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WELLINGTON RESERVOIR DYNAMICS AND ITS RELATIONSHIP TO THE STORAGE RETENTION TIME OF WITHDRAWAL

Water Resources Section
Planning Design &
Investigation Branch
PUBLIC WORKS DEPARTMENT

APRIL 1977

WELLINGTON RESERVOIR

DYNAMICS AND ITS RELATIONSHIP

TO THE STORAGE RETENTION TIME OF WITHDRAWAL

I. LOH

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WELLINGTON RESERVOIR DYNAMICS AND ITS RELATIONSHIP TO THE STORAGE RETENTION TIME OF WITHDRAWAL

1. INTRODUCTION

Pressure for recreational use of reservoirs and catchment areas is increasing and will continue to increase in the future. Increased human activity in these areas will increase the risk of pathogenic organisms entering the water storage. In this context the time that water is held in storage becomes of critical importance since biological activity in the storage can destroy the pathogens if given sufficient time (typically 30 days). Consequently knowledge about storage retention times of different waters within a reservoir is becoming increasingly important.

While the average retention time of water in a reservoir is influenced by the ratio of reservoir withdrawal to reservoir storage the retention time of a specific slug of water is controlled by the (often complicated and subtle) dynamic fluid motions within the reservoir. Fluid motions are in turn influenced by the density structure in the reservoir, the density of the inflowing water relative to the reservoir density structure, the surface meteorological effects of radiation and wind energy inputs and the reservoir operational policy. Both field investigations and modelling studies carried out by the University of W.A.'s Civil and Mechanical Engineering and Mathematics Departments under the direction of Dr Imberger (Refs 1 & 2) have shown that the retention time of withdrawal from Wellington Reservoir could vary from as much as 6 months to as little as 5 days.

2. SEASONAL PATTERN OF WATER MOVEMENT IN WELLINGTON RESERVOIR

Temperature and salinity profiles typical of Wellington Reservoir at different stages of the year are listed at the end of this report. The general seasonal mixing processes which cause these distributions are described below.

2.1 Summer

During the summer months the reservoir becomes temperature stratified. Long wave radiation selectively heats the surface waters while short wave radiation only penetrates to intermediate levels. Little or no heating occurs at the base of the reservoir. Diural variations in heat input and short term variations in wind strength maintain a uniformally well mixed surface layer to a depth of up to 12 metres which is ligher than the underlying water. The water density below the well mixed layer increases with depth as the temperature decreases. The density gradient may be accentuated by more saline water at the base of the reservoir caused by inflow from the previous winter. As the density gradient inhibits vertical movement withdrawal from the central offtake during the summer is restricted to a narrow horizontal layer at the offtake level. As the summer withdrawal period continues, water above the withdrawal layer drops vertically and concentrates the density gradient (forms a thermocline) at the offtake level. Consequently wind mixing effects are restricted to above the thermocline and little or no movement occurs in the storage below the offtake level.

Withdrawal from the base of the reservoir is similar in principle but weakens the density gradient throughout the reservoir. This causes the withdrawal layer to be broader and allows wind effects to penetrate to greater depths.

While the reservoir is density stratified vertical movement is minimised but diffusion processes can still occur. Slow diffusion of salt from the base of the reservoir can significantly increase the salinity of the top well-mixed layer over the summer period.

2.2 Autumn

Similarly to withdrawal from the base of the reservoir, cooling of the surface waters throughout Autumn weakens the density gradient and enables wind mixing to penetrate deeper into the reservoir. Any thermocline structure present at the end of the summer stratification period is successively eroded by a series of storms until mixing to the full depth of the reservoir is achieved. This usually occurs by the start of June so that the reservoir is uniform in both temperature and salinity before the first winter inflows occur.

2.3 Winter

As the first winter inflows enter at the head of the reservoir they are usually colder and more saline than the reservoir and consequently underflow the stored water. As the inflow moves down the reservoir bed it entrains (drags in) and mixes with varying amounts of reservoir water. This combined inflow will continue to move further down slope only if it remains heavier than the surrounding water. Once a point of neutral buoyancy is reached the inflow will enter the main body of the reservoir at that level. The degrees of entrainment mixing is a complex function of the inflow velocity and density difference between the stored and inflow waters. Simulation results (Ref. 2) indicate that volumes of entrained fluid can vary from 0.1 to over 10 times the initial inflow volume.

During winter, inflows from the main Collie River generally underflow the complete reservoir and take approximately 5 days to reach the dam wall. Local tributaries generally enter at an intermediate level and are often directly mixed into the surface uniform layer.

Further surface cooling, wind action and diffusion processes continue to contribute to the reservoir structure during the winter period. However wind mixing does not penetrate to the full depth since a density barrier has been developed by the cold and saline Collie River inflow at the base of the reservoir.

Since the bulk of the inflow (70%) comes from the main Collie River during winter it can be said that the reservoir generally fills from the base and lifts previously stored water up, and if there is sufficient inflow, over the spillway.

2.4 Spring

River temperatures rise at a faster rate than the reservoir temperatures during the spring warming cycle. Consequently Collie River inflows during Spring tend to flow in above the colder winter inflow and lodge at intermediate levels within the reservoir. As heating continues and inflow volumes decrease all inflow enters at or just above the thermocline and is mixed into the surface layer. By October - November the reservoir surface temperature has increased by approximately half its annual variation (14^{o} to 26^{o}) while no changes have occurred in the temperature at the bottom since winter. Consequently a thermal gradient has developed which is the beginnings of the strong thermal structure characteristic of the summer period.

3. RETENTION TIMES OF WATER WITHDRAWN FROM WELLINGTON RESERVOIR

The retention time of water withdrawn from Wellington Reservoir is a function of the withdrawal layer thickness (and consequently the density structure at the time) and all water movements since the last time the reservoir was uniformally mixed. Consequently retention times are dependent on the complex mixing processes outlined in Section 2. They can be highly variable. For example water withdrawn from the base of the reservoir during winter may have been held in storage for less than a week. However water withdrawn from the base towards the end of summer may have been in storage for 6 months. Water withdrawn from the well mixed surface layer will have at least a small component of recent inflow from local tributaries whereas water drawn from below the well mixed layer rarely contains any.

While general comments about the source and retention time of different reservoir waters can be made the only precise calculations can be based on simulation of the actual reservoir operation which accurately models all the important processes governing the internal dynamics of the reservoir. A computer simulation model has been developed by Drs Imberger and Patterson (Refs 1 & 2) to predict the temperature and salinity distribution in the reservoir on a daily basis. The model simulates all the important time scales from wind mixing (hourly) to reservoir heating and cooling (monthly) and calculates the withdrawal layer thickness each day. Modifications could be made to calculate the storage retention time of daily withdrawal.

4. IMPLICATIONS FOR OTHER STORAGES

Computer simulations (Refs 1 & 2) have indicated that water movements in Wellington Reservoir are highly sensitive to the relative density between the inflow and the reservoir, and also the level of withdrawal from the reservoir. For example small changes in the temperature of inflow ($\pm$ 1^{o}C) can dramatically affect the level of neutral buoyancy of inflow, while supplying water from the base rather than the central offtake weakens the density structure and significantly increase the effect of wind action.

Therefore, while the processes causing (1 dimensional) water movement in reservoirs are relatively defined, differences in both the characteristics of inputs to and physical features of other reservoirs in the South West of Western Australia preclude any direct comparison with Wellington Reservoir. For example, a completely different winter inflow pattern occurs on Padbury Reservoir (capacity only 61 x $10^3 m^3$) where the density of major flood inflows is often less than the reservoir water. Consequently inflows often pass over the top of stored water and are lost as spillage. Filling from the base tends to occur in spring rather than winter as, in this case, the reservoir heats more rapidly than the inflow.

5. CONCLUSIONS

The mixing processes in Wellington Reservoir are complex and often subtle but have a direct affect on the time that water drawn from the reservoir has been in storage. To accurately predict the retention time of withdrawal requires the application of a detailed simulation program of the reservoir dynamics. As the density structure in Wellington Reservoir is so sensitive to the inflow density history and the previous reservoir operation direct comparison with other reservoirs cannot be made. Similarities will undoubtedly exist particularly with other South West reservoirs of similar storage volume but some detailed measurement of inflow and reservoir densities would be necessary to confirm the seasonal mixing processes in each case.

If greater human activity on or near water supply reservoirs is to be tolerated in the future then it is essential that there are adequate means of ensuring that the storage retention time of water drawn from the reservoir is sufficiently long to maintain existing Public Health Standards. This could only be achieved with confidence by operating multiple offtake structures subject to day to day predictions of retention times of water from different levels in the reservoir using detailed on line computing simulations of the reservoir mixing processes.

6. REFERENCES

1. Imberger, J., Patterson, J., Hebbert, R. & Loh, I. (1976) Simulation of the Salinity Structure in a Reservoir of Medium Size. A.S.C.E., Hydraulics Division, in press.

2. Patterson, J., Loh, I., Imberger, J. & Hebbert, R. (1977) Simulation as a Guide to Reservoir Management. To be published.

APPENDIX

TEMPERATURE AND SALINITY PROFILES

OF WELLINGTON RESERVOIR

The following diagrams show the seasonal changes in the density structure of Wellington Reservoir from December 1974 to February 1977. Data up to August 1976 was collected by staff of the University of W.A. under AWRC research project No. 74/70. More recent data has been collected by the Public Works Department.

While some inconsistencies in the data are apparent the diagrams give the general pattern of both the salinity and temperature distributions throughout the reservoir.

The following points should be noted

(i) The development of a thermocline during summer and its increased concentration through both the 1974/75 and 1975/76 irrigation seasons when withdrawal was from the mid level offtake (16 metres below the crest).

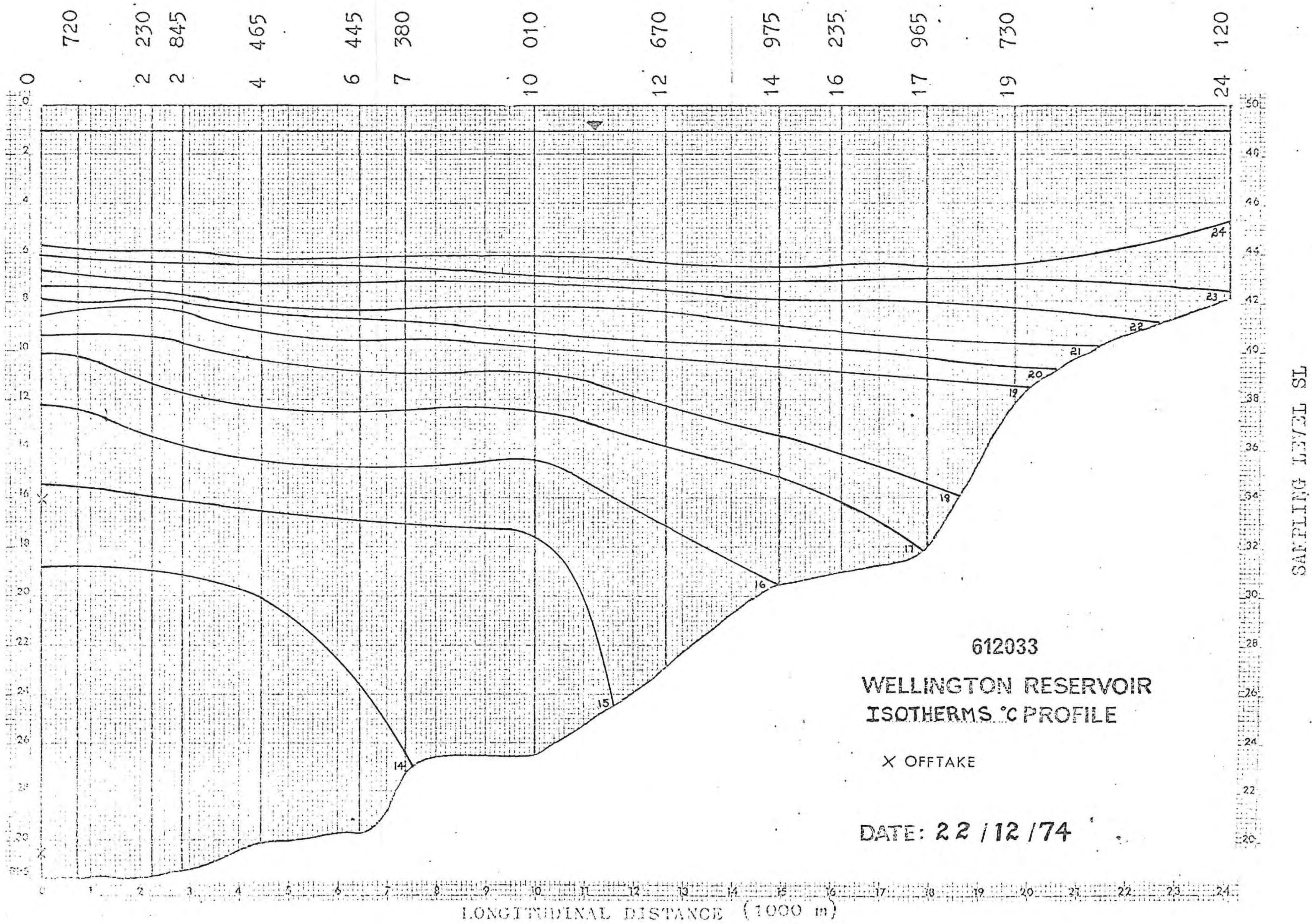
(ii) The development of an observable withdrawal layer at the mid level offtake during 1974/75 when there were vertical lines of equal salinity.

(iii) The seasonal cooling during April and May each season.

(iv) The under flow of cold saline water in the winters of 1975 and 1976.

(v) The fact that saline water was successfully removed from the base of the reservoir as scour before and as a component of supply during the 1976/77 irrigation season.

(vi) That while removing saline water from the base improved the overall reservoir quality continued wind mixing and diffusion of salt (together with evaporation) were significant in increasing the salinity of the well mixed layer over the 1976/77 summer.



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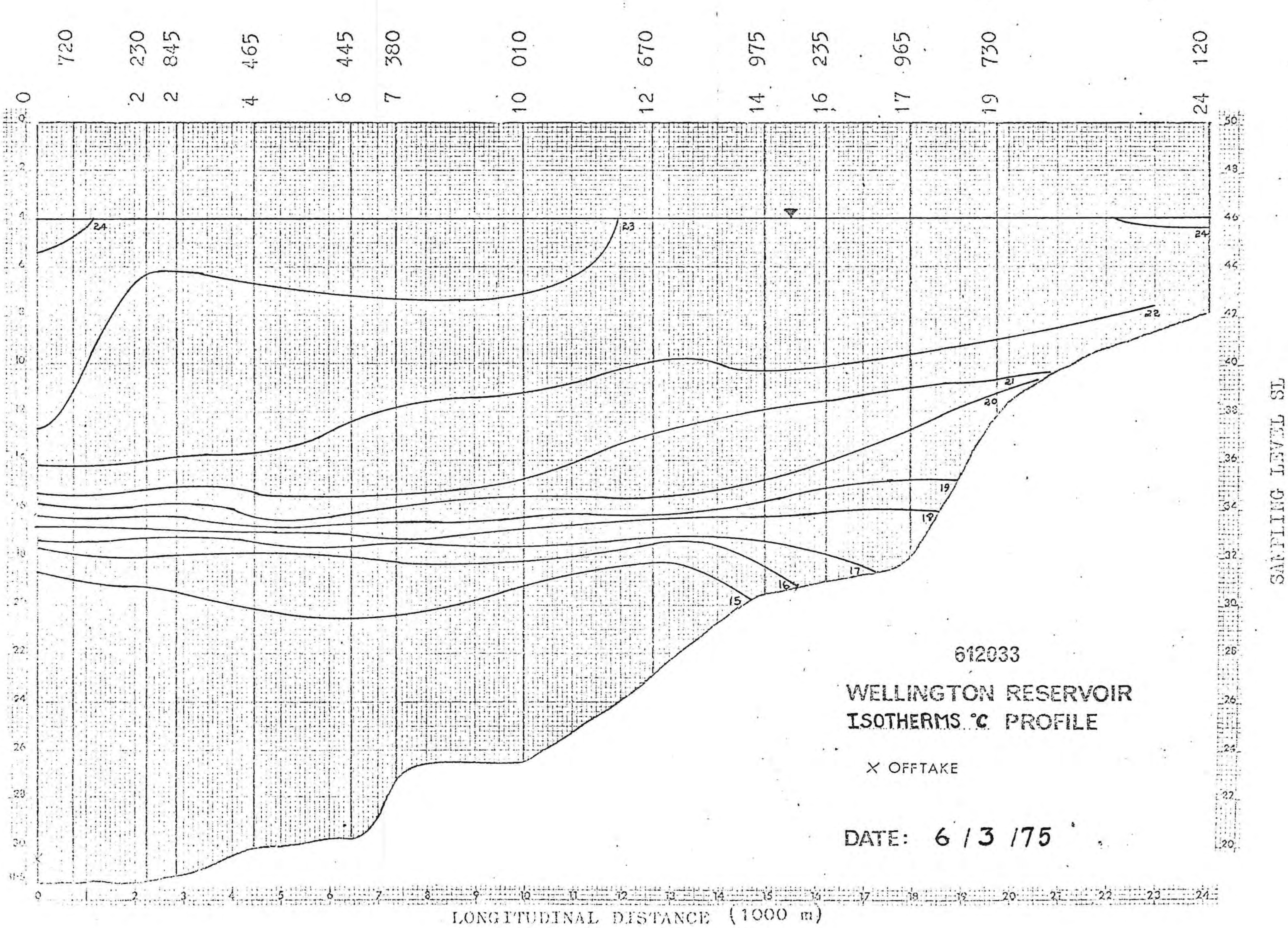

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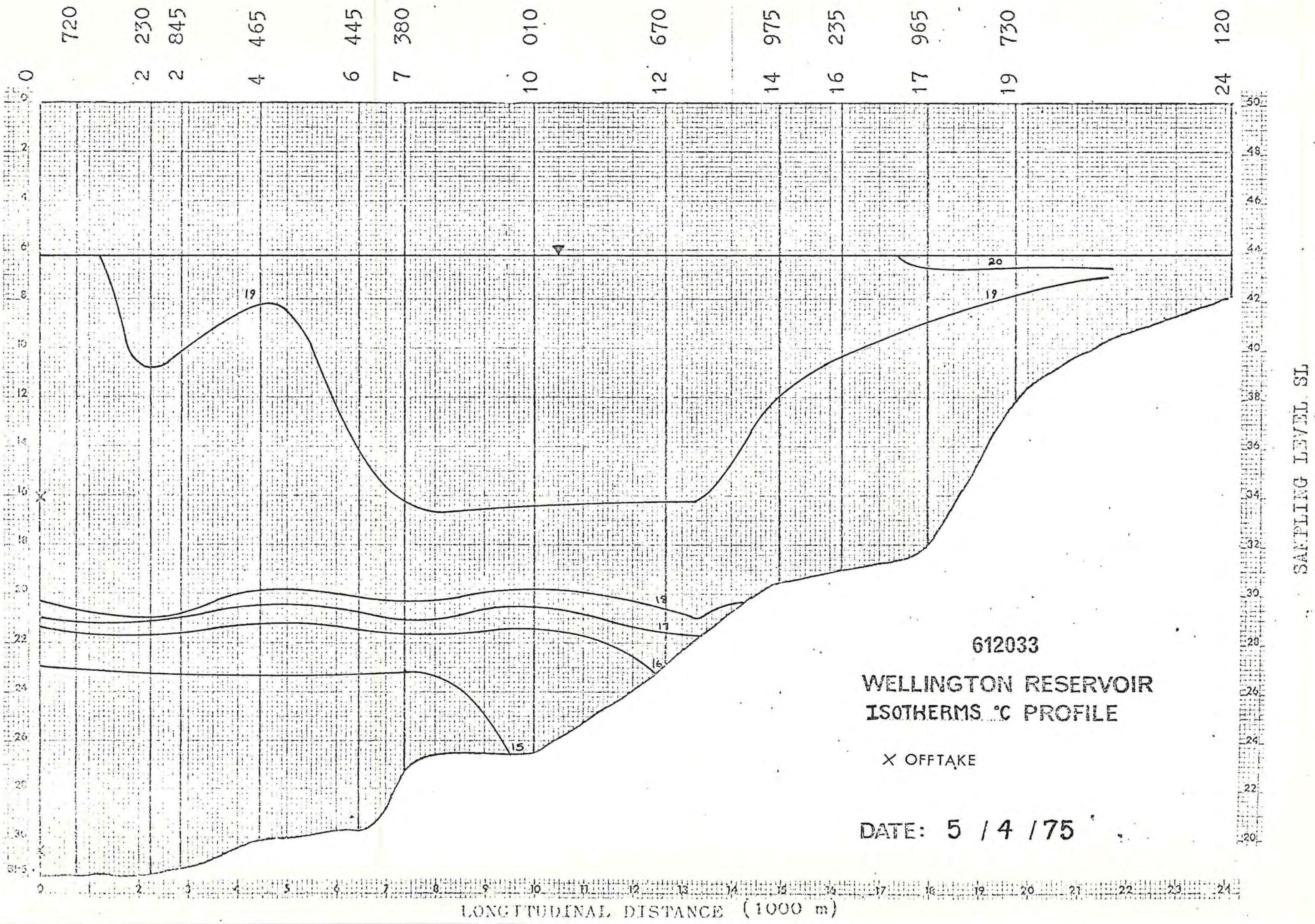
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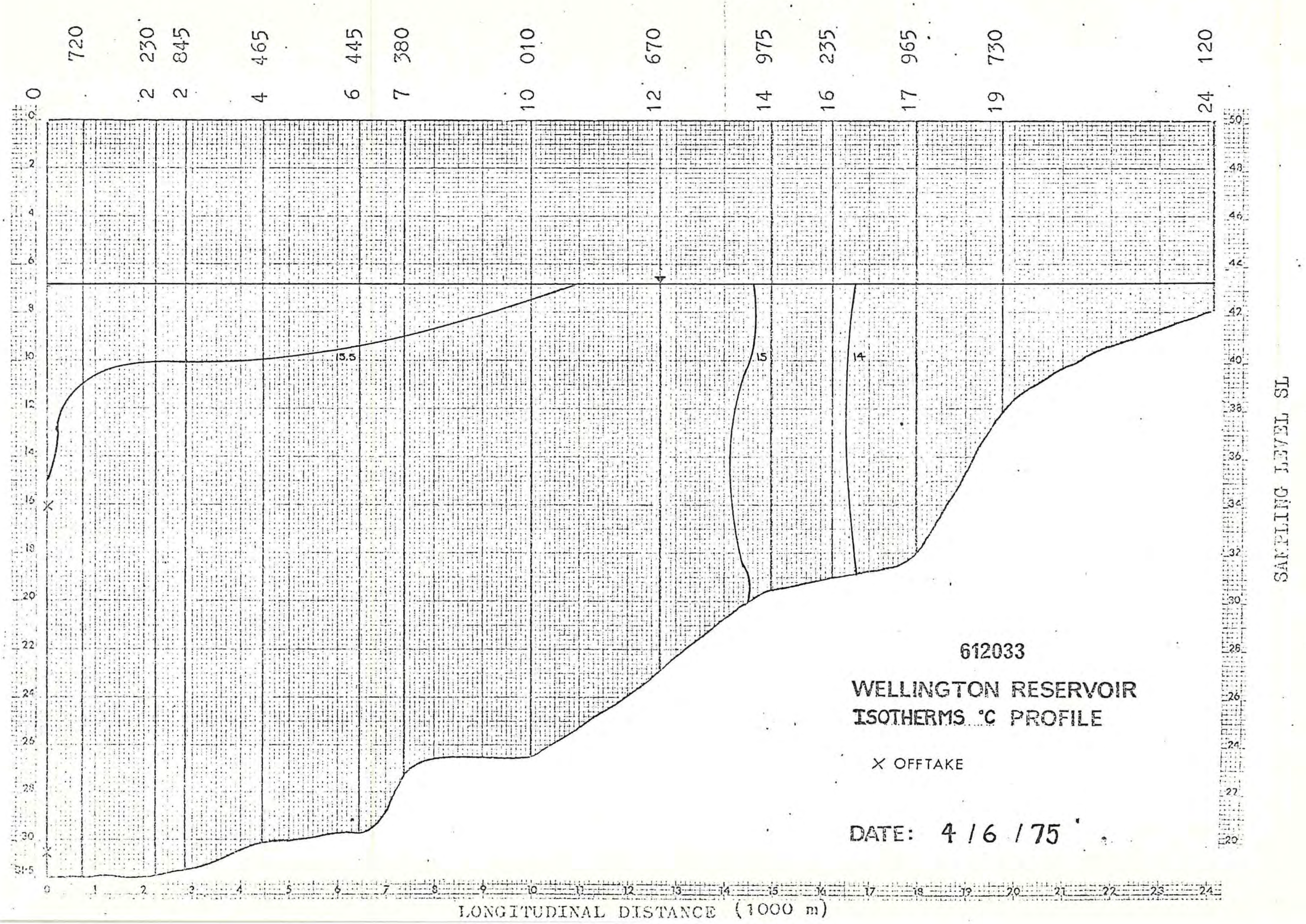
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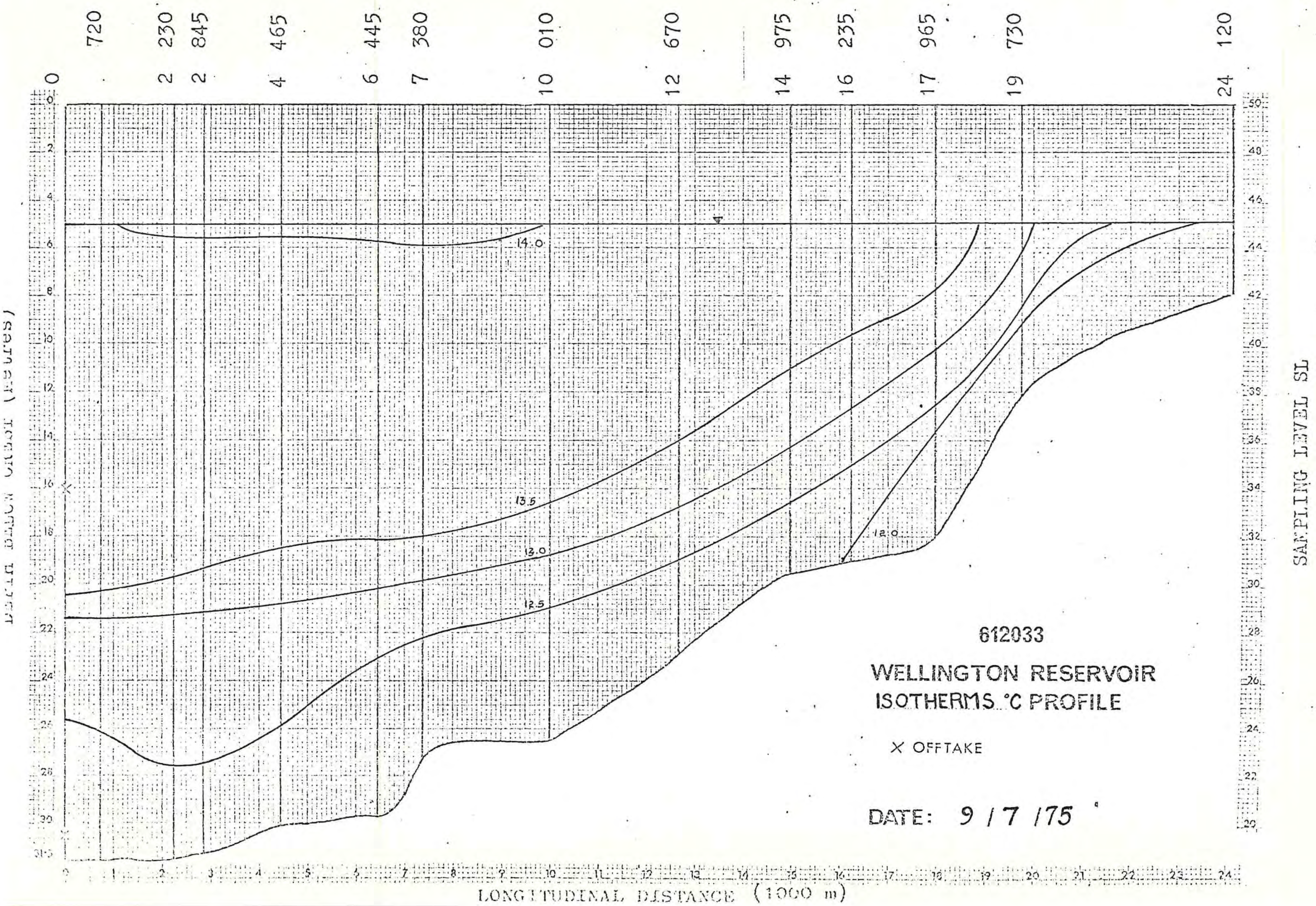
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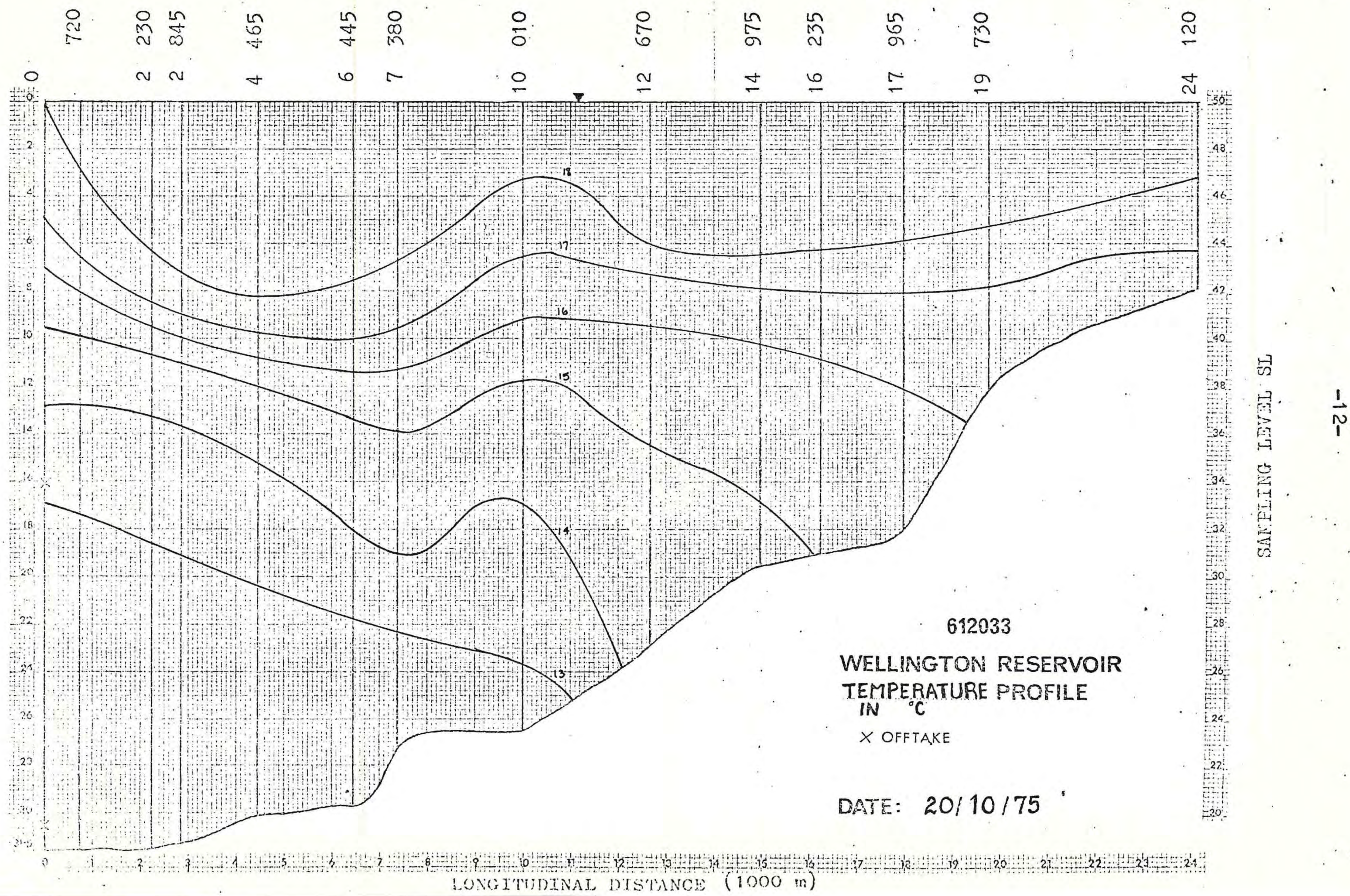
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WELLINGTON RESERVOIR
TEMPERATURE PROFILE
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LONGITUDINAL DISTANCE (1000 m)
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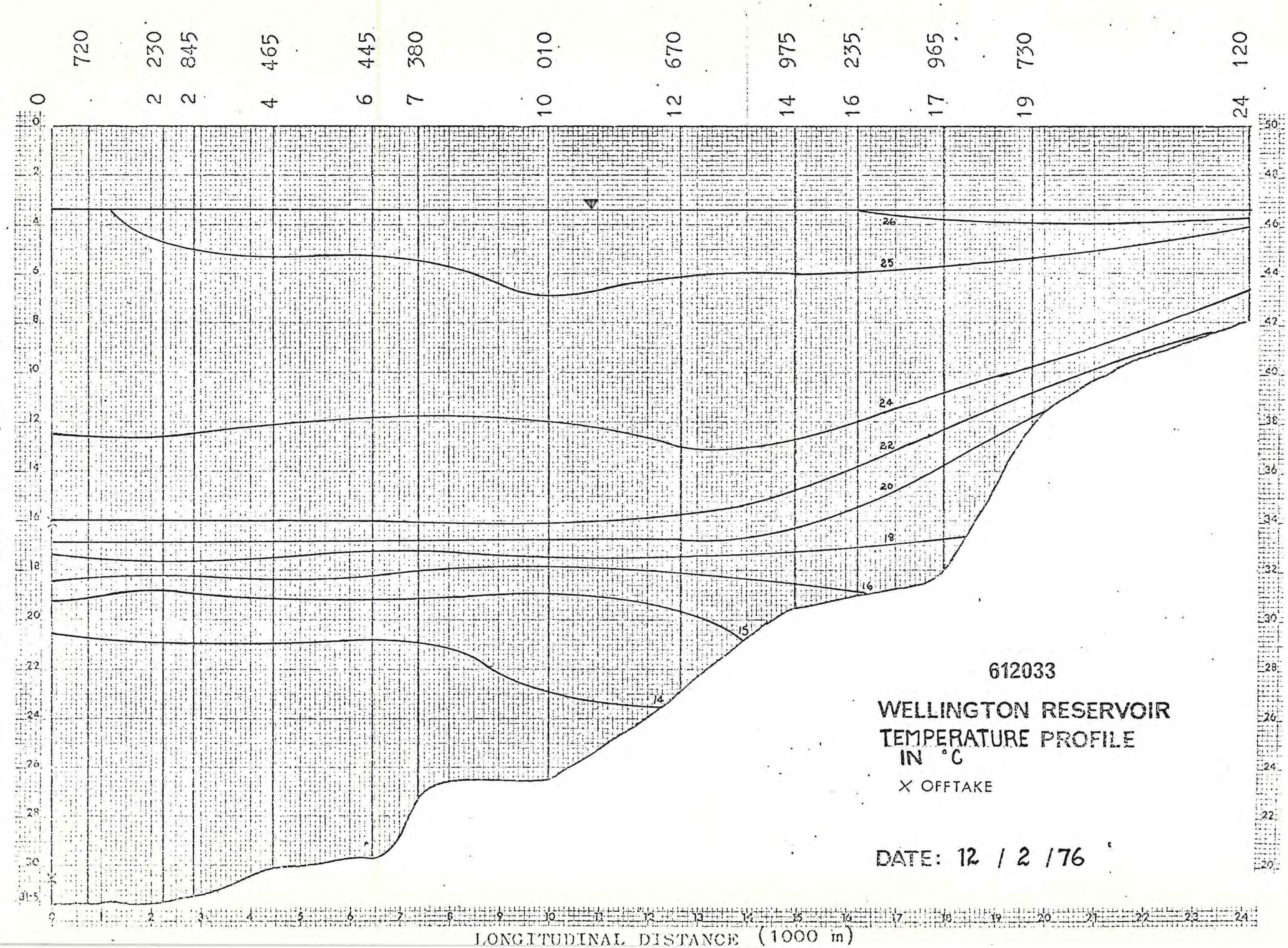
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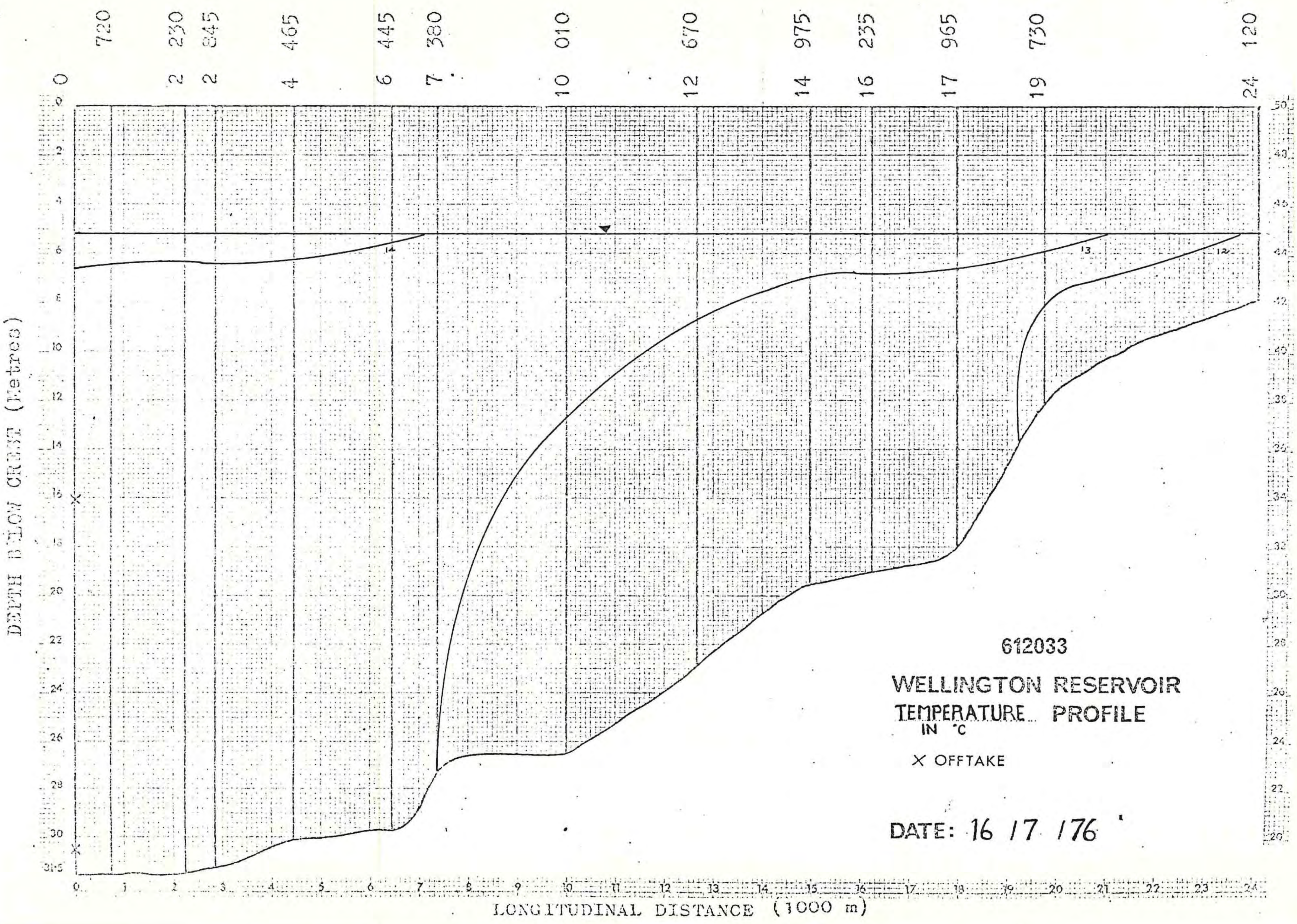

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DEPTH BELOW CREST (Metres)
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TEMPERATURE PROFILE
IN °C
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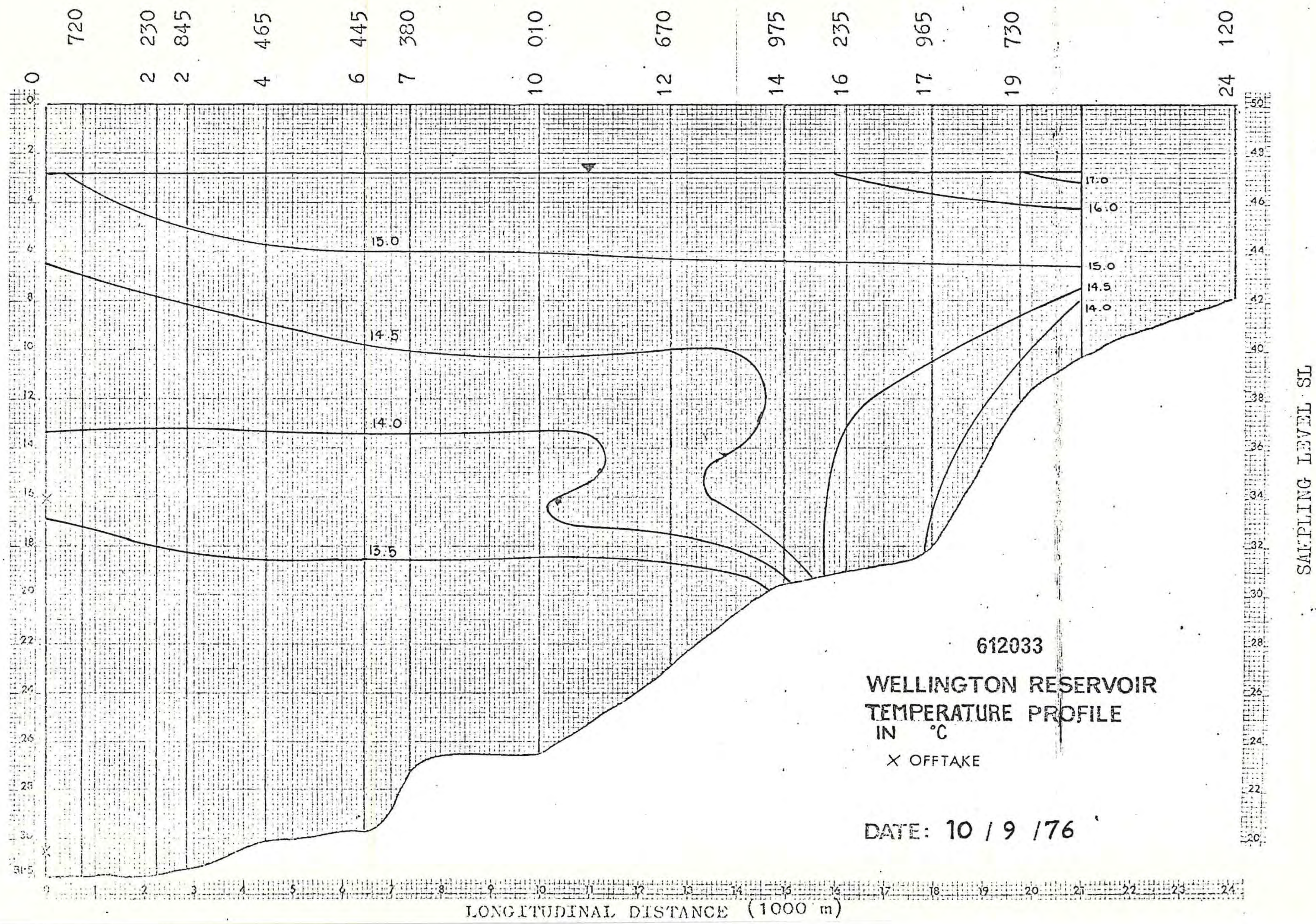

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IN °C
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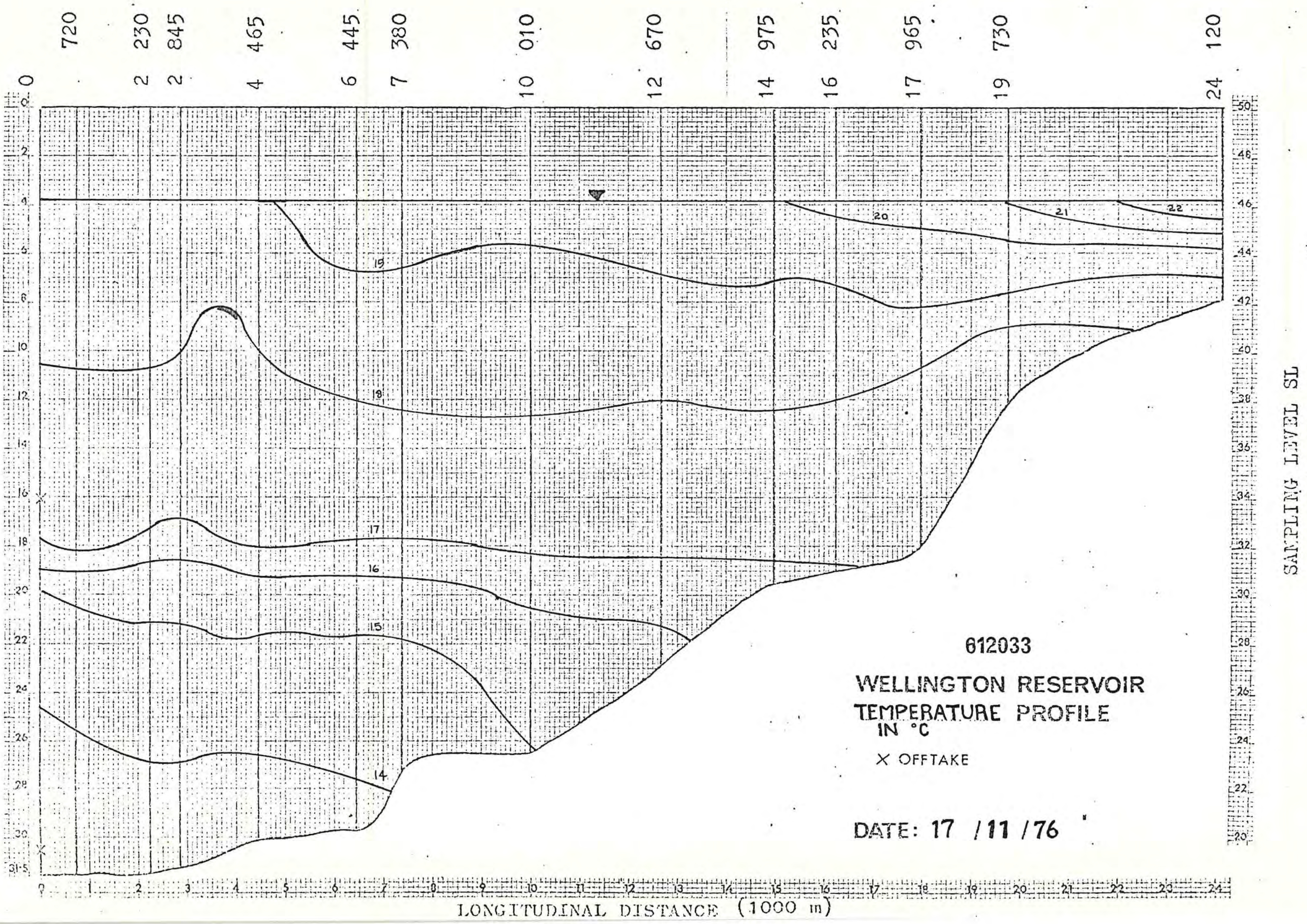
LONGITUDINAL DISTANCE (1000 m)



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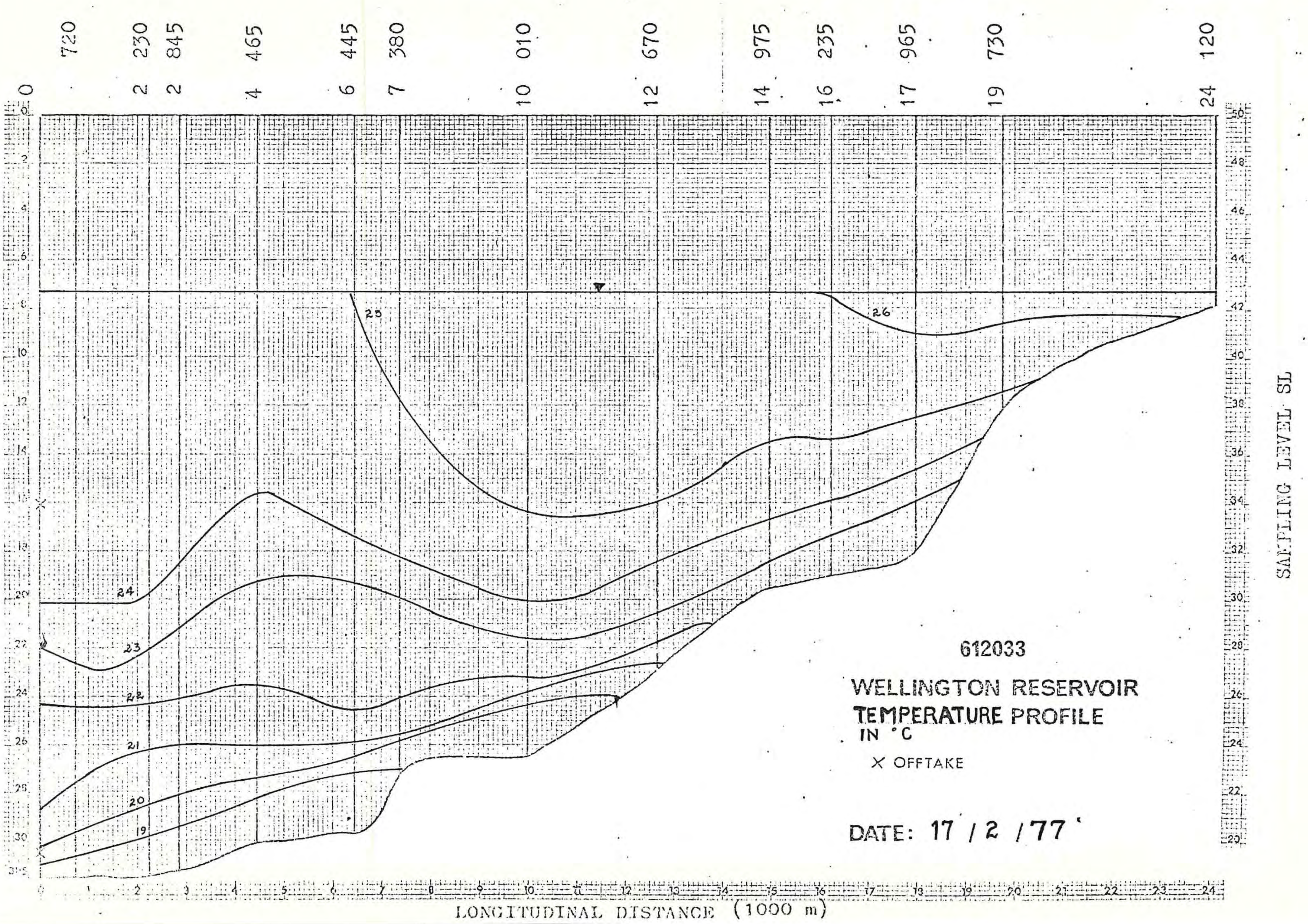
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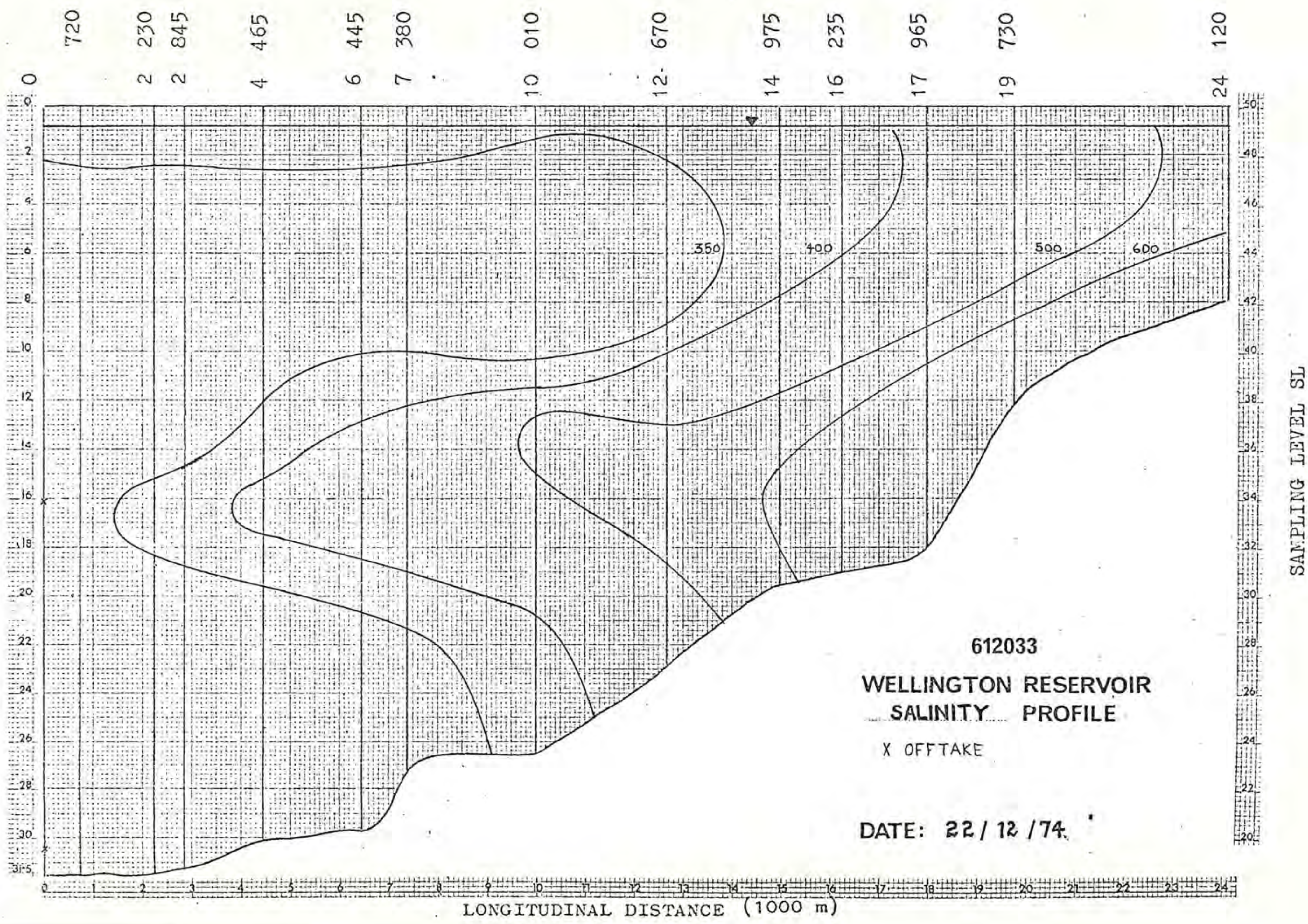
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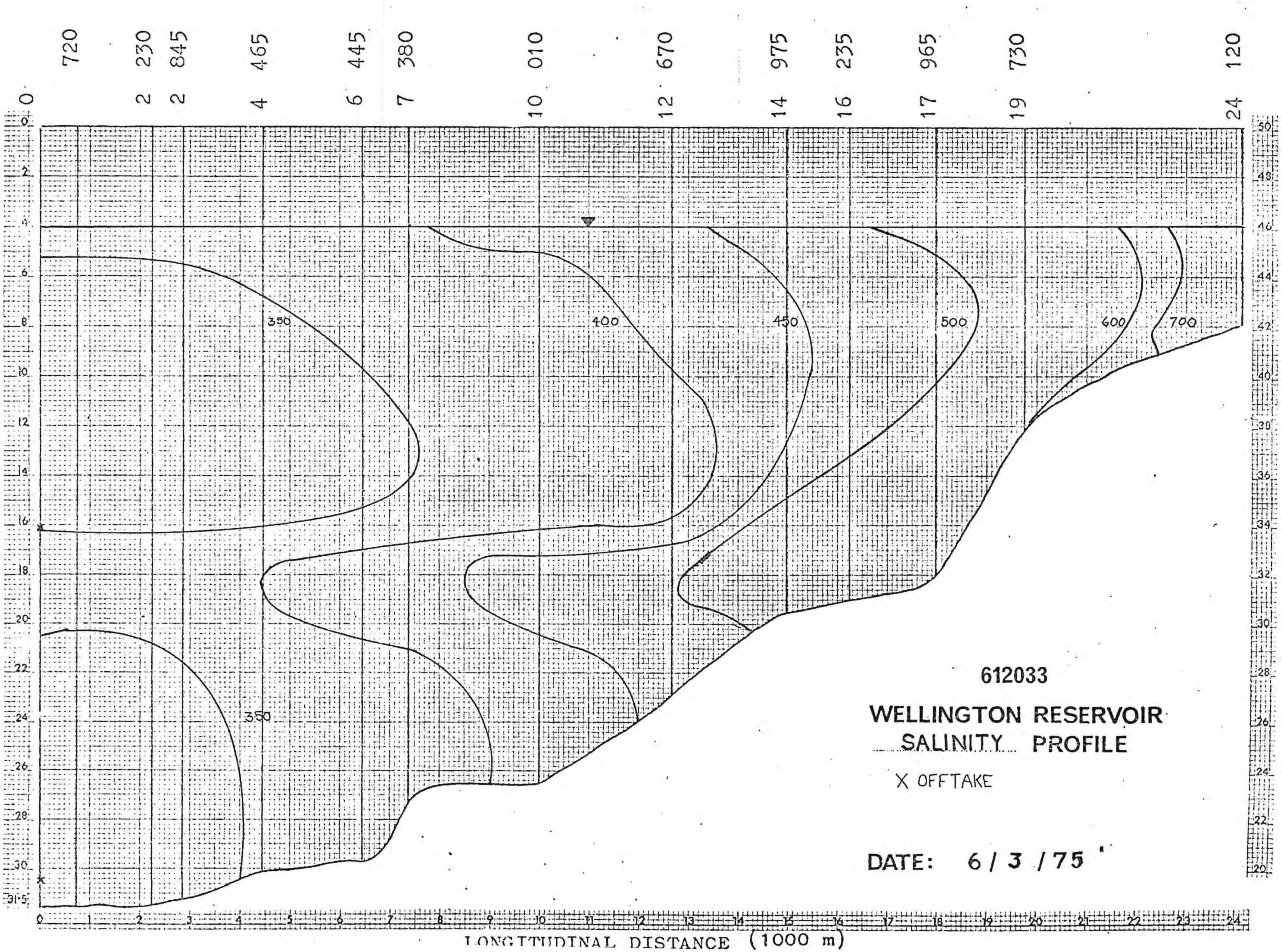

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WELLINGTON RESERVOIR SALINITY PROFILE

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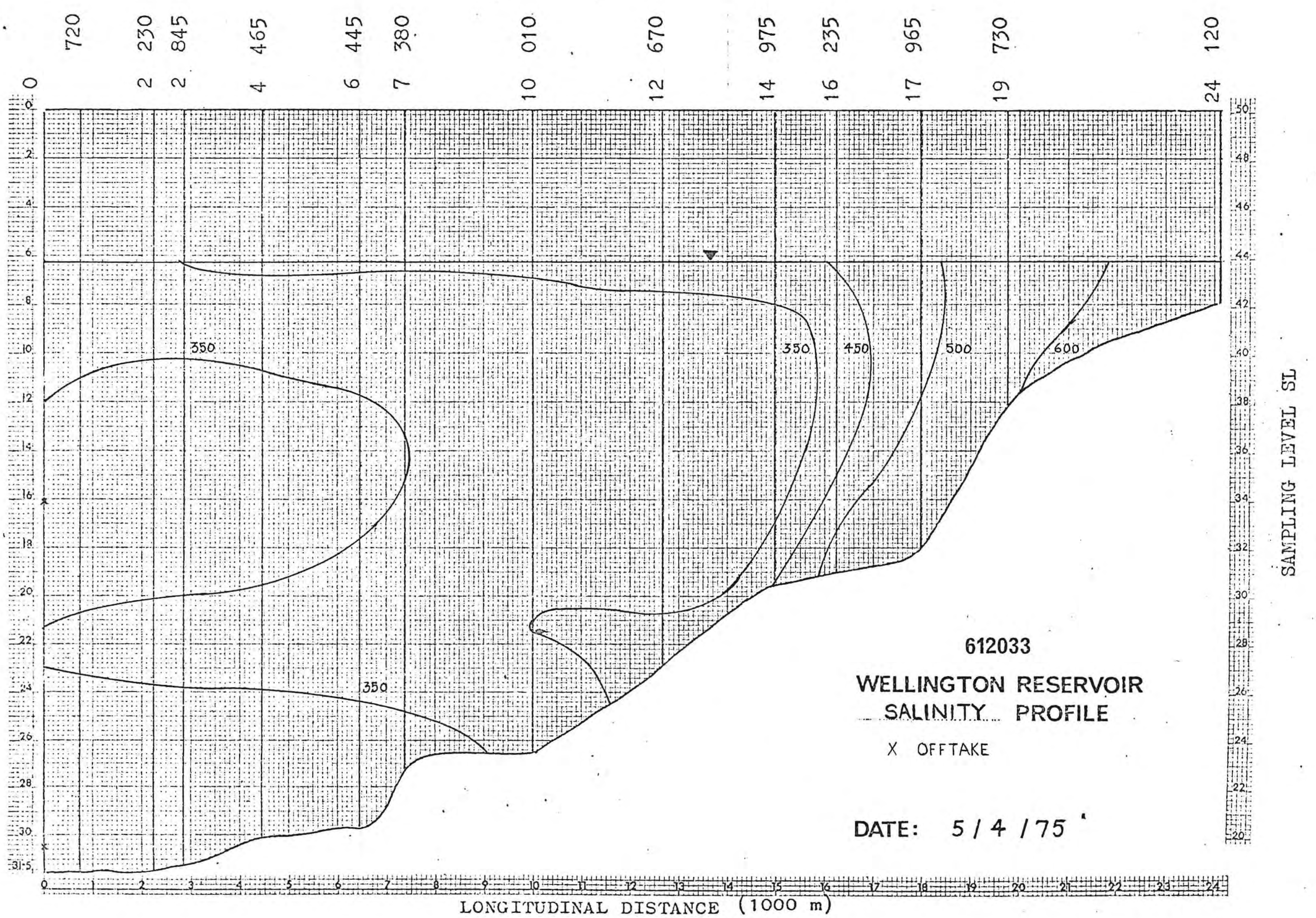
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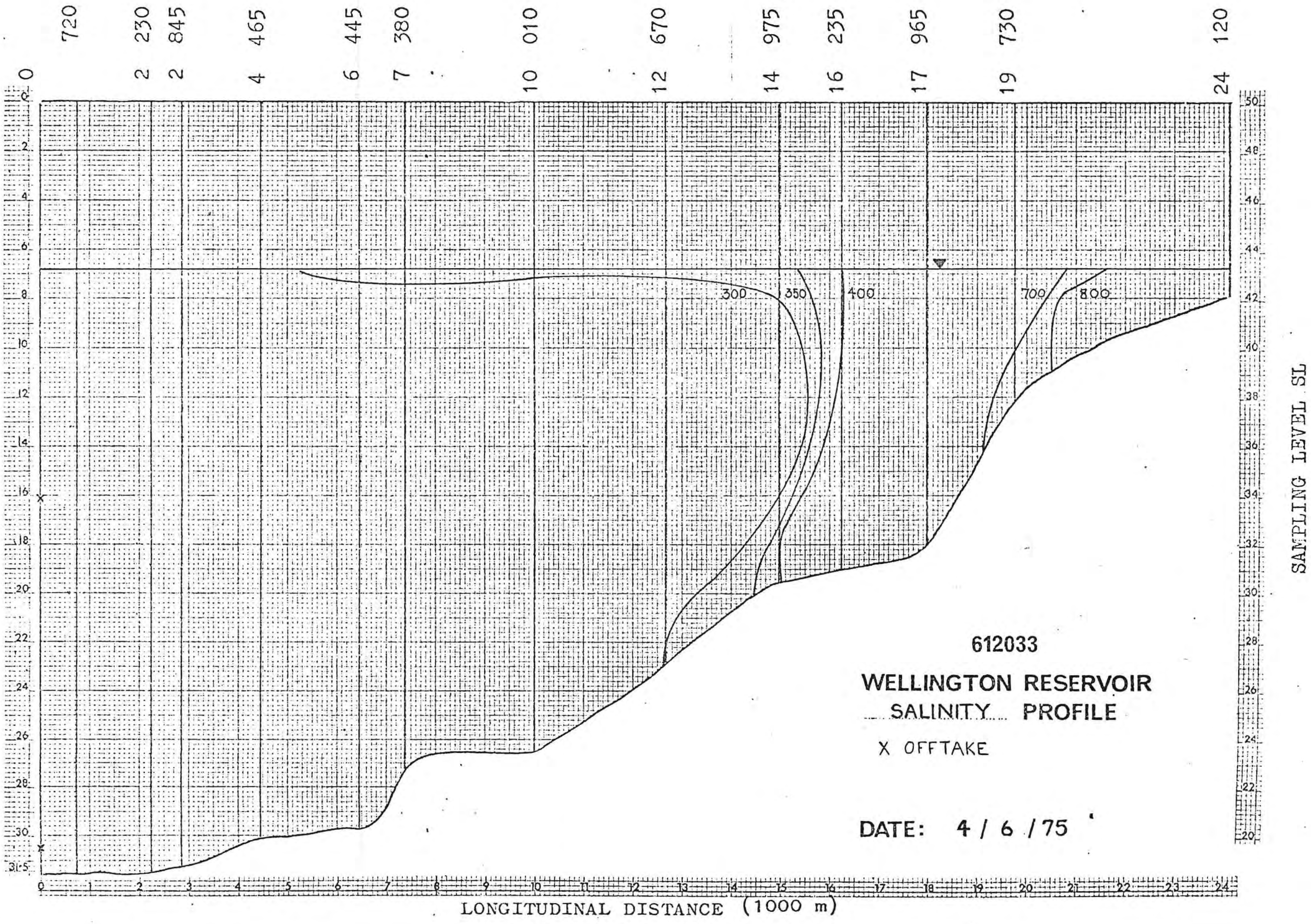

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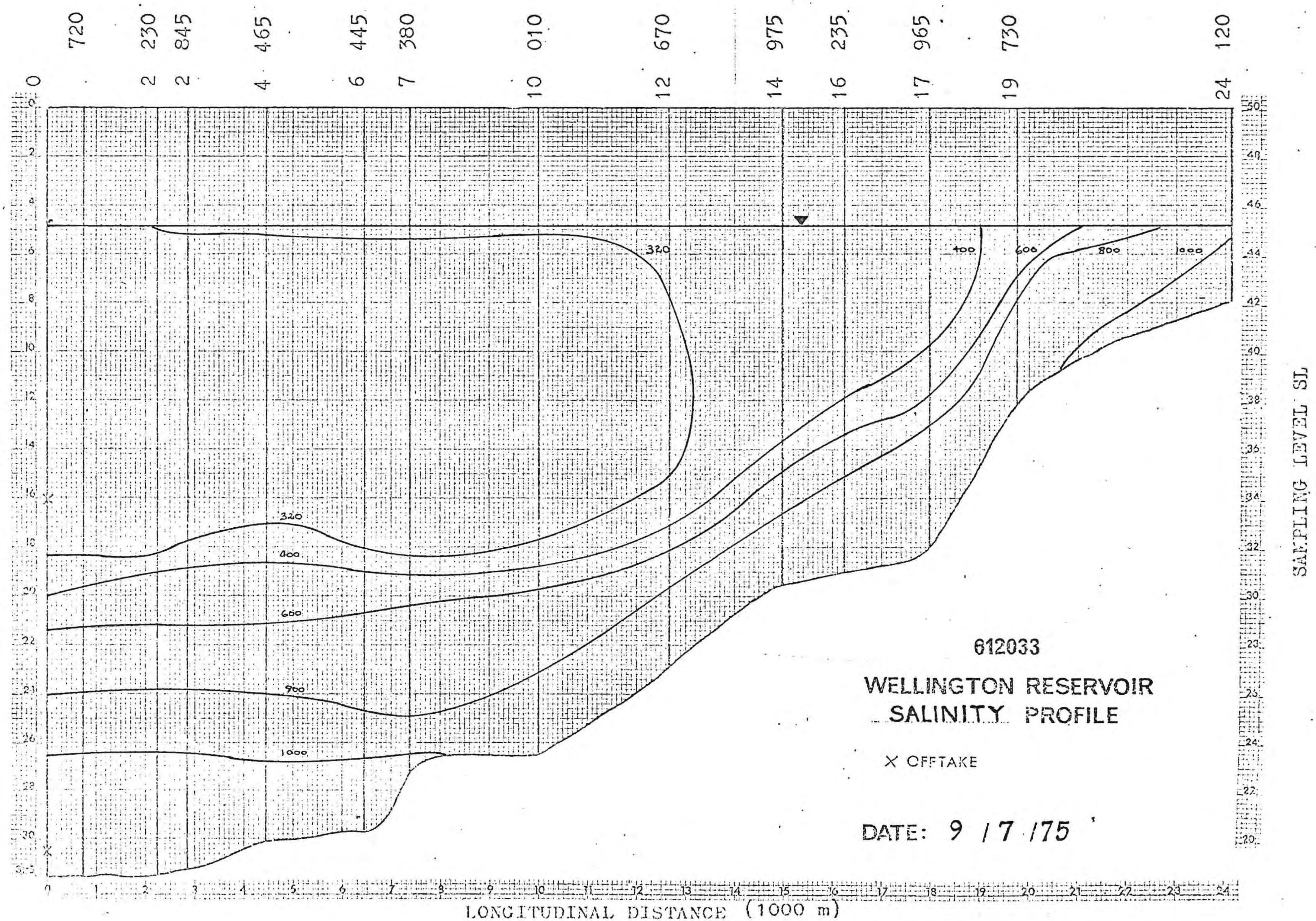

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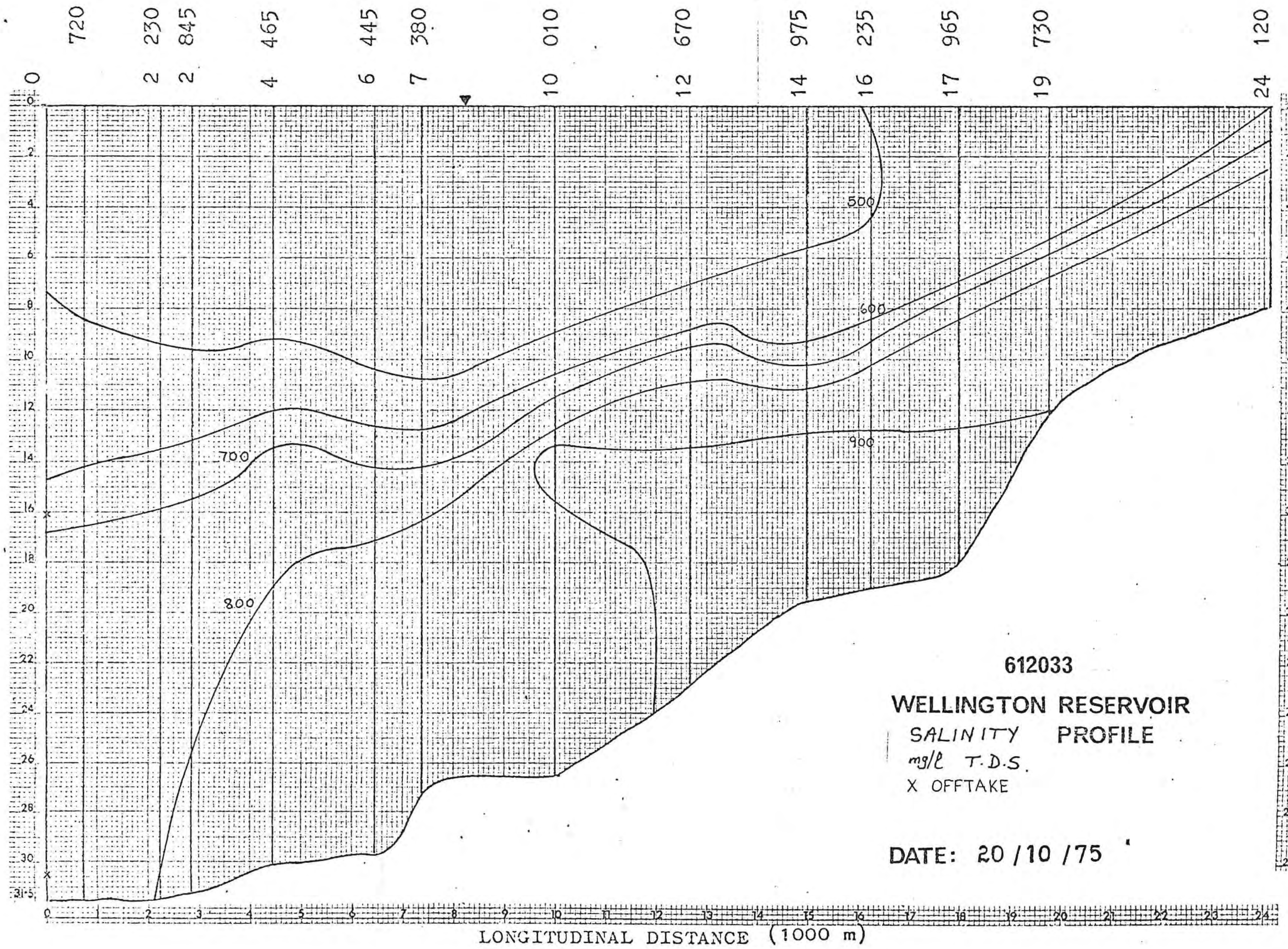
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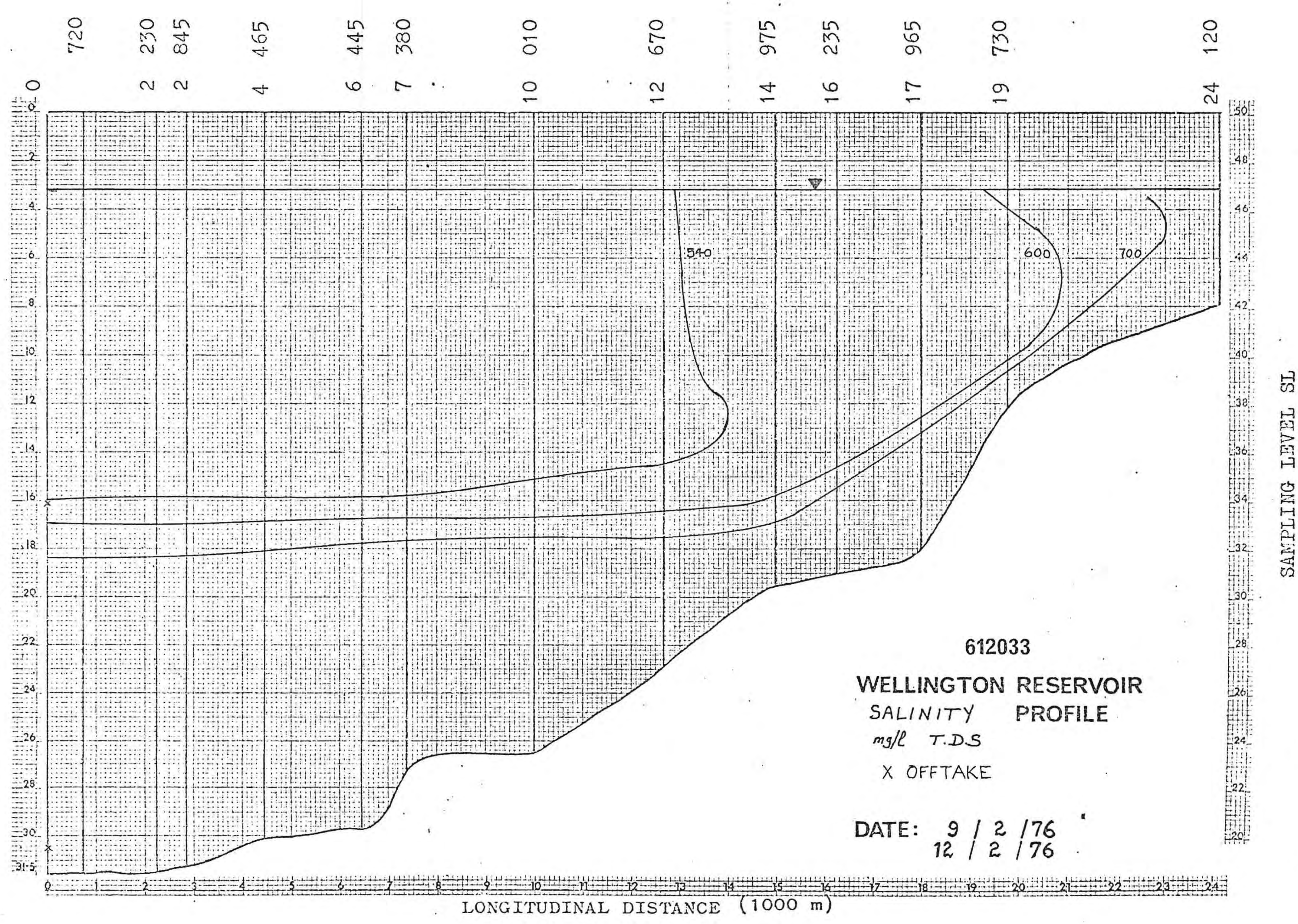
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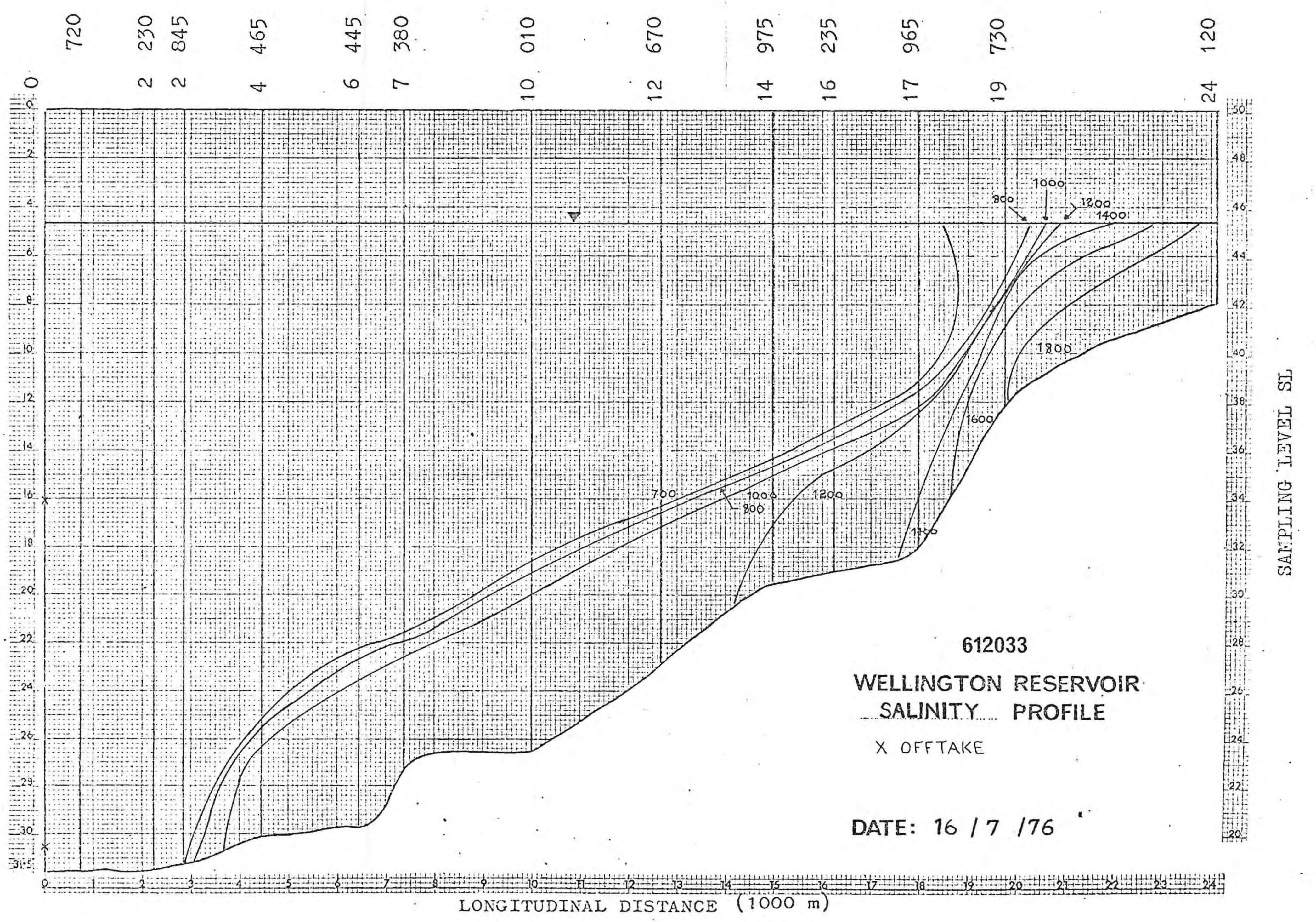
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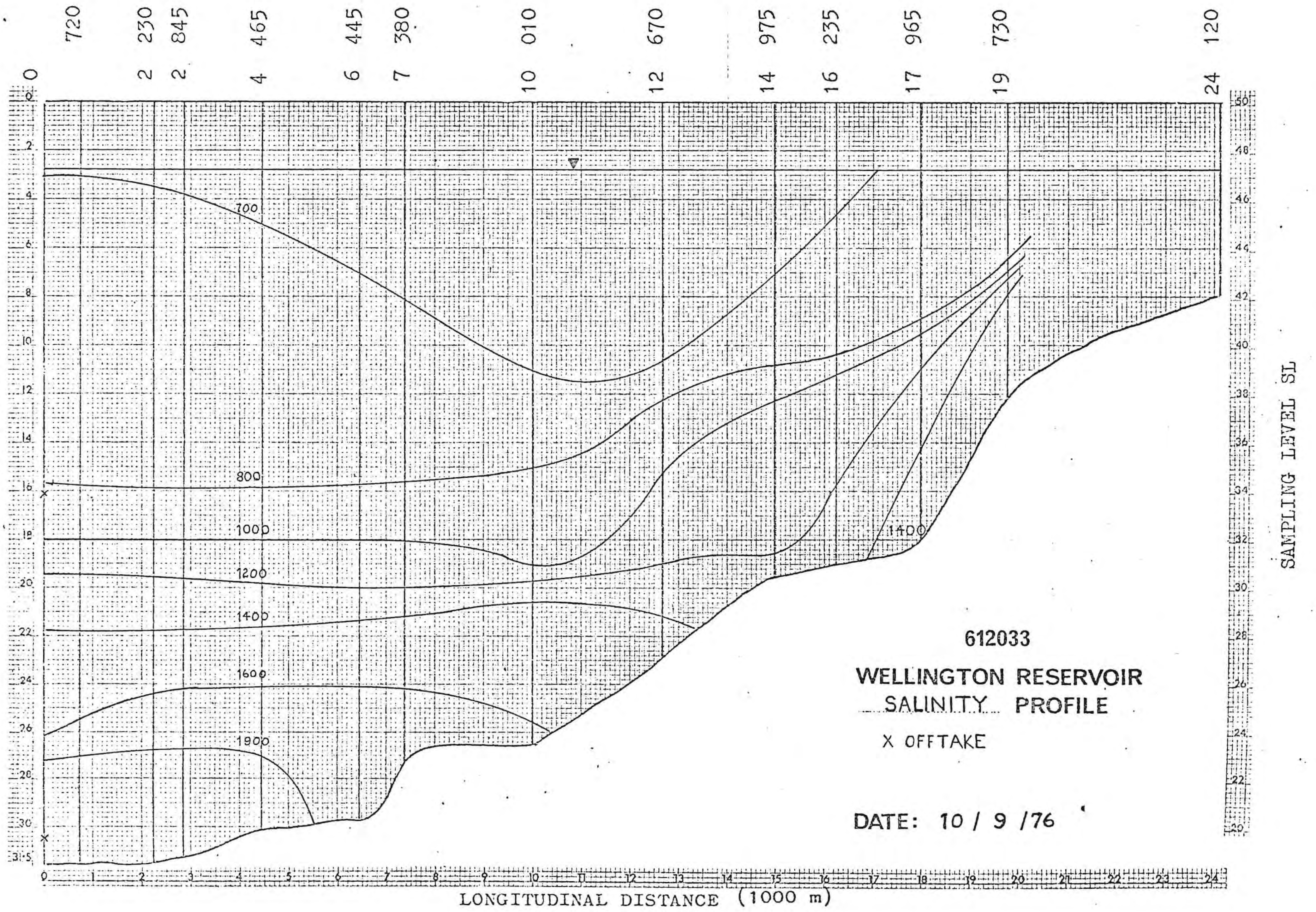
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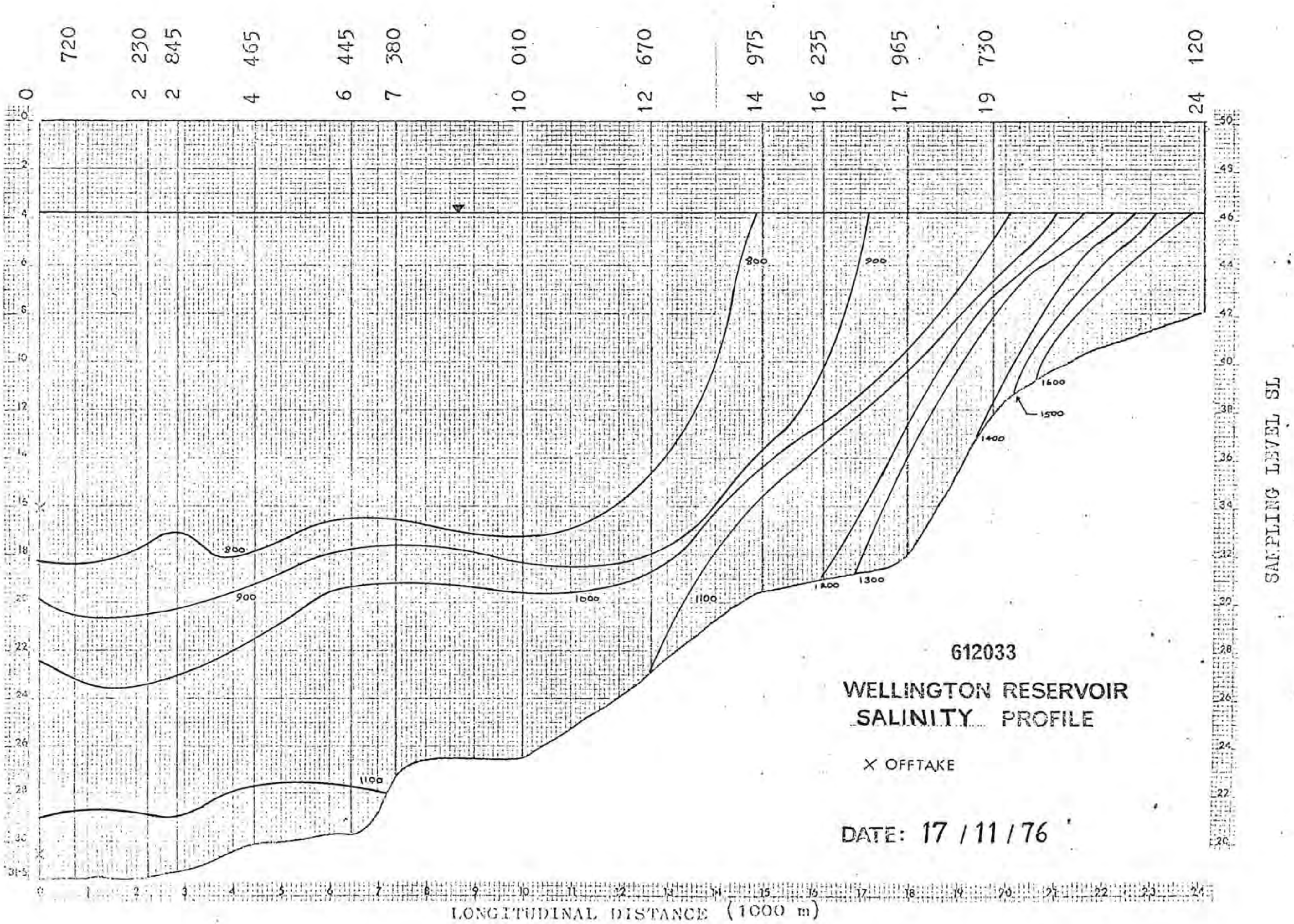
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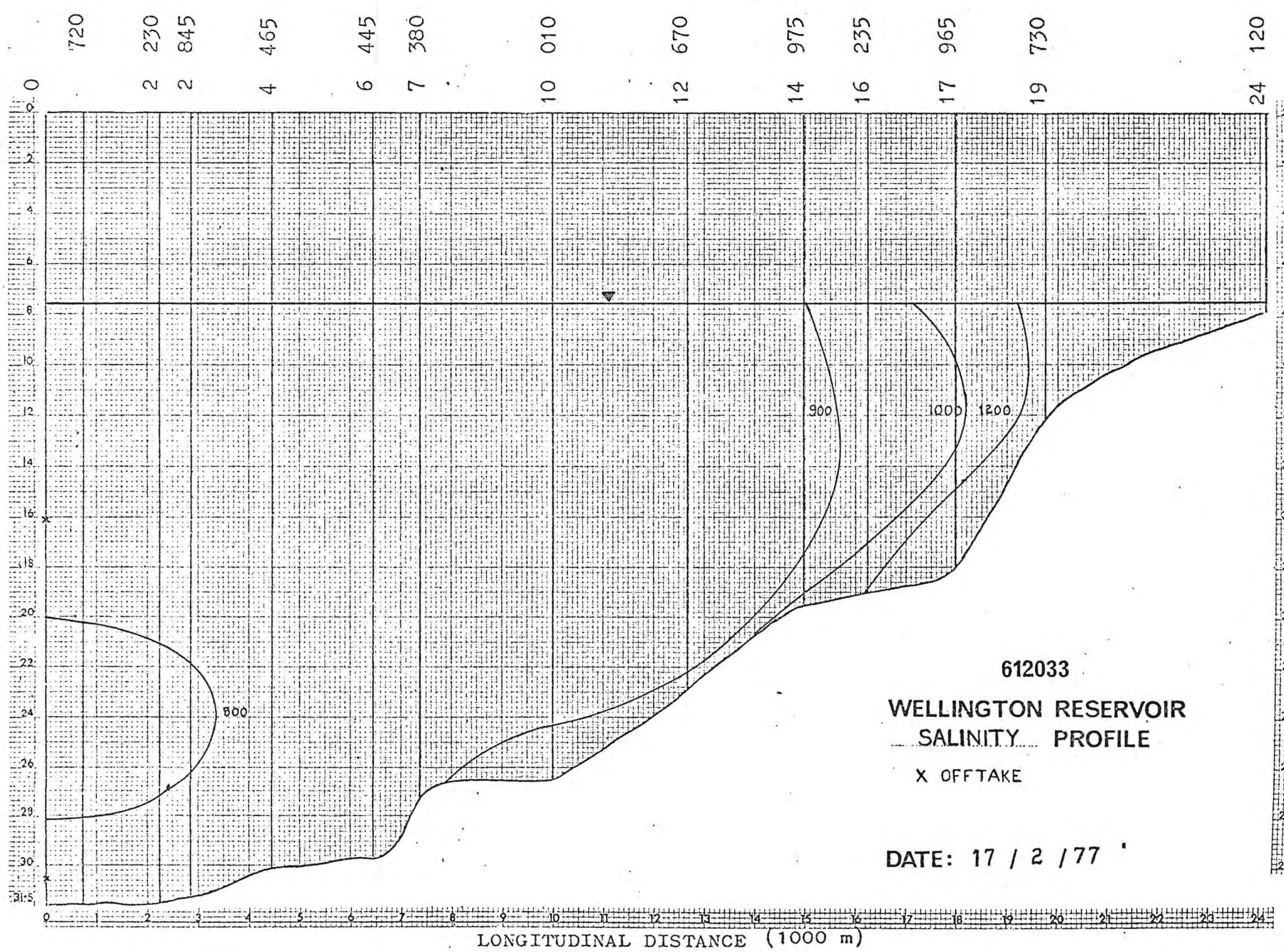

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