6.1 PRECIPITATION DISTRIBUTION IN THE LAKE PUKAKI CATCHMENT, NEW ZEALAND

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1. INTRODUCTION

Attempts at hydrological modelling in the Lake Pukaki catchment (Figure 1) have met with limited success (e.g. Anderton 1974; Bowden 1994; Peters 1996; Thompson 1997; Ibbit et al. 2001). One identified limiting factor is the unknown precipitation distribution in the upper catchment (Anderton 1974; Bowden 1994; Ibbit et al. 2001). This lack of knowledge is a function of the remote and mountainous nature of the upper catchment leading to a paucity of observations. Operationally, the only gauges that consistently provide near real time precipitation data are located within close proximity of each other near the middle of the catchment (point “A” in Figure 1), thereby providing no distribution information. In an attempt to improve distribution estimates, all available historic precipitation observations within the catchment, augmented with those from nine new observation sites, have been used to prepare an average annual precipitation distribution. Further, five wind classed precipitation distributions have been prepared. These distributions have enabled improved daily catchment mean precipitation estimates to be derived

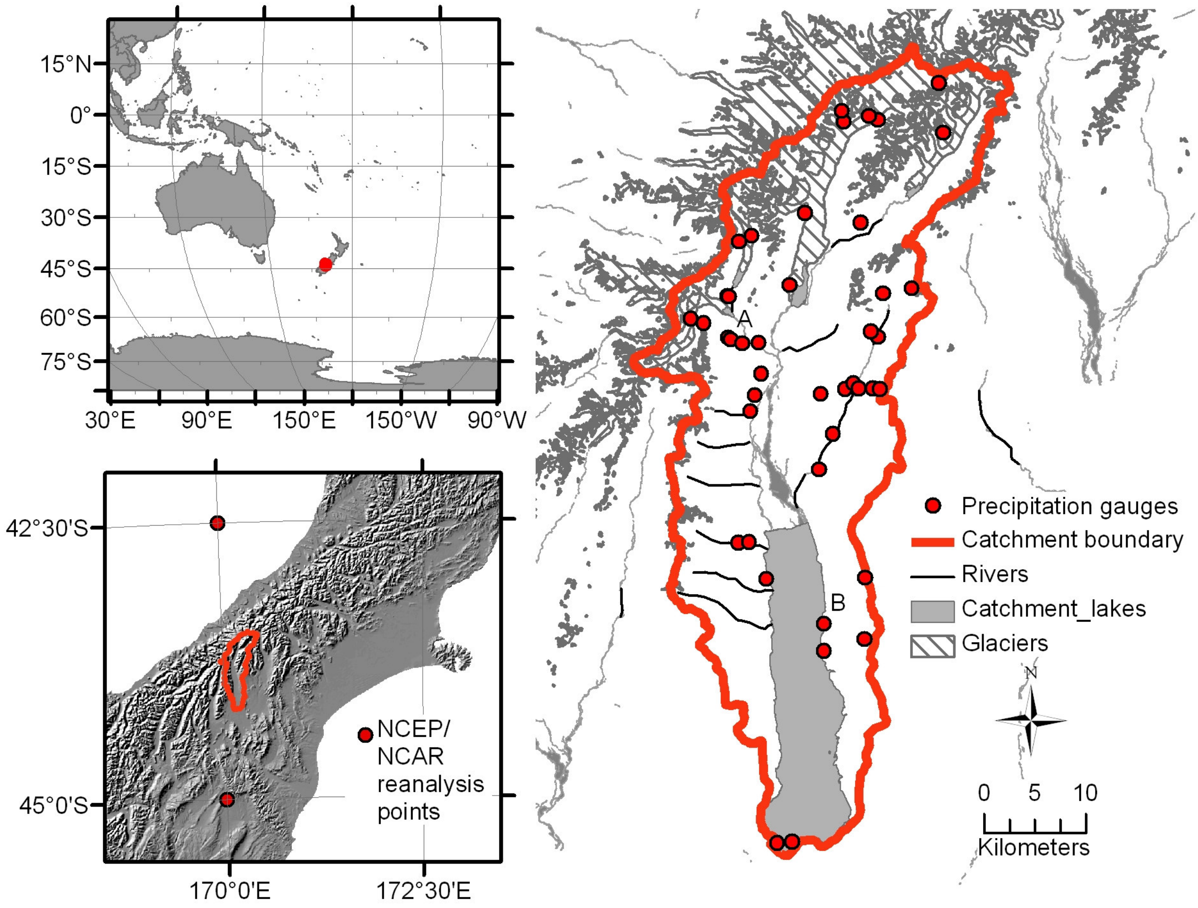

Figure 1. Location of the Lake Pukaki catchment, precipitation gauge positions and nearest NCEP/NCAR reanalysis points. Aoraki/Mt Cook Village is labelled “A”, Braemar Station is labelled “B”.

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from the central precipitation observations.

In the following section, the location and use of the catchment is described together with the lake inflow regime. Catchment precipitation observations and sites are then discussed leading to the presentation of the average annual precipitation distribution. Following this, the wind regime is explored, and an outline of the preparation of the wind classed distributions given. Lastly, the results of including the wind classed distributions in a simple snow storage model are provided.

2. STUDY AREA

The Lake Pukaki catchment drains a heavily glacierized region of the Southern Alps of New Zealand (Figure 1). At 44° south, the catchment is wholly within the Southern Hemisphere westerly wind belt. The elongated 1360 km^2 catchment (80 km x 23 km) has a north-south orientation, is barely 30 km from the Tasman Sea to the west, just 15 km from the western boundary of the Southern Alps but is in the lee of the locally 3000 m high mountain range. The upper catchment is designated a national park, with a small tourist village (Aoraki / Mt Cook, population 200) located near the fot of the large valley glaciers at 730 m. The 169 km^2 lake (524 m) at the southern end of the catchment is surrounded by farm land on rolling countryside largely covered in till deposited in association with the Last Glacial Maximum (Cox and Barrell 2007). The lake itself is managed as a reservoir for hydro-electricity generation, with six generation stations down stream. The 13.8 m of controllable lake level makes the lake the largest controllable hydroelectricity storage reservoir in the country, with hydro being the nationally dominant form of electricity generation.

Inflows to the lake show a clear seasonal cycle (Figure 2) characteristic of a glacierized catchment (Fountain and Tangborn 1985) with low flows in the winter, and high flows in summer associated with the maximum available melt energy. Consideration of water balance components lead to an estimate of catchment average annual precipitation of 3500 mm (Kerr 2008, PhD. thesis, in prep.).

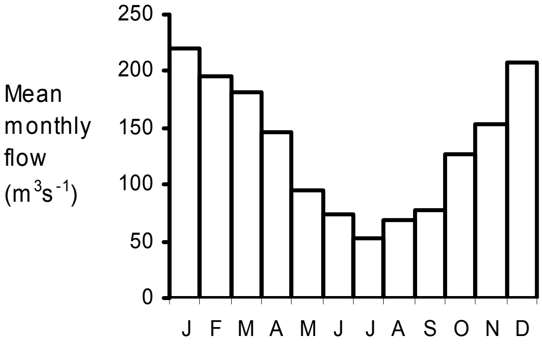

Figure 2. Seasonal lake inflow regime 1971—2000 (Source: National Institute of Water and Atmospheric Research, New Zealand).

3. PRECIPITATION OBSERVATIONS

Observations at Aoraki / Mt Cook Village show an average annual precipitation total of 4000 mm with only a minor seasonal cycle (Figure 3). 30 km to the south east and just 200 m lower, an average annual precipitation of 900 mm is returned, with even less of a seasonal cycle evident (Figure 3). This high variation in precipitation magnitude and regime over a small distance and at similar elevations highlights the difficulty of using elevation based precipitation lapse rates or catchment lumped precipitation estimates in application of hydrological models to the region.

Since 1904, 51 precipitation gauges at 43 sites (Figure 1) have been installed for various lengths of time throughout the catchment. The gauges

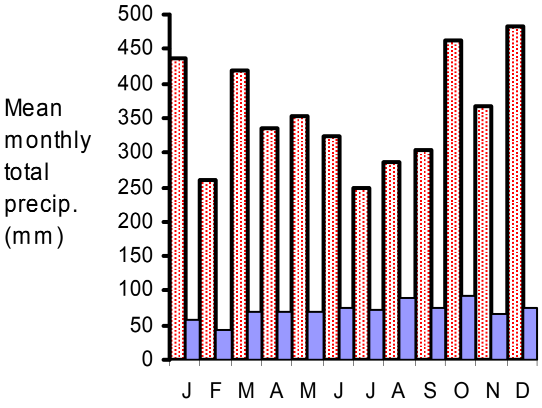

Figure 3. Seasonal precipitation regime 1971—2000. Red/stipled: central catchment site (Aoraki/ Mt Cook Village), blue/solid: south eastern catchment site (Braemar Station).

have been installed as part of national networks, for local needs and for short to long term scientific investigations. Agencies operating the gauges have ranged from private organisations, to commercial operators to government bodies, to university students. The gauges used vary from daily manual rain gauges, to manual storage gauges, to fully automated, telemetered tipping buckets. Through correlation of undercatch corrected measurements between observation sites, a 1971-2000 average annual precipitation total has been generated for each site. These values have in turn been interpolated across the catchment using ordinary kriging to provide an average annual precipitation distribution (Figure 4). The distribution indicates over 10000 mm of precipitation in the north west of the catchment rapidly declining to the south east. The overriding control on the distribution is the distance to the north-west boundary with no strong elevation component evident.

This distribution is consistent with the predominant westerly winds uplifting saturated air along the base of the Southern Alps 15 km to the north west of the catchment.

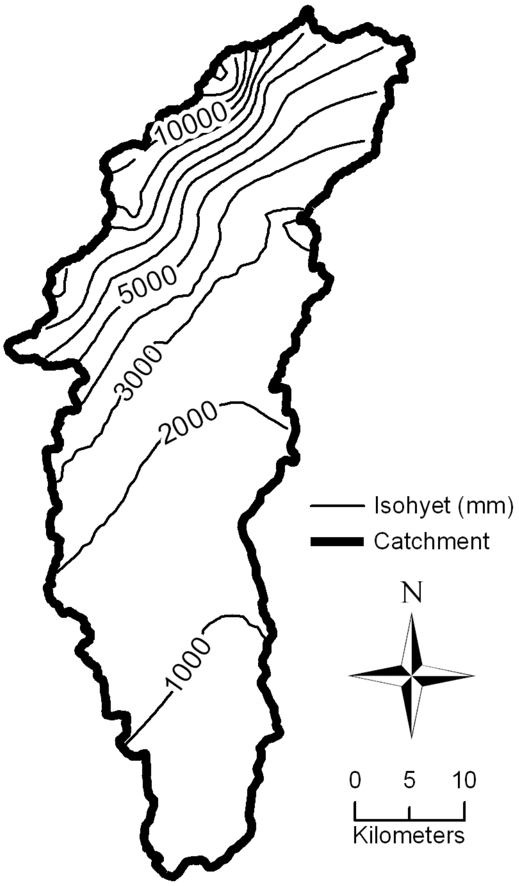

Figure 4. Average annual precipitation distribution.

4. WIND REGIME

Reanalysis data from NCEP/NCAR (Kalnay et al. 1996) enable an assessment of the synoptic air flow over the catchment. Average 850 hPa (~ 1450 m) wind speeds and directions for the two reanalysis points either side of the catchment (Figure 1) show the dominance of the westerly flow over the region (Figure 5(a)). When only those days that precipitation was observed at Aoraki / Mt Cook Village are considered, the winds slightly north of west become more dominant with the magnitude of the precipitation events increasing as the wind moves from the south west to the north (Figure 5 (b)).

Observed precipitation frequency and magnitude for each 10° of wind direction from three sites within the catchment were subject to cluster analysis, leading to the division of the NCEP/NCAR wind directions into five classes as shown in Figure 5(c).

5. WIND CLASSED PRECIPITATION DISTRIBUTIONS

For each of the five wind classes, ratios were determined between daily precipitation gauge site observations throughout the catchment and those obtained at Aoraki / Mt Cook Village, for days when precipitation was observed at both sites. Interpolation of these ratios provides a precipitation distribution normalised to Aoraki / Mt Cook village. These ratio distributions may be represented as wind classed equivalent average annual distributions through multiplication by the long term (1971—2000) average daily wind classed precipitation total at Aoraki / Mt Cook, multiplied by 365. Examples for the north west and south south west wind classes are shown in Figure 6. The north west distribution shows similar magnitudes and horizontal gradients to the general average annual precipitation distribution. It would be expected that the north west distribution would have a much

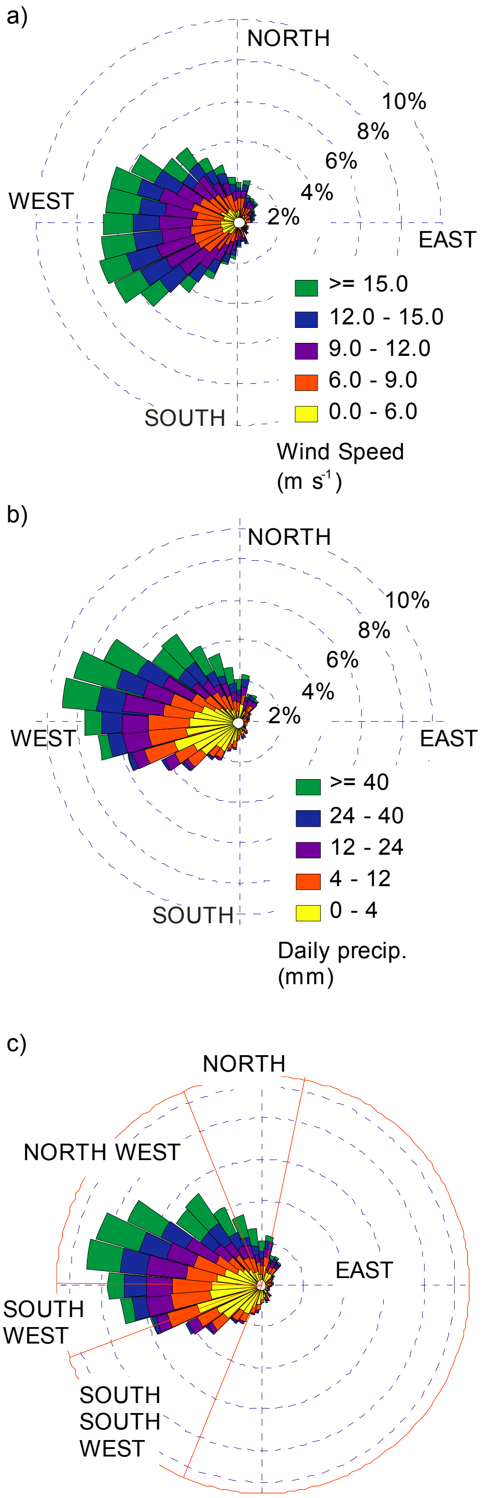

Figure 5. Wind direction from nearby NCEP/ NCAR reanalysis points at 850 hPa. a) NCEP/ NCAR wind speeds for all days that an average wind was determined, b) wind direction (NCEP/ NCAR) and precipitation magnitude at Aoraki/ Mt Cook Village on precipitation days only, c) Division of the wind directions into five sectors.

greater magnitude than the general distribution. What is represented in the wind classed distributions is based on what is observed on Aoraki / Mt Cook Village precipitation days. No account is made of precipitation that falls in the catchment when nothing is observed at the village. The general average annual precipitation distribution has no such limitation. This difference has implications on estimating mean catchment precipitation totals as described later. The south south west average annual precipitation distribution shows a lower horizontal gradient and a lower maximum magnitude. This is likely to be a reflection of the increased distance that the catchment is to the south south west windward orographic barrier, compared to the north west orographic barrier.

Average annual precipitation distributions may be used to determine catchment mean precipitation given an observation within the catchment. An example of estimated catchment mean daily precipitation in early June 2002 is shown in Figure 7. Two estimations for each day are given, firstly, using the general average annual precipitation distribution, and secondly, using the wind classed distributions. For each day, the proportion of the Aoraki / Mt Cook Village average annual precipitation is determined (either general or wind-classed). This proportion is then multiplied by the respective distribution, enabling a catchment mean to be obtained. The relative difference between the catchment mean daily precipitation estimates varies depending on the wind class. This approach assumes catchment-wide precipitation occurrence on every (and only on) Aoraki / Mt Cook precipitation day. For the general situation, on village precipitation days, this leads to an over allocation of precipitation in those regions where precipitation is more common than at the village, and an under allocation where precipitation is less common. As the wind classed distributions were derived on precipitation days only, they do not lead to an over estimation from those regions where precipitation is more common than at the village, but will now overestimate in those regions where precipitation is less common. Under north west conditions, a

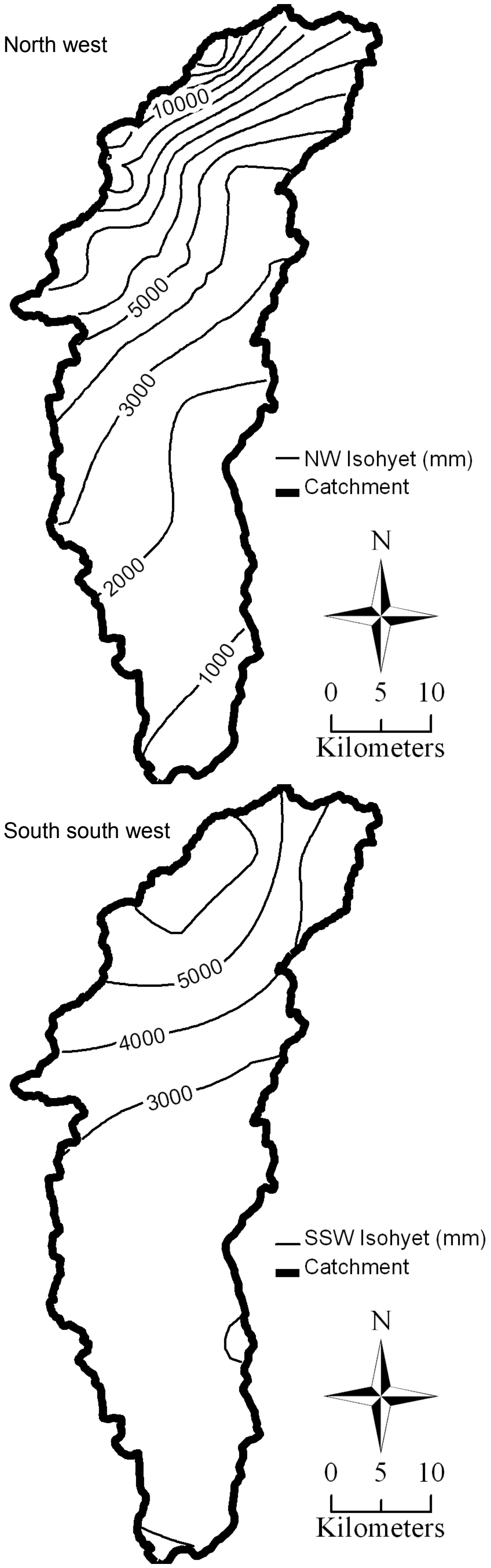

Figure 6. Wind classed equivalent average annual precipitation for Aoraki/Mt Cook Village precipitation days.

decrease in precipitation magnitude is returned, reflecting the reduced impact of the regions of the catchment where precipitation is more common than at the village. During the south south west situation, the wind classed distribution leads to increased catchment precipitation. This reflects the relative increased importance of the lower catchment for this wind class (from the reduced horizontal precipitation gradient), giving reduced upper catchment precipitation but increased lower catchment precipitation, and an increased catchment mean precipitation overall.

To test whether these new wind classed distributions lead to improved catchment estimates, they were used as input to a degree-day snow storage model, SnowSim-Pukaki (Kerr 2005). The snow storage model enables the consideration of the effect of solid precipitation and melt water on catchment liquid water. By comparing 14 day running averages of this daily catchment liquid water total with a 14 day running average of lake inflows, a measure of model efficiency is gained. A comparison of model efficiency with and without the wind classed precipitation distribution enables an assessment of whether it provides an improved representation of actual precipitation. The Nash-Sutcliffe model efficiency criterion was used, where a value of 100 % indicates the model has improved to become an exact match to observations, a value of 0 % indicates there is no improvement, and a negative value indicates the model has become worse than the model it is being compared to (Nash and Sutcliffe 1970).

For each precipitation system the model was tuned to optimise the model efficiency using one year of inflow data. For the tuning year (April 1st 2002 to March 31st 2003), the wind classed precipitation distributions led to a 41 % model efficiency improvement. For four years of model validation (2000, 2001, 2003, 2004) a 21 % model efficiency improvement was returned.

6. CONCLUSIONS

Consideration of all available precipitation observations in the Lake Pukaki catchment has en-

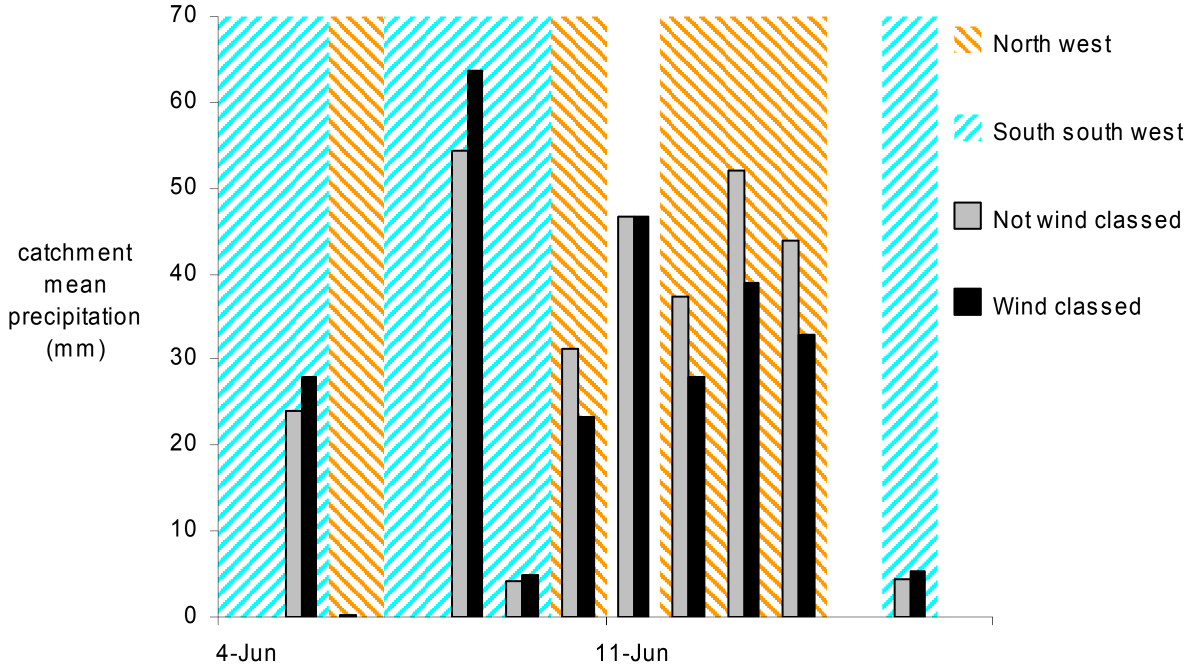

Figure 7. Estimated daily catchment mean precipitation derived using the general average annual precipitation distribution (not wind classed), and the wind classed average annual precipitation distribution.

abled the preparation of a 1971-2000 average annual precipitation distribution. The distribution highlights the principal control of orographic precipitation associated with the predominant westerly flow. Over 10000 mm of precipitation is estimated in the north west of the catchment, rapidly dropping to below 3000 mm over 15 km horizontal distance. The obvious influence of wind direction on the precipitation distribution has led to the generation of five different wind-classed precipitation distributions. The different wind classed distributions enable wind direction to be taken into account when estimating daily catchment mean precipitation totals. Application of these wind classed precipitation totals to a degree day snow storage model has led to improved lake inflow estimates. This result indicates that the catchment precipitation estimates are improved through the use of wind-classed precipitation distributions.

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