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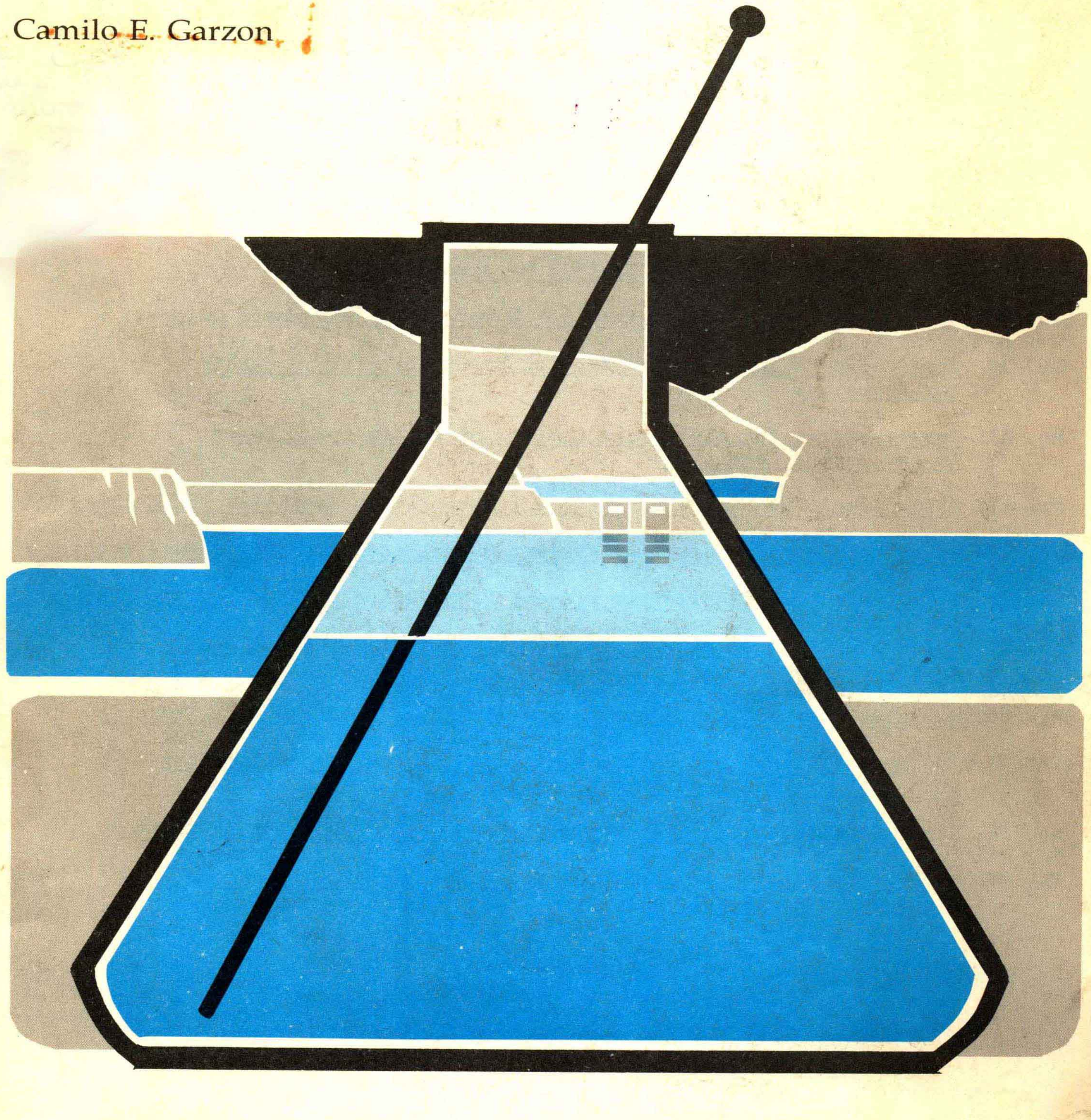
Considerations for Planning in Tropical Forest Regions

Camilo E. Garzon



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ABSTRACT

This paper identifies and describes the studies necessary to predict water quality changes, at an early state of planning, in large tropical reservoirs with long retention times. Emphasis is placed on both the reservoir area and the region downstream. The need for defining the "baseline" environment is presented as a requirement for conducting studies associated with the flooding and operating stages. These studies are classified according to the stage of project development.

In the reservoir area, aspects such as biomass quantification, reservoir thermal stratification, water circulation, dissolved oxygen consumption and reservoir recovery are of major importance. Downstream from the project, the stress is placed on river recovery capacity, water uses and conflicts, and flow requirements. The results obtained from the studies serve as the basis for deciding the extent of forest clearing and other mitigatory measures.

The paper illustrates that biological degradation in tropical reservoirs follows a significantly different path from that in reservoirs in temperate zones, thus, conventional approaches to reservoir clearing and filling may not be adequate for projects in forested tropical regions. Two approaches - for project feasibility and project design - are suggested in order to meet the need for successive refinement in the results, and to take advantage of the increasing availability of project and environmental information.

ABSTRAIT

Ce document identifie et décrit les études à effectuer pour prédire, à un stade peu avancé de la planification, les variations de la qualité de l'eau dans les grands réservoirs tropicaux à longue durée de rétention. Il met l'accent à la fois sur la superficie du réservoir et sur la région en aval. La nécessité de définir les éléments de base de l'environnement est présentée comme une condition nécessaire à l'exécution des études liées aux stades de la submersion et de l'utilisation. Ces études sont classées selon le stade d'avancement du projet.

Vis-à-vis de l'étendue couverte par le réservoir, certains aspects tels que l'évaluation quantitative de la biomasse, la stratification thermique du réservoir, la circulation de l'eau, la consommation d'oxygène dissous et la remontée du niveau de l'eau sont particulièrement importants. En aval du projet, l'accent est mis sur la capacité de rétablissement du débit du cours d'eau, sur les utilisations de l'eau et les conflits à ce sujet, ainsi que sur les besoins en matière de débit. Les résultats de ces études servent de base aux décisions concernant l'étendue de forêt à déboiser et autres mesures destinées à améliorer la qualité de l'eau.

Cette étude montre que la dégradation biologique qui se produit dans les réservoirs tropicaux suit une voie sensiblement différente de celle que l'on observe dans les réservoirs des zones tempérées, de sorte que les méthodes classiques de déboisement et de remplissage pourraient ne pas convenir aux projets d'aménagement de réservoir dans les régions tropicales. Deux formules sont préconisées - pour les études de faisabilité et la conception des projets - afin de répondre à la nécessité d'apporter plusieurs améliorations successives aux résultats et de tirer profit de la disponibilité croissante d'informations sur les projets et sur l'environnement.

EXTRACTO

En este trabajo se identifican y describen los estudios necesarios para predecir, en una etapa inicial de la planificación, los cambios de la calidad del agua que ocurren en los embalses grandes con períodos de retención prolongados que se construyen en zonas tropicales, dándose especial importancia a los estudios tanto de la zona del embalse como de la situada aguas abajo del proyecto. Además, se subraya la necesidad de definir el medio ambiente "básico" para la realización de los estudios relacionados con las etapas de inundación y funcionamiento. Estos estudios se clasifican de acuerdo con la respectiva etapa de ejecución del proyecto.

En lo que se refiere a la zona del embalse, aspectos tales como la cuantificación de la biomasa, la estratificación térmica, la circulación del agua, el consumo de oxígeno disuelto y la recuperación revisten primordial importancia. En cuanto a la zona situada aguas abajo, se hace especial hincapié en la capacidad de recuperación del río, en los usos del agua y los posibles conflictos al respecto y en los requisitos en materia de caudal. Los resultados que se obtienen con los estudios sirven de base para las decisiones relativas al alcance del desbroce de la zona forestal y otros paliativos.

Se muestra gráficamente en el trabajo que la degradación biológica en los embalses de las zonas tropicales sigue una trayectoria notablemente diferente de la que sigue en los de las zonas templadas; por lo tanto, es posible que los métodos usuales de desbroce y llenado no sean adecuados para los proyectos que se llevan a cabo en regiones forestales tropicales. Se sugieren dos enfoques --para la evaluación de la viabilidad y el diseño de los proyectos-- a fin de satisfacer la necesidad de refinamiento sucesivo de los resultados y de aprovechar la disponibilidad cada vez mayor de información sobre los proyectos y los aspectos ambientales.

PREFACE

This paper is a summary of material presented at a World Bank Seminar on March 1, 1983, sponsored by the Energy and Industry Staff, and by the Office of Environmental Affairs. The intent is to outline tropical reservoir water quality management as related to the various aspects of the planning process.

The paper presents an analytical appraisal and predictions stemming from poor water quality conditions as a result of the decomposition of great amounts of biomass flooded by their associated reservoirs. This issue is important because of the increasing number of hydroprojects being planned in regions with tropical wet forests. The predictions presented serve as a basis for the decision and extent of forest clearing and the need for structural and managerial remedial measures.

The World Bank Seminar and paper resulted from the World Bank's requirement for environmental consideration of the Urra Hydroproject, located in northeastern Colombia, which is expected to begin operating in 1988. The environmental studies conducted by the author clearly show both the technical aspects of the project layout and the elements of the surrounding environment. The need for further quantitative analysis and the complexity of the phenomena involved suggest the need for an innovative and technologically advanced approach. The efforts made at the Urra Project represent a step in this direction.

I wish to thank Mr. R. Goodland and Mr. J.J. Fish for their kind invitation to present the seminar, to write this paper and their most helpful and detailed improvements. Several people involved with the Urra Project have contributed to the ideas introduced, and their contribution is gratefully acknowledged. The views presented here are personal and should not be attributed to the World Bank.

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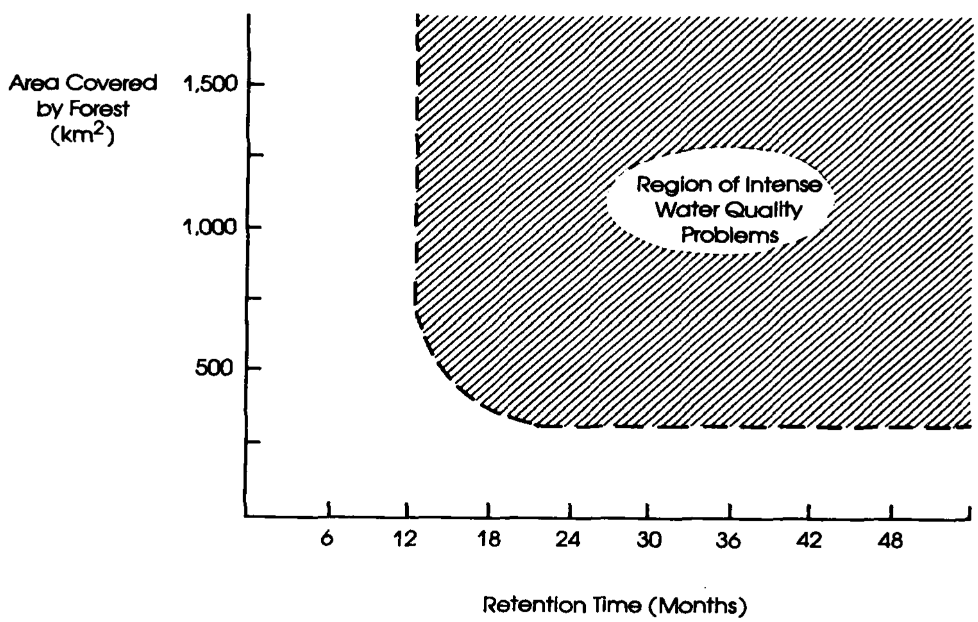
INTRODUCTION

The water quality problems addressed by this paper refer mainly to the situation encountered when large amounts of tropical vegetation (i.e., tropical rain forest) are flooded by new reservoirs. The original river water quality deteriorates so drastically as to impair human consumption and most economic uses. In hydroelectric projects which require relatively large river flows, this situation becomes exacerbated when the reservoir's retention time (mean volume/mean flow) is also large. Figure 1 shows the region of main concern. The boundary line shown between regions is arbitrary. In addition to retention time and area, other variables such as mean depth, climatic conditions and reservoir morphometry, can increase or decrease water quality problems.

This particular reservoir category has not been sufficiently studied mainly because very few hydroprojects have presented those characteristics. However, the few projects built under these conditions have developed various kinds of environmental problems--water quality being one of the most serious. A good example of this is the Brokopondo Lake (Afobaka Dam) in Suriname, built in 1964, which is illustrated in Section 2.2 (Heide, 1976; Panday 1977). Several other important hydroelectric projects are in the planning process in tropical developing countries, for example in the Amazon basin (Goodland, 1978) and in Colombia's Pacific Region (DNP, 1979). They will require detailed analyses if water quality and other environmental disturbances are to be prevented. The potential for similar water quality problems also is significant in Equatorial Africa and Southern Asia.

FIGURE 1

Water Quality as a Function of Reservoir Retention Time and Area



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This paper points out the need for two successive approaches in predicting water quality changes, and answering the question of how much forest clearing should be carried out in order to ensure the required quality of water. Extensive clearing is such a costly remedial measure, that it could compromise the feasibility of the project itself.

1. PROBLEM OVERVIEW

Aspects directly or indirectly related to the water quality issue are summarized in Table 1. They are organized both by geographical location and by stage of project development. The column entitled "Baseline Environment" comprises the studies which will become the bases for the predictions listed on the two following columns.

1.1 Upstream Area

Inflowing tributaries acquire their physical, chemical and biological characteristics in the watershed, upstream from the reservoir. Parameters such as water temperature, nutrient concentration, pH and organic content define significant properties of the incoming rivers that will partially determine the nature of the water quality in future reservoirs. However, this influence is more noticeable in short retention-time reservoirs than in stagnant reservoirs. In the latter, the effect will be manifested over a longer time span, i.e., during the reservoir "recovery" period. (See Section 2.4) For the same reason, prediction of future changes in land use and in the ensuing water quality characteristics will become necessary.

1.2 Reservoir Area

The reservoir area, which is to be inundated, requires several descriptive studies. First, it needs a quantification of the amounts and

TABLE 1

Aspects Related To Water Quality Management
- Descriptive and Predictive Studies-

STAGES / LOCATION	BASELINE ENVIRONMENT	RESERVOIR FORMATION	PROJECT OPERATION
UPSTREAM	WATERSHED Land Use RIVER CHARACTERISTICS Quantity Quality		WATERSHED Land Use Changes RIVER CHARACTERISTICS Quality Changes
RESERVOIR AREA	VEGETATION Amounts Types Elemental Composition SOIL CHARACTERISTICS CLIMATIC ASPECTS Ambient Temperature Solar Radiation Relative Humidity Cloud Cover Wind Direction/Speed	FLOODING PROCESS Areas Covered Duration HYDROTHERMAL BEHAVIOR Development of Stratification DISSOLVED OXYGEN BUDGET Aerobic/Anaerobic Conditions CIRCULATION PATTERNS Changing Morphometry LOW-LEVEL DISCHARGES	RESERVOIR USE Fishing Recreation Others HYDROTHERMAL BEHAVIOR Stratification/ Stability CIRCULATION PATTERNS Morphometry WATER QUALITY Fertilization Recovery INTAKE CONFIGURATION
DOWNSTREAM	RIVER CHARACTERISTICS Biochemical Hydraulic, Hydrologic QUANTITY-QUALITY RELATIONSHIPS Tributaries Delta Other Features WATER USES Human Consumption Fishing Irrigation Waste Water Disposal Others	MINIMUM FLOWS REQUIRED Seasonal Requirements Water Uses WATER QUALITY Parameter Profiles	HYDROLOGIC ASPECTS "Dry" Reaches Flow Fluctuations WATER QUALITY Parameter Profiles Effect of Tributaries Assimilation Capacity RECOVERY

types of existing vegetation. This task is better conducted in two stages, as outlined below. At the outset, an estimate of the readily degradable fraction of the vegetation will suffice. 1/ Later, for more detailed analyses, the elemental composition of the biodegradable fraction will be required in order to estimate the input of nutrients into the water. The input of the superficial soil also has to be taken into account. Although tropical forest soils are usually nutrient-poor, this characteristic varies from one region to another. Soil organic content, on the other hand, tends to be relatively high when compared to temperate forests. Estimates based on data from forest ecosystem studies conducted in similar regions have proven useful, even though forest studies are not usually conducted with the same purpose in mind.

Second, the climatic characteristics of the region should be evaluated. This is usually an easier task, since most needed data are collected routinely by weather stations in the area and by engineering studies. For instance, ambient temperature, relative humidity and wind direction and speed data are gathered this way. Solar radiation and cloud cover may require additional measurements on the part of the water quality analysts. Climatological data serve as the bases for predicting the hydrothermal and mixing behavior of the future reservoir.

1/ Degradable fraction of vegetation includes leaves, twigs, flowers, fruits, portions of the bark and other softer outer tissues which decompose during the first few months. Knowledge of the biodegradable fraction, expressed in tons/hectares, for example, will allow calculation of the amount of dissolved oxygen which will be extracted from the water during the decomposition process following flooding.

During reservoir formation, increasingly larger areas of forest will be flooded. The longer the reservoir retention time, the longer this process will last. Topographic characteristics of the area (the future reservoir morphometry), together with the hydrologic behavior of the tributaries will determine the probable amounts of organic matter added to the water mass per unit time. This relatively simple calculation (see Section 2.3) provides initial estimates of dissolved oxygen content, and consequently, of other parameters intimately related to this vital component. The quality of the waters discharged through any low-level (i.e., deep) outlets will be impaired if anaerobic conditions developed within the water column.

After filling, the reservoir will behave in a manner resembling that of a natural lake. If large amounts of vegetation are flooded, the reservoir will undergo a slow recovery process. Depending on need, this recovery process can be somewhat accelerated by intake configuration and reservoir water level control (Garzon, 1983).

1.3 Downstream Area

Additional studies are needed in the areas located along the river, downstream from the project site as summarized in Table 1, to determine the river self-purification capacity, and the existing and potential water uses. The river self-purification capacity can be reliably estimated from its hydraulic and hydrologic characteristics. Deoxygenation and reaeration coefficients which are functions of molecular diffusion, water velocity, depth and temperature, will serve to estimate the dissolved oxygen levels along the river course. 2/ Other features such as incoming tributaries, interconnected seasonal lakes, estuaries and salt water intrusion at the river delta will have to be evaluated. The latter may play an important role if the reservoir filling process is protracted. During this period, in the absence of major tributaries downstream from the project site, a substantially reduced river flow can cause a detrimental increase in salinity concentrations near the delta.

Once the predictions for both the filling and the operational periods of the reservoir water quality have been made, estimates on the river water quality can be derived downstream from the project. Thereafter, possible conflicts with highly demanding uses, such as human

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2/ The differential equation (simplified for our case) that describes the rate of change of oxygen concentration in the river is of the form:

$$\frac{dO}{dt} = K_2\,(O^*-O) - K_1\,L$$

where O = concentration of oxygen (mg/l)

O^* = saturation concentration of oxygen at the local temperature and pressure

K_2 = reaeration coefficient

K_1 = deoxygenation coefficient (temperature dependent)

L = bioquemical oxygen demand (B.O.D.)

Numerous equations have been developed to compute the reaeration coefficient. An example is the O'Conner and Dobbins approach:

$$K_2 = \frac{(D_m\,v)^{0.5}}{d^{1.5}} \quad \text{at } 20^{o}C$$

where Dm = molecular diffusion coefficient
v = mean water velocity in the river
d = mean stream depth

consumption and fisheries, should be identified. Similarly, minimum flows required during filling, and even during project operation, should be determined; and lastly, river recovery, corresponding to the slow reservoir recovery also should be established.

In developing countries, water use downstream will normally determine the water quality required from the project. River water quality studies, thus, become a critical task. Fortunately, adequate technological tools exist to make this a relatively easy and reliable operation. However, this cannot be said about reservoir water quality predictions. These predictions still pose a great challenge that will have to be at least partly circumvented both by ingenuity and by simplification of the real processes involved. The following sections deal in more detail with the major aspects to be considered.

2. RESERVOIR WATER QUALITY PREDICTIONS

There are four major topics in the reservoir water quality prediction process: a vegetation inventory and decomposition study; an analysis of the thermal stratification and wind-driven circulation patterns; an estimate of dissolved oxygen consumption within the water mass; and a projection of the recovery process.

2.1 Biomass Decomposition

Biodegradable Fraction

The great diversity of organic chemical compounds which constitute the various parts of the vegetation can hardly be overestimated. After flooding, each substance decays following unique chemical pathways, producing different intermediate compounds and interacting at various rates with other substances. Detailed predictions