PUBLIC POWER CORPORATION
D.M.K.Y.

ARAKHTHOS RIVER
MIDDLE COURSE HYDROELECTRIC PROJECTS

REPORT ON ALTERNATIVE STUDIES

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CHAPTER 6 : HYDROLOGY

6.1. DISCUSSION OF DATA PROVIDED BY PPC

In terms of the Specification, the hydrometeorologic data needed by ASAG for evaluation of the energy output from the scheme, the design flood data as well as data on sediment loads are to be provided by PPC. The obligation of ASAG is to comment on this data and to ensure that it is reliable before using it for project design purposes.

The data that have been provided by PPC up to the present time are listed in chapter 2 of this report. As noted there, PPC have not yet provided a full and final hydrological report for the Middle Course projects, but have provided a preliminary set of data for use in the comparative designs required for the Alternative Studies. The methods of calculation used by PPC, the adequacy of the data and the form of presentation, which are similar to those of the data supplied by PPC for the Upper Course projects, were commented upon by ASAG in the October 1981 Interim Report on the Steno-Kalaritikos hydroelectric project. As a result of ASAG's comments, certain aspects of the hydrological studies for the Upper Course, in particular the design storm duration and the design flood peaks and volumes, were reviewed and modified by PPC.

For the initial reservoir operation studies and also for the sizing of spillways and diversion works, ASAG has had to modify the preliminary Middle Course data provided by PPC to take into account ASAG's comments noted above. The way in which this has been done is described in the relevant parts of this section.

A summary of the major features of the hydrological data provided by PPC for the Aghios Nikolaos and Pistiana dam sites is given in Table 6.1.

Table 6.1

Summary of hydrometeorologic data provided by PPC

Dam site	Aghios Nikolaos	Pistiana
1. Total catchment area at the site	1.118 km^2	1.222 km^2
2. Mean annual precipitation (1950 - 1978)	1.669 mm	1.679 mm
3. Mean annual discharge (1950 - 1978) a)	46,2 m^3/s	50,9 m^3/s
b)	1.303 mm	1.313 mm
4. Flood peaks :		
20 year return period (diversion works)	1.916 m^3/s	2.100 m^3/s
10.000 year return period (spillways)	4.461 m^3/s	4.895 m^3/s

6 2. MONTHLY STREAMFLOW DATA

Composite monthly flow sequences covering the period between October 1950 and September 1978 at Plaka, Aghios Nikolaos and Pistiana were provided by PPC, in addition to those provided for sites further upstream. These show generally that the intermediate catchments downstream of Stenon and Kalaritikos dam sites contribute substantially to the discharge of the Arakhthos river, and that the provision of regulating storage capacity in the Middle Course reservoirs should therefore be investigated.

The monthly discharges for the hydrological years 1979 and 1980 at the upstream sites and the corrected monthly discharges for the Pournari dam site were provided by PPC during the course of the studies but too late for them to be included in the reservoir operation studies presented in 7.2. They will be taken into account during the Master Plan studies.

6.3. FLOOD STUDIES

6.3.1. Alternative approaches

In order to estimate the discharges for which a spillway must be designed, it is necessary to route the design inflow sequence through the reservoir, in order to estimate the attenuating effect of any flood storage provided between the normal and maximum flood levels of the reservoir.

In the case of a reservoir with a small flood storage volume, or where the spillway incorporates gates so that the flood level is not significantly higher than normal reservoir level, flood routing is less important and the spillway can be designed to cater for the peak of the design inflow sequence without serious loss of accuracy. However, in cases where the reservoir has a large flood storage capacity, for example in the case of High Pistiana, significant attenuation of the design flood is likely, and a flood routing analysis becomes important if an accurate assessment of spillway capacity is to be provided.

The design floods estimated by PPC were based on the assumption of a characteristic storm duration, which is determined by the mean annual precipitation of the basin and the catchment response time. A duration of 15 hours was used in the Upper Course flood studies, and it would appear that the same duration was adopted for the Middle Course.

Depending on the characteristics of observed storms and measured maximum precipitations for various storm durations, it is possible and indeed likely that the flood peaks produced by storms of longer duration could be higher than those for shorter durations such as the 15-hour characteristic duration estimated by PPC. Certainly the flood volumes associated with longer-duration events are bound to be greater.

For a reservoir with a large flood storage, a flood having a larger volume but a smaller peak than the flood with the maximum peak could require a larger maximum spillway capacity. The critical storm is thus not necessarily the storm with the largest peak flow. In order to determine the critical storm duration for any particular reservoir using this approach, it is therefore necessary to perform routing analyses using floods produced by a range of storm durations and to determine the maximum spillway discharge in each case.

The use of the approach outlined above implies that the precipitation occurring during the design storm has a certain characteristic distribution. This may be first or second quarticle, two-peaked etc. The most appropriate distribution could either be selected on the basis of observed storm distributions, or alternatively various alternative distributions could be tested in order to determine that which produces the maximum runoff.

An alternative method of distributing the precipitation, which must inevitably lead to a conservative assessment, is that used by Verbund-Plan (1972). In this method, the blocks of rainfall occurring at selected intervals during a storm with adequately long duration are systematically arranged in such a way that they produce maximum runoff. As pointed out by Verbund-Plan, this method automatically leads to the flood having the maximum peak flow rate being combined with the flood producing the largest volume, which must of course be that having the longest possible duration. By comparison, longer duration events examined using the first-mentioned method above do not necessarily incorporate the highest rates of precipitation occurring during shorter-duration events.

6.3.2. Tentative estimation of design floods

In the absence of design floods for storms having durations longer than 15 hours it was decided to generate tentative design floods for use in estimating the capacity and hence cost of spillways for purposes of the Alternative Studies.

It was appreciated that PPC would in due course supply all necessary design flood data, which would be used in preference to the tentative assessments described herein. Nevertheless it was considered necessary to produce these assessments as it was obvious that the cost of spillways for Middle Course dams would in some cases represent an appreciate proportion of total development cost.

The results of the studies are summarized in Table 6.2, the more important aspects of which are discussed as follows :

(i) Reservoir top water levels

At the time the studies were performed, the possible geological and hydrogeological limitations on the maximum top water levels had not been determined. A broad range of top water levels was taken to cover all possibilities that might have come out of the subsequent studies. The full range of maximum water levels are presented in this chapter so that trends can be observed. The spillway crest levels which correspond to developments whose feasibility is doubtful are given in brackets.

(ii) Spillway characteristics

At the time when the studies were performed, it was thought that the chute spillways at Aghios Nikolaos site D and High Pistiana would be ungated. Spillway crest lengths were calculated on the assumption that a maximum surcharge of 7 m would be provided in each case.

Table 6.2

Summarised results of flood studies

Dam site		Aghios Nikolaos						Pistiana			
		Site B1			Site D			High			Low
Spillway Crest level		+ 250	+ 270	*** (+ 290)	+ 250	+ 270	*** (+ 290)	+ 250	*** (+ 270)	*** (+ 290)	+ 170
Spillway Type		Morning Glory (Double)			Ungated ogee			Ungated ogee			Gated ogee
Spillway Geometry (m)					L=123.3	L=123.3	L=121.0	L=104.3	L=95.4	L=88.4	
Capacity (m³/s)		5200	5200	5200	5300	5300	5200	4500	4100	3800	6000
Design storm characteristics	Critical storm duration (h)	36	36	36	36	36	36	36	36	36	36
	Time pattern	50 % Second quartile storm									
	Total rain depth (mm)	332	332	332	332	332	332	442	488	488	332
	Losses (%)	12	12	12	12	12	12	12	12	12	12
	Losses (mm)	40	40	40	40	40	40	53	58	58	40
	Net rain depth (mm)	292	292	292	292	292	292	389	430	430	292
Inflow hydrograph characteristics	Flood duration (W)	78	78	78	78	78	78	104	116	116	80
	Net flood volume (m³ 10⁶)	327	327	327	327	327	327	475	525	525	357
	Total flood volume (m³ 10⁶)	397	397	397	397	397	397	566	631	631	429
	Peak inflow rate (m³/s)	5400	5400	5400	5400	5400	5400	5422	5080	5080	5917
	Time to peak (h)	22	22	22	22	22	22	33	39	39	22
Outflow hydrog. characteristics	Routing duration (h) *	78	79	83	78	79	84	178	212	261	80
	Peak discharge (m³/s)	5061	4987	4930	5287	5216	5128	4443	4075	3756	5916
	Time to peak (h) peak (h)	24	24	24	23	23	24	37	43	46	22
Routing characteristics **	Inflow volume (m³ 10⁶)	189	189	189	170	170	189	326	368	410	
	Outflow volume (m³ 10⁶)	164	155	146	148	139	197	195	209	220	
	Storage volume (m³ 10⁶)	24	34	43	22	31	42	130	159	187	

* Time until D-I 1 m³/s

** Volumes until the time to outflow peak

***Feasibility doubtful - see 6.3.2 (i).

(iii) Design storm characteristics

For both sites at Aghios Nikolaos and for all the spillway levels examined, a storm duration of 36 hours has produced the maximum spillway discharge. This is because the 36-hour storm produces a higher flood peak than the 24-hour or 48-hour storm, and the attenuation provided by the Aghios Nikolaos reservoir is insufficient to reduce the maximum spillway discharge to a rate below that of the 48-hour storm. On the other hand it may be noted that the critical storm duration increases from 36 hours in the case of Low Pistiana to 60 hours in the case of Pistiana (250 m), and increases further to 72 hours for higher levels at Pistiana. In this context it is interesting to note that a design storm duration of 72 hours was also used by PPC to determine the design flood for Pournari dam.

The storm distribution assumed, a 50 % second quartile storm, was based on the assertion in the PPC hydrological report on the Steno-Kalaritikos project, to the effect that such a distribution produced the maximum runoff for the basin.

Storm losses of 12 % were assumed in the calculations, these being consistent with the values used by Verbund-Plan (1972) and close to the 11 % assumed by PPC in the case of Pournari.

(iv) Inflow and outflow hydrograph characteristics

The magnitude and characteristics of the attenuation of the inflow floods which will be provided by the dams in the Upper Course of the Arakhthos river was not available at the time these studies were carried out. The conversative assumption was therefore made that there would be no attenuation. The actual attenuation will be taken into account in future studies. The attenuation provided by the Aghios Nikolaos reservoirs is very small, the spillway discharge being almost as large as the peak inflow. However, at High Pistiana the routing effect is quite substantial, with spillway discharges between 74 % and 82 % of the peak inflow rate depending on the spillway level.

The inflow and outflow peaks for durations other than 36 hours, where calculated, are shown in Tables 6.3 and 6.4. Comparison of these peak inflows at Aghios Nikolaos and Pistiana with those given by PPC for a storm duration of 15 hours reveals that the values in Table 6.3 are about 14 % higher than the PPC values. The differences can be explained almost entirely by the difference in assumed storm losses. It may be noted that the design flood data supplied by PPC for the Steno-Kalaritikos project assumed losses of about 26 %, compared with those of 12 % assumed in the tentative flood calculations under discussion here.

It may be deduced from comparison of the relative magnitudes of the 48-hour peak inflow and the 36-hour peak outflows for Aghios Nikolaos that the 48-hour peak outflow must always be smaller than the 36-hour peak outflow. This is not immediately apparent at site B1 but a single check, for the case of spillway level 290 m, is sufficient to confirm that the 36-hour peak outflow is critical in all cases at this site as well.

At Pistiana, it is seen that for spillway crest level 250 m the 60-hour flood peak is higher than both the 48-hour and the 72-hour peaks, and is thus the critical flood. For higher crest levels this is not the case, as the 72-hour flood peak is higher than the 60-hour value. Again, however, a single check (for the 84-hour flood peak) is sufficient to confirm that the 72-hour flood peak is critical.

Table 6.3

Inflow hydrograph peaks (m³/s)

Rain duration (h) / Site	15	24	36	48	60	72	84
Aghios Nikolaos Sites B1 and D	5082.2	5370.8	5399.5	5021.1	-	-	-
Pistiana	5530.6	5875.6	5916.5	5564.2	5421.9	5080.3	4743.4

Table 6.4

Outflow hydrograph peaks (m³/sec)

Rain duration (h) / Site		15	24	36	48	60	72	84
Aghios Nikolaos								
Site B1	CL=250	-	-	5061.3	-	-	-	-
	CL=270	-	-	4987.5	-	-	-	-
	(CL=290)**	-	-	4930.4	4809.0	-	-	-
Site D	CL=250	-	-	5286.6	-	-	-	-
	CL=270	-	-	5216.2	-	-	-	-
	(CL=290)**	-	-	5217.6	-	-	-	-
Pistiana								
Low	CL=170	5530.6	5875.6	5916.5	5564.2	5421.9	5080.3	4743.4
High	CL=250	-	-	4276.1	4380.8	4442.9	4412.6	-
	(CL=270)**	-	-	-	-	4053.6	4075.1	-
	(CL=290)**				3582.5	3703.7	3756.3	3674.2*

Note

CL : Crest level

** : Feasibility doubtful - see 6.3.2 (1)

- : Not calculated

* : Estimated (not directly calculated)

6.4. RESERVOIR SEDIMENTATION

As is pointed out in ASAG's Interim Report on the Steno-Kalaritikos project, the derivation of a reliable relationship between sediment load and discharge is a hazardous procedure, and could lead to serious inaccuracy in the estimation of the volume that might be expected to enter the reservoirs during their operating lives.

On the other hand, the measured rates at Arta between 1962 and 1975 suggest an average erosion of 3060 m^3/km^2/year or nearly 3 mm over the catchment as a whole.

It is suggested in the Interim Report referred to above that a representative value for the Middle Course catchments might be 1500 m^3/km^2/year, compared with 1000 m^3/km^2/year in the Upper Course catchment areas. These values are more consistent with erosion patterns in Greece as a whole.

Difficulties in predicting the rates of sedimentation in the Middle Course reservoirs are expected to arise not only from uncertainties regarding the suspended sediment load which is transported from remote parts of the catchments, but also regarding the contribution from steep erosion scars immediately adjacent to the reservoir. One scar has an estimated volume of more than $2 \cdot 10^6 m^3$, and the rate at which is and others like it might be expected to grow will require careful consideration in the Master Plan studies.

As pointed out in 4.7.2. (ii) the slumping of material into the reservoir upon initial filling will require careful assessment, althouth this will not necessarily lead to a significant reduction of the live storage.