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DEVELOPMENT OF BASIS FOR ESTABLISHING EUTROPHICATION MANAGEMENT PROGRAM FOR SPANISH IMPOUNDMENTS

by

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INTRODUCTION

A four-year cooperative study is being conducted by the Centro de Estudios Hidrográficos of the Spanish Ministry of Public Works and the Environmental Engineering Program of the Department of Civil Engineering at Colorado State University, for the purpose of assessing the current trophic status of and providing a framework for developing a eutrophication-related water quality management program for the reservoirs in Spain. While almost no natural lakes exist in Spain, there are over 700 dams, some of which are several centuries old, impounding surface waters throughout the country. Development of this large number of impoundments has been in response to the highly irregular rainfall volume and distribution in the country. The main uses of the impounded waters include irrigation, drinking water supply, stream flow regulation, as well as electric power generation. Many of Spain's reservoirs are experiencing or have the imminent potential to experience water quality problems associated with excessive fertility, problems which will be aggravated in future years due to increasing population and urbanization, and a lack of nutrient control programs. This study was undertaken to provide the foundation for assessing and controlling these problems.

OVERALL APPROACH

The overall approach being taken in this study is to define the nutrient (P) load - eutrophication-related water quality response relationship for a representative group of P limited Spanish impoundments. Governmental agencies and others within Spain will then be able to evaluate the water quality in the remaining waterbodies by estimating their

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nutrient loads and then predicting the associated eutrophication-related water quality characteristics of the waterbodies based on this load-response relationship. For those reservoirs determined to be excessively fertile (eutrophic), the degrees of water quality improvement that could be achieved could then be predicted based on estimates of the amount of nutrient load reduction possible under various control strategies.

As discussed herein, preliminary investigations by the authors indicated that the OECD eutrophication modeling approach would be the most appropriate approach to take to define nutrient load - eutrophication response relationships for Spanish impoundments and to evaluate the benefits to eutrophication-related water quality of various nutrient management strategies. The OECD (Organization for Economic Cooperation and Development) eutrophication study program, completed in 1979, was a five-year, multination study undertaken to define the relationships between nutrient (P) load and eutrophication (planktonic algal) related water quality response in waterbodies. Load and response data were evaluated for about 200 lakes, impoundments, and estuaries in 22 OECD member nations (including the U.S., Canada, Japan, Australia, and countries in Western Europe). These waterbodies were divided into four Regional Projects. The approximately 34 U.S. waterbodies or parts thereof were included in the North American Project; the results of the U.S. portion of this project's study were published by the US EPA (Rast and Lee, 1978). One Spanish waterbody, El Burguillo, an impoundment located near Madrid, was included in the OECD study in the Shallow Lakes and Reservoirs Project. The results of the several year study of El Burguillo and the studies of the project's other waterbodies were published by Clasen (1979). The overall OECD eutrophication study synthesis report, as well as the other project reports, are currently in the process of being published.

The framework for evaluating the data collected in the OECD eutrophication study was provided by R. Vollenweider (1968, 1975, 1976) who developed a number of correlations between the P load to a waterbody and the waterbody's water quality. Among the more practical was the relationship he defined between the P load to a waterbody normalized by the waterbody's mean depth and hydraulic residence time, and the mean summer chlorophyll concentration in the waterbody. While Vollenweider's original correlation was based on a limited data base, it showed considerable promise. Rast and Lee (1978), using the more extensive US OECD data base, refined this relationship and defined corollary relationships between normalized P load and Secchi depth and between normalized P load and hypolimnetic oxygen depletion rate. Recently Jones and Lee (1980a) provided further refinement of the P load - chlorophyll and P load - Secchi depth relationships by adding the load-response characteristics for another 40 or so U.S. waterbodies. They found that these relationships were essentially the same as those developed by Rast and Lee. The remaining OECD waterbodies have also been found to follow relationships similar to those developed based on the US OECD waterbody data.

This widespread applicability of the Vollenweider-OECD P load-response relationships provided the initial foundation for selecting this approach for use in this Spain-U.S. cooperative study. However, many of the reservoirs in Spain experience large-scale fluctuations in mean depth and hydraulic residence time, major factors in the

Vollenweider-OECD eutrophication models, over the annual cycle due to climatic characteristics and operation of the reservoirs. One of the first tasks of the cooperative Spain-U.S. study is, therefore, to assess the applicability of these models to Spanish impoundments and to develop and evaluate modifications in the model that may have to be made to accommodate the characteristics of these reservoirs.

To accomplish the objectives of the study, 14 waterbodies have been selected for study. These waterbodies and some of their pertinent characteristics are listed in Table 1; their locations in Spain are shown in Figure 1. The selection of the study reservoirs was done on the basis of 1) their being located in areas where local laboratories could collect and analyze water samples, and make field measurements according to the specifications of the principal investigators (Lee and Jones, 1979; Lee et al. 1979; Lee and Jones, 1980), 2) their amenability to study, i.e., their being located in well-defined watersheds with a limited number of tributaries, and having accessibility for sampling; 3) their being representative of the wide ranges of characteristics of Spanish impoundments, including size, hydraulic residence time, nutrient sources, and climates and terrain of the country. The study programs for each of these reservoirs typically include weekly flow and nutrient concentration measurements in each of the major tributaries to the reservoirs and biweekly measurement of in-lake characteristics such as chlorophyll, Secchi depth, dissolved oxygen, nutrient concentrations, etc., over a two to three year period. Through this study program, which has been discussed in detail by Lee and Jones (1979), the limiting nutrient, nutrient (N and P) loads, and eutrophication-related water quality response of the waterbodies will be defined.

PRELIMINARY RESULTS

Preliminary nutrient load and eutrophication-related water quality estimates needed for application of the OECD eutrophication models are available for five of the reservoirs being studied (Table 2). The phosphorus load estimates were made on the basis of the types of land-use in the watershed (which for these waterbodies was predominantly rural), the amount of rainfall, and the number of people in the watershed. These three sources are typically the major P sources to waterbodies. The specific nutrient export coefficients used in making the load estimates were based in part on those found for nutrient export from land in the U.S. (Rast and Lee, 1978) and the experience of the authors in viewing the waterbodies' watersheds, determining an appropriate classification and making a judgment as to an appropriate export value. The P load estimates presented in Table 1 are, therefore, relatively crude. Only for El Burguillo is there reliable P load information, which was derived from the OECD study (Ortiz, 1978). For El Burguillo, the load determined by Ortiz was essentially the same as that estimated based on land-use, indicating that the export coefficients for that waterbody were likely appropriate. However, for Sau Reservoir on which there had been a previous study (Vidal, 1976), the two P load estimates were a factor of 4 different. This points to the need to obtain reliable measurements of phosphorus loads and define nutrient export coefficients that are suitable for Spain's land-use categories. The chlorophyll and Secchi depth values reported in Table 1 for all but El Burguillo and Sau are based on results of ongoing water quality monitoring studies being

Table 1. BACKGROUND DATA OF THE SPANISH RESERVOIRS SELECTED FOR THE COOPERATIVE PROJECT

Reservoir	Year of impound-ment	Catchment area (Km^2)	Average annual rainfall (mm)	Storage capacity (Hm^3)	Maximum water surface area (Km^2)	Maximum depth (m)	Mean depth(2) (m)	Retention time(3) (days)	Human population (4): Total	Human population (4): In area not covered by tributary sampling stations	Major land-use type
El Burguillo	1913	1,050	850	213	8.9	69.5	23.9	155	21,000	-100	rural
Picadas (1)	1952	218	570	17	0.9	52.0	18.8	11	5,582	840	rural
Pinilla	1967	246	900	40	4.7	29.9	8.5	62	2,089	0	rural
Riosequillo (1)	1956	385	800	49	3.1	45.0	15.7	75	1,322	400	rural
El Atazar (1)	1972	923	750	468	12.0	126.4	40.1	665	1,179	1,179	rural
Valmayor	1975	78	800	124	7.5	51.0	16.5	3,187	16,000(5)	?	rural
Guajaraz	1971	37	360	25	1.6	34.5	15.6	255	4,180	294	rural
La Concepcion	1971	115	900	61	2.1	68.4	28.5	578	1,546	0	rural
Ribarroja (1) (6)	1969	11,757	400	291	21.5	34.0	13.5	5	215,000	4,000	rural
Sau (6)	1963	1,784	900	177	7.6	73.5	23.0	115	67,044	4,876	rural
Foix (6)	1928	295	650	<6	0.6	12.0	<10.0	<195	30,000	3,700	rural
San Pons	1957	292	850	24	1.3	54.6	19.2	102	2,253	0	forest
Añarbe (1)	1976	52	2,000	44	2.0	68.0	22.0	?	50	0	forest
Articutza	1962	11	2,500	3	0.2	32.0	15.0	?	0	0	forest

(1) Reservoir located downstream from a dam; catchment area does not include that of the upstream impoundment.
(2) Refered to full pool conditions in impounded water.
(3) Theoretical values calculated according to the average annual water load and the reservoir storage capacity.
(4) Data obtained from the Instituto Nacional de Estadistica, refered to the period 1960-1970.
(5) 10,000 additional inhabitants during four months have been taken into account.
(6) Significant inputs from industrial sources (Ribarroja, paper mill; Sau, sausage mills; Foix, liquor industry; San Pons, pig farms).

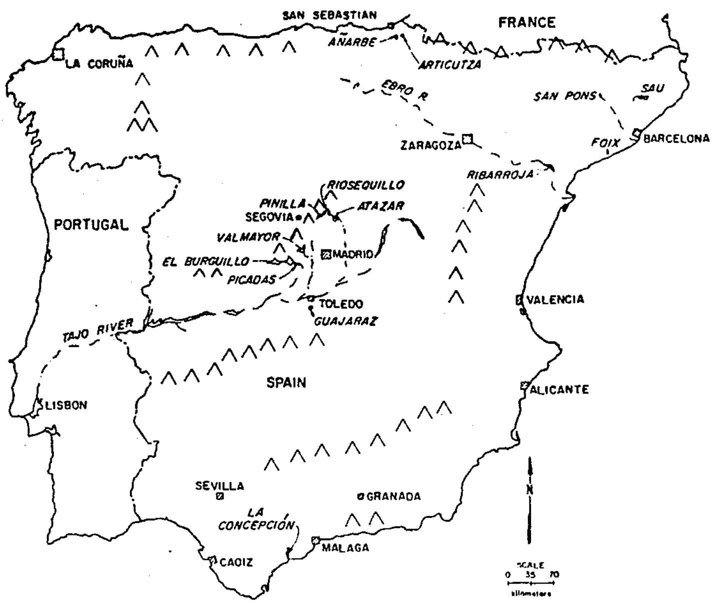

Figure 1. Spanish Impoundments Included in Cooperative Study.

TABLE 2. PRELIMINARY ESTIMATES OF PHOSPHORUS LOADING (based on land use) AND WATER QUALITY IN FIVE RESERVOIRS SELECTED FOR THE NUTRIENT LOAD-EUTROPHICATION RELATIONSHIP STUDY

	Identi-fication Number	P load from land runoff(1) (kg P/yr)	P load from rainfall & dry fallout(2) (kg P/yr)	P load from domestic wastewater(3) (kg P/yr)	Est. total P load (kg P/yr)	Areal P load ($g P/m^2/yr$)	Mean Summer Chlorophyll (mg/m^3)	Mean Summer Secchi depth (m)
El Burguillo	1	10,500	445	15,825	26,770(25,000(4))	3.85(4,5)	13	2
Guajaraz	2	370	80	3,150	3,600	2.25	2.2	4
La Concepción	3	1,150	105	1,200	2,460	1.17	2	2.3
Sau	4	17,840	380	53,940	72,160(282,000(6))	37	21	1.6
San Pons	5	2,920	65	1,720	4,700	3.61	2	2.5

(1)Total P rural land export coefficient, 0.01 $g P/m^2/yr$.

(2)Total P precipitation and dry fallout coefficient, 0.05 $g P/m^2/yr$.

(3)Annual per capital total P output, 750 g P/person/yr.

(4)Ortiz (1978).

(5)Based on average water surface area (6.5 Km^2), mean depth (20.5m) and hydraulic residence time (0.36 yr.).

(6)Vidal (1976).

conducted by the Centro de Estudios Hidrográficos, Madrid.

Figure 2 shows the Vollenweider-OECD relationship between phosphorus loading and relative eutrophication-related water quality in terms of recreational suitability. Using this model, it has been found (Vollenweider, 1975; Rast and Lee, 1978) that waterbodies which are typically thought to be eutrophic plot in the upper part of the figure; those which are oligotrophic tend to plot in the lower portion. Further, it has been found that for a set of waterbodies having the same mean depth/hydraulic residence time ratio, but different areal P loadings, or for a single waterbody under different P loading conditions, there is a gradation of water quality among them with those having poorer water quality plotting above those with better water quality. Figure 2 shows that these five Spanish waterbodies plot in the area where waterbodies characterized as eutrophic to eutrophic-mesotrophic typically plot. Based on the overall OECD eutrophication study results, Vollenweider (personal communication) developed a probability distribution of how the OECD principal investigators classified their waterbodies, based on the chlorophyll concentration. Using this system and the estimated average chlorophyll concentrations, El Burguillo would be classified as mesotrophic-eutrophic, Sau as eutrophic, La Concepción as oligotrophic-mesotrophic, and Guajaraz and San Pons as mesotrophic. These classifications match reasonably well with the general locations of these waterbodies in Figure 2, except for La Concepción, and reflect the actual and potential eutrophication-related water quality problems existing in these reservoirs.

Figure 3 shows the line of best fit developed for the P load-chlorophyll response couplings for the US OECD waterbodies and the positions of the five Spanish impoundments based on the preliminary data. While the data points lie within the general variability of the points upon which this line was developed, they deviate somewhat from it. It must be recalled that the data bases for characteristics of all but El Burguillo are extremely limited; it is expected that when the P loads have been measured and the chlorophyll concentrations and Secchi depth monitored over several summer periods, these points will fall substantially closer to the line of best fit. If they do not, investigations will be made into the characteristics of these waterbodies, such as the variability of their mean depths and hydraulic residence times, existence of stratified flow conditions, nutrient input patterns, etc., to try to account for their nutrient behavior. The fact that these waterbodies plotted fairly close to the line of best fit found applicable to about 300 waterbodies and the fact that El Burguillo, for which there is a several-year data base, fits the line, indicates that the basic approach has utility for these waterbodies.

Figure 4 presents the Vollenweider-OECD P loading - Secchi depth relationship developed for the US OECD waterbodies and the five Spanish impoundments relative to it. These waterbodies appear to have about the same P load-Secchi depth couplings as the US OECD waterbodies, a fact which further increases confidence that the basic approach of the OECD eutrophication models is appropriate for Spanish impoundments.

Figures 5 and 6 are temperature and oxygen isopleths for a sampling location near the dam of El Burguillo for 1976, an unusually dry year in

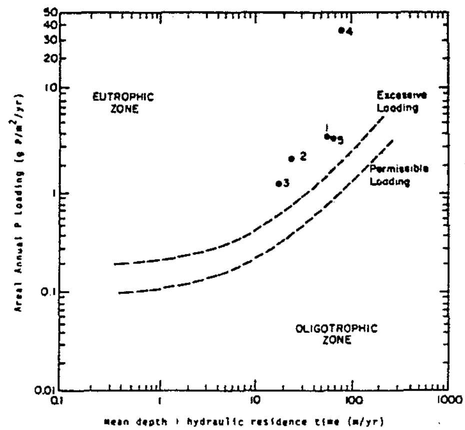

Figure 2. Vollenweider P Loading - Relative Eutrophication-Related Water Quality Diagram (See Table 2 for reservoir identification)

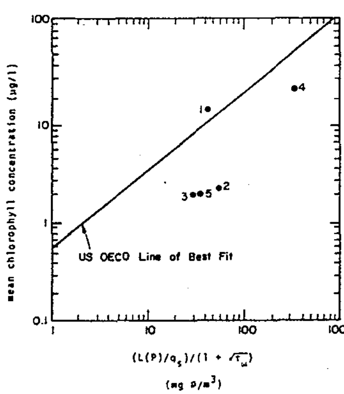

Figure 3. US OECD P Load - Chlorophyll Relationship Applied to Spanish Impoundments (See Table 2 for reservoir identification)

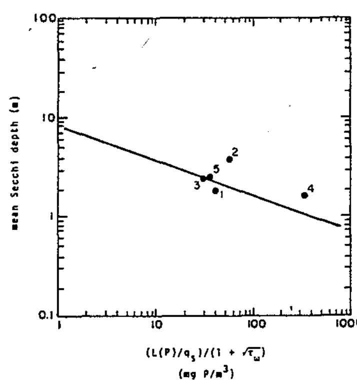

Figure 4. US OECD P Load - Secchi Depth Relationship Applied to Spanish Impoundments (See Table 2 for reservoir identification)

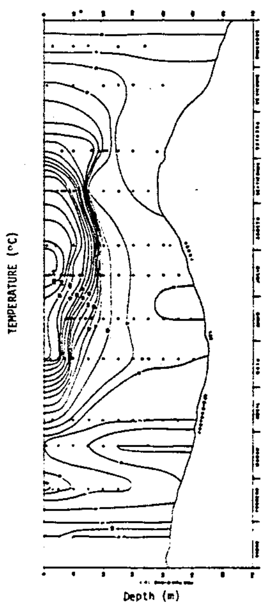

Figure 5. Temperature Isopleths for El Burguillo near Dam.

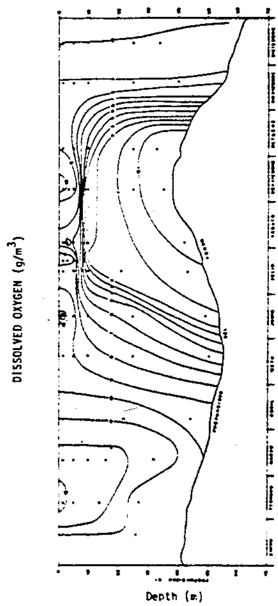

Figure 6. Dissolved Oxygen Concentration Isopleths for El Burguillo near Dam.

Western Europe. They show the characteristic seasonal oxygen depletion typical of eutrophic waterbodies. As part of this cooperative study an attempt will be made to define the relationship between P load and hypolimnetic oxygen depletion rate since for many waterbodies hypolimnetic oxygen depletion appears to be accounted for by the amount of algae grown in the surface water, which decompose and use oxygen in the bottom waters. Definition of such a relationship would allow predictions to be made of what the P load would have to be to maintain any given level of dissolved oxygen in the hypolimnetic waters of the waterbody. A reasonably good correlation has been developed by Rast and Lee (1978) for the US OECD waterbodies, between P load and hypolimnetic oxygen depletion rate. However, the Spanish reservoirs typically have a variable water withdrawal depth; sometimes the water is withdrawn from the hypolimnion, sometimes from the epilimnion or from areas in between. Hypolimnetic withdrawal will cause a change in the hypolimnetic volume which may necessitate modification in US OECD P load-oxygen depletion rate model, which was based for the most part on lakes which have a more "constant"-natural hypolimnetic volume.

SUMMARY AND CONCLUSIONS

A U.S.-Spanish cooperative study has been undertaken for the purpose of providing a framework upon which to develop a program to manage eutrophication-related water quality in Spain. From the preliminary investigations discussed above it has been concluded that the Vollenweider-OECD eutrophication modeling approach will be suitable for describing the P load-response relationships for Spanish impoundments and for describing the benefits to eutrophication-related water quality that can result from various management-operation options including increasing or reducing P loads or altering the mean depths or hydraulic residence times of the reservoirs.

Fourteen "representative" Spanish waterbodies are currently being intensely monitored; it is expected that these nutrient loading and response data will be collected over a two to three year period for most of these waterbodies. These data will be used to refine nutrient export coefficients for Spanish terrain and to verify or modify the load-response models for these reservoirs. Characteristics peculiar to Spain's waterbodies as well as other reservoirs that could necessitate modification of the models include their highly varying mean depth and hydraulic residence time and in some areas very limited rainfall. The results of this study will enable the Spanish government to estimate the load-response relationships for the other nearly 700 Spanish reservoirs and to make decisions regarding degrees of nutrient control or types of reservoir management necessary for particular waterbodies to achieve desired eutrophication-related water quality characteristics.

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