# Hydrological implications of a lake-level control weir for Wainono Lagoon, south Canterbury

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A B S T R A C T

A water balance model was developed on an Excel spreadsheet to help assess the impact of a lake-level control weir on a major source of inflow to the Wainono Lagoon, a large shallow coastal lagoon impounded behind a low shingle bar along the coast near Waimate. The lagoon is a regionally significant natural feature and a wetland of international importance, but is subject to storm damage and flooding. Inputs to the model included estimates of daily evaporation off the lake, rainfall, inflow, and seepage loss through the barrier beach. The model suggested that the construction of a weir in the upper Dead Arm would not achieve its intended purpose during the greater part of any year when daily nett evaporation rates exceeded 2–3 mm.

Keywords: water balance, computer model, lake level, Wainono Lagoon, south Canterbury.



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# 1. Introduction

Wainono Lagoon, on the coast to the northeast of Waimate in the lower South Island, is a large shallow coastal lagoon impounded behind a low shingle bar (Fig. 1) and covering about 376 ha. The water is brackish, and usually less than 1 m deep. It is a regionally significant natural feature and a wetland of international importance. It provides important habitat for waterfowl, migratory birds, coastal birds, and native fish. It is also a popular recreation area, providing opportunities for fishing, bird watching, and gamebird shooting. However, it is subject to damaging storms, for example one on 19 July 2001 lowered beach levels by about 2 m and flooded a large area of adjacent farmland.

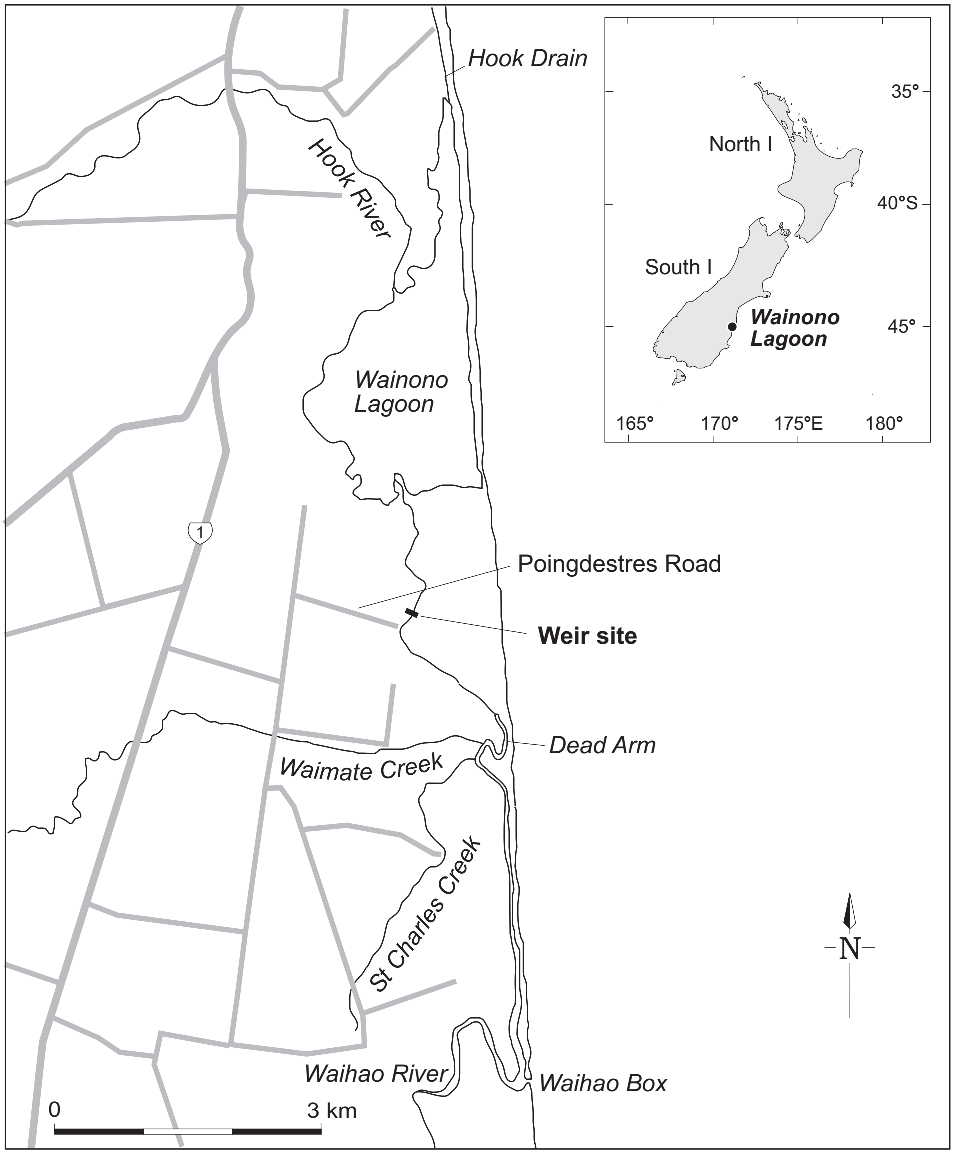


Figure 1. Location map for Wainono Lagoon.

To assist management of lake levels, primarily for conservation purposes, establishing an adjustable weir on the upper Dead Arm of Wainono Lagoon was investigated. This would be designed to return the lake to a water level of 1 m a.s.l within a reasonable time after significant flood-producing rainstorms and coastal storms, so as to avoid excessive and attenuated flooding of farmland around the perimeter of the lake and adjacent to the Hook River and coastal drains. The investigation involved constructing a water balance model for the lake allowing for the determination of a nominal lake level at the end of each day. This would be computed from the lake level at the beginning of the day and water gain and loss estimates over a 24 hour period. This model provided a basis for gaining an understanding of the lake dynamics and how it might respond to the presence of the lake level control weir.

# 2. Development and use of water balance model

## 2.1 FORM AND OPERATION OF MODEL

The water balance model used has been developed on an Excel spreadsheet. Inputs include estimates of daily evaporation off the lake, rainfall, inflow, and seepage loss through the barrier beach.

The model provides for changes to the water stored in the lake on a daily basis by assessing volumetric changes arising from rainfall and evaporation over the lake surface, the loss of water by seepage through the barrier beach, and surface and groundwater inflows into the lake. This last function incorporates inflows from a number of surface water sources to the lake directly, or indirectly via the Dead Arm. This function can be used to input flood hydrographs which represent flood inputs from any or all of the surface water sources in part (e.g from the Waihao River) or in full (e.g. Hook River). When nett inflow is negative, the mean sum of losses in the lake over the 24-hour period exceed the inputs, leading to a reduction in storage and a lowering of lake level.

The procedure for using the model requires initialisation on the spreadsheet of the following data for day 1: start lake level; lake surface area associated with the start lake level (from Fig. 2); lake storage volume associated with the start lake level (from Fig. 3). The initial beach seepage loss was set at 880 L/s for a start level of RL 1.0 m a.m.s.l. or 830 L/s for a start level of RL 0.9 m a.m.s.l. Linear interpolation for other values of start lake levels was made using these two values.

Daily rainfall totals (mm) for the particular days on which rainfall occurs and daily evaporation totals (mm) for all days were entered on the model being used. In the nett evaporation column, the value is negative if evaporation exceeds rainfall.

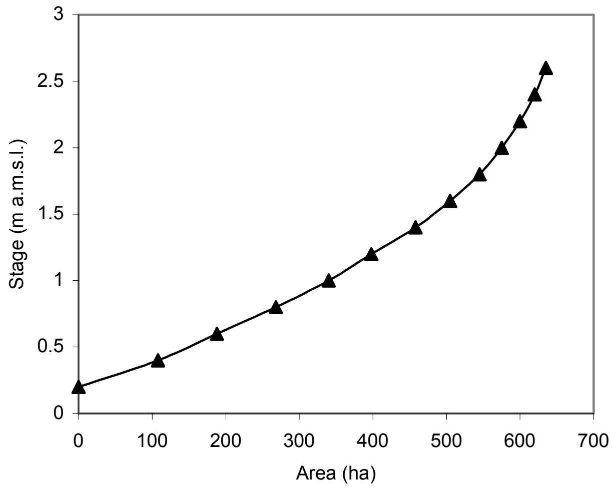


Figure 2. Plot of stage (m a.m.s.l.) v. area covered (ha) for Wainono Lagoon.

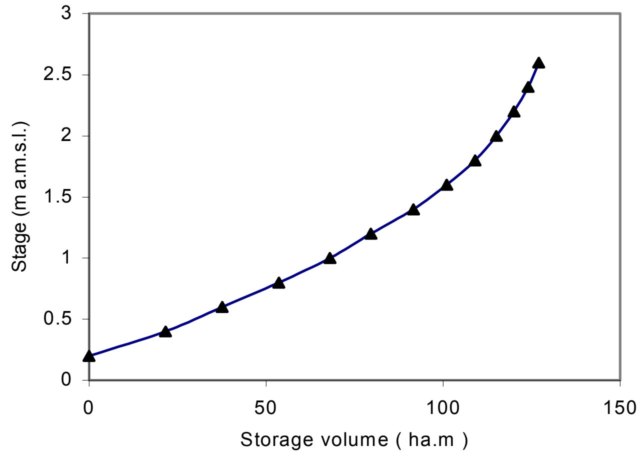


Figure 3. Plot of stage (m a.m.s.l.) v. storage volume (ha.m) for Wainono Lagoon.

The values for Inflow are the estimated sum of surface and groundwater inflow to the lake, including that sourced from the Dead Arm; a constant value can be used in order to determine a steady-state situation, or a daily mean flow basis can be used in the form of an input hydrograph superimposed on a baseflow.

Once this procedure is complete the spreadsheet will generate 100 days of lake level data and transfer them on the adjoining plot in graphical form which can be printed out, as can the spreadsheet after highlighting the area for which a plot is required. The spreadsheet is interactive, so the start level and corresponding lake area, storage volume and beach seepage values, rainfall, evaporation or nett evaporation values, and/or inflow can be changed. No other values on the spreadsheet should be altered; otherwise the calculations on the spreadsheet will be corrupted.

The following relationships have been employed in the model:

Lake area at the end of the day (ha) = – 93.239* $(RL)^2$ + 524.09* (RL) – 93.699

where (RL) is the lake level at the end of the day.

Volume at the end of the day (ha.m) = [vol. at start of day + (0.086 × Nett Inflow)]

Beach seepage loss (L/s ) = [224 – 56* (change in lake level on preceding day)]

The beach seepage loss equation incorporates a hydraulic conductivity for the beach of 0.006 m/s, a beach length of 4.5 km, and a flow path through the barrier beach of 100 m; it uses the Darcy equation to estimate daily loss, allowing for the available head integrated over the day based on the difference between lake level and tidal changes in sea level.

The model was calibrated using rainfall/evaporation and lake levels during January 1996, with a lake start level of 1.0 m a.m.s.l., and estimating the inflow function on a daily basis in order that the model lake level at the end of each day of that month matched the record for lake level at the beginning of the next day.

## 2.2 ASSUMPTIONS AND LIMITATIONS

The standard time step for the iterations was set at 24 hours in order to match evaporation and precipitation data adopted for this location and daily mean lake level data provided by Environment Canterbury. The data specification does not allow a full level pool routing exercise to be undertaken, but this is not seen as a major limitation because the exercise is principally one in which time steps on a daily basis are considered acceptable in terms of lake level response. As a general rule, if flood routing were the principal issue, level pool routing would be appropriate and this would demand time steps in the order of 20% of the time of rise of inflow hydrographs. For example, the time of concentration of the Hook Catchment is estimated to be in the order of 3 h, which for a 24 h storm duration would yield a hydrograph time of rise in the order of 14–15 h. This situation would require a time step for level pool routing in the order of 3 h.

The model assumes a positive hydraulic gradient will exist between the lake and the sea at all times. It is acknowledged that during major coastal storms reverse gradients could exist between the sea and the lake for brief periods during which seepage inflow to the lake might occur. However, as a rule these conditions are likely to be very brief and small in scale, to occur infrequently and be unlikely to materially affect the model results.

Environment Canterbury operates a lake level recorder at Poingdestres Road in the upper Dead Arm at the southern end of the lake. It is evident that wind over the lake will influence lake level and consequently also lake-level records. These influences include wave height and procession up the Dead Arm from the lake, wave set-up, seiching, and atmospheric pressure changes. It is estimated that the combined effects of these factors could result in variations in lake level over a day in the order of 100–150 mm. Accordingly, at best the lake-level record is indicative. Although this limits the model predictions, they are satisfactory for evaluating changes on a daily basis in order to gain an appreciation of the lake dynamics and how it might respond to the presence of a lake-level control weir.

# 3. Results

Notwithstanding the model limitations described above, the model demonstrates a clear sensitivity to rainfall/evaporation and inflow functions. The complexity of the inflow function does not permit a breakdown into its surface and groundwater components, but it is anticipated that inflow from the Dead Arm would contribute significantly to the total daily inflow to the lake. Environment Canterbury staff are endeavouring to measure water velocities in the Dead Arm in order to quantify this flux. Results to date are not conclusive because of the complexity of the velocity distribution over the depth at the monitored section and the difficulty of measuring the very low flow velocities observed across a large cross-section of flow. Measurements to date have indicated the possible existence of stratified flow over the depth, with different flow directions occurring between surface and bed. These conditions may indicate the presence of a saltwater wedge.

The results of the calibration were correlated with mean daily flows on the Waihao River in order to try and crudely determine the influence of inflow to the lake from the Dead Arm from the south. No clear trend was evident until Waihao flows exceeded approximately 5 cumec at McCulloughs Bridge. However, this analysis suggests there were daily average flows of about 200–300 L/s into Wainono Lagoon from the south, sourced from the combination of Waihao River, Waimate Creek and St. Charles Creek flows via the Dead Arm (see Fig. 4). Inflows of this order have a significant effect on maintaining lake levels particularly where nett evaporation (evaporation less rainfall) exceeds 2 mm per day.

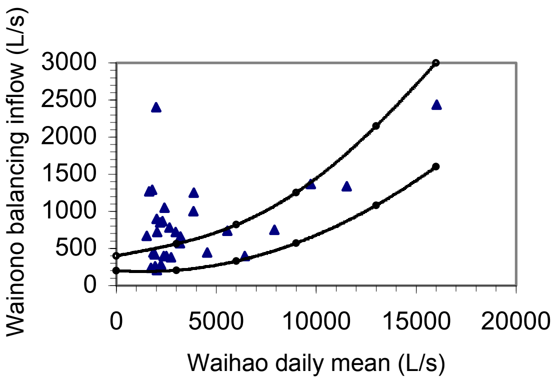


Figure 4. Correlation of the January 1996 Waihao River flow with the Wainono Lagoon balancing inflow.

If a lake control weir, designed to maintain lake levels at or about 1.0 m a.m.s.l., was to be constructed in the upper Dead Arm, the deprivation of this balancing inflow from the Dead Arm arising from the presence of the weir could result in a rapid decline in lake level once nett evaporation exceeded 2–3 mm per day (see Fig. 5). In other words the presence of the weir would itself generate the conditions which it was intended to avoid. To preserve this critical inflow, a flood gate could be incorporated into the weir to allow water to move from the Dead Arm into the lake through it, but this is equivalent to retaining the status quo, i.e. an uncontrolled outlet from the lake.

Under flood conditions it would be necessary to have the facility to increase the flow capacity of the weir where lake levels exceeded those in the Dead Arm. Otherwise it would exacerbate the extent, depth and duration of flooding and elevated water tables on farmland around the lake perimeter and in the low-lying areas in the coastal backshore to the north of the lake. To lessen this flooding, this facility could be used to restrict inflow to the lake from the Dead Arm when the Waihao River was in flood and/or water levels in the Dead Arm were high because the Waihao Box was impeded, blocked or surcharged. However, in these circumstances if operated in this way it could cause greater flooding on farmland adjoining the Dead Arm south of the control weir than would occur in the absence of the weir. Consequently, it is doubtful if this operational aspect could realistically be promoted without consideration of some form of compensation to properties affected in this way.

A curve of lake level v. duration has been compiled from the record of daily mean lake levels at the Poingdestres Road recorder site for the period 1986–

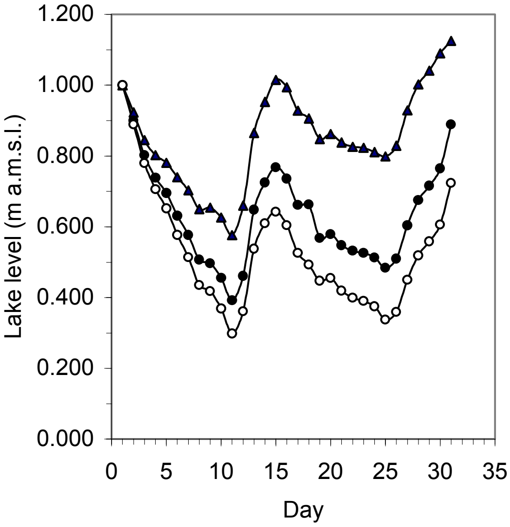


Figure 5. Lake levels 1996 for Wainono Lagoon with and without a control weir:
▲ no weir;
● with weir (– 200 L/s);
○ with weir (– 300 L/s).

2001 (see Fig. 6, Table 1). This record should be interpreted with caution, as it is comparatively short (15 years) and about 9% of the record is missing.

Curves of lake level v. frequency for the annual series of high and low daily mean lake levels have been compiled from the Poingdestres Road site record (see Fig. 7) for the lake as it presently stands. This indicates that the likely extreme daily mean lake levels based on the existing record are: maximum 3.0 m a.m.s.l., minimum 0.2 m a.m.s.l. (for average annual exceedance probabilities in the order of 1%).

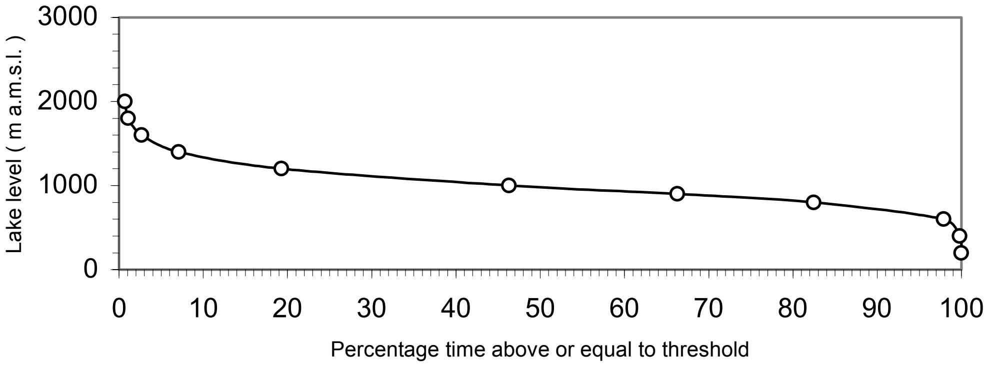


Figure 6. Duration of lake levels > threshold level, Wainono Lagoon, 1986–2001.

TABLE 1. SUMMARY OF LAKE OPERATING LEVELS, WAINONO LAGOON, 1986–2001.

| STATISTIC | 1966–83 | 1986–2001 |
|---|---|---|
| Max imum recorded | 260 | 2806 |
| 10% percentile | 1310 | 1320 |
| Mean recorded | 960 | 1010 |
| 50% percentile | 950 | 980 |
| 90% percentile | 690 | 760 |
| Minimum recorded | 140 | 258 |

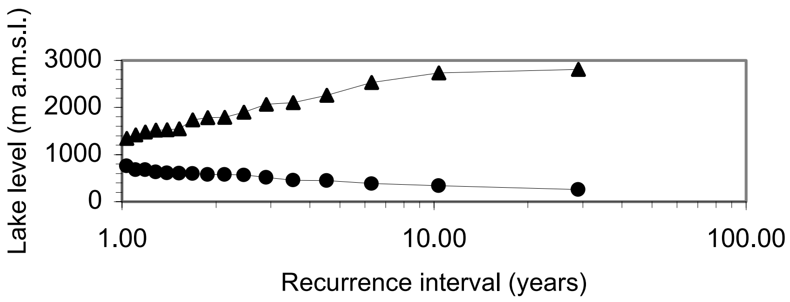


Figure 7. Lake level frequency analysis, Wainono Lagoon, 1987–2001. Upper curve, annual series highest level; lower curve, annual series lowest level.

Five-year moving means have been calculated from the annual mean lake levels for 1987–2001 (see Fig. 8). This analysis suggests a trend developing towards a higher lake level from RL 0.960 m a.m.s.l. to RL 1.040 m a.m.s.l. The five-year moving means on the Waihao River daily mean levels at McCulloughs bridge do not show a similar trend, but suggest in contrast that annual mean flows are decreasing. If this change in lake level patterns is real, it would result from either an increase in inflow or a reduction in outflows from the lake or a combination of these factors. The results for the Waihao River suggest that surface water inflows from the Dead Arm are not increasing, which implies that either the groundwater component of inflow into the lake is and/or beach permeabilities are declining. The former may be the result of an increase in irrigation activity influencing shallow groundwater which provides recharge to the lake. The latter alternative is considered unlikely to vary sufficiently to account for changes of this kind without (i) a major change in beach profile attenuating the seepage path, (ii) clogging of the landward face of the barrier beach below the water line by lake fines or (iii) an increase in the percentage of fines in the beach gravels. An alternative explanation might be that the relative scale of inflows and losses have not materially changed but that sediment accumulation is causing water levels to rise.

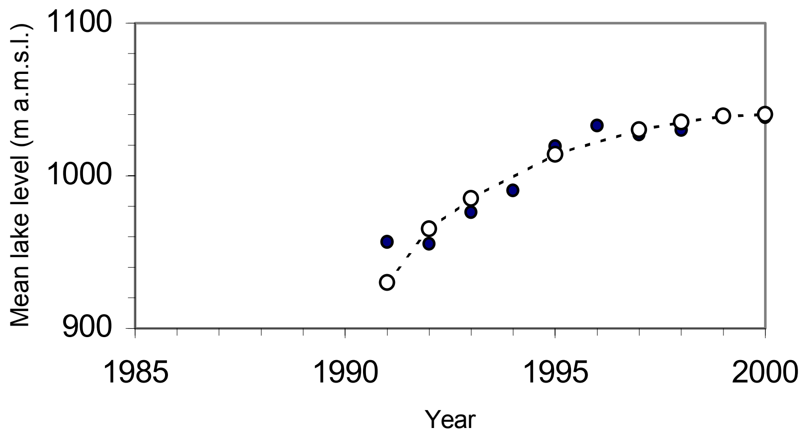


Figure 8. Wainono Lagoon, annual mean lake levels, five-year moving means, 1987–2000.

# 4. Conclusions

The water balance model developed for Wainono Lagoon suggests that the construction of a weir in the upper Dead Arm would not achieve its intended purpose during the greater part of any year when daily nett evaporation rates exceeded 2–3 mm. This situation arises as a result of the deprivation of balancing inflow from the Dead Arm to the south.

If the weir were to be constructed it would be necessary to provide pumping facilities to restore the Dead Arm balancing inflow at a rate sufficient to maintain the desired target level of 1.0 m a.m.s.l., with this water being sourced from the Dead Arm south of the weir.

If the weir and pumping facilities were constructed and the level maintained above 1.0 m a.m.s.l., about 40 additional hectares of land would be inundated around the perimeter of the lake or rendered marginal for farming use as a result of elevated groundwater levels and an associated rise in the capillary fringe. A proportion of the land that might be affected in this way already experiences these effects from time to time as lake levels rise above RL 1.0 m a.m.s.l. However, the duration of this effect would increase as a direct result of the manipulation of the lake to an extent depending on the installation and operation of pumping facilities and the auxiliary spilling rules applying at high lake levels. If, for example, the level was maintained at or above RL 1.0 m a.m.s.l. for 95% of the time and assuming auxiliary spill could ensure no additional attenuation of lake levels above that presently experienced, then it could be expected that the lake would hold at RL 1.0 m a.m.s.l. on average some additional 180 days per year (see Fig. 6). Although this would undoubtedly have significant benefits for the lake ecology, it would also adversely affect the farmland adjoining the lake and further to the north.

Moreover, it is likely that some shoreline erosion would occur in response to a lake level managed in this way. There is evidence of this having already occurred around the landward perimeter, either as a result of lake stands being higher than at present or of periodic but temporary lake elevations. However, such readjustment in shoreline position is not likely to be excessive and could be counteracted by planting erosion- and salt-resistant species compatible with this particular environment around the perimeter. This would also help to maintain the general aesthetic and intrinsic value of the lake setting.

# 5. Acknowledgements

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