A hydrological drought index for the Clutha catchment

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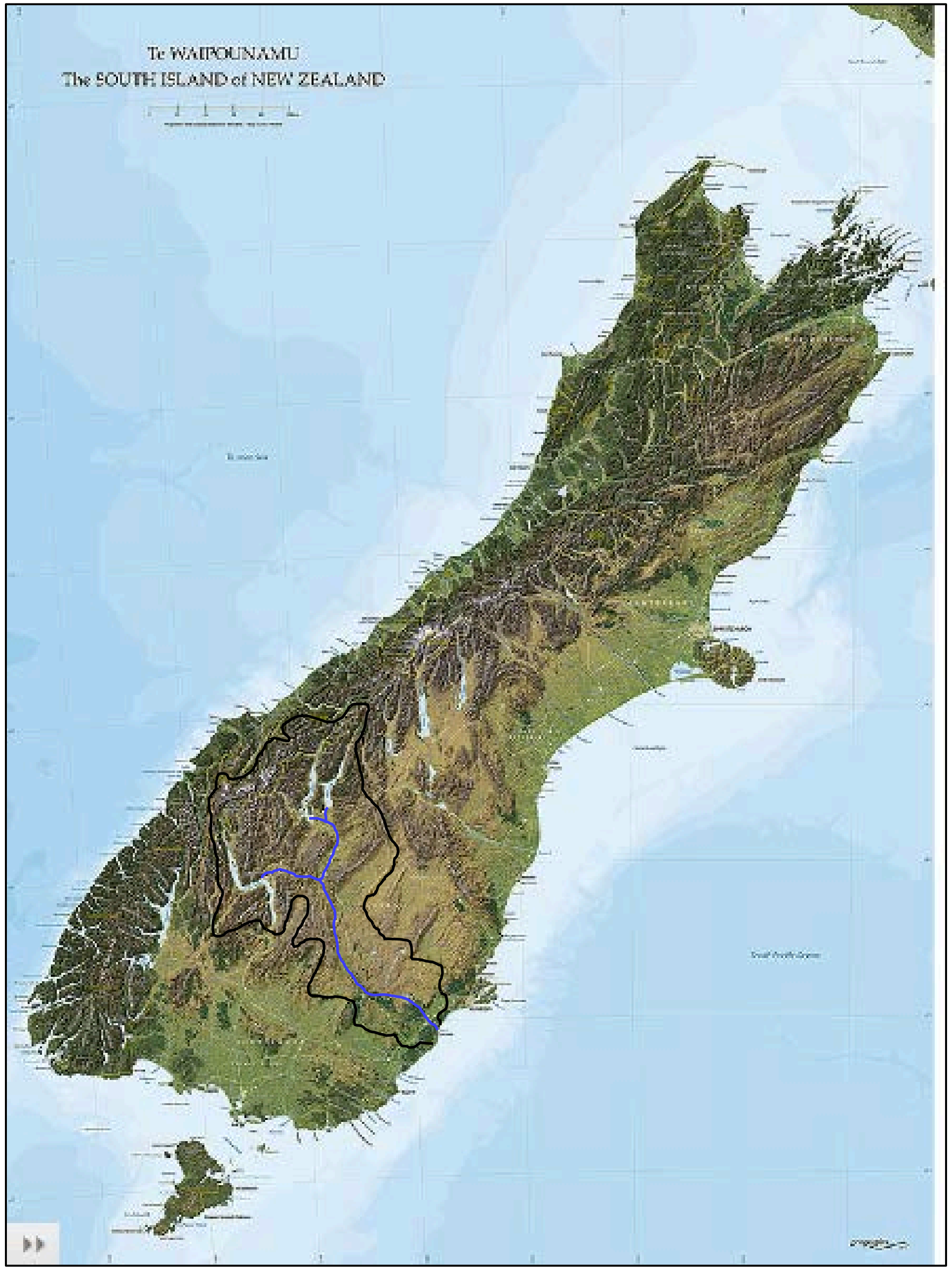
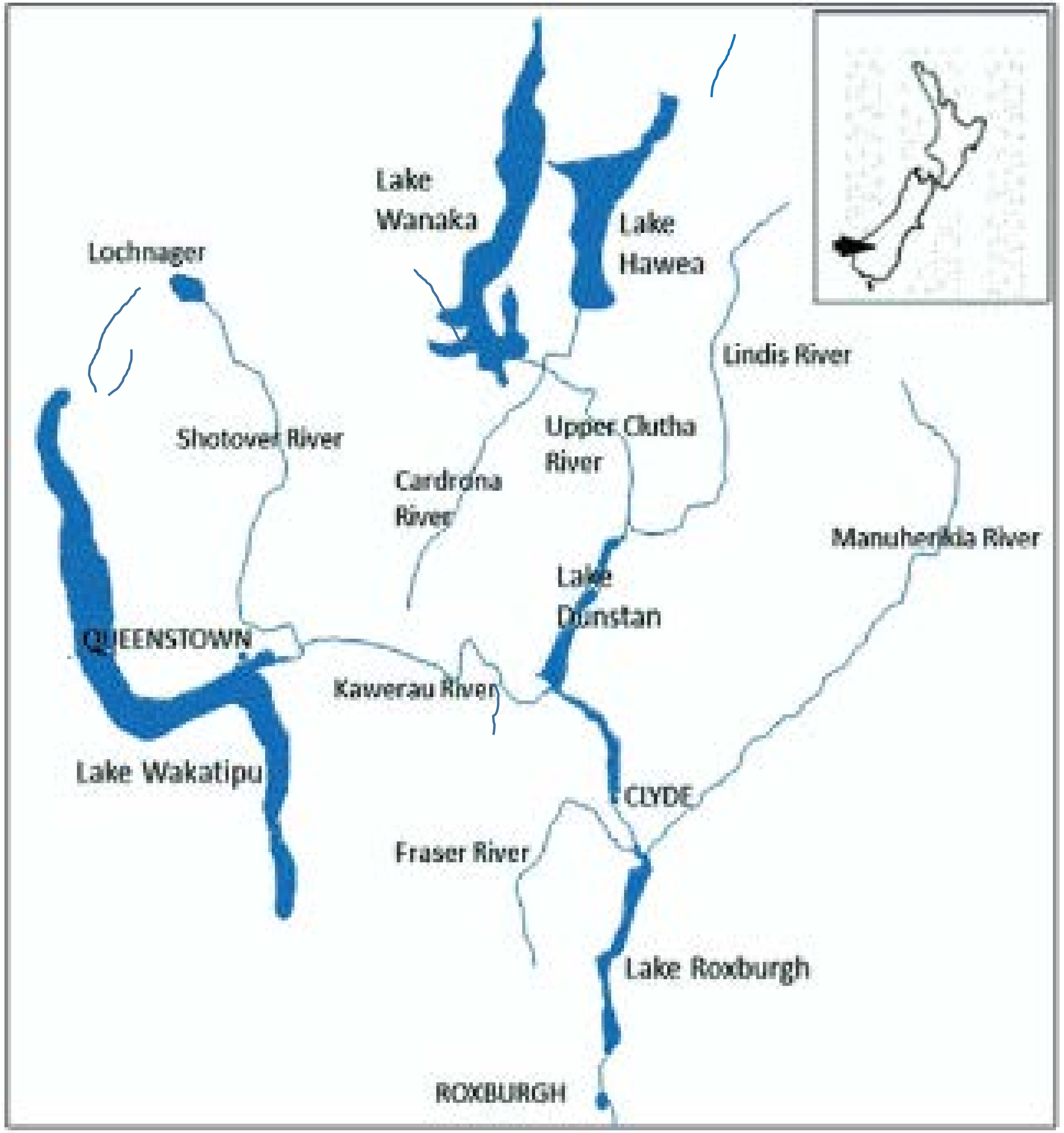
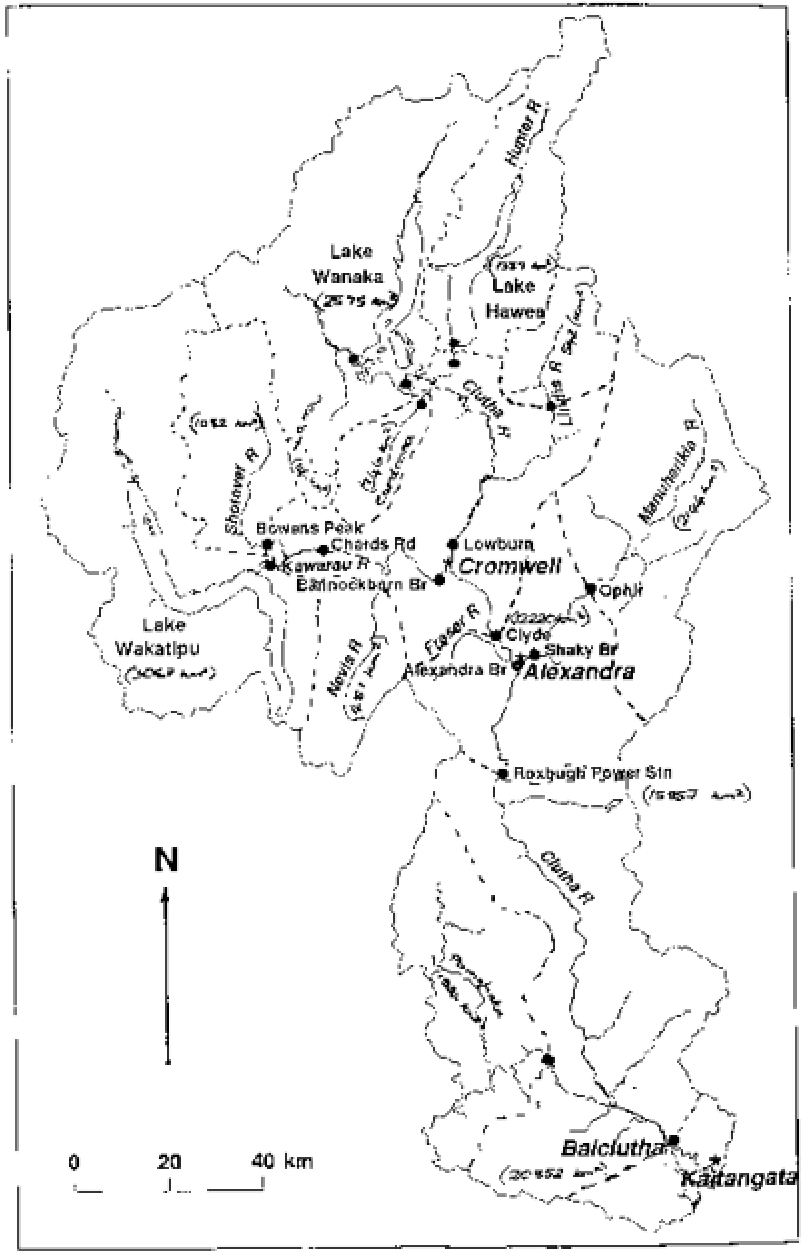
Where is The Clutha Catchment







New Zealand's largest river

Total catchment area 21,956 km^2

Mean discharge to sea 615 m^{3}s^{-1}

Length 338 km – 2nd longest in NZ

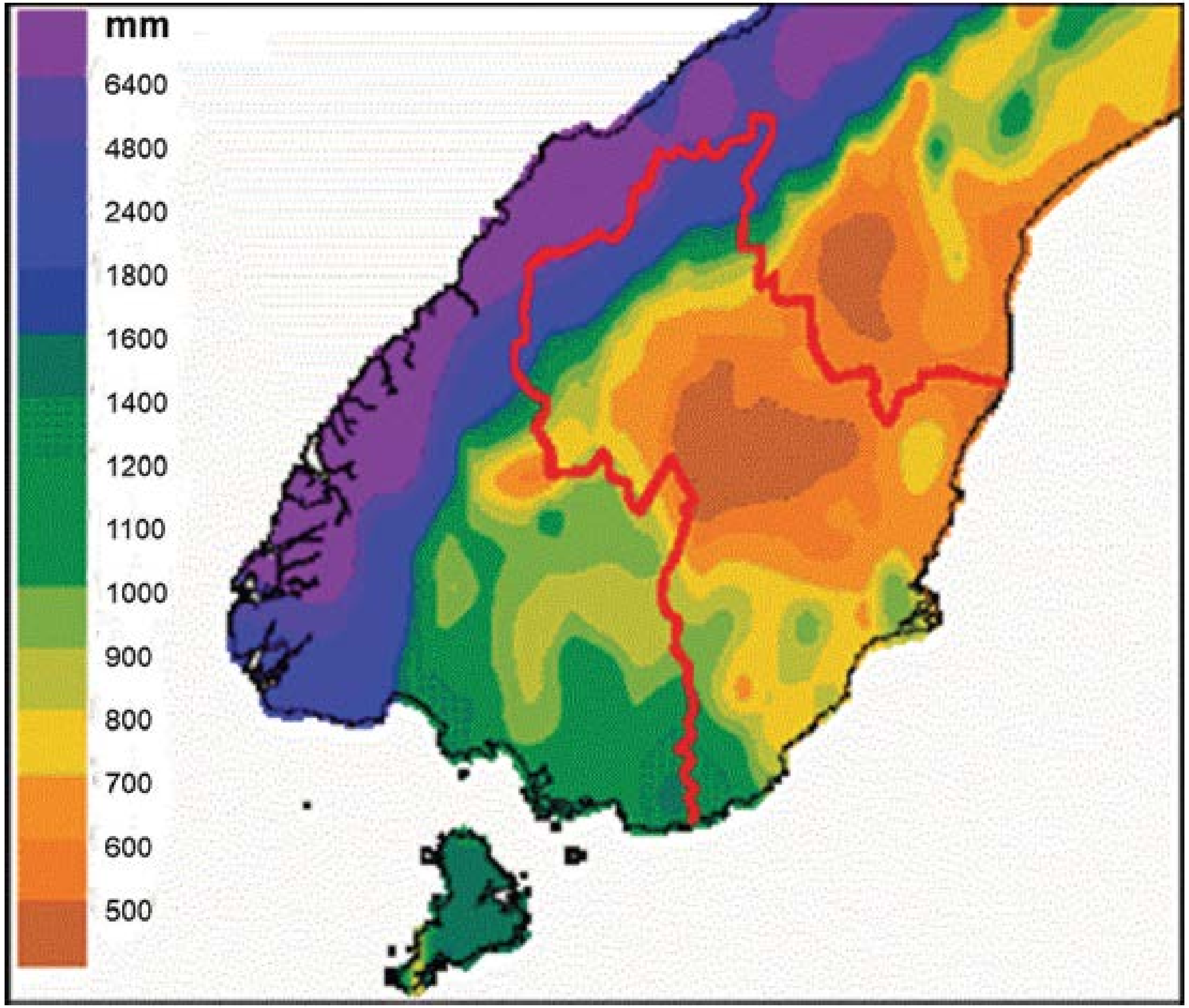
Large seasonal flow variations

Highest point - Mt Aspiring (3027 m or 9931 ft)

40% of catchment is higher than 900 m (3000 ft)

Main part of the catchment is in a rain shadow.

Otago rainfall variability



Taylor, M. and Bardsley, E., 2015. The Interdecadal Pacific Oscillation and the Southern Oscillation Index: relative merits for anticipating inflows to the Upper Clutha lakes. *Journal of Hydrology*, *54*(2), p.67.

All of these activities rely on a sustainable and consistent amount of water and can be severely impacted during times of drought. Yet so far no index for measuring Clutha droughts has existed.

Flooding

1878 - 5663 m3/s

1948 - 2662 m3/s

1957 - 3540 m3/s

1972 - Unknown

Queenstown Mall and Eicharts Hotel - 1999

1978 – 4634 m^3/s

1994 – 2673 m^3/s

At Roxburgh

1995 - 3050 m^3/s

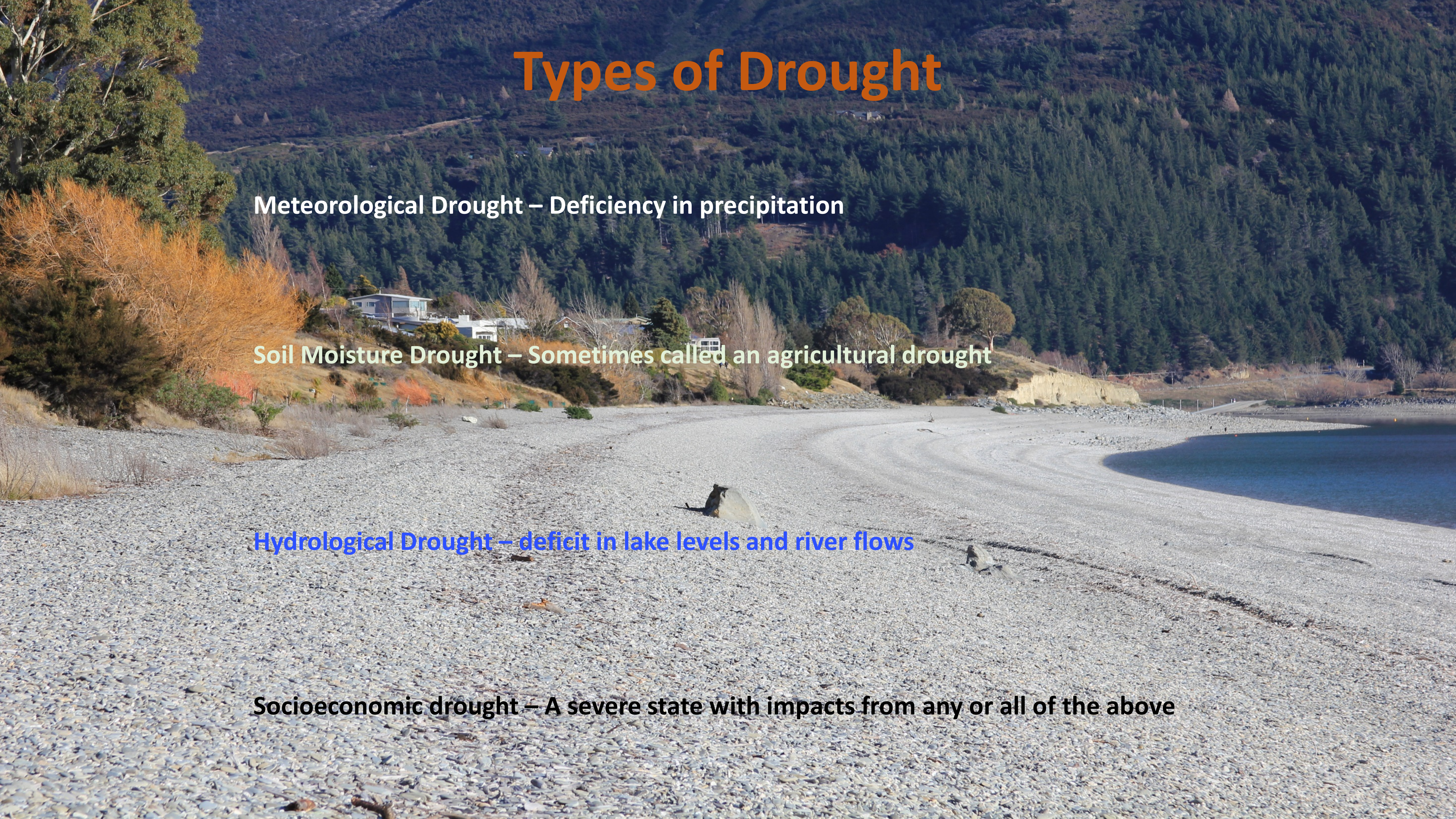
At Roxburgh

1999 - 3679 m^3/s At Roxburgh

- 4165 m^3/s At Balclutha

Drought   The creeping disaster

Types of Drought



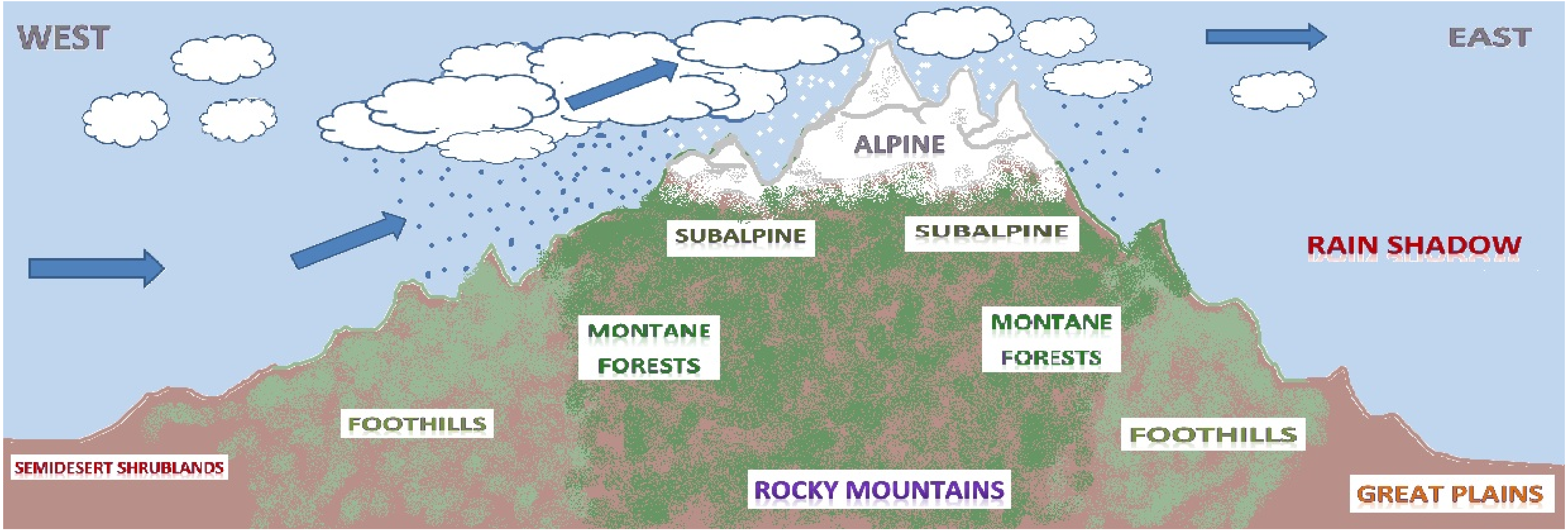
Meteorological Drought – Deficiency in precipitation

Soil Moisture Drought – Sometimes called an agricultural drought

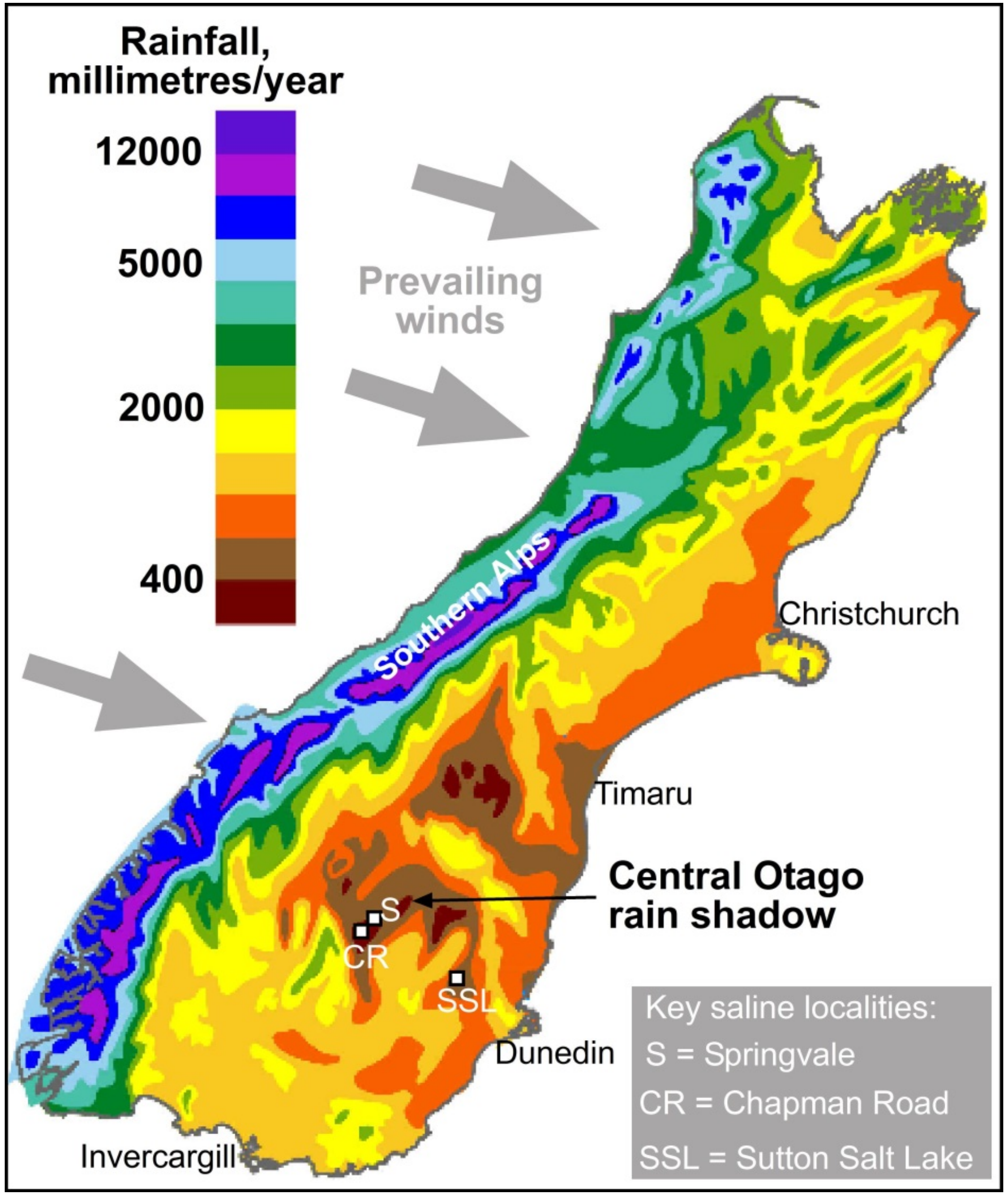
Hydrological Drought – deficit in lake levels and river flows

Socioeconomic drought – A severe state with impacts from any or all of the above

Orographic precipitation and rain shadows



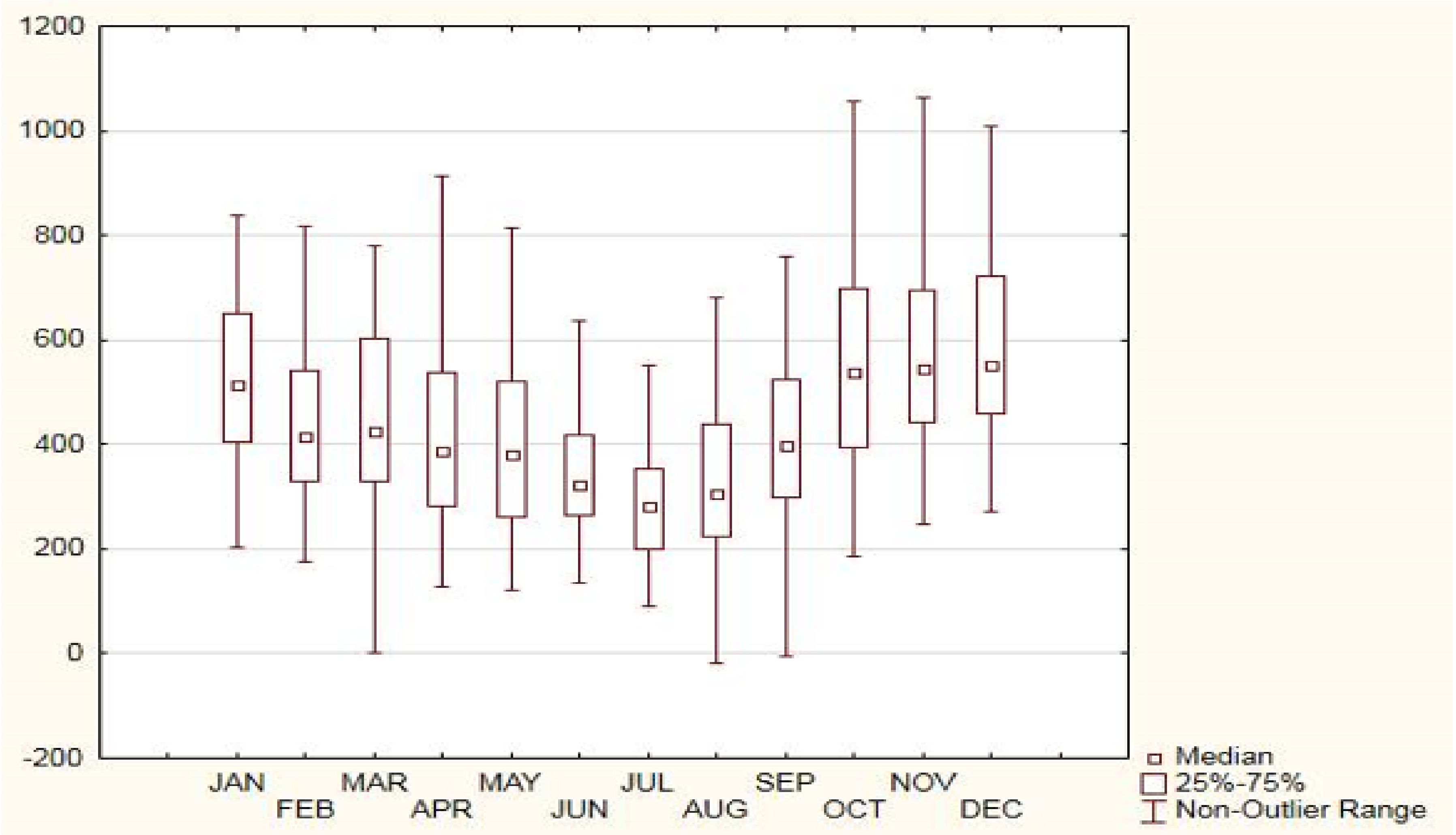
Warm moist air cools by 0.5 deg C per 100m altitude (1.5 C per 1000’)



Cool dry air warms by 1.0 deg C per 100m altitude (3.0 C per 1000’)

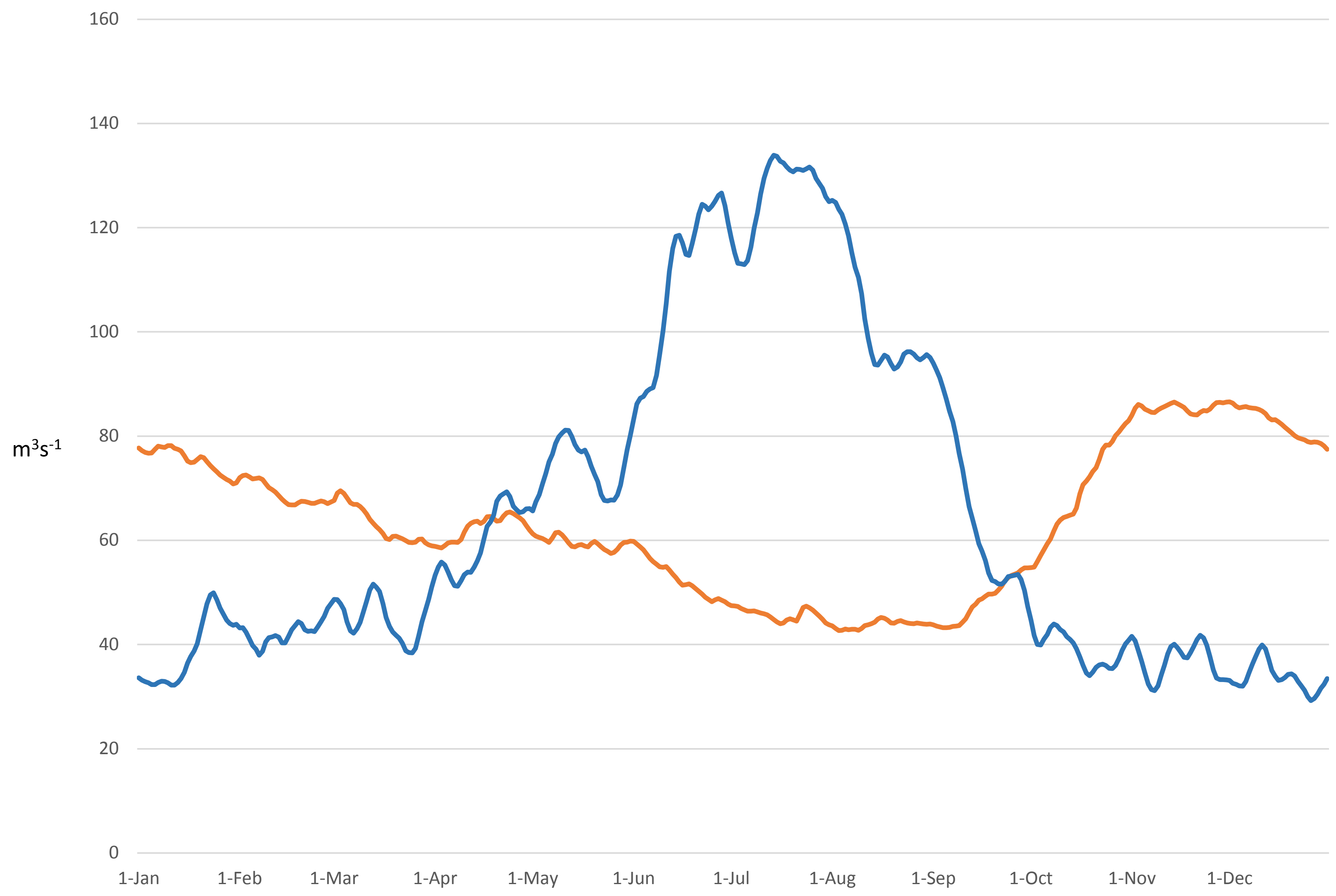
Image from http://www.otago.ac.nz/geology/research/environmental-geology/geomorphology/evaporative-salts-central-otago.html

Monthly variation on inflows



Combined Clutha lakes mean monthly inflows (Wakatipu, Wanaka, and Hawea).

Mean annual Clutha River flow at Roxburgh prior (brown line) and post (blue line) Hawea Dam



Mean annual Hawea River flow prior (brown line) and post (blue line) Hawea Dam

Issues with using a various types of Drought Indices

The large spatial variability in precipitation

- Difficulty with using an SPI

Evaporation exceeds rainfall

- Part of the catchment is in permanent soil moisture deficit

The large temporal variability in the lake inflows
And Modified nature of the river flow

- Can be allowed for with a hydrological drought Index

Image courtesy of RNZ

Steps required to develop a Hydrological Drought Index for the Clutha Catchment

1.

Select a flow site that:

Is representative of the main parts of the catchment

Has a long, continuous and accurate flow record

Not influenced by coastal precipitation

Roxburgh Power Station

Steps required to develop a Hydrological Drought Index for the Clutha Catchment

2.

Obtain natural discharge from Roxburgh by removing the outflow from Lake Hawea

Steps required to develop a Hydrological Drought Index for the Clutha Catchment

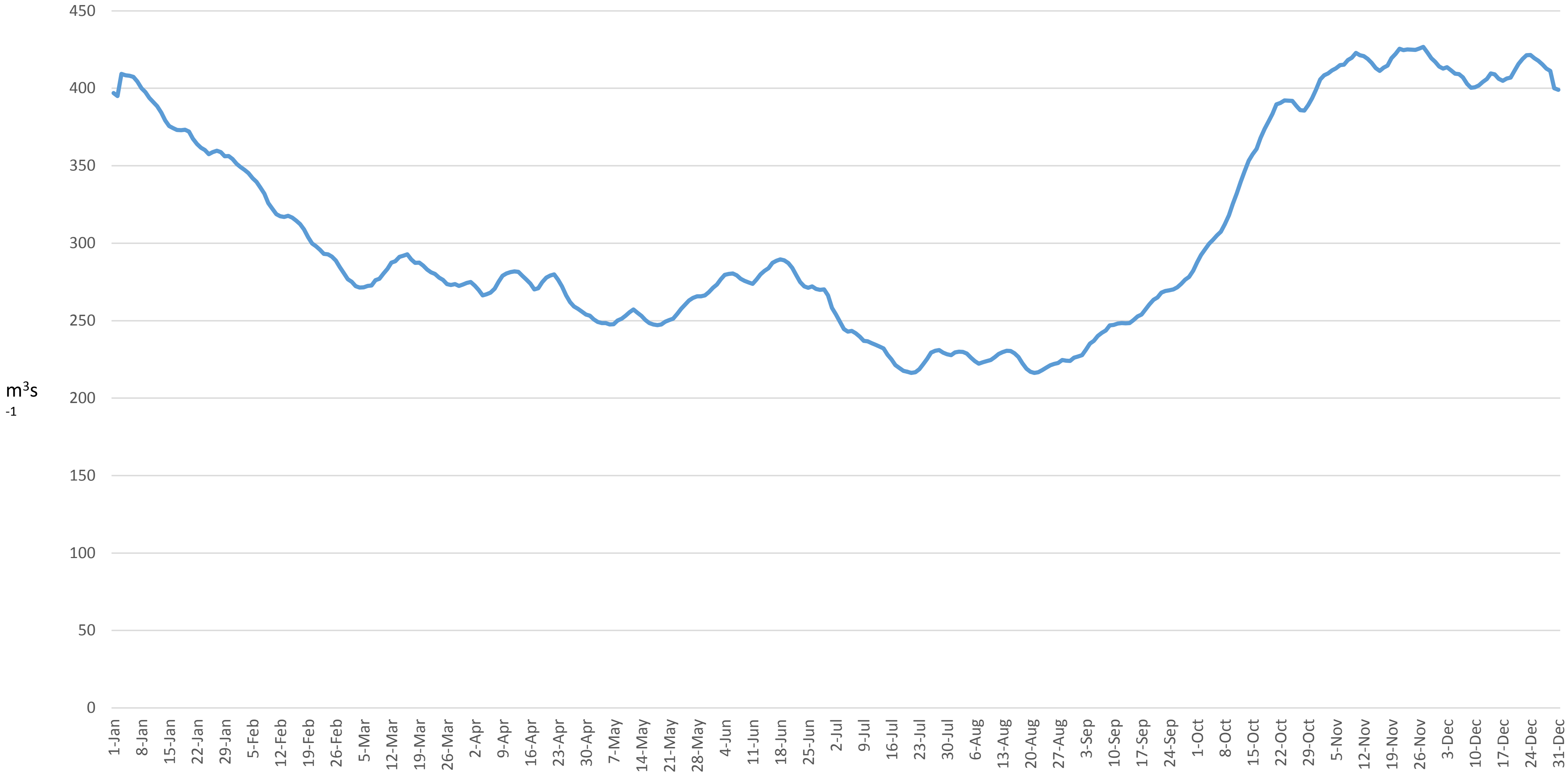
3.

The natural flows are sorted from lowest to highest for each individual date

A threshold value is chosen that is close to, but within, 1 σ below the mean.

A 1:5 year low flow standard was selected as the initial trigger point.

01-Jan	296	304	322	329	336	346	364	386	391	392	392	394	394	396	400	4
02-Jan	310	315	315	326	340	344	355	377	377	380	384	391	392	396	401	4
03-Jan	304	324	329	331	341	359	366	367	370	375	380	386	394	395	397	3
04-Jan	298	321	330	342	344	358	358	365	368	378	385	388	388	389	392	4
05-Jan	298	319	335	348	350	351	352	353	357	371	375	381	392	394	399	4
06-Jan	299	318	339	343	344	345	352	357	360	367	374	377	386	390	392	4
07-Jan	291	314	337	341	343	347	353	355	356	363	369	378	381	392	393	3
08-Jan	282	308	331	337	344	352	354	359	359	363	367	379	381	388	390	3
09-Jan	284	302	328	328	345	354	354	366	366	372	376	381	381	385	389	3
10-Jan	281	296	324	326	345	346	359	360	374	376	378	381	381	385	386	3
11-Jan	275	288	321	321	333	337	360	363	366	374	381	383	383	389	391	3
12-Jan	277	284	316	320	321	335	353	357	361	373	378	381	384	385	385	3
13-Jan	279	281	307	312	321	327	345	348	348	370	373	376	379	381	383	3
14-Jan	277	287	303	305	314	320	336	339	340	349	365	367	371	375	377	3
15-Jan	273	296	300	300	305	325	328	330	340	345	353	362	365	366	369	3
16-Jan	269	289	295	295	315	316	322	331	341	355	358	358	358	358	362	3
17-Jan	264	282	287	290	309	316	318	327	331	342	350	350	355	358	362	3
18-Jan	257	275	285	286	312	314	319	322	332	335	338	345	352	354	365	3
19-Jan	252	270	278	279	307	318	326	327	328	329	334	334	339	355	365	3
20-Jan	248	272	272	273	302	304	312	320	327	329	334	338	356	363	367	3
21-Jan	245	267	272	277	288	296	313	316	320	326	337	339	356	360	364	3
22-Jan	241	253	262	265	281	312	317	324	324	328	329	342	351	355	355	3
23-Jan	240	243	256	260	279	312	319	322	324	338	339	340	346	347	350	3
24-Jan	222	242	253	257	307	316	318	321	328	329	332	341	344	349	350	3
25-Jan	219	247	248	252	314	324	326	326	326	327	332	335	343	347	354	3



Threshold values to trigger deficit measurements

Steps required to develop a Hydrological Drought Index for the Clutha Catchment

4.

When the natural flow is less than the threshold flow a flow deficit is calculated

The flow deficit is accumulated until such time as the natural flow exceeds the threshold flow

The accumulated deficit is increased by the natural flow until there is no longer a deficit

YEAR	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
23-Nov	-2	0	0	-8	-1292	0	-242	-3814	0	-227	0	0	0	0	0	0	0	0
24-Nov	427	0	0	-25	-1406	0	-297	-3834	0	-295	0	0	0	0	0	0	0	0
25-Nov	0	0	0	-48	-1528	0	-350	-3407	0	-365	0	0	0	0	0	0	0	0
26-Nov	0	0	0	-67	-1659	0	-403	-2945	0	-432	0	0	0	0	0	0	0	0
27-Nov	0	0	0	-76	-1792	0	-456	-2414	0	-490	0	0	0	0	0	0	0	0
28-Nov	0	0	0	353	-1916	0	-510	-1800	0	-529	0	0	0	0	0	0	0	0
29-Nov	0	0	0	0	-2032	0	-568	-1102	0	-548	0	0	0	0	-3	0	0	0
30-Nov	0	0	0	0	-2137	0	-628	-338	0	-555	0	0	0	0	-25	0	0	0
1-Dec	0	0	0	0	-2207	0	-691	474	0	-140	0	0	0	0	-70	0	0	0
2-Dec	0	0	0	0	-2248	0	-755	0	0	275	0	0	0	0	-115	0	0	0
3-Dec	0	0	0	0	-2274	0	-818	0	0	0	0	0	0	0	-154	0	0	0
4-Dec	0	0	0	0	-2283	0	-875	0	0	0	0	0	0	0	-187	0	0	0
5-Dec	0	0	0	0	-1869	0	-922	0	0	0	0	0	0	0	-216	0	0	-4
6-Dec	0	0	0	0	-1877	0	-959	0	0	0	0	0	0	0	-237	0	0	-11
7-Dec	0	0	0	0	-1896	0	-988	0	0	0	0	0	0	0	-265	0	0	-24
8-Dec	0	0	0	0	-1915	0	-1013	0	0	0	0	0	0	0	-300	0	0	-41
9-Dec	0	0	0	0	-1932	0	-1035	0	0	0	0	0	0	0	-342	0	0	-59
10-Dec	0	0	0	-7	-1936	0	-1061	0	0	0	0	0	0	0	-391	0	0	-80
11-Dec	0	0	0	-24	-1513	0	-1093	0	0	0	0	0	0	0	-454	0	0	-99
12-Dec	0	0	0	-51	-1057	0	-1130	0	0	0	0	0	0	0	-528	0	0	-118
13-Dec	0	0	0	-87	-569	0	-1169	0	0	0	0	0	0	0	-609	0	0	-141
14-Dec	0	0	0	-135	-57	0	-1213	0	0	0	0	0	0	0	-702	0	0	-174
15-Dec	0	0	0	-189	464	0	-1257	0	0	0	0	0	0	0	-800	0	0	-214
16-Dec	0	0	0	244	0	0	1297	0	0	0	0	0	0	0	900	0	0	267

Steps required to develop a Hydrological Drought Index for the Clutha Catchment

5.

For each year the annual peak deficit is calculated

The mean annual peak flow deficit is calculated (2362 cumec-days)

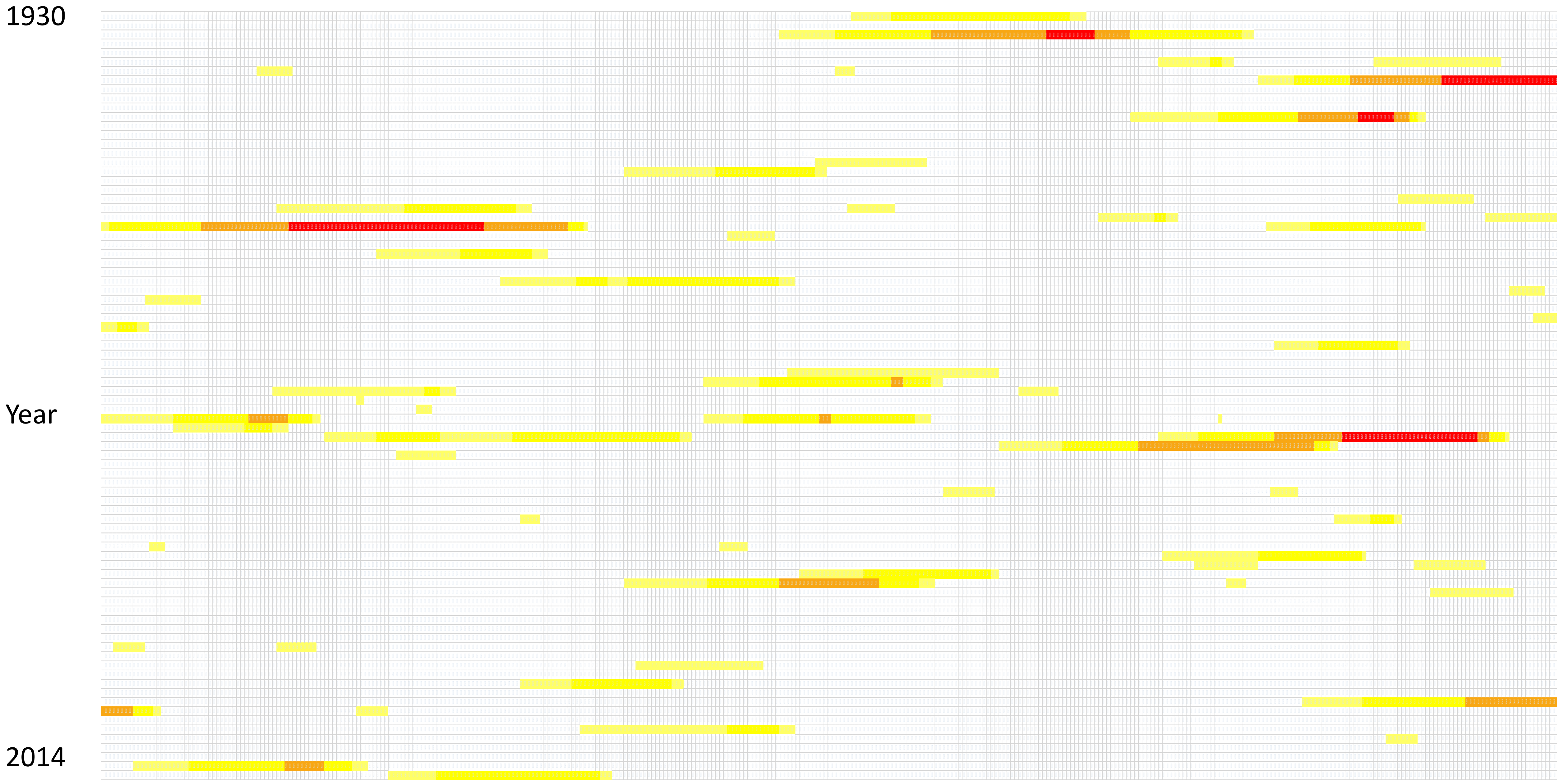
The daily flow deficit is standardised by dividing by the mean peak deficit to give an index value

YEAR	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
26-Feb-30	0.00	0.00	0.00	0.00	0.00	0.61	0.00	3.33	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.09
27-Feb-30	0.00	0.00	0.00	0.00	0.00	0.62	0.00	3.37	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.11
28-Feb-30	0.00	0.00	0.00	0.00	0.00	0.64	0.00	3.41	0.00	0.00	0.41	0.00	0.00	0.01	0.00	0.13
1-Mar-30	0.00	0.00	0.00	0.00	0.00	0.65	0.00	3.45	0.00	0.00	0.43	0.00	0.00	0.02	0.00	0.14
2-Mar-30	0.00	0.00	0.00	0.00	0.00	0.67	0.00	3.49	0.00	0.00	0.44	0.00	0.00	0.04	0.00	0.15
3-Mar-30	0.00	0.00	0.00	0.00	0.00	0.69	0.00	3.53	0.00	0.00	0.46	0.00	0.00	0.05	0.00	0.15
4-Mar-30	0.00	0.00	0.00	0.00	0.00	0.70	0.00	3.57	0.00	0.00	0.47	0.00	0.00	0.08	0.00	0.03
5-Mar-30	0.00	0.00	0.00	0.00	0.00	0.73	0.00	3.60	0.00	0.00	0.49	0.00	0.00	0.10	0.00	-0.10
6-Mar-30	0.00	0.00	0.00	0.00	0.00	0.75	0.00	3.64	0.00	0.00	0.51	0.00	0.00	0.12	0.00	0.00
7-Mar-30	0.00	0.00	0.00	0.00	0.00	0.77	0.00	3.67	0.00	0.00	0.53	0.00	0.00	0.14	0.00	0.00
8-Mar-30	0.00	0.00	0.00	0.00	0.00	0.79	0.00	3.71	0.00	0.00	0.55	0.00	0.00	0.17	0.00	0.00
9-Mar-30	0.00	0.00	0.00	0.00	0.00	0.82	0.00	3.74	0.00	0.00	0.58	0.00	0.00	0.19	0.00	0.00
10-Mar-30	0.00	0.00	0.00	0.00	0.00	0.85	0.00	3.78	0.00	0.00	0.61	0.00	0.00	0.22	0.00	0.00
11-Mar-30	0.00	0.00	0.00	0.00	0.00	0.88	0.00	3.82	0.00	0.00	0.64	0.00	0.00	0.23	0.00	0.00
12-Mar-30	0.00	0.00	0.00	0.00	0.00	0.90	0.00	3.86	0.00	0.00	0.67	0.00	0.00	0.24	0.00	0.00
13-Mar-30	0.00	0.00	0.00	0.00	0.00	0.93	0.00	3.89	0.00	0.00	0.71	0.00	0.00	0.11	0.00	0.00
14-Mar-30	0.00	0.00	0.00	0.00	0.00	0.95	0.00	3.91	0.00	0.00	0.74	0.00	0.00	-0.03	0.00	0.00
15-Mar-30	0.00	0.00	0.00	0.00	0.00	0.96	0.00	3.93	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00
16-Mar-30	0.00	0.00	0.00	0.00	0.00	0.98	0.00	3.95	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
17-Mar-30	0.00	0.00	0.00	0.00	0.00	0.99	0.00	3.96	0.00	0.00	0.83	0.00	0.00	0.00	0.00	0.00
18-Mar-30	0.00	0.00	0.00	0.00	0.00	1.01	0.00	3.98	0.00	0.00	0.86	0.00	0.00	0.00	0.00	0.00
19-Mar-30	0.00	0.00	0.00	0.00	0.00	1.03	0.00	4.01	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00
20-Mar-30	0.00	0.00	0.00	0.00	0.00	1.05	0.00	4.04	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00

Hydrological Drought Index for the Clutha Catchment

The resulting index is a measure of both the duration and the intensity of a drought

0 – 0.5	Low flows, but not yet a drought
0.5 – 1.0	Mild Drought
1.0 – 2.0	Moderate Drought
2.0 – 3.0	Severe Drought
> 3.0	Extreme Drought



Drought severity: Grey – No drought, pale yellow – mild drought, dark yellow – moderate drought, orange – severe drought, red – extreme drought

Conclusion

This Hydrological Drought Index is:

- Desirable to enable stream and river users to determine the point at which a drought actually starts, how severe it actually is and also when it is actually over
- Based on readily available data
- Integrates the effects of precipitation, snow melt and accumulation, and evaporation across diverse topographies
- Allows for very large flow variability over small time frames.

- The methodology could equally be applied to similar catchments.

Acknowledgements

I would like to thank:

- Contact Energy who provided most of the historical data
- The Otago Regional Council who make up to date flow data available on their website

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- Assoc. Prof. Earl Bardsley who continuously provides the motivation and guidance for my research.


The Drought Breaker