

The Interdecadal Pacific Oscillation and the Southern Oscillation Index: relative merits for anticipating inflows to the Upper Clutha lakes

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Abstract

Spring values of the Southern Oscillation Index (SOI) and the unfiltered Interdecadal Pacific Oscillation (IPO) are compared for anticipating summer inflows to the lakes of the upper Clutha River, New Zealand. Earlier work proposed the spring SOI to forecast summer inflows. However, more recent data, which includes a change of state of the IPO, indicate the spring SOI only has a degree of predictive ability for the low summer flows. Furthermore, this low-flow predictability requires La Niña conditions (spring $SOI > 5$). The spring IPO index, in contrast, can anticipate both high and low summer inflows when the spring $SOI > 0$, and thus has a wider range of applicability for summer inflow forecasting than the SOI. Both the IPO and SOI appear to have no summer inflow forecasting ability when the spring SOI is negative.

Keywords

Southern Oscillation Index, Interdecadal Pacific Oscillation, Clutha River, Summer Inflows

Introduction

The Clutha River drains the largest catchment in New Zealand, with a total area of 21,400 km² (Murray, 1975). It incorporates three large headwater sub-catchments that respectively drain into lakes Wakatipu,

Wanaka and Hawea (Fig. 1). Clutha tributaries downstream of the lakes include the Shotover, Nevis, Lindis, Arrow, Manuherikia, Teviot, Tullaburn, Beaumont and Pomahaka rivers.

The Clutha catchment lies to the east of the Southern Alps and is subject to spill-over rain from north-westerly fronts when rain extends into the catchment from the west. The westerly extremities of the catchment are subject to high annual precipitation in excess of 10 metres. In contrast, the central part of the catchment experiences a continental climate with rainfall as low as 0.4 metres per annum (Fig. 2) (Fitzharris, 1992).

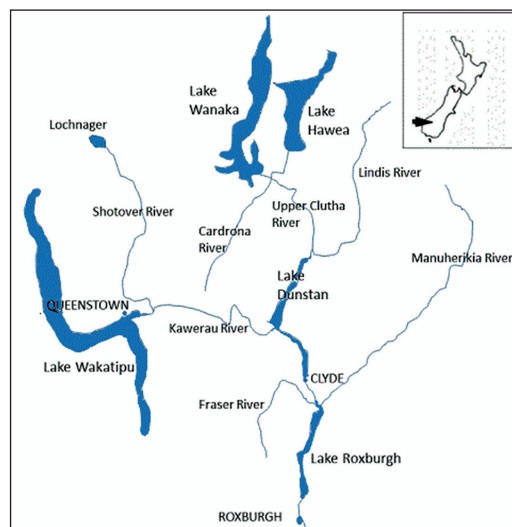


Figure 1 – Map of Clutha Catchment and surrounding area.

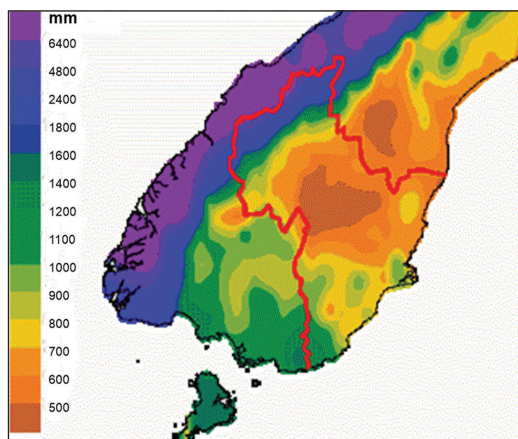


Figure 2 – Annual rainfall distribution in Otago in mm per year.

The lowest discharges in the Clutha occur in mid to late winter, when much precipitation arrives as snow. The highest inflows to the three lakes generally occur in

late spring to early summer with a discharge contribution from snowmelt. October, November and December often have the highest mean monthly flows, with much lower discharges in January and February (Fig. 3). Early March usually also has low inflows with a large increase in the weeks following the equinox.

There is a small degree of serial correlation of spring to summer lake inflows, with some tendency for higher spring inflows to be followed by higher summer inflows (Fig. 4). This might be due, for example, to a larger than normal winter snowpack melting over a longer period of time. This serial correlation was also noted by McKerchar and Pearson (1994).

Flow variability over short to medium timescales is a major concern for the operation of the two Clutha River power stations at

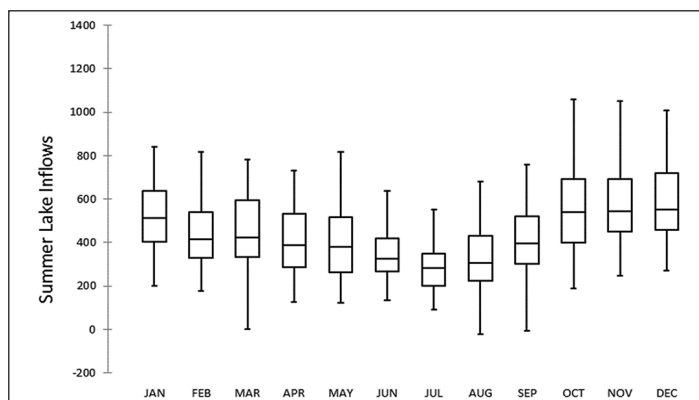


Figure 3 – Combined Clutha lakes mean monthly inflows (Wakatipu, Wanaka, Hawea) in m^3s^{-1} . The box plot shows the 25%-75% range with the median indicated by a solid line. The whiskers are the 5%-95% non-outlier range.

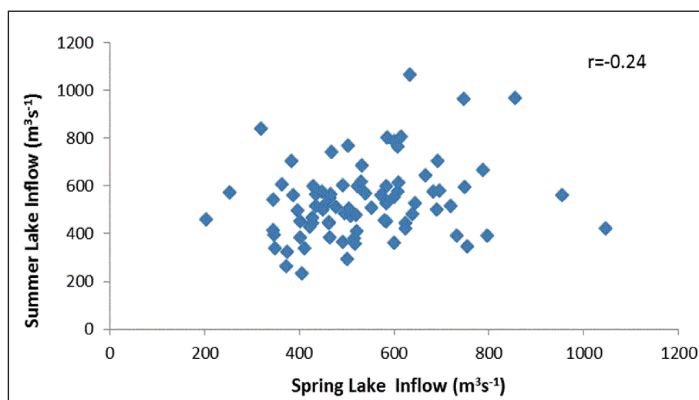


Figure 4 – Spring to summer lakes inflow 1935-2000. The r value is significant at the 5% level ($p = 0.027$).

Clyde and Roxburgh. These stations have a combined capacity of 784 MW and on average supply almost 10% of New Zealand's electricity (MED, 2012). Operation is essentially run-of-river because Lake Hawea provides the only controlled seasonal storage, and the Hawea sub-catchment contributes only about 15% of Clutha flow at Roxburgh. Floods and high flow events are of less operational importance as they can be managed via dam spillways. However, low flows caused by extended dry periods in the South Island can create more serious issues such as a need for greater use of fossil-fuelled thermal generation in the North Island. At such times, constraints in the New Zealand electricity transmission system can result in Clutha water being used inefficiently for power generation and reserves.

This further exacerbates the local low hydro lake levels by using additional water from an already depleted catchment.

Within the last 25 years there were extreme dry periods affecting the New Zealand electricity system: in 1992, 2001 and 2008. There was also risk of extended dry periods developing in 2012 and 2013. New Zealand came close to experiencing power blackouts during the 1991-92 electricity crisis. Similar situations occurred in the 1950s and also in 1970 (Fitzharris, 1992).

Identifying the drivers of Clutha River seasonal flow variability and, in particular, establishing some seasonal discharge predictive capability would allow better river water use for both hydro power and irrigation. There has been some attempt to identify such flow drivers over the years in terms of various factors (Fisher, 1948; Manning, 1978; Murray, 1975; Jowett and Thompson, 1977), but most recent work has sought to relate mean flows to various climatic indices.

The index most often considered is the Southern Oscillation Index (SOI), which is a scaled measure of the sea level atmospheric pressure difference between

Darwin and Tahiti. This index is often also used as a measure of the El Niño Southern Oscillation (ENSO). Correlations between the SOI and New Zealand's weather, linking to river flows, have been demonstrated by various investigations (Gordon, 1986; McKerchar and Pearson, 1994; Mullan, 1995; McKerchar *et al.*, 1998). Of particular interest is an evident time lag between ENSO and New Zealand weather patterns (Mullan, 1998; Kidson and Renwick, 2002), which gives possibilities for seasonal river flow forecasting.

Another index, the Interdecadal Pacific Oscillation (IPO), has been shown to have an association with mean river flows on longer time scales (McKerchar and Henderson, 2003; McKerchar, 2004). Although the IPO and ENSO operate on different time scales, their index values are both influenced by tropical Pacific sea surface temperatures. The IPO is known to exert a modulating effect on ENSO whereby the positive phase of the IPO is associated with enhanced and more frequent occurrences of El Niño and the negative phase of the IPO is associated with fewer and less intense occurrences (Power *et al.*, 1999; Salinger *et al.*, 2001; Folland *et al.*, 2002).

For the Clutha River the best result to date correlating climate drivers with flow forecasting is the study by McKerchar and Pearson (1994), demonstrating a negative relation between the spring SOI and the subsequent summer Clutha lakes inflow, for the period 1935 to 1992. A positive SOI (La Niña) in spring appeared to be associated with lower inflows while periods of negative SOI (El Niño) had higher and more variable inflows. This apparent predictive association was subsequently extended to cover inflows to all lakes in the Southern Alps (McKerchar *et al.*, 1996).

It would seem, however, that factors in addition to the SOI have an impact on Clutha flow variability. For example, fairly

persistent positive SOI conditions existed from late 2007 to mid-2012 with 47 out of 60 months being positive, with only a weak El Niño in the 2010 summer (BOM, 2015). The negative predictive relation should therefore anticipate low summer inflows for this period. However, quite high flows in the summer of 2011 followed the strong positive SOI in the spring of 2010.

This paper revisits the findings of McKerchar and Pearson (1994) with specific reference to forecasting the Clutha catchment summer lake inflows using the spring SOI, in the light of almost 20 years of additional data subsequent to that study. A case is made that the change in state of the IPO within the period of the new data requires a modification of the conclusions of the 1994 study. Specifically, it is proposed here that the spring IPO index provides better predictive warning of Clutha lakes low summer inflows than does the spring SOI. The focus is only on this specific comparison of the SOI and IPO indices and other external factors such as the Southern Annular Mode (Kidston et al., 2009), solar effects, and climate change are not considered.

Data

Lake level and outflow data for each of the three main Clutha sub-catchments were obtained from Contact Energy Ltd for all years available (1930-2014). Seasonal inflows were deduced by water balancing the lake level differences and outflows. The seasonal inflows for the individual lakes were then summed to obtain a total Clutha upper catchment inflow. Most discharge data is available from 1930, with Wanaka lake level data from mid-1933. Some of the earliest data is of lower quality due to lake and river levels being manually read from staff gauges and sometimes the levels were only estimated.

The unfiltered IPO index data based on HadISST1 (Parker *et al.*, 2007), available

from 1871, was obtained from the Hadley Centre of the UK Met Office. Monthly SOI data was obtained from the Australian Bureau of Meteorology (BOM). Spring is taken as the months of September, October and November, and summer as the months of December, January and February. The seasonal data for SOI, IPO and inflow were derived as the simple average of the monthly data for each of the respective seasons.

Significance testing

Randomisation testing was applied for checking whether data correlations and differences between means may have arisen by random chance. For example, given an observed correlation coefficient r_o , a large number of r values are then generated from repeated random re-orderings of the x -variable, with the value p defined as the proportion of generated r values greater than or equal to r_o . If p is sufficiently small ($p < 0.05$ say) then a correlation is deemed significant at the 5% level. This approach is more robust than testing against tabulated values of r because sometimes artificially high r values may result from one or two outliers in a sample when the data does not follow a bivariate normal distribution. Similarly, the statistical significance of a difference between two sample means is evaluated by repeated random reallocation of the data values between the two samples concerned, and differences between those means calculated each time. The randomisation tests require no specific assumptions concerning the distributions of the data values, but serial correlation must be negligible.

Randomisation testing is also used here to determine whether a data-sparse zone in a scatter plot might reflect some physical inhibiting factor or could have arisen simply by random chance. That is, given a scatter plot with a data-sparse corner region containing k recorded data points, the probability p is

obtained of randomly generating a larger zone that also incorporates k or fewer data points (Bardsley and Vetrova, 2012).

There is, in fact, some minor serial correlation involved in the spring inflow data from one year to the next. However, the correlation is low, $r = 0.21$, and is unlikely to have much influence on calculated p values.

Henceforth specified statistical significance referenced in this paper will be as obtained from randomisation testing. Statistical significance cited in previous work is with reference to classical statistical testing where the usual parametric data assumptions are assumed to hold.

It is recognised that establishing statistical significance is not the same as verifying useful predictive capability, because there are, at best, weak correlations involved in seasonal forecasting.

Southern Oscillation Index as an inflow forecaster

Using the combined inflows of the three Clutha lakes (1935-1991), McKerchar and Pearson (1994) found a negative correlation between the spring SOI and inflows of the summer directly following ($r = -0.34$ significant at the 1% level). The same negative correlation is found in the present study for time period 1935-2000. This yields

a similar r value of -0.32 , which is again significant at the 1% level. However, the negative association appears to have been somewhat weaker since 2000, with $r = -0.26$ for the period 1935-2013, although it is still significant at the 5% level. (Fig. 5)

If the summer inflows are classified by whether the spring IPO index is positive or negative, it appears that any negative association between the spring SOI and summer inflows holds only for those years when the spring IPO index is positive. That is, $r = -0.24$ for the positive case, compared to $r = -0.10$ when the IPO is negative (Figs. 5 and 6). However, any negative association is open to question because the data yields no statistical significance for the r values in either case ($p = 0.12$ and 0.54 , respectively).

With respect to the data as a whole, it is questionable whether the sign of the spring SOI indicates that the coming summer inflow can be regarded as originating from a distribution of flows with a different mean. That is, if the 1935-2013 summer inflows are classified by the positive or negative sign of the spring SOI then the overall mean summer discharge values are $510 \text{ m}^3 \text{ s}^{-1}$ and $564 \text{ m}^3 \text{ s}^{-1}$, respectively. This $54 \text{ m}^3 \text{ s}^{-1}$ difference in means is not quite statistically significant ($p = 0.06$), although the lack of significance might change with a larger sample.

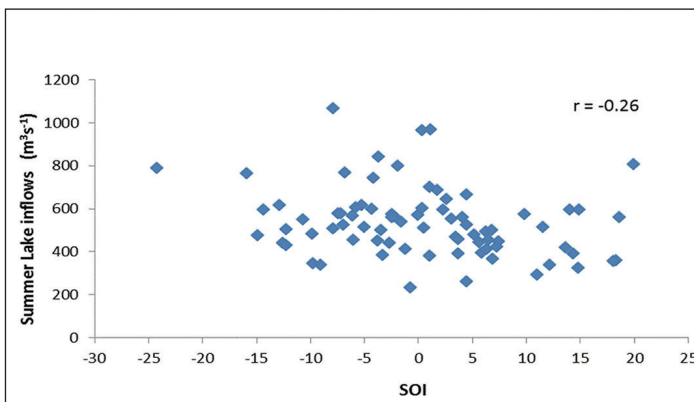


Figure 5 – Scatter plot of summer inflows and spring SOI (1935-2013).

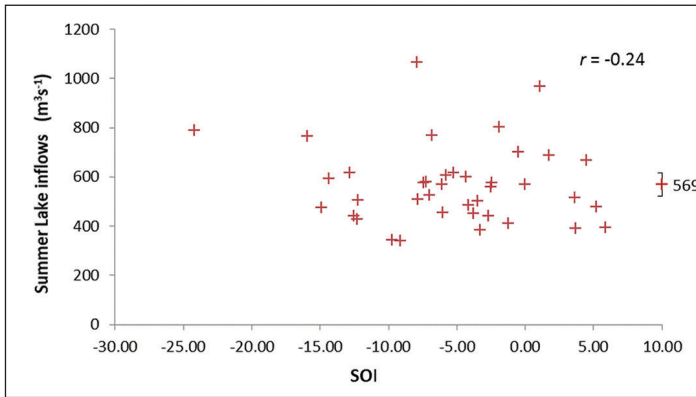


Figure 6 – Clutha lakes summer mean inflows and spring SOI for the period 1935-2013, plotted only for positive spring IPO values. The error bar is the 95% confidence interval for the mean discharge under these conditions.

A similar comparison of discharge means can be carried out for a finer division of the spring SOI defined as: El Niño ($\text{SOI} < -5$), neutral ($-5 < \text{SOI} < 5$), and La Niña ($\text{SOI} > 5$). This classification gives respective mean summer inflows of $572 \text{ m}^3\text{s}^{-1}$ (23 years), $569 \text{ m}^3\text{s}^{-1}$ (32 years) and $460 \text{ m}^3\text{s}^{-1}$ (23 years). There is clearly a negligible difference between the respective summer mean flows for the two situations of a spring El Niño classification and a spring neutral classification of the SOI. However, comparing the summer mean flows for a spring La Niña classification and for a spring non- La Niña classification ($460 \text{ m}^3\text{s}^{-1}$ and $570 \text{ m}^3\text{s}^{-1}$, respectively), the $110 \text{ m}^3\text{s}^{-1}$ difference between the two means is highly significant ($p = 0.001$).

Overall, the SOI is therefore not a good indicator for summer Clutha lake inflow forecasting in general but might be used to

warn against coming summer low inflows given a spring La Niña classification.

Interdecadal Pacific Oscillation as an inflow forecaster

The evident interaction of the SOI with the IPO suggests the alternative possibility of using spring IPO values for summer inflow forecasting. There is an indication, for example, that the mean summer inflow value is somewhat greater for positive spring IPO values (Figs. 6 and 7).

Looking first for a general association between summer inflows and the IPO, running means of both monthly IPO values and summer inflows shows a similar pattern over time (Fig. 7). That is, higher values of the smoothed IPO tend to be associated with higher smoothed discharge values. A similar

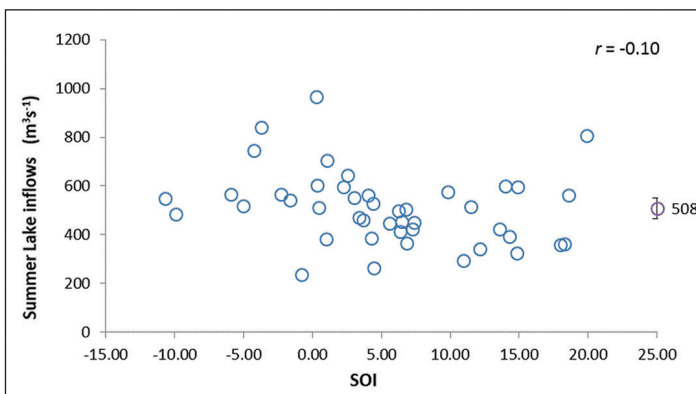


Figure 7 – Clutha lakes summer mean inflows and the spring SOI for the period 1935-2013, plotted only for negative spring IPO values. The error bar is the 95% confidence interval for the mean discharge under these conditions.

pattern was noted for winter lake inflows in the neighbouring Waitaki catchment, albeit over a shorter period of record (Vetrova and Bardsley, this issue).

Smoothed IPO data are used in Figure 8 to illustrate similarity with smoothed summer river flows. For all other calculations and comparisons we use unsmoothed IPO and unsmoothed discharge data.

When the 1935-2013 summer Clutha lake inflows are grouped by the associated positive or negative spring IPO values, the respective means are $508 \text{ m}^3\text{s}^{-1}$ (from 42 years) and $569 \text{ m}^3\text{s}^{-1}$ (from 36 years). The $63 \text{ m}^3\text{s}^{-1}$ difference between these two means is statistically significant ($p = 0.032$).

In addition to this degree of association between summer flows and spring IPO value,

the spring IPO index has potential to serve as a predictor of both low and high summer inflows when the spring SOI is positive (Fig. 9). That is, for positive spring SOI values the correlation between summer inflows and the spring IPO is given by $r = 0.42$ ($p = 0.004$), which rises to $r = 0.53$ if the outlier of $807 \text{ m}^3\text{s}^{-1}$ is excluded (which followed a negative IPO value in the spring of 2010). For negative spring SOI values there is no evident predictive association between the spring IPO value and summer inflows ($r = 0.20$). The association in Figure 9 of positive IPO values with negative SOI has been noted by previous studies, as mentioned in the Introduction.

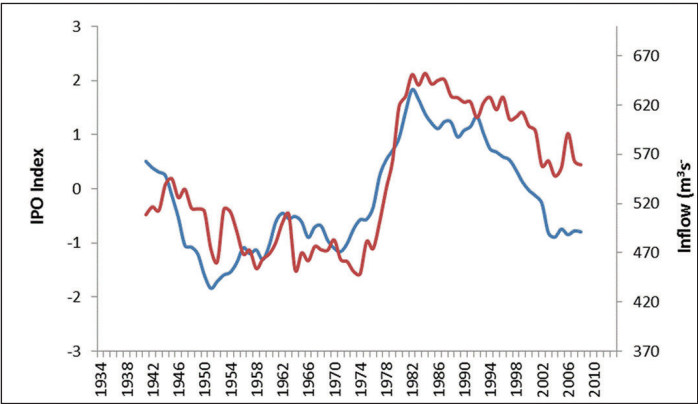


Figure 8 – Eleven-year running means: summer Clutha inflows (red line) and all-year monthly IPO values (blue line), 1935 to 2013.

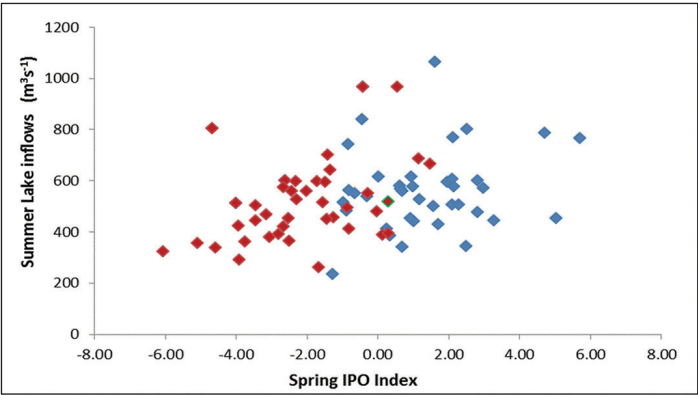


Figure 9 – Clutha lakes summer mean inflows vs. spring IPO for the period 1935-2013. Red denotes spring SOI positive ($r = 0.42$, $p = 0.006$) and blue denotes spring SOI negative ($r = 0.20$, $p = 0.11$). Lower quality data from 8 early years have been included as they fall within the general pattern.

Discussion

Spring values of climatic indices cannot have a direct causal linkage to summer lake inflow magnitudes. Any index-based forecasting capability therefore derives from the persistence of oceanic conditions that are associated by some mechanism with synoptic conditions, giving higher or lower inflows. As an indication of persistence of oceanic conditions from spring to summer, the serial correlations between the respective spring and summer indices were obtained. The IPO shows somewhat greater spring to summer persistence than the SOI (serial correlations of $r = 0.92$ and $r = 0.83$, respectively), consistent with the spring IPO having more potential as a predictor.

It may be that the weakening of the McKerchar and Pearson (1994) negative correlation reflects the influence of the change in phase of the IPO since 2000. However, it is beyond the scope of this paper to consider the physical process behind the correlations noted here. As a working hypothesis it could be speculated that the IPO is more closely related than the SOI to Pacific ocean-atmosphere processes influencing summer Clutha flow variation. Low values of the IPO have a strong association, via the definition of the two indices, with positive values of the SOI. That is, low values of the IPO index are related to a constraining influence on the Clutha

discharges and the association of positive SOI with lower flows derives from a degree of correlation between the indices resulting from their respective definitions. The SOI is an atmospheric proxy for the sea surface temperature anomaly associated with ENSO, while the IPO is a direct EOF (empirical orthogonal function) pattern of sea surface temperatures in the greater Pacific region.

There is a degree of hydrological persistence of spring to summer river discharges. As mentioned earlier, an unusually large slow-melting snow pack might lead to higher inflows in both spring and summer, depending on the timing of the melt season. This suggests that spring inflow might be combined with the spring IPO index to improve the summer inflow predictive ability for the case of a positive SOI. Taking this approach via a multiple linear regression gives the linear predictive expression for application when the spring SOI is positive:

$$Q_{djf} = 0.318 \cdot Q_{spr} + 32.28 \cdot I_{spr} + 401$$

Where Q_{djf} is the summer flow, Q_{spr} is the preceding spring flow, and I_{spr} is the preceding spring IPO. Figure 10 compares the predicted versus recorded flows from this model. There appears to be some degree of predictive ability and the plotted data could serve as the calibration set, to be validated against future summer discharge data.

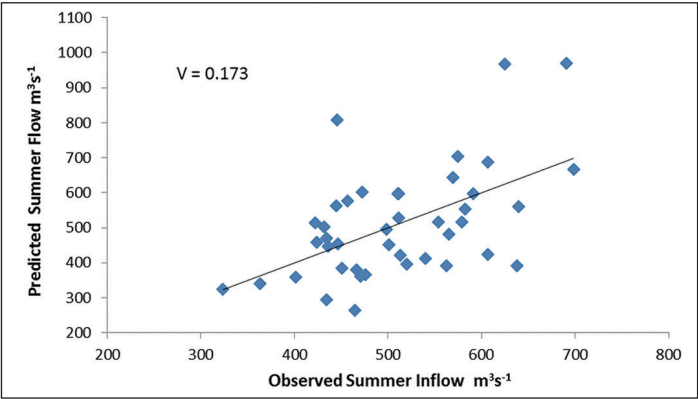


Figure 10 – Observed and predicted discharges for spring SOI positive, using prediction from a multiple linear regression with Spring IPO and Spring inflow as independent variables. The line shows the 1:1 relation and the V measure of model predictive ability is from Bardsley (2013), where V varies from 0.0 (no predictive ability) to 1.0 (all points plot on the 1:1 line).

Conclusion

An extended data series shows the negative correlation between summer Clutha lake inflows and the spring SOI to be weaker now than reported by McKerchar and Pearson (1994), although the presence of spring La Niña conditions might indicate low summer inflows. Neither the spring IPO nor the spring SOI provide summer inflow predictive ability when the spring SOI is negative. However, for positive spring SOI conditions the spring IPO gives a better inflow prediction over a greater range of flows than the SOI itself. As a forecasting tool, the IPO-based discharge prediction can be improved a little by incorporating the effect of serial correlation between spring and summer inflows.

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