks (e.g., coho versus sockeye) or to different lake systems (e.g., glacial versus clear-water lakes). Until such time (if ever) that specific guidelines covering all lake-fertilization techniques for all lake types and fish species are compiled, fertilization of specific lakes will have to be handled on a case-by-case basis under the guidelines outlined above. However, if nutrient enrichment proves itself in Alaskan waters, then fisheries managers will have a potent tool to enhance and rehabilitate salmon stocks. Salmon enhancement by fertilization of under-productive lakes and streams may, in a relatively short period of time, result in significant increases in native salmon stocks.