Institute of
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NOTES ON THE FURTHER
ANALYSIS OF FUTURE
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NOTES ON THE FURTHER ANALYSIS OF FUTURE LAKE VICTORIA LEVELS

1. General

1. The stochastic simulation model for Lake Victoria presented in the report 'A Review of the Hydrology of Lake Victoria and the Victoria Nile' suggested that the levels of the lake likely to be experienced in the future have a large range. In particular the model results gave an unacceptably high probability that the lake levels would reach so high as to endanger the Owen Falls dam.

2. One aim of these notes is to assess the order of magnitude of the changes necessary either to the release policy at the dam, or by way of structural changes to increase the discharge capacity from the lake, so that the dam should not be endangered.

3. A second aim is to assess the effects of operating the dam for hydropower generation, so that relatively higher releases would be sustained at lower levels than currently, with the possibility of compensating for this by decreasing the release when levels are moderately high.

4. To a certain extent these two problems can be treated separately provided that changes to the release policy made at high levels are not so substantial as to affect the probability of occurrences of low levels, and vice versa. A common approach to the two problems has been used which enables an assessment of this separation to be made.

5. No attempt has been made to arrive at a best overall policy for the future: obviously this would require careful assessment of the consequences of any changes in terms of the affect on the regimes of both the lake levels themselves and the flows in the Victoria Nile and further downstream.

6. As in the previous report we take as the base line for comparisons the release policy defined by

$$V = \begin{cases} 5.73\ (L - 7.96)^{2.01} & , \ L > 7.96 \\ 0 & , \ L < 7.96 \end{cases} \qquad (1.1)$$

where V is the outflow in million m^3/day and L is the lake level in metres above the Jinja gauge. This curve gives a good approximation to the currently adopted agreed release policy over the range of the established tables and provides a reasonable extrapolation for higher levels.

7. Results from the model tests by HRS suggest that the natural flows at high levels may have been higher than given by (1.1), and as an approximation to these we have briefly considered modifying the releases above 13 metres to

$$V = 3.58\ (L - 7.96)^{2.30} \qquad , \ L > 13.023 \qquad (1.2)$$

and otherwise using (1.1). The precise change point is chosen to ensure a continuous curve.

8. Because of the modified forms of release policy that were to be considered it was necessary to reformulate the lake level simulation program so as to avoid numerical problems arising from discontinuous outflow-level curves. A series solution of the integral equation for lake levels was adopted, and trials showed that this gave very good agreement with the previous approach when applied to the continuous outflow-level relation (1.1).

9. Possible modified released policies or structural changes to the dam itself are sought for which the safe limit on lake levels would be exceeded in any one year with a probability of the order of one in ten thousand. We have taken a lake level of 14.0 metres to represent the current limit of safe operation, and some results are also given relating to critical levels of 14.5, 15 and 15.5 metres in order to provide some comparison between the options of increasing the capacity of the dam and increasing the release capability.

10. When considering the possible operation of the dam to generate a firm hydropower requirement by maintaining a minimum release from the lake, there is no effective structural limit to how far levels in the lake could be drawn down. However we have taken the lowest recorded lake level of 10.22 metres as a critical point, since it is likely that many lake shore facilities would have been designed with this level in mind. The earlier report showed that the stochastic simulation model gave quite a high probability for lake levels falling below this level, but it is not suggested that the dam should be operated so as to make this probability extremely small. Rather an acceptable strategy might be to ensure that any modified release rule would result in lake levels falling below 10.22 metres about as often as they would have done if the agreed "natural" release curve were followed.

11. Our reservations about the stochastic model, which were noted in our report, still hold. However, the results reported here using this model should give a good indication of the trade-off between the various options available and do represent our current best assessment of the likely behaviour of future lake levels.

12. The results given here for high lake levels relate to the maximum monthly lake level within each year, while the results for low levels refer to the minimum level within the year. This is in contrast to the results quoted in our report which were in terms of end-of-July levels. The simple adjustments suggested in that report have been found to be adequate, but the results reported here have been calculated directly from the simulated annual maxima and minima to avoid any possible problems with the approximation.

2. High Lake Levels

13. A first question is: supposing it were required to follow the release curve (1.1) at all levels, how much higher would the dam have to be to ensure safe operation? It would take a large amount of computer resources to achieve relatively precise estimates of the extreme percentage points of the distribution of maximum level in any year, but for the purposes here fairly rough estimates are possibly all that are needed. From limited simulations our best estimates of the 1/10,000, 1/5000 and 1/1000 points of the distribution are 15.53, 15.25 and 14.75 metres respectively: the standard error of estimation of these levels due to the limited simulations are assessed as 0.30, 0.20, and 0.05 metres respectively.

14. Since it is not clear what releases might be adopted as representing the natural flow over Owen Falls at high levels we have considered also the release rule (1.2). Releases according to (1.1) and (1.2) at 14 metres would be 212.8 and 224.0 million m^3/day respectively, while at 15 metres the corresponding values would be 289.6 and 318.6. For the higher releases of (1.2) the 1/10000, 1/5000 and 1/1000 points of the distribution of annual maxima were estimated to be 15.30, 15.13 and 14.67.

15. The present discharge capacity of the dam is in practice limited. If the release rule for the dam were taken to be given by (1.1) with an upper limit of 216 million m^3/day (2500 m^3/sec), then the 1/10,000, 1/5000 and 1/1000 points of the marginal distribution would be increased to 16.13, 15.75 and 15.10 metres respectively: the limit on outflow would come in effect of lake levels over 14.04 metres. If a more conservative limit of 172.8 million m^3/day (2000 m^3/sec) were taken, which would come into effect at 13.41 metres, then the corresponding levels would be 17.06, 16.59 and 15.69 metres.

16. For the release policy (1.1) and assuming an unlimited storage capacity, the long run probability that lake levels would exceed 14.0 metres in any one year is 0.0087: the standard error of estimation of this probability is approximately 0.0007.

17. With releases made according to (1.2) 14 metres would be at the 0.0077 probability point of the distribution of annual maxima.

18. The amount of warning of the likelihood of levels exceeding 14.0 metres is the subject of Figure 2.1(a). This shows for various initial lake levels at the beginning of January in year 1, the probability that the maximum level within each succeeding year will exceed 14 metres. In fact these probabilities assume that catchment conditions at the start of the period are average, and so if the lake levels were to rise sharply to 13.5 metres say, then the probabilities of exceeding 14 metres in the succeeding years would be higher than reported in Figure 2.1(a) because the catchment would be relatively more responsive to future rainfalls. An exact analysis taking into account initial catchment conditions has not been attempted, but the magnitude of the effect can be estimated by adding 0.3 m to the initial starting level to account for the extra inflows to be expected with an initially wet catchment rather than with average conditions.

19. The results above are based on 3000 simulated sequences of 30 years length, with the last 15 years being pooled to form estimates of the long-run distributions of lake levels. Most of the subsequent results are based on only 1000 simulated sequences, and for this reason some of the extreme percentage points presented in graphical form may not correspond exactly with those given above.

20. As a reasonable type of modification to the 'natural' release policy (1.1) we have examined the following: it is assumed that there is a maximum possible release from the dam and that the policy is to discharge water from the lake at this maximum rate as long as the lake level is above a given threshold, otherwise the release is according to the natural curve. A range of representative values for the maximum release rate has been taken and it is of interest to see at what point the threshold would have to be set in order to meet the safety requirements. The maximum discharge rate from the lake would be achieved by the combination of releases from the dam itself and from any diversion channels necessary to meet the required rate.

21. Maximum release rates of 172.8, 216, 270, 324 and 432 million m^3/day have been taken: ie 2000, 2500, 3125, 3750 and 5000 m^3/sec respectively. Releases this high would not be made until the lake level reached 13.41, 14.04, 14.76, 15.40 and 16.55 metres respectively, if the "natural" curve were followed.

22. The effects of some modifications of the release rule on the year-on-year probabilities of exceeding 14 m are shown in Figure 2.1(b) (which is similar to Figure 2.1(a)), for a maximum release of 2000 m^3/sec.

23. Figures 2.2 (a) and (b) show the effect of varying both the maximum release rate and threshold on the probability that the lake levels in any year would exceed critical levels of 14, 14.5, 15 and 15.5
metres. The results show that with the currently available discharge capacity, the maximum rate of discharge would have to be employed at levels lower than 11 metres in order to reduce the probability of levels reaching 14 metres to acceptable levels.

24. Also shown in Figure 2.2 are the results obtained by using an independent set of simulated sequences with the maximum release rate set at 324 million m^3/day. It is clear that very extensive simulations would be needed to get good estimates of the combinations of discharge rates and threshold that would, for example, just achieve a 1 in 10000 probability for the lake levels exceeding 14 metres in any one year.

25. The extent to which modifying the releases from the lake in the above way affects the probability of the lake levels passing given critical values within a 30 year time horizon is the subject of Figures 2.3and 2.4, and these also provide some comparison with the effects of modifying the release policy at low lake levels which are considered in Section 3. In all cases an initial lake level of 12.0 metres is assumed.

26. Figures 2.3 and 2.4 show the effect of the various choices on the probabilities of the lake levels either rising above 14 metres or falling below 10.22 metres in any month within a 30 year time

horizon. The latter shows that there is little effect on the probabilities of low lake levels provided that the threshold at which increased discharge is made is above 13 metres.

27. The way in which the distribution of annual maximum lake levels is affected by changes in the release policy is shown in Figure 2.5. More details of the effects are shown in Figures 2.6(a) and (b).

28. Figure 2.7 shows the effects of different release policies on the lake levels for a given sequence of lake inflows which were found to produce high lake levels under the 'natural' release rule.

Probability of exceeding 14·0 m in given year for various starting levels at beginning of January [Releases according to 'natural' curves (1·1)]

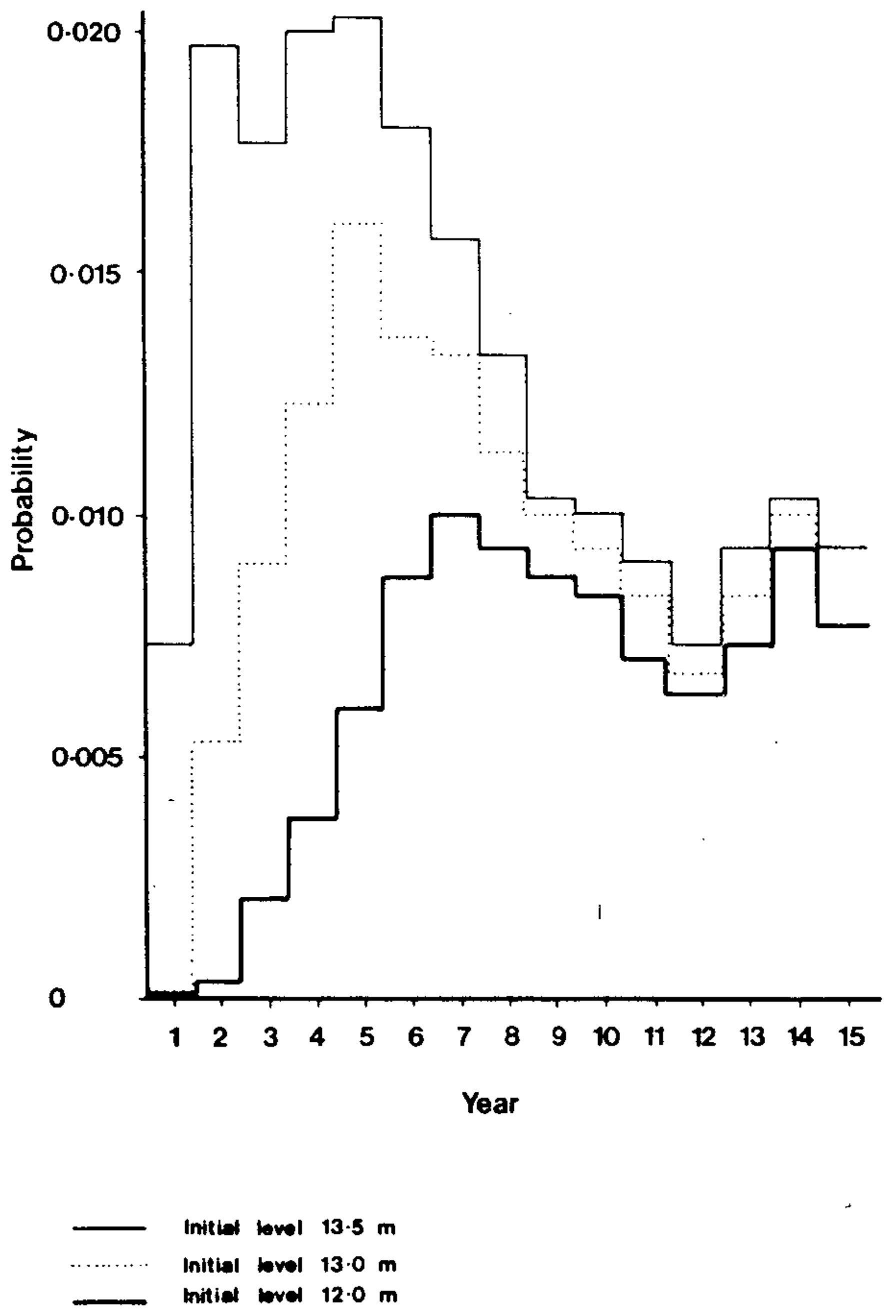


Figure 2·1 [a]

Probability of occurrence in each year of levels exceeding 14·0 m

[Starting level 12·0 m]

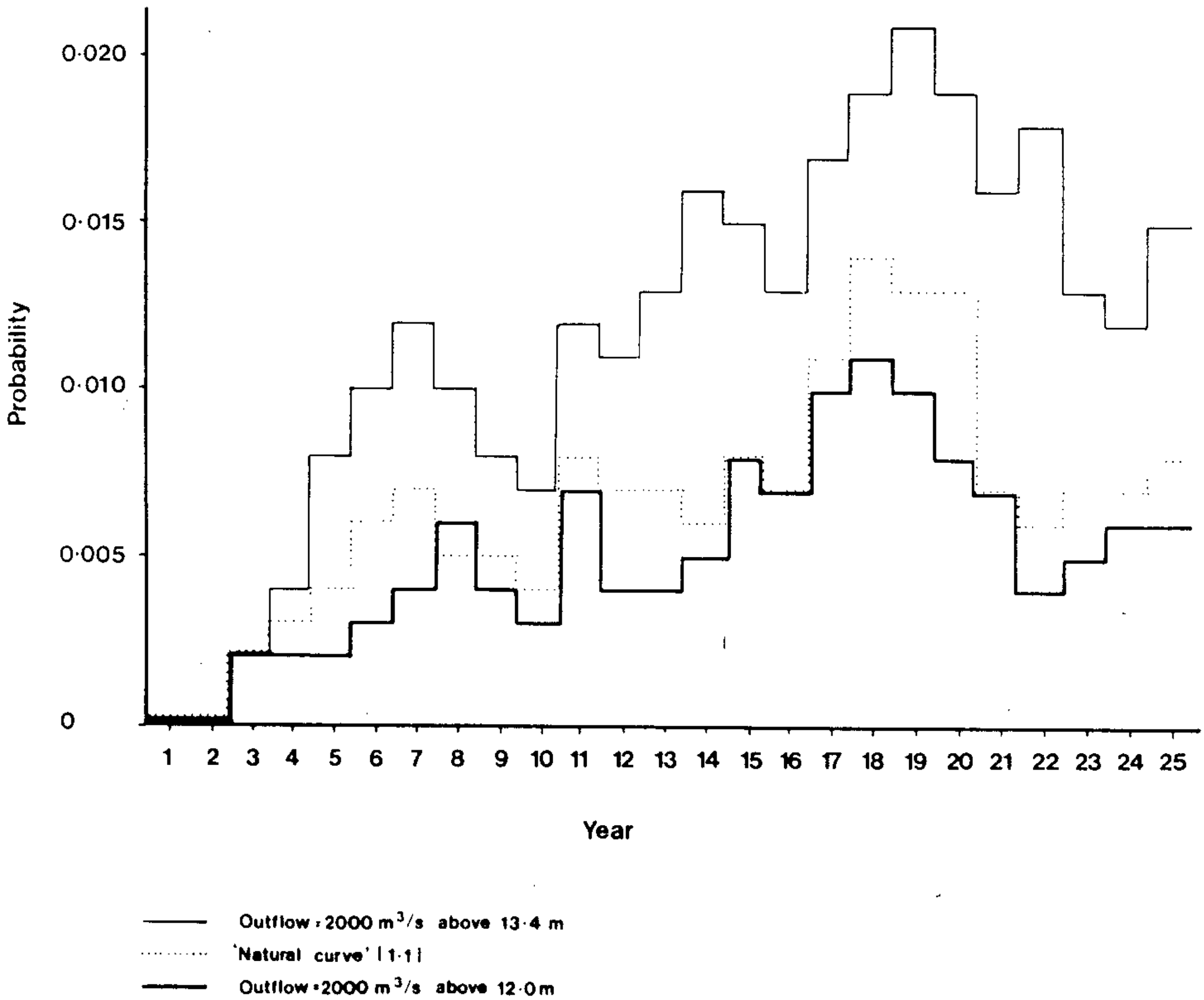
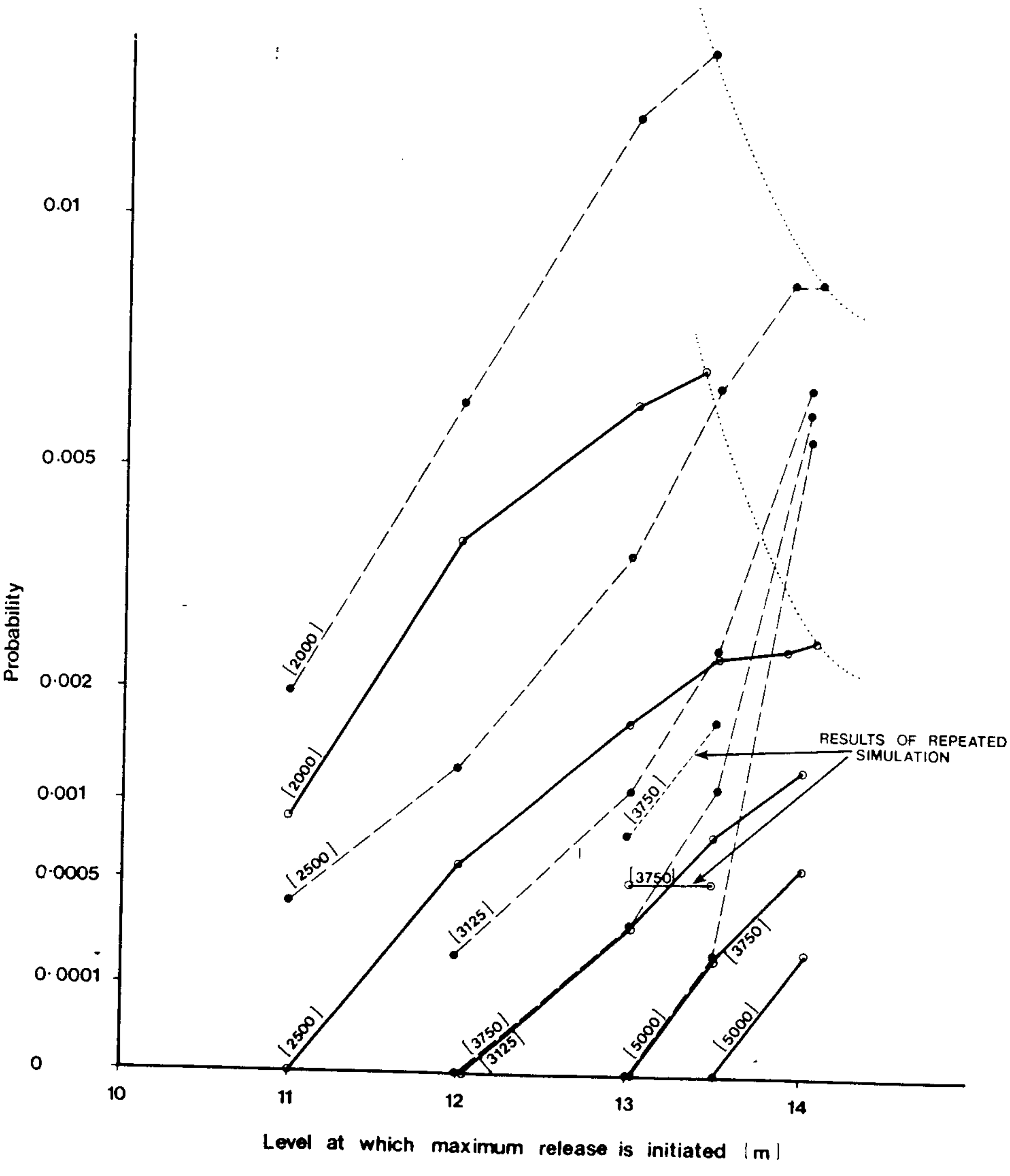


Figure 2·1[b]

Probability of a maximum level in a single year exceeding a critical level



Critical level . 14·0 m

Critical level . 14·5 m

No release exceeding natural curve [1·1]

[ ] Maximum release m³/s

Figure 2·2 [a]

Probability of a maximum level in a single year exceeding a critical level

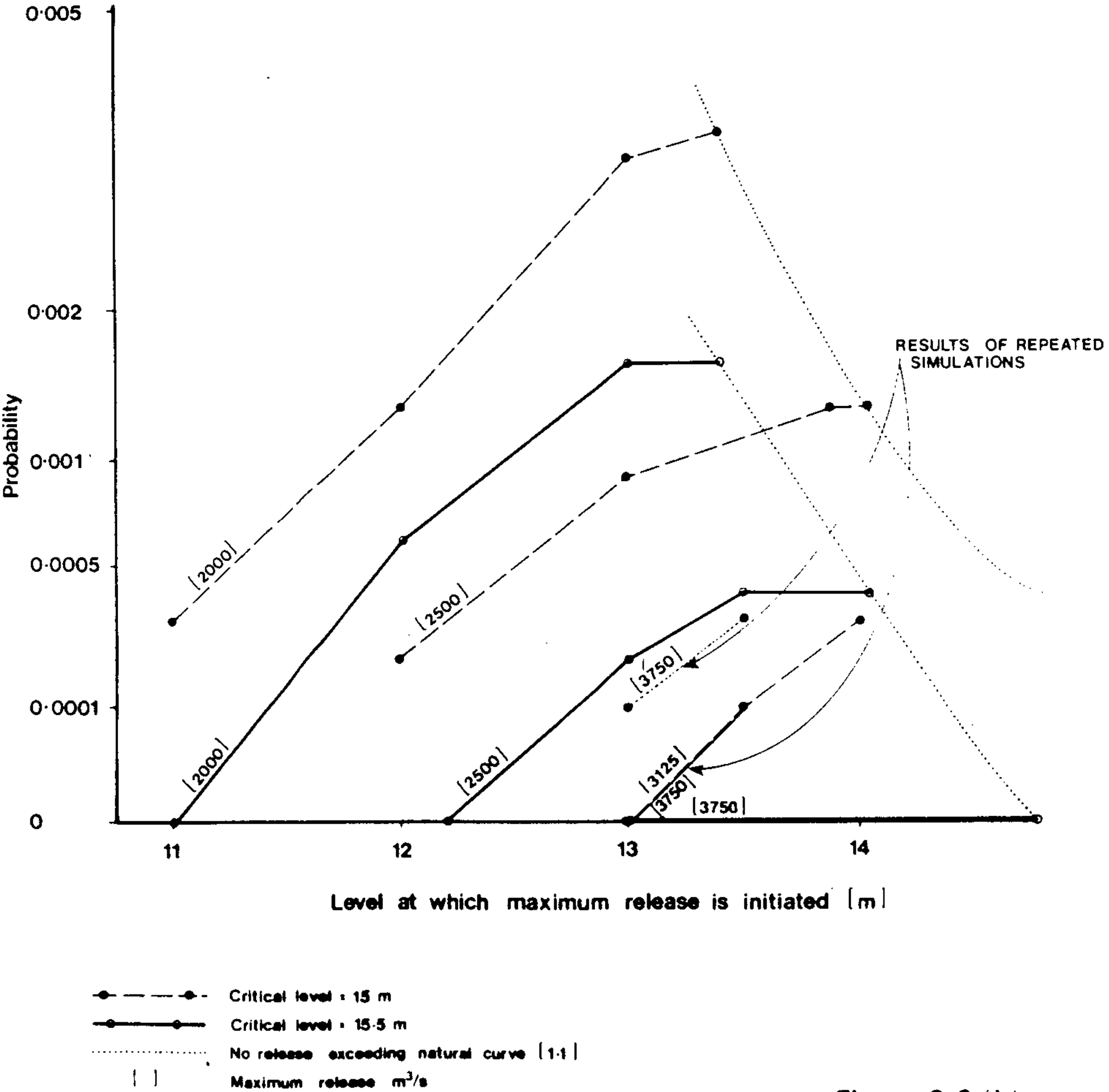


Figure 2·2 (b)

Probability of maximum level in 30 year time horizon exceeding a critical level [Starting at 12m]

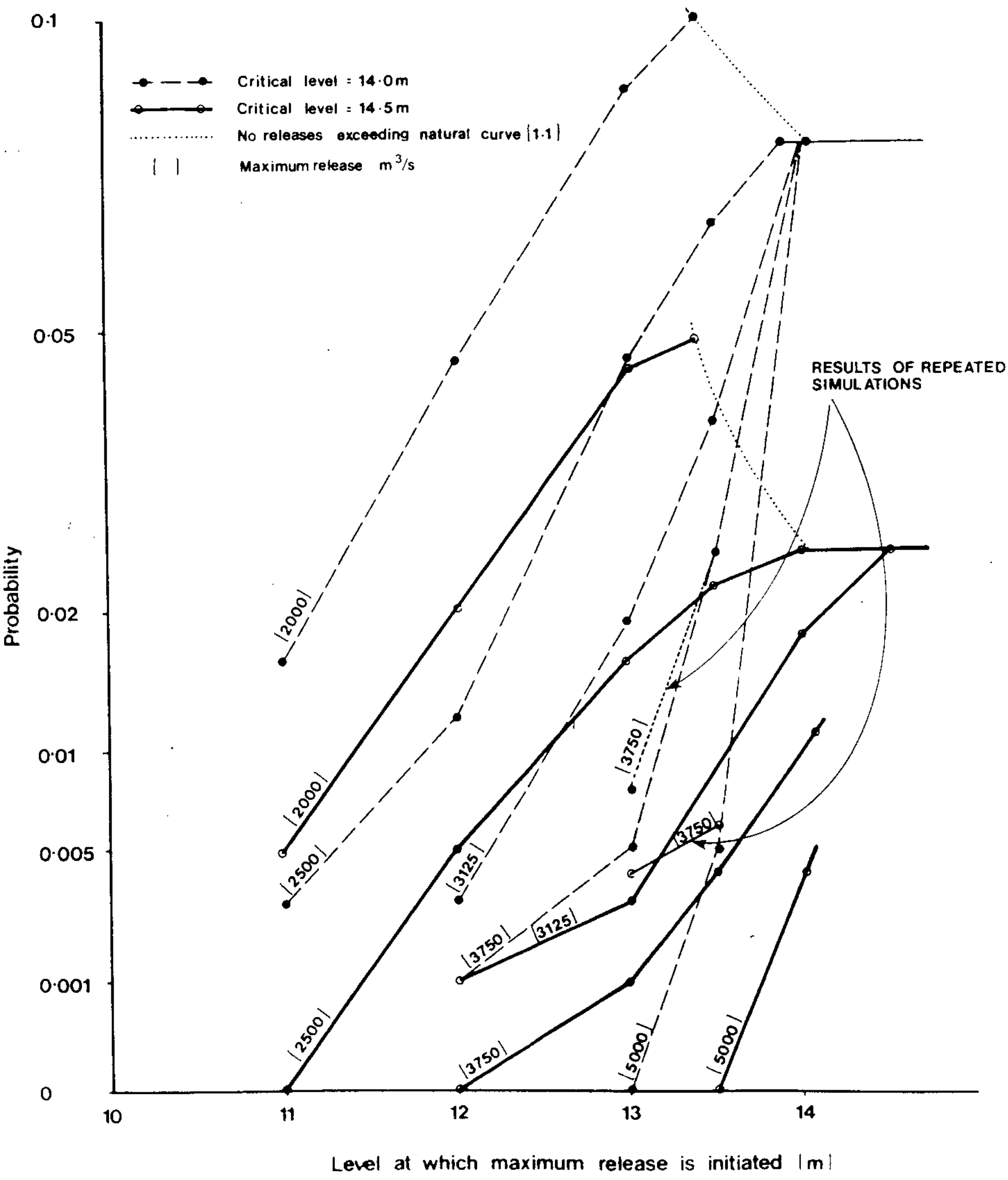


Figure 2·3 [a]

Probability of maximum level in 30 year time horizon exceeding a critical level [Starting at 12m]

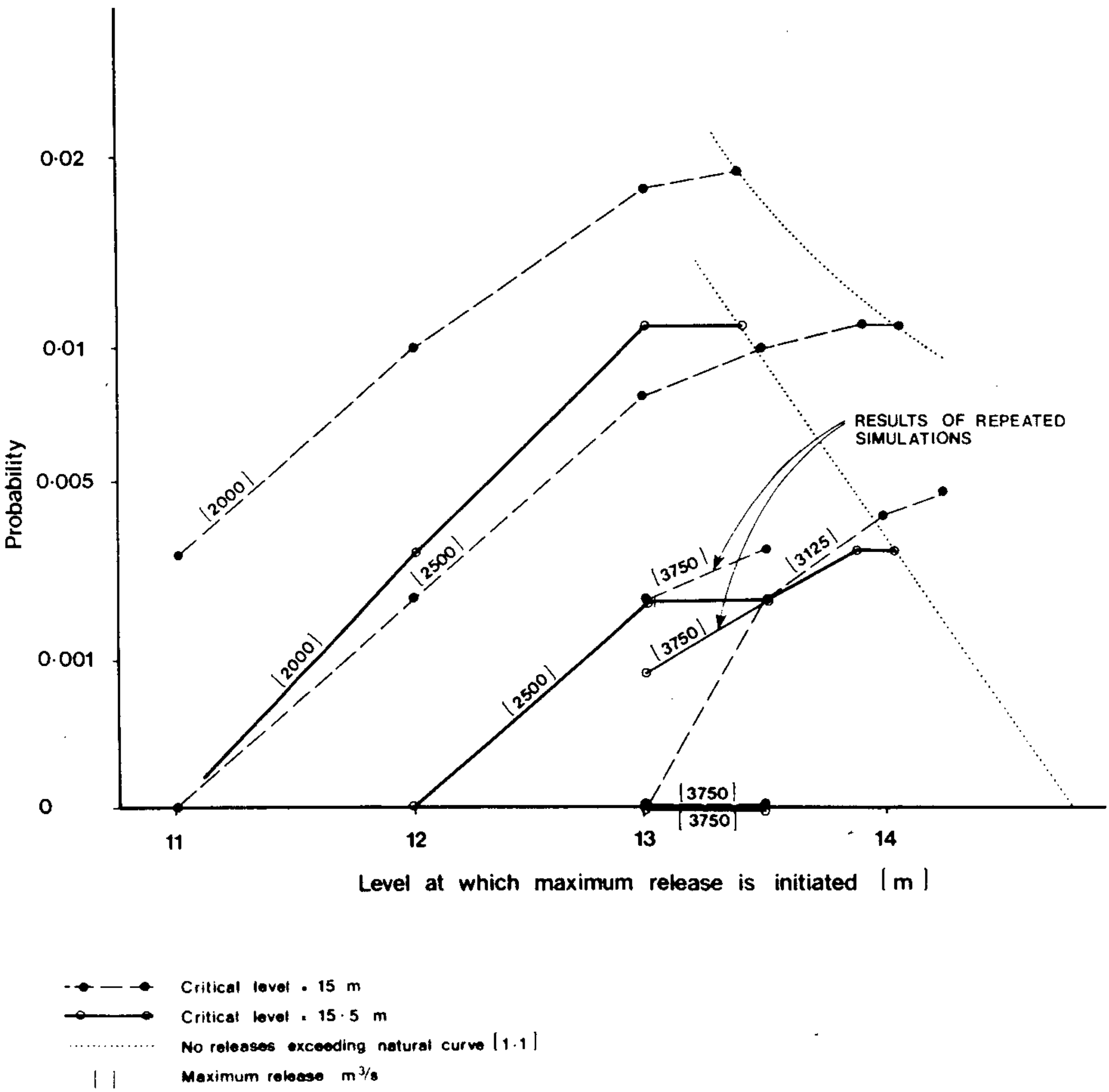
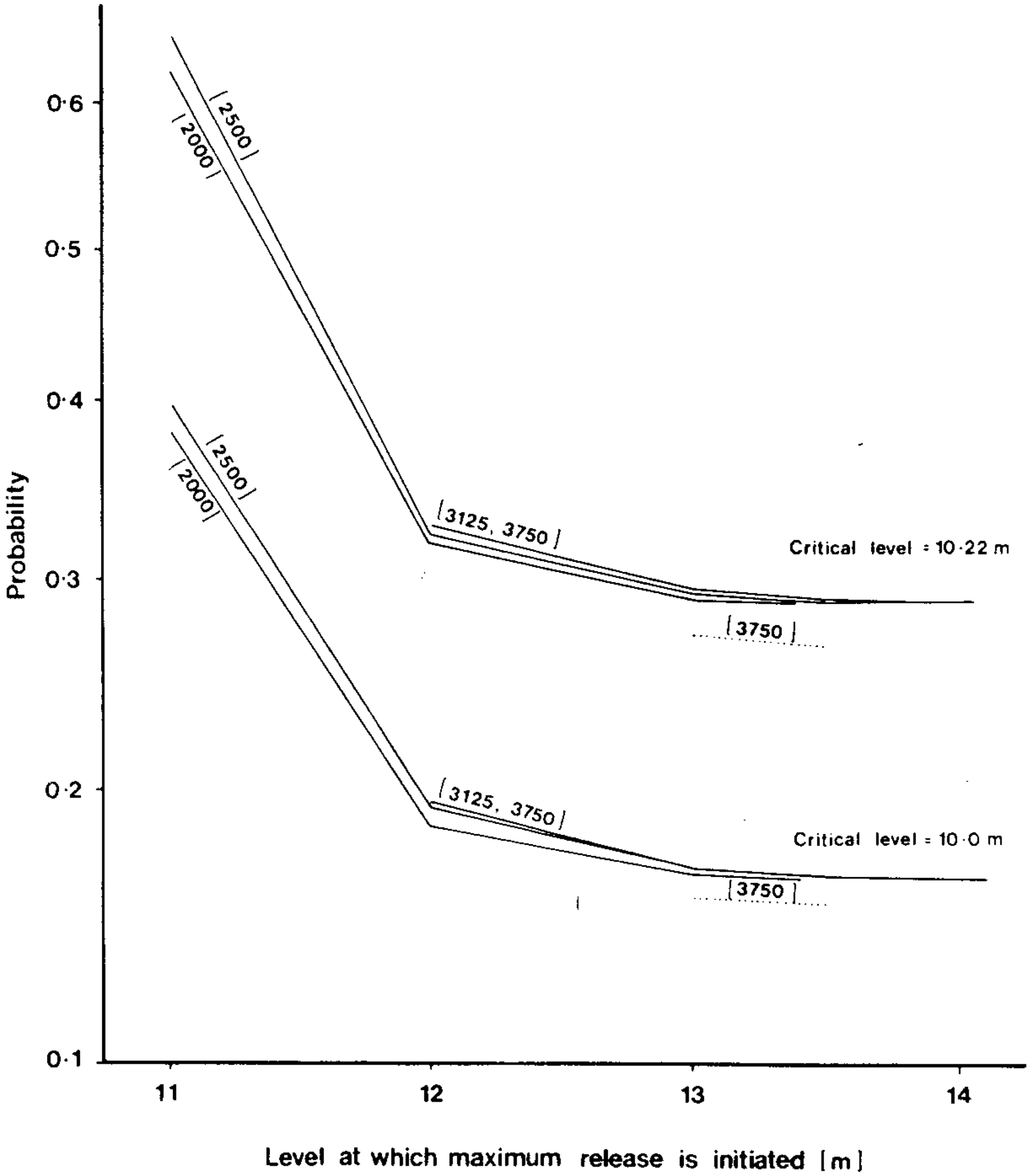


Figure 2·3 [b]

Probability of minimum level in 30 year time horizon falling below a critical level [Starting at 12 m]



[ ] Constant release m^3/s

Figure 2·4

Equilibrium distribution of annual maximum lake levels

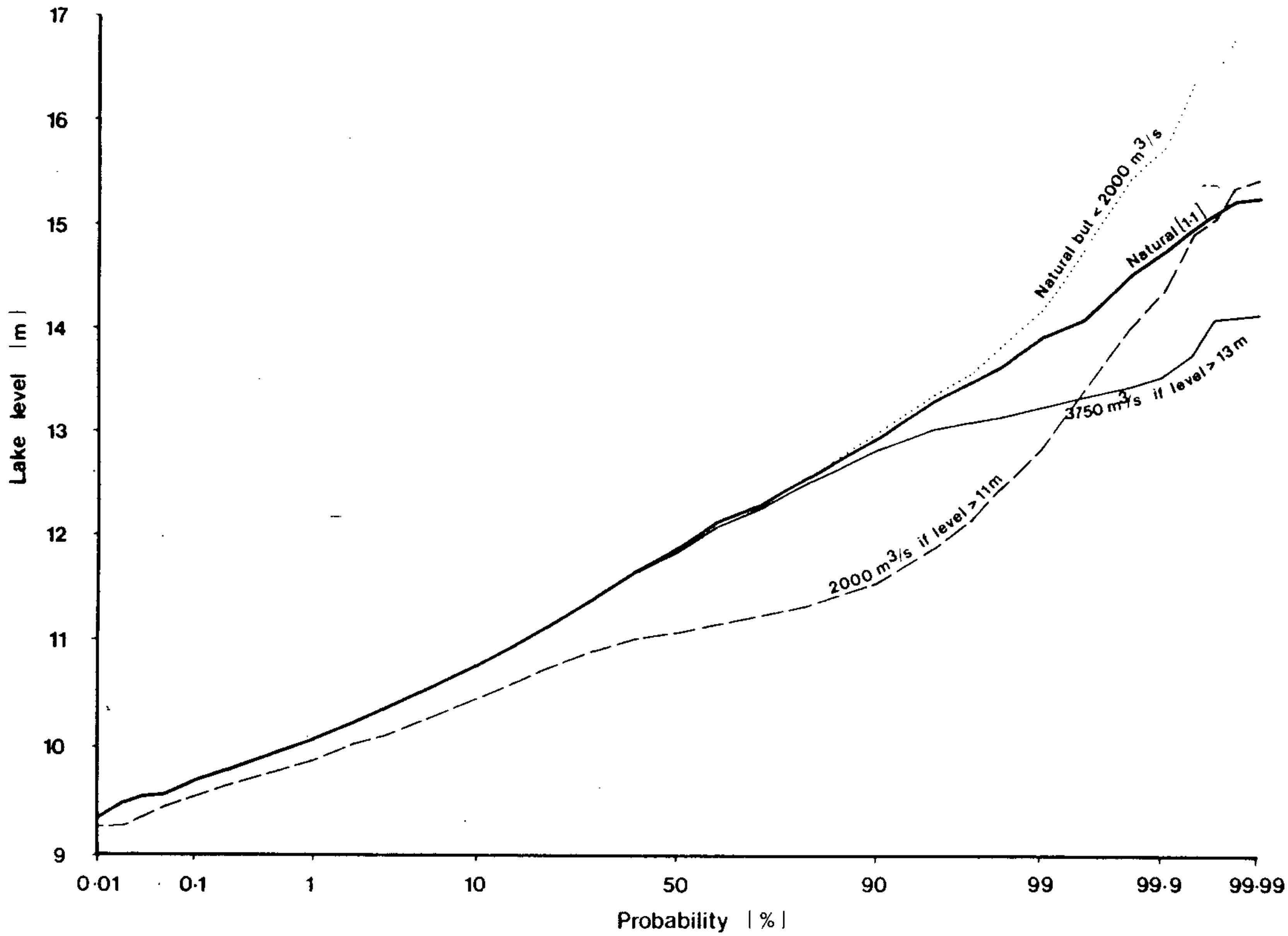


Figure 2·5

Effect of release policy on equilibrium distribution of annual maximum level

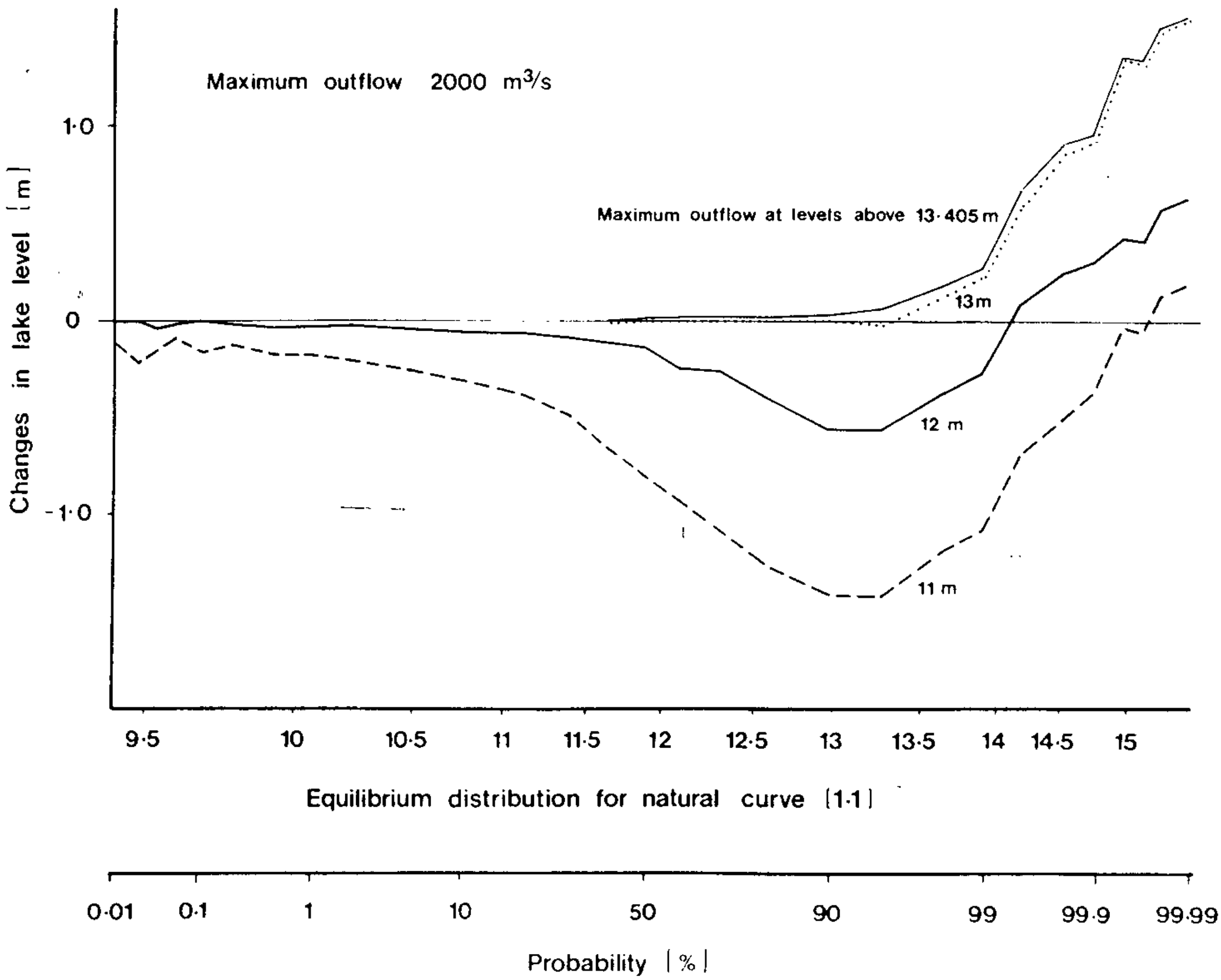


Figure 2·6 [a]

Effect of release policy on equilibrium distribution of annual maximum level

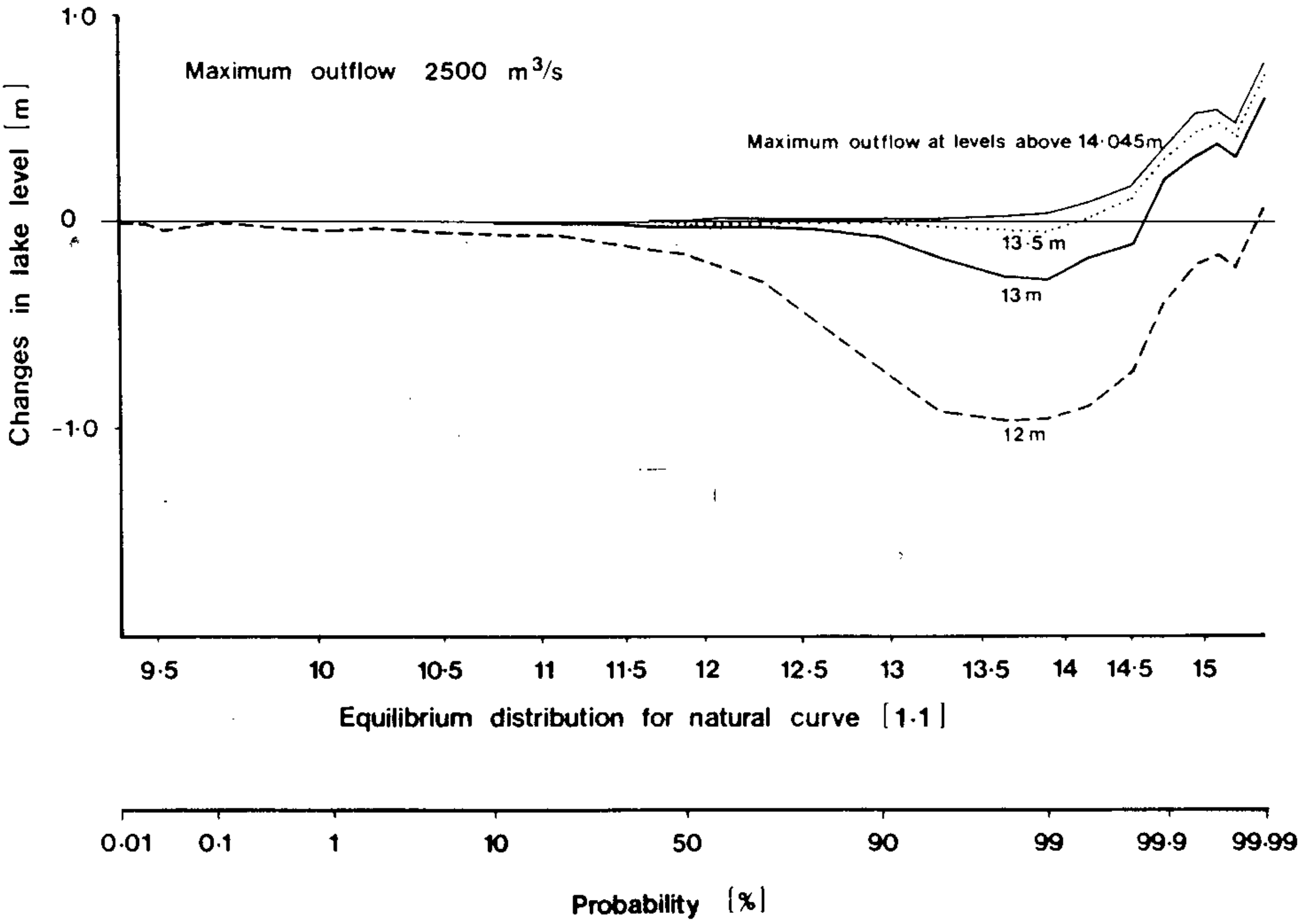


Figure 2·6 [b]

Possible development of lake levels for different release policies

[End of July levels]

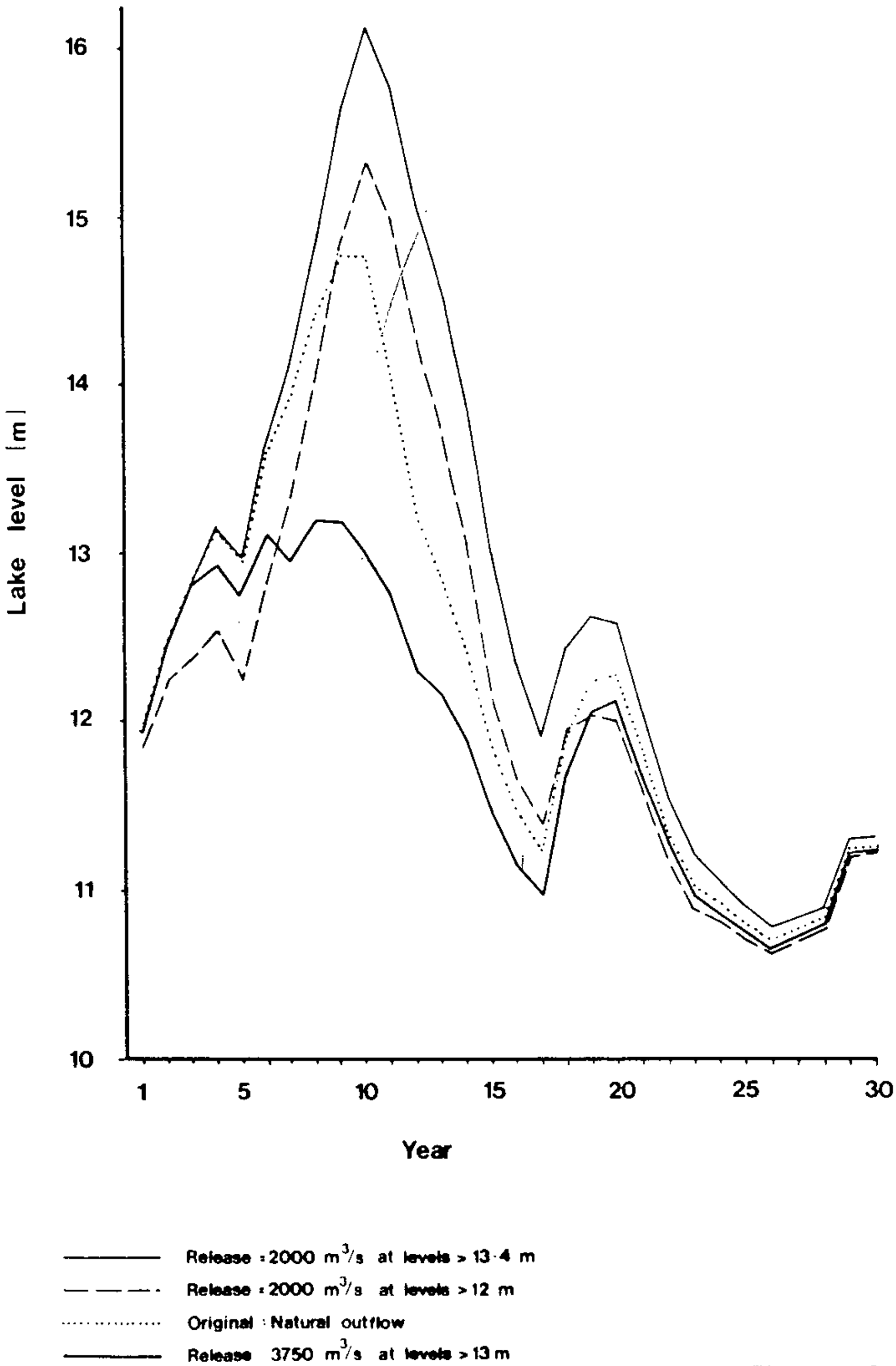


Figure 2·7

3. Low Lake Levels

29. If a minimum release were to be introduced into the operating policy of the dam, so as to assure a fixed amount of hydropower generation, this would tend to draw the lake down to lower levels than otherwise and possibly, depending on the release policy adopted, to such low levels as 5 or 6 metres above the Jinja datum. Such policies would probably not be acceptable and the type of release rules chosen for study here reflect this. All the discharge rules considered are defined so that, if the lake level drops below 10.22 metres, the release is computed according to the "natural" curve (1.1). This is obviously only one choice out of many other possibilities.

30. Four levels of minimum release have to be taken as a representative range: these are 29.5, 43.63, 54.43 and 64.8 million m^3/day, or equivalently 254.9, 505, 630 and 750 m^3/sec. These releases correspond to lake levels of 10.22, 10.71, 11.02 and 11.30 metres on the "natural" release curve. Thus, in the simplest case, a release of 750 m^3/sec would be made if the lake level were between 10.22 and 11.30 metres and would otherwise be according to the natural curve. However, the release policies have been further modified to consider making compensating low releases to adjust for the higher releases by extending the region in which the minimum release is made up to some threshold level. A number of such minimum releases and thresholds have been considered.

31. The evolution over time of the probability of lake levels falling below 10.22 metres is shown in Figure 3.1 for several of the different release policies.

32. Figure 3.2 shows the equilibrium probability that the lake levels in a given year will fall below 10.22 metres, and how this changes with the minimum release and threshold for the compensating decreased discharges. Results for a critical level of 10.0 metres are also included.

33. Figures 3.3 and 3.4 are similar to Figures 2.3 and 2.4 in that they show how the changes in release policy affect the distributions of the maximum and minimum lake levels within a thirty year time horizon. There is little effect on the probability of levels exceeding 14.0 metres as long as the threshold for the compensating flow remains below 11.5 metres. However there is the possibility that modifying the releases at low lake levels would have a more dramatic effect on the probability of high lake levels if one of the modified release policies considered in Section 2 were already implemented so as to reduce the probability of exceeding 14 metres to a acceptably small value.

34 The results here show that if a release of 630 m^3/sec were chosen as a target release, then (from Figure 3.2) this rate of discharge would have to be maintained up to a level of 12.25 metres in order not to increase the occurrence of lake levels below 10.22 metres: the marginal proability would be reduced to slightly below 0.074 which is the corresponding value for the "natural" release curve. This policy would then have the effect of increasing the probability of lake levels exceeding 14 metres: for example (from Figure 3.3) the probability of lake levels exceeding 14 metres within a 30 year time horizon would increase from 0.08 to 0.11 if no other measures were taken. The overall effect of the new policy, as shown in Figure 3.4, would be to decrease the probability of reaching 10.22 metres within 30 years from 0.29 to 0.22.

35. The effect of modifying the release policy for low levels on the general distribution of lake levels is shown in Figure 3.5. The changes to the releases have a greater effect on the distribution than that shown in Figure 2.5 since the changes come into effect at levels more in the centre of the distribution. Figures 3.6(a) and (b) show in more detail the effect of changes to the release policy. It can be seen that the effects at high levels are small in terms of changes in level, but this may equate with a large change in the probability of exceedance.

36. It is clear from these results that any decision about modifying the release policy to achieve a firm hydropower yield, would have to be taken into account in decisions about the action to be taken to protect against high lake levels.

37. Although other ways of introducing compensation for the increased releases at low levels could be considered, for example by having a smoother transition back to the "natural" curve the above results should give a good guide to the type of behaviour to be expected.

Probability of occurrence in each year of levels below 10·22 m

[Starting level 12·0 m]

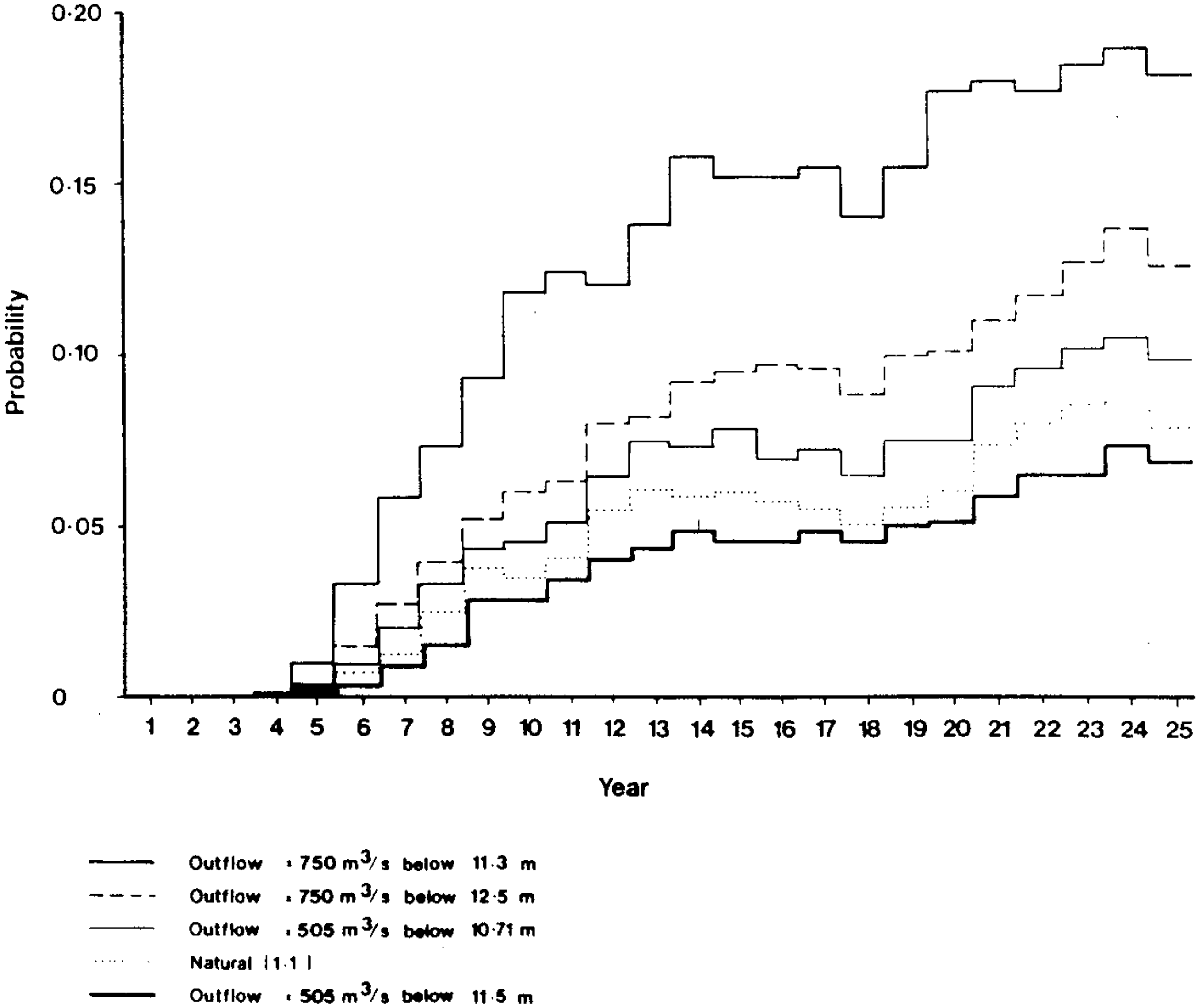


Figure 3·1

Probability of minimum level in a single year falling below a critical level [Starting at 12 m]

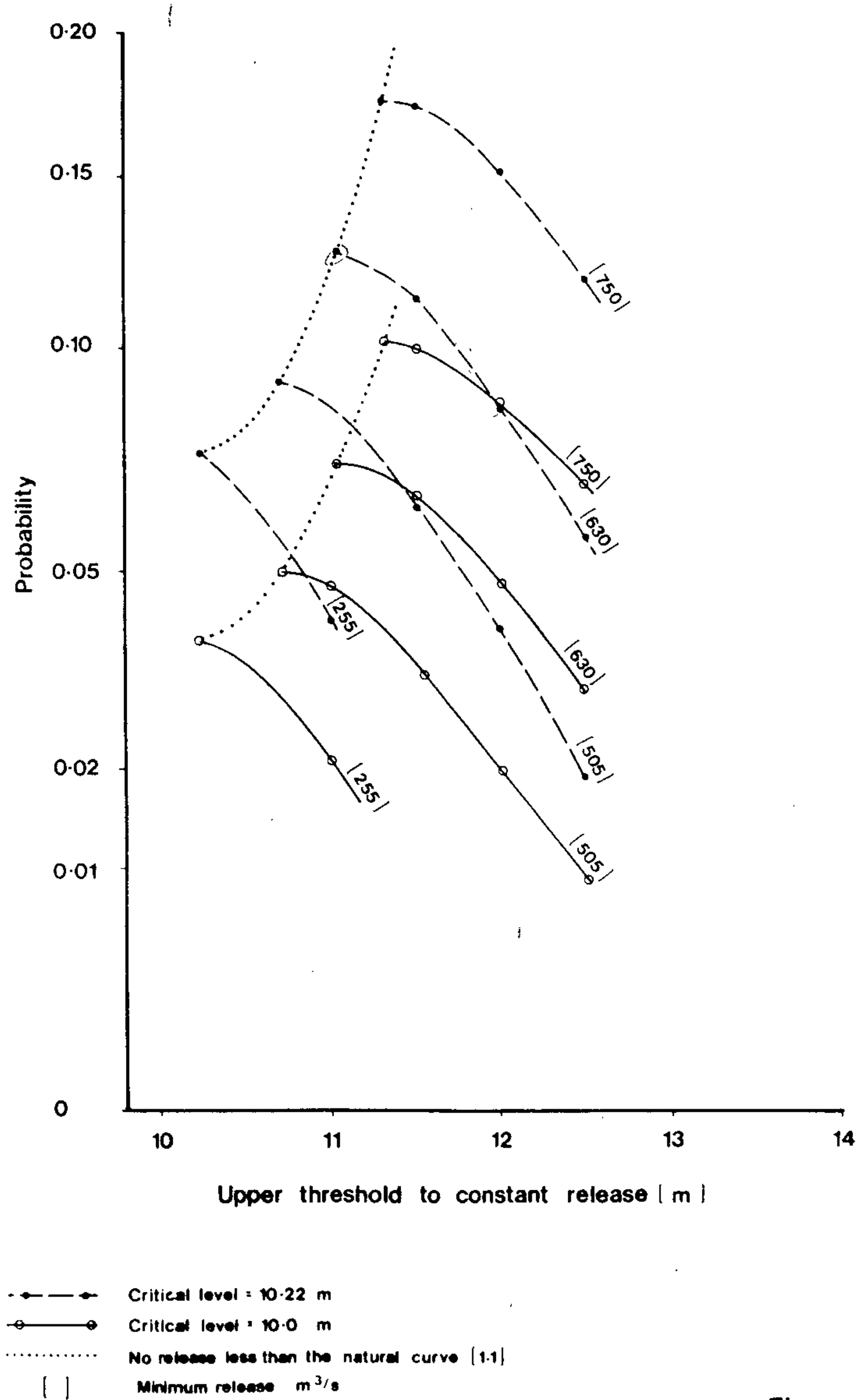
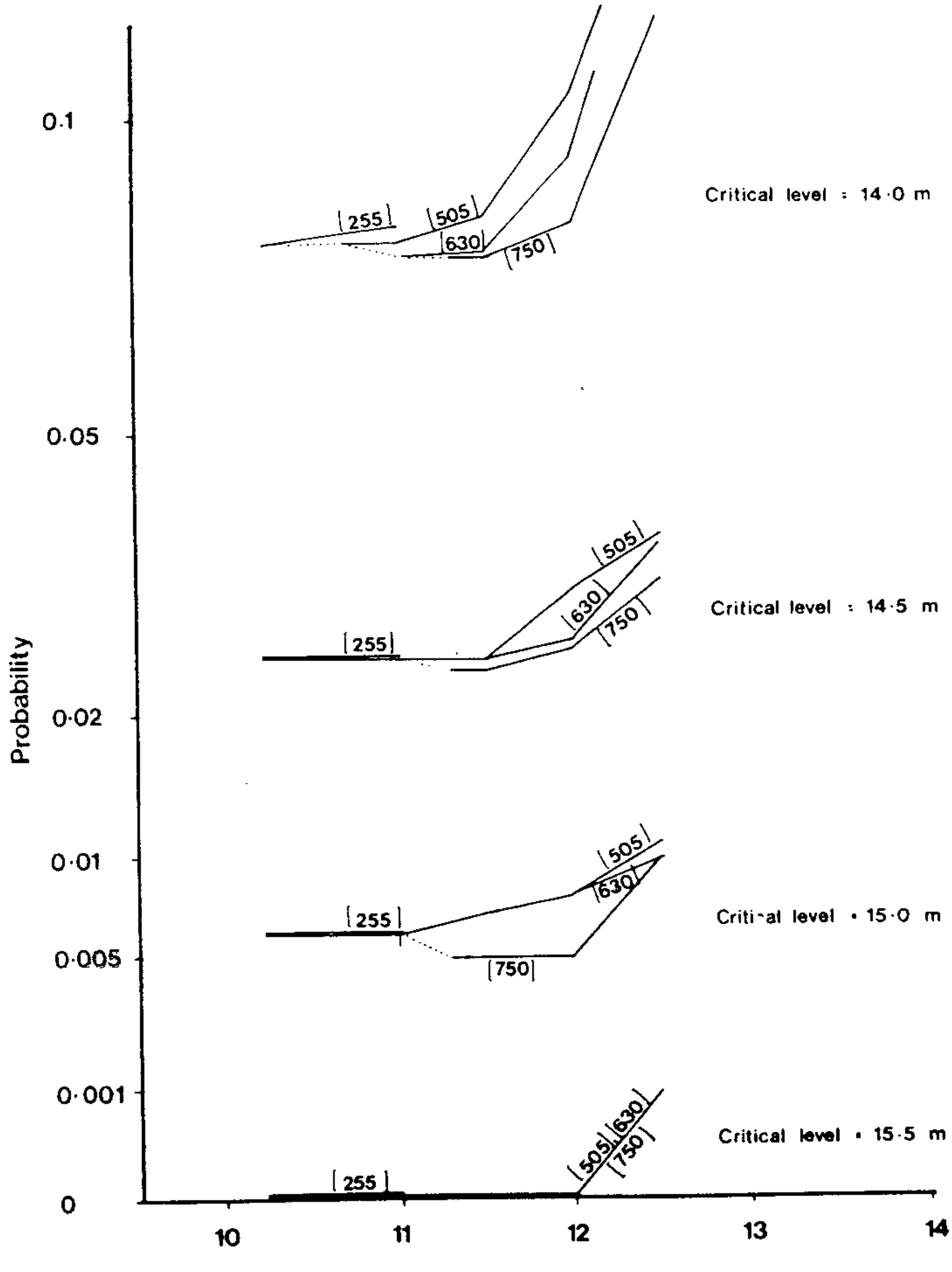


Figure 3·2

Probability of maximum level in 30 year time horizon exceeding a critical level [Starting at 12 m]



[ ] Constant release m^3/s

No releases less than the natural curve [1.1]

Figure 3.3

Probability of minimum level in 30 year time horizon falling below a critical level [Starting at 12 m]

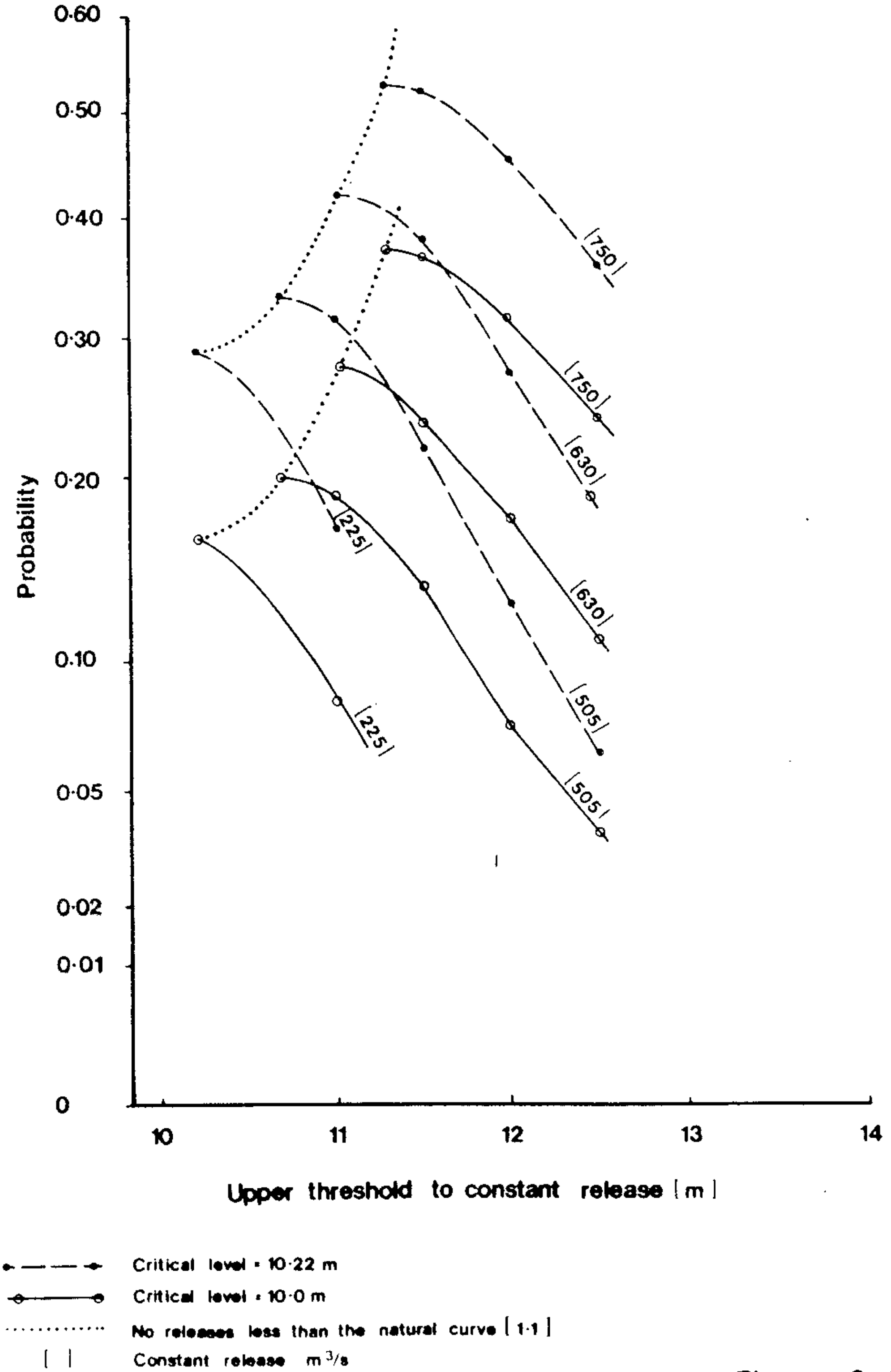


Figure 3·4

Equilibrium distribution of annual minimum lake levels

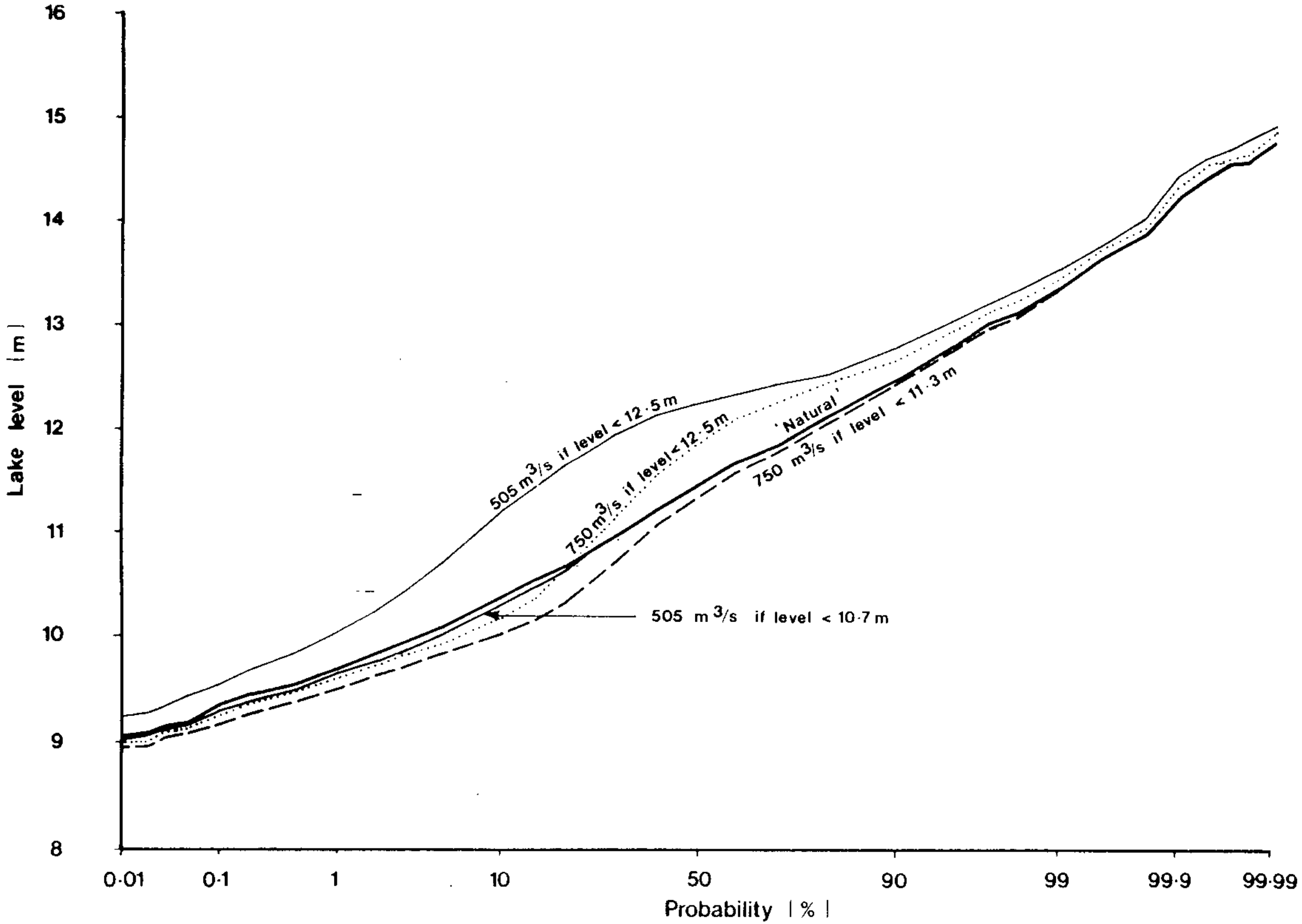


Figure 3·5

Effect of release policy on equilibrium distribution of annual minimum levels

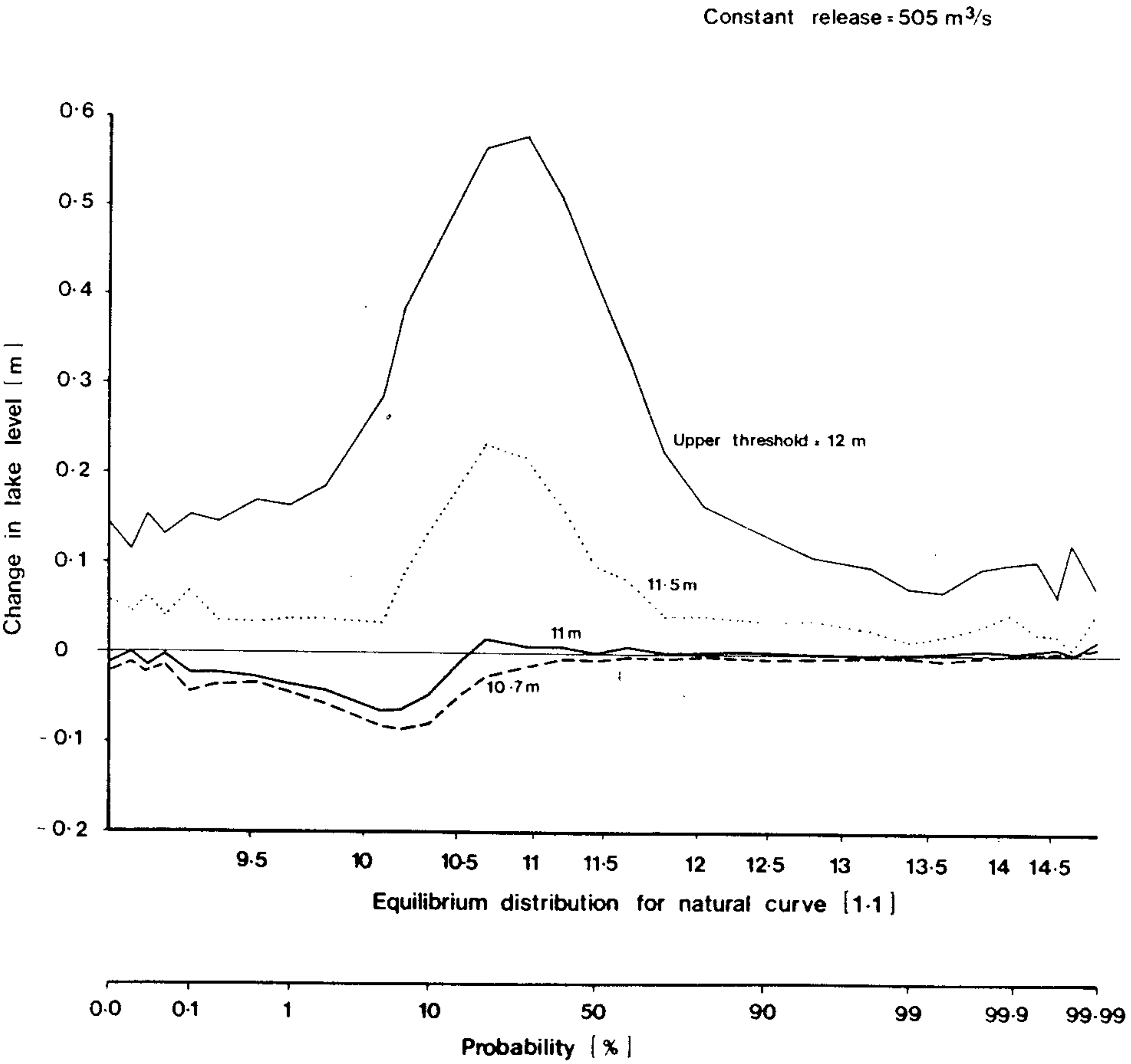


Figure 3·6 [a]

Effect of release policy on equilibrium distribution of annual minimum levels

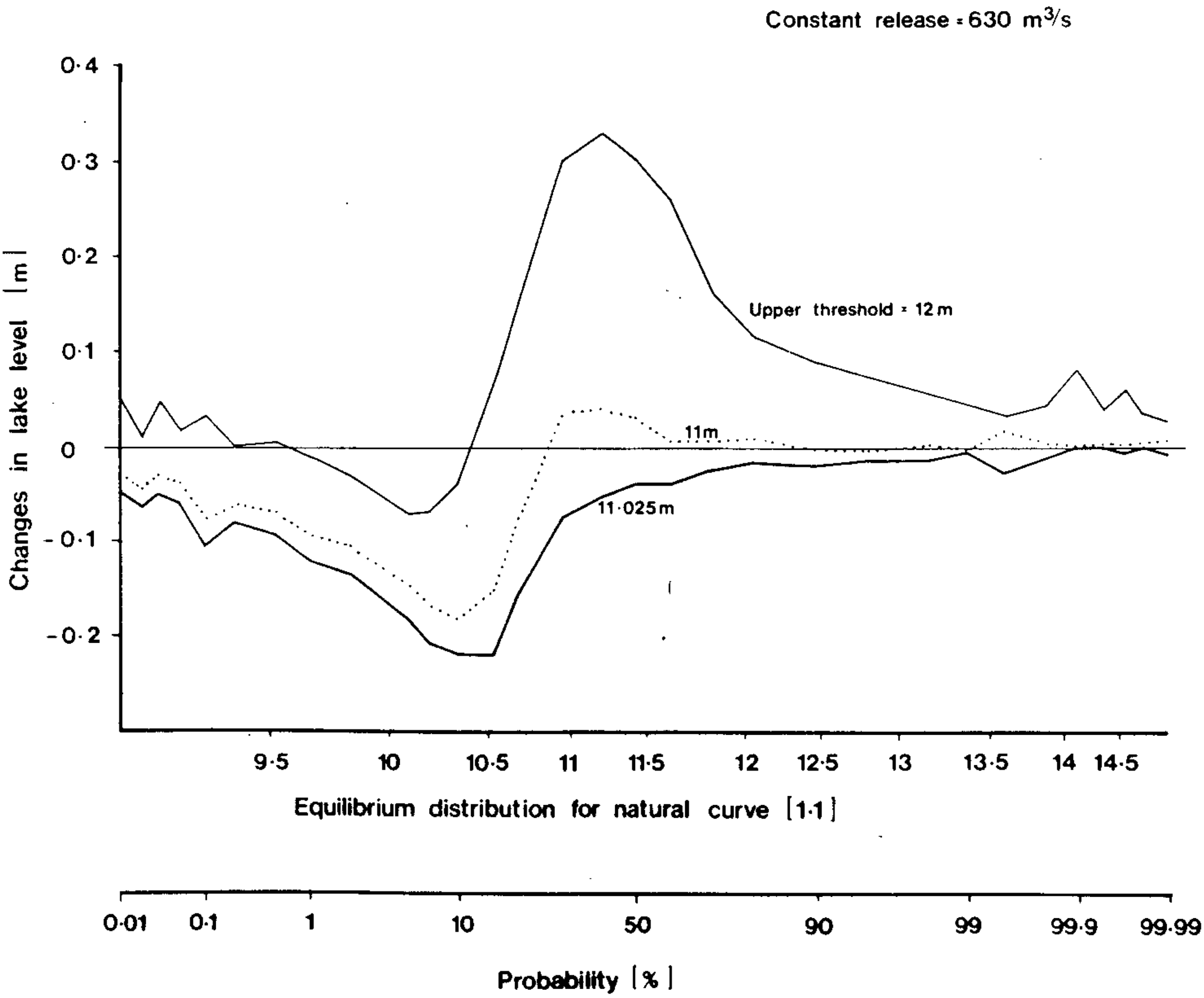


Figure 3·6 [b]

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