TRAINING COURSE

ON

RESERVOIR OPERATION

(UNDER WORLD BANK AIDED HYDROLOGY PROJECT)

Module 18

Reservoir Operation

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A Case Study

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RESERVOIR OPERATION - A CASE STUDY

1.0 INTRODUCTION

The rules used to regulate water resources system should be based on the economic trade off among the effects of alternative decision possibilities. However, the operator in the field has neither the time nor the facts for economic analysis before making individual operating decisions. The only practical approach is to analyse the various factors ahead of time to device a body of rules which, when followed will produce results close to the economic optimum as possible. The rule must be expressed in a form which can be readily understood and followed by the project operator.

The operating rules tell the operator of each facility what to do in specific situation described by the current state of the system for reservoir storage, expected stream flows, demand for project output and various other parameters. The rules are not intended as rigid and inflexible limit on pool elevations as of a given date. Those are rather a guide based on analysis of all past records to aid the operator in his continuous gamble to attain maximum efficiency from a project designed for several basically opposed uses.

The multipurpose Sardar Sarovar Project is being constructed at the down stream reach of river Narmada to provide irrigation, power and flood control benefits to vast area of Gujarat, Madhya Pradesh and Maharashtra. The Gross Capacity of the reservoir is 9.50 TMCM, having 5.80 TMCM live storage capacity, it will generate power with installed capacity of 1450 MW and irrigate an area of 17.92 lakh hectares annually. In view of the conflicting requirements of the above objectives, an in depth study to lay down policies for their optimal as well as safe regulation, both during monsoon and non monsoon seasons is presented. The compromising filling schedule have been proposed for the reservoir to ensure gradual filling of the reservoir up to the FRL and at the same time, adequate flood storage space is made available to absorb the floods during filling season. Other data is given in Table-1.

Operation policies for different service levels for regulation of reservoir for non monsoon period is evaluated for minimum alarming level. During monsoon seasons filling schedule will serve the same purpose.

During the flood, outflow from the reservoir excluding conduit and irrigation releases is proposed to be slab system of releases. Accordingly twelve different slab levels having eleven release values are proposed to serve the purpose of flood moderation. The regulation of three largest historic flood which occurred on September 1970, August 1973 and September 1978 are studied with these release guides and found to be quite effective.

1.1 DERIVATION OF FILLING RULE CURVE

The general procedure to accomplish filling rule curve is to find out the storage space required to absorb the flood impinged on particular date, assuming that the reservoir can be permitted to reach maximum Water Level (MWL) at the end of regulation period, such that regulated discharges are safe for down-stream. Thus obtained storage space required for absorption of particular flood, may be deducted from storage capacity at MWL and the balance storage would be the permissible storage at the beginning of flood. This can be achieved by mass-curve analysis of incoming flood and regulated floods also. Like this storage spaces required and balance storages permissible may be obtained for various floods occurred on respective dates. These permissible storage may then be plotted on graph against data and smooth curve is drawn touching to FRL at end of filling season. The curve thus prepared will be the filling rule curve.

Since there are only five floods out of which three floods were occurred practically the same date so we can get only one point. To get the approximate idea of these points, the methodology used by Damodar Valley Corporation, can be used. The Sardar Sarovar reservoir is assumed to be full at the end of September. According to this methodology, the reservoir content at the beginning of September is obtained by subtracting surplus of September months inflow after serving the necessary targeted requirements successively. The storage of beginning of September be the storage at the end of August. Now the storages at beginning of August and July are also calculated on the same manner. These storages against respective dates is the filling rule curve for that particular monsoon season.

Now inflows of 90, 85, 80 and 75 percent dependable monsoon seasons are analysed and resulting filling rule curves are plotted. Computation work involved is explained in Table 2 and rule curves in Figure 1.

Now simulation can be used for testing these rule curves. Let us explain 80% dependable flow condition. According to this rule curve, the initial levels on 1st July to be 124.85 m, end of July or beginning of August to be 127.60 m, end of August or beginning of September to be 135.14 m and same way end of September to be 138.68 m. The reservoir storages to be 5.725, 6.282 and 8.315 TMCM respectively. So the maximum water level at 1st July or 31st June should not exceed 124.85 m and storages 5.725 TMCM as per 80% dependable flow. All the above set of rule curves were tested. A comparative statement of various deficits in supply are given in Table 3. After that by trial and error a number of sets of values of rule curves were assumed and were checked for satisfactory conditions. After that we come to a particular combination of points which satisfy most of the time as well as makes enough space for flood absorption. The final filling schedule is given in Table 4.

From the Table 3 it is seen that conventional method of operation gives the least deficit in both irrigation and energy requirement, but it may not define the space needed for flood control. The final filling curve gives 13 months deficit in irrigation and 62 months deficit in power out of 264 months, i.e., 5% and 23.5% deficit respectively.

1.2 DERIVATION OF DEPLETION CURVE

With the operating procedure mentioned here, regulation of reservoir under study has been simulated sequentially for 22 years following filling schedules of reservoir, such that during wet years targeted demands are served and during dry years as much as possible water is utilized from reservoir accepting elimination of services and/or curtailment of services continued over a season or a year according to priority of water use. From the old historical records it is seen that during this period, i.e., October - June there were no remarkable floods, so no need for flood storage space. Since the inflow to the reservoir is the only uncertain so we can't say that 100 percent of the times the reservoir will fill up to FRL.

Since the reservoir may not fill up to FRL every year, an operation rule curve is proposed which will alarm the operator that if just on the curve then it will serve all demands for 90% of the times. But if the levels falls below the indicated levels then we have to curtail supply of water to services as per priority of uses. But if we follow this rule curve up to June end of the reservoir level will reach to Dead Storage Level. So the operator may be advised to release the water as required for targeted demand if the reservoir level is well above the indicated level.

The above mentioned rule curve is evaluated as follows. It is assumed that at the end of operating season, i.e., end of June reservoir may be allowed to reach dead storage level if required. Then considering 90% dependable flow year, the reservoir contents at beginning of June is obtained by subtracting surplus of June Month's inflow after serving the targeted requirements successively. In the same way the beginning storages for all the months up to October are calculated. However, October beginning storage can be taken at FRL. If we plot the levels corresponding to these storages and join by a curve, that will be the depletion rule curve. The computational work involved is given in Table 5 and the rule curve is given in Figure 2.

1.3 MULTIPURPOSE OPERATION

For reasons of economy, multiple use of reservoir storage is almost invariably resorted to by combining flood control with other uses like irrigation and hydropower. In such cases, effort is to strike maximum compromise between the conflicting requirements of flood control and conservation by resorting joint use of as much storage space as possible for both the objectives.

Flood control requires that the reservoir should have the necessary storage space available to regulate the floods and absorb the water above the safe limit at all the times during which floods are expected. In fact, the Central Water Commission (C.W.C. 1976) criteria stipulates, that even the maximum possible flood should be expected to occur any time throughout the filling period. This would mean that the reservoir should have the maximum empty storage throughout the filling season. On the other hand, post filling season requirements need that as large a storage as possible should be available at the end of the filling season. Where power generation is involved, it would be preferable to have the reservoir near a level which will give the design head as long as possible.

At lower heads, the plant generation capacity is considerably reduced and the load capacity is adversely affected. At very low head operation is risky as cavitation damages are likely to be heavy.

Since space requirements for flood control may reduce towards the end of flood season, and since filling of storage for conservation takes place only progressively, some compatibility can always be achieved without sacrificing too much. Thus, it is possible to provide more flood control space in the early part of the filling season and recover it partly or wholly as the flood season approaches to its end. This multiple purpose operation is accomplished by specifying a "rule curve" which partitions the total space by setting upper limits for the conservation storage, and thereby allocating certain space for flood control on any given date. This rule curve is "filling rule curve", and is essentially part of the overall operation policy which would effect both the flood control and conservation benefits.

1.4 PROPOSED RELEASE GUIDES

The Full Supply Level of reservoir is 138.68 m where as the crest level of spillway is 121.92 m which is far below, so spillway is to be controlled, by gates and release guides proposed are to be stepped pattern. The storage capacity above Full Supply Level is only 5.28 TMCM. But from the old historical record it is seen that all the major floods occurred in the month between end of August and 1st week of September. So at this time according to filling rule curve reservoir level is less than F.R.L. which provide additional storage for floods.

Eleven different slabs of release having twelve different elevations are proposed for Sardar Sarovar Reservoir. At respective levels, free discharging capacities of spillways (see Figure 3) are larger than proposed one. With gradual increase of level ranges, release slabs are also gradually increased such that at MWL the maximum permissible releases are equal to safe down stream discharges. In case of Sardar Sarovar safe discharge for down stream is assumed to be 60,000 cumecs. Permissible release Guide during flood operation is given in Table 6.

1.5 MODERATION OF SOME HISTORIC FLOOD

Three very high recorded floods are considered for moderation and to examine whether given filling schedule and release slabs are successful or not. The flood, which occurred in September 1970, was extra ordinarily high, substantially larger than any previously recorded flood, but the flood which occurred in Aug.-Sept.'73, though peak was somewhat less than 1970, but total volume was more. The third flood considered, occurred in Aug.-Sept.'78. A study for the above three floods has been carried out by the flood routing method, i.e., proposed slab releases. The results are shown in Figures 4 to 6.

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Table - 1 : Downstream Irrigation and Energy requirments

S.No.	Month	Percentage of annual target	Monthly Requirment	Percentage of Annual target	Volume of water TMCM (monthly)	Percentage of Annual target	Monthly Targeted Energy(MWHR)
1	July	0.4	0.005	3.959	0.388	7	171780
2	August	0.4	0.005	8.028	0.786	8	196320
3	September	12.2	0.159	19.429	1.903	9	220860
4	October	3.0	0.039	11.057	1.083	9	220860
5	November	10.1	0.132	13.373	1.310	9	220860
6	December	5.0	0.065	8.720	0.854	10	245400
7	January	14.8	0.193	12.825	1.256	10	245400
8	February	22.2	0.290	11.347	1.111	9	220860
9	March	11.6	0.152	4.599	0.451	8	196320
10	April	6.8	0.089	1.770	0.173	7	171780
11	May	6.2	0.081	1.753	0.172	7	171780
12	June	7.3	0.097	3.140	0.308	7	171780
Total		100.00	1.307 TMCM	100.000	9.795 TMCM	100	2454000

Table - 2 : Sardar Sarovar Reservoir Approximate Filling Schedule for various percentage of Depdendable Flows

% Dependable Man-soon Flow	Month	Initial Reservoir level (m)	Initial Reservoir storage (TMCM)	Inflow to the Reservoir (TMCM)	Total reservoir storage at Beg. (TMCM)	Irrigation requir-ment for power (TMCM)	Water requir-ment for power (TMCM)	Evapora-tion loss (TMCM)	Total Releases (TMCM)	Reservoir storage at end (TMCM)	Reservoir level at end (m)	Energy Genera-ted (MWhr)
90%	July	128.67	6.524	1.657	8.181	0.388	0.709	0.058	1.155	7.026	130.72	171780
	Aug	130.72	7.026	3.342	10.368	0.786	0.768	0.058	1.612	8.756	136.48	196320
	Sep	136.48	8.756	3.552	12.308	1.903	0.847	0.058	2.808	9.500	138.68	220860
85%	July	127.90	6.350	1.321	7.671	0.388	0.723	0.058	1.169	6.502	128.58	171780
	Aug	128.85	6.502	3.556	10.08	0.786	0.774	0.058	1.618	8.440	135.53	196320
	Sep	135.53	8.440	3.873	12.313	1.903	0.852	0.058	2.813	9.500	138.68	220860
80%	July	124.85	5.725	1.733	7.458	0.388	0.730	0.058	1.176	6.282	127.60	171780
	Aug	127.60	6.282	3.654	9.936	0.786	0.777	0.058	1.621	8.315	135.14	196320
	Sep	135.14	8.315	4.000	12.315	1.903	0.854	0.058	2.815	9.500	138.68	220860
75%	July	112.90	3.932	1.714	5.673	0.388	0.819	0.058	1.265	4.408	116.61	171780
	Aug	116.61	4.408	5.348	9.756	0.786	0.781	0.058	1.625	8.131	134.57	196320
	Sep	134.57	8.131	4.186	12.317	1.903	0.856	0.058	2.817	9.500	138.68	220860

Table - 3 : A comperative Statement of Monthwise deficit during the period of 22 years

Rule curve on the Basis of	Deficit in Irrigation												Total No. of Months of Deficit
	J	A	S	O	N	D	J	F	M	A	M	J	
90% Dependable Flow	0	0	0	0	3	0	2	5	1	0	0	0	11
85% Dependable Flow	0	0	0	0	3	0	2	7	1	0	0	0	13
80% Dependable Flow	0	0	0	0	3	0	2	7	1	0	0	0	13
75% Dependable Flow	0	0	0	0	3	0	3	9	1	0	0	0	16
Proposed	0	0	0	0	3	0	2	7	1	0	0	0	13
Conventional	0	0	0	0	1	0	2	4	0	0	0	0	7
	Deficit in Energy												Total No. of Month Deficit
	J	A	S	O	N	D	J	F	M	A	M	J	
90% Dependable Flow	1	1	3	3	3	3	4	12	7	6	6	6	55
85% Dependable Flow	1	1	3	3	3	4	4	11	7	6	6	6	55
80% Dependable Flow	1	1	4	3	3	3	6	12	8	7	6	6	60
75% Dependable Flow	3	3	5	3	4	6	9	14	10	8	7	7	79
Proposed	2	2	3	3	3	5	6	12	8	6	6	6	62
Conventional	1	1	2	1	2	7	5	5	6	5	6	6	47

* There is no deficit for down stream/Municipal & Industrial use.

Table - 4 : Proposed Reservoir Filling Schedule

	1st July	15th July	1st August	15th August	1st September	15th September	30th September
Reservoir level in meter	127.91	128.25	128.58	134.57	135.57	136.63	138.68
Reservoir storage in TMCM	6.350	6.426	6.502	7.316	8.131	8.816	9.500

Note : The intermediate values are found by linear interpolation.

Table - 5 : Operation Schedule for depletion period

Month	Initial Reservoir level (m)	Initial reservoir storage (TMCM)	Inflow to the Reservoir (TMCM)	Total Reservoir storage of Beginning (TMCM)	Irrigation requiremen t (TMCM)	Water require for power (TMCM)	Evaporation requirement (TMCM)	Total Releases (TMCM)	Reservoir storage at end (TMCM)	Reservoir level at end (m)	Energy Generated (MWHR)
Oct	136.35	8.714	1.292	10.006	1.083	0.883	0.058	2.024	7.982	134.09	220860
Nov	134.09	7.982	1.255	9.237	1.310	0.914	0.058	2.282	6.955	130.45	220860
Dec	130.45	6.955	1.455	8.410	0.854	1.035	0.043	1.932	6.478	128.47	245400
Jan	128.47	6.478	1.472	7.950	1.256	1.082	0.043	2.381	5.569	124.01	245400
Feb	124.01	5.569	1.333	6.902	1.111	1.031	0.036	2.178	4.724	118.85	220860
Mar	118.85	4.724	0.993	5.717	0.451	0.945	0.036	1.432	4.285	115.70	196320
Apr	115.70	4.285	0.885	5.170	0.173	0.840	0.036	1.049	4.121	114.43	171780
May	114.43	4.121	0.917	5.038	0.172	0.852	0.058	1.082	3.956	113.10	171780
Jun	113.10	3.956	0.988	4.944	0.308	0.878	0.058	1.244	3.70	110.64	171780

Table - 6 : Permissible Release Guide During Flood Operation For Sardar Sarovar Reservoir

S.No.	Reservoir Level Range (m)	Slab Releases (cumecs)
1.	134.57 - 135.00	10,000
2.	135.00 - 135.50	14,000
3.	135.50 - 136.00	20,000
4.	136.00 - 136.50	25,000
5.	136.50 - 137.00	35,000
6.	137.00 - 137.50	45,000
7.	137.50 - 138.00	48,000
8.	138.00 - 138.68	50,000
9.	138.68 - 139.00	53,000
10.	139.00 - 139.50	55,000
11.	139.50 - 140.21	60,000*

* For very high floods.

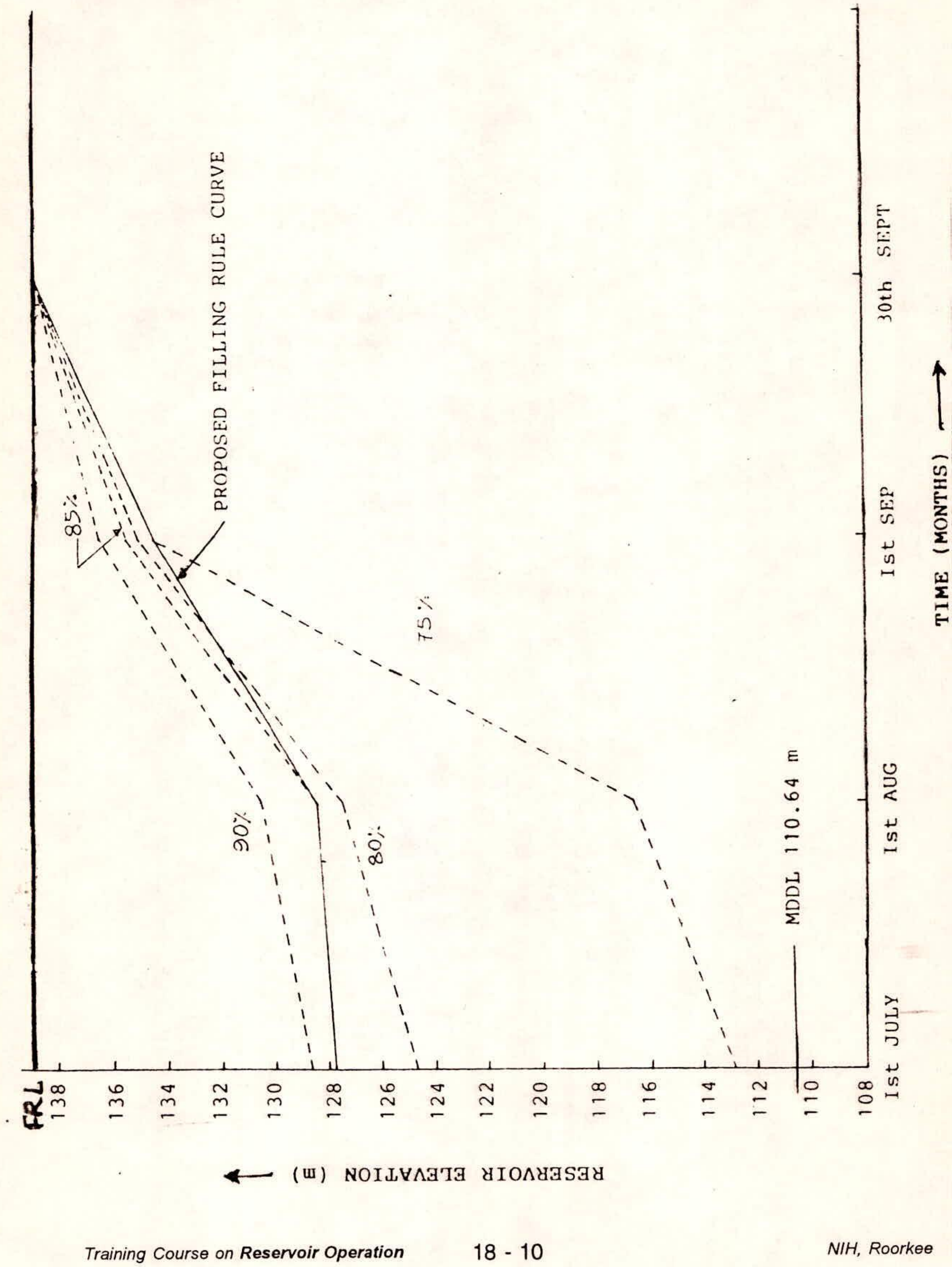

Fig. 1 Sardar Sarovar Reservoir Filling Rule Curve

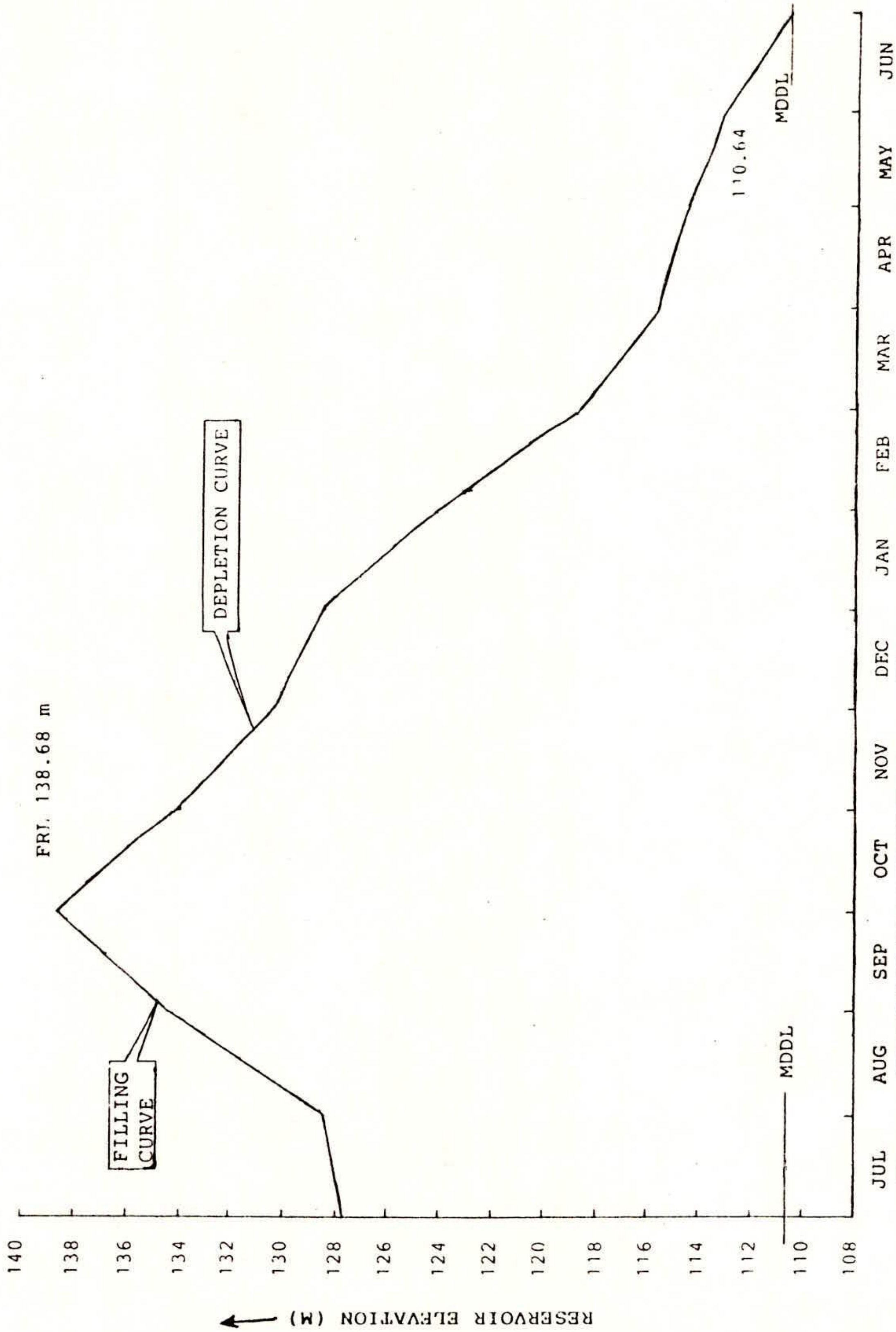

Fig. 2 Sardar Sarovar Operation Rule Curve

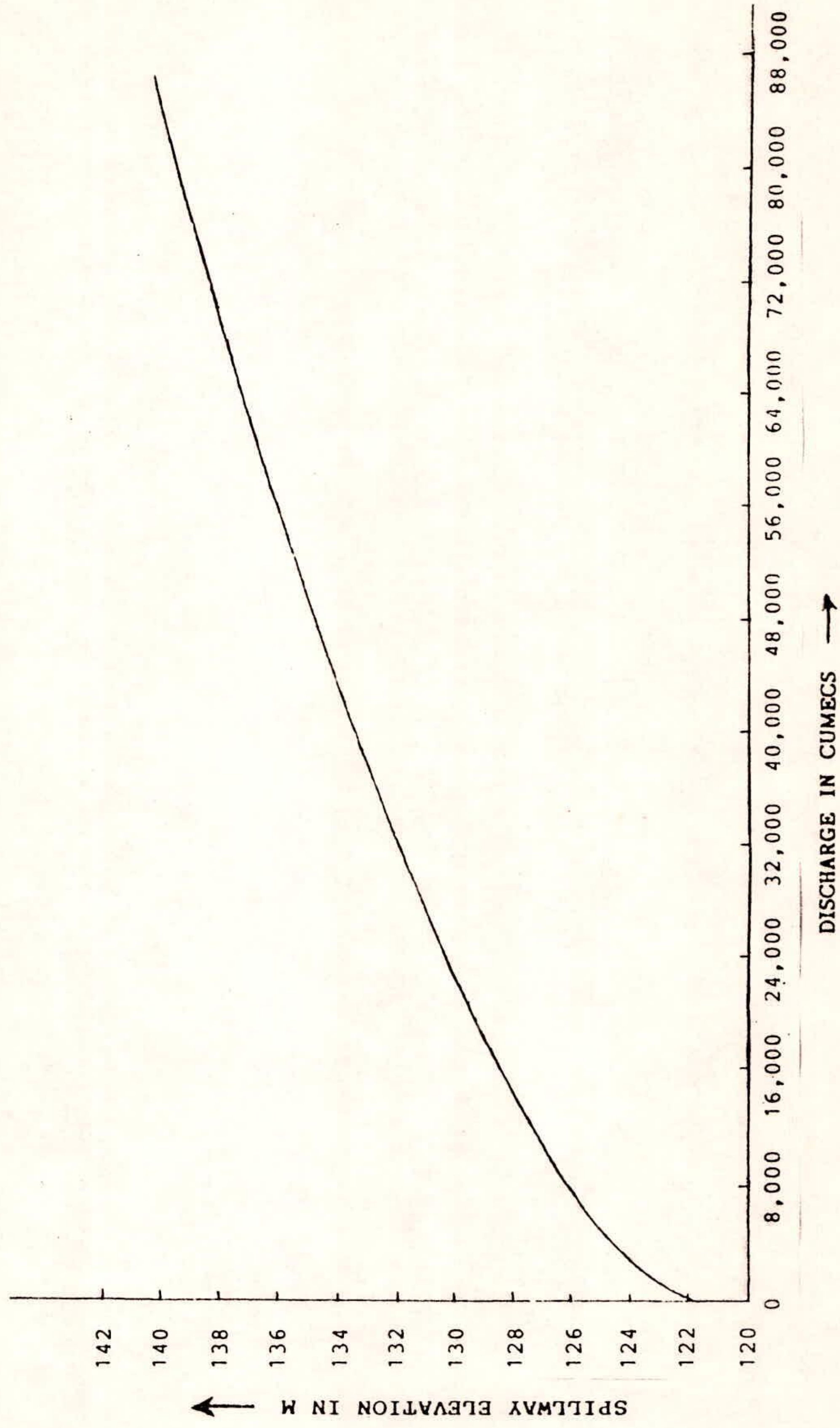

Fig. 3 Spillway Rating Curve of Sardar Sarovar Dam

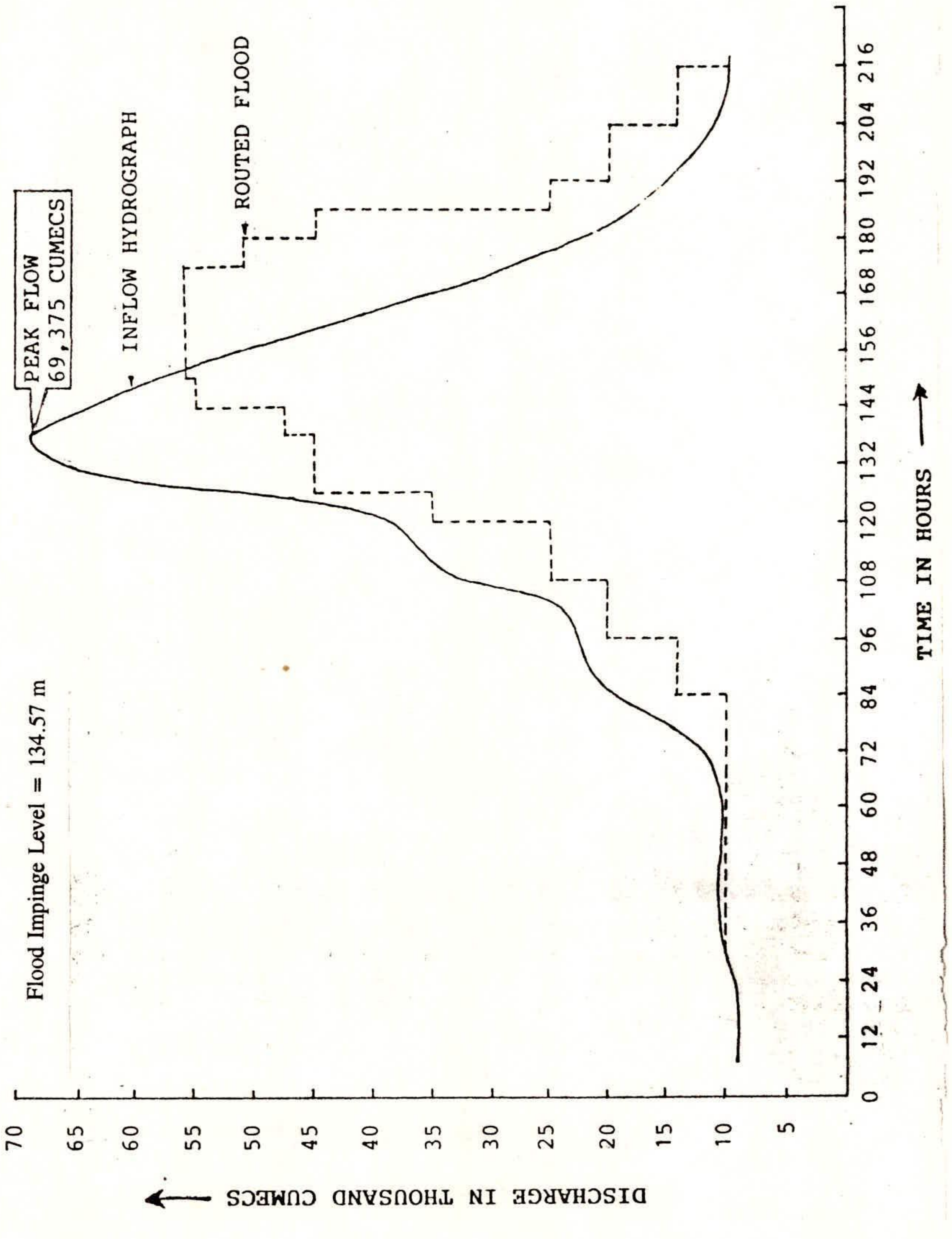

Fig. 4 Moderation of September 1970's Flood

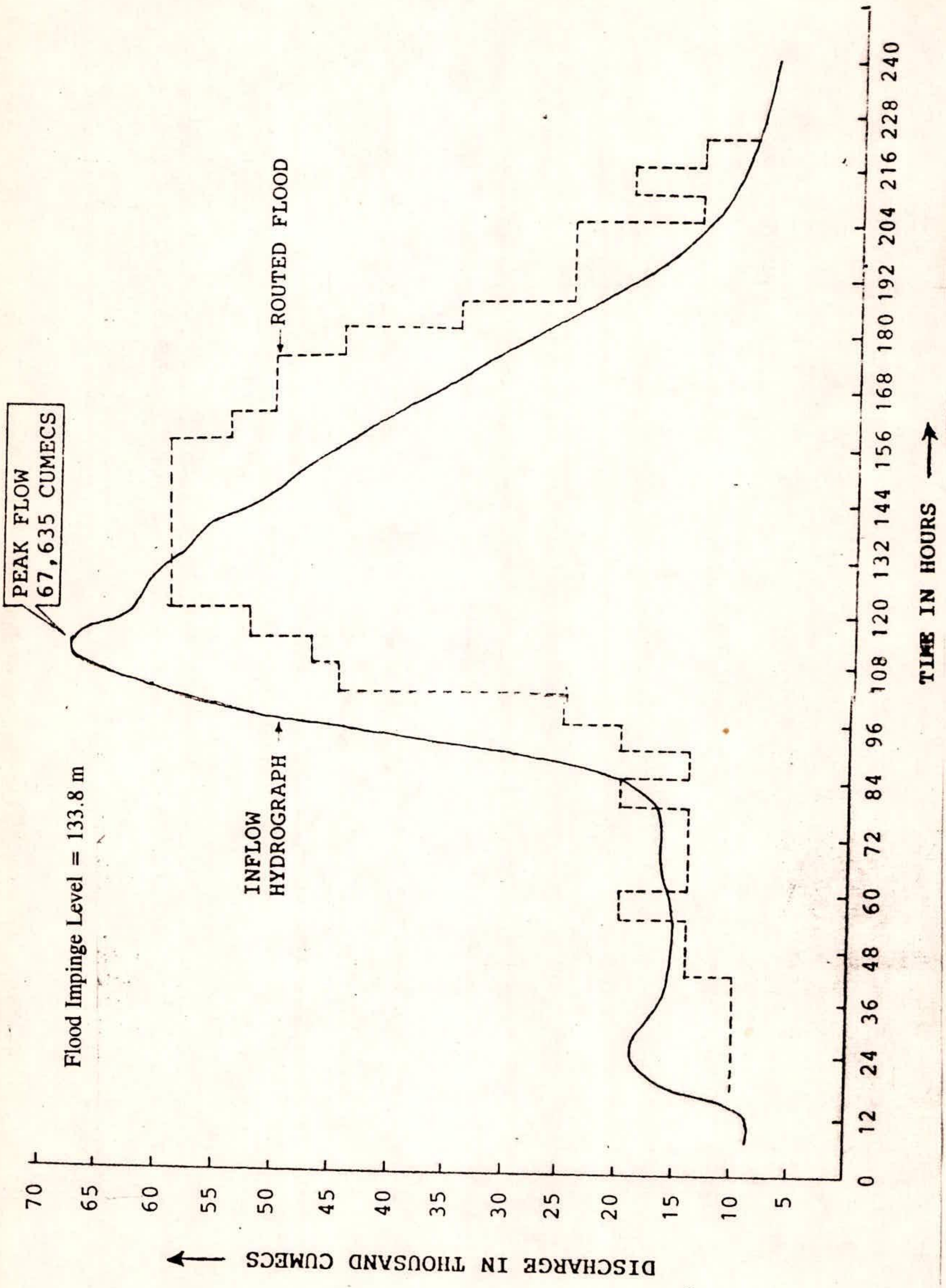

Fig. 5 Moderation of 1973's Flood

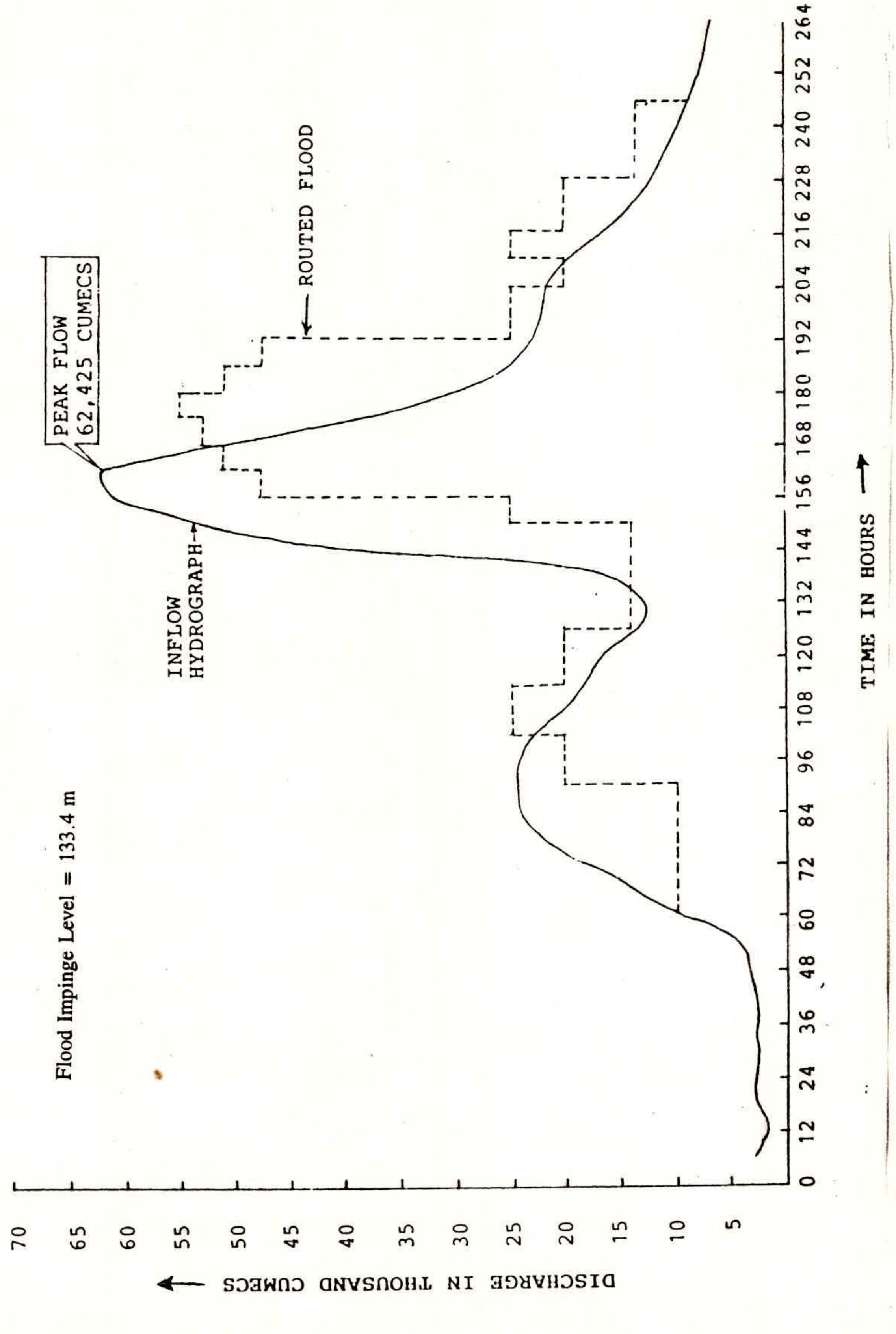

Fig. 6 Moderation of 1978's Flood