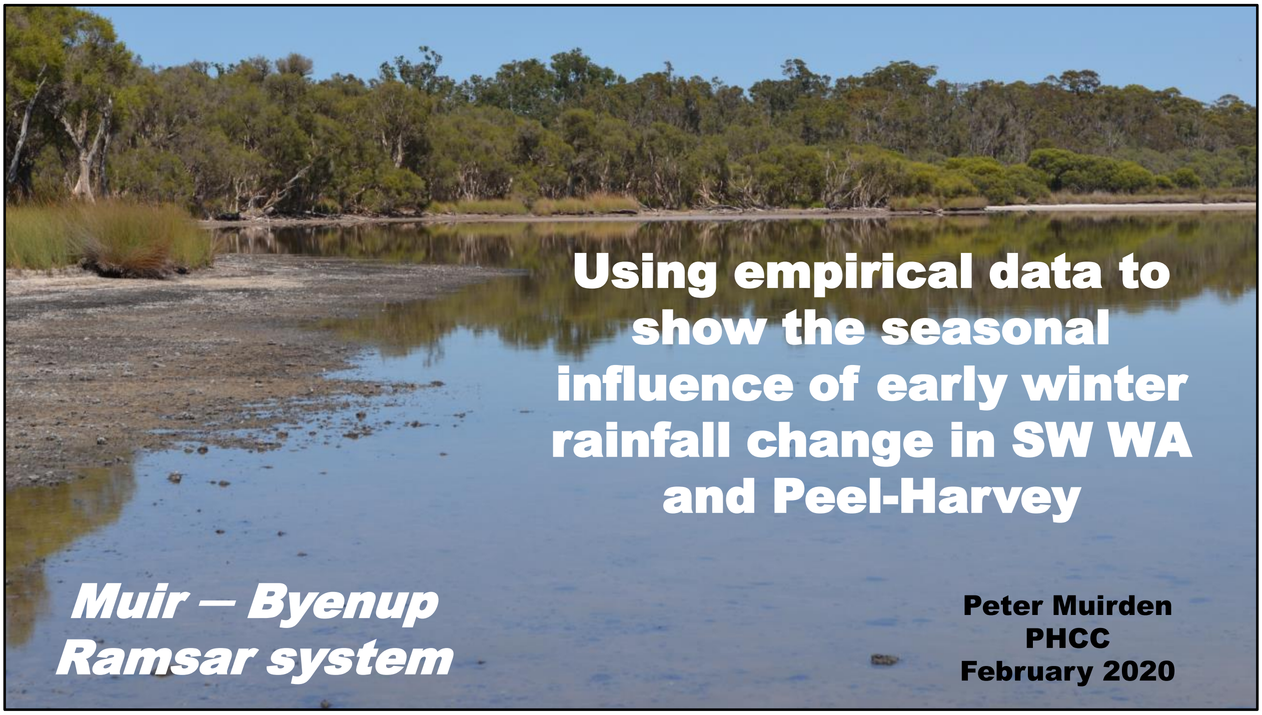
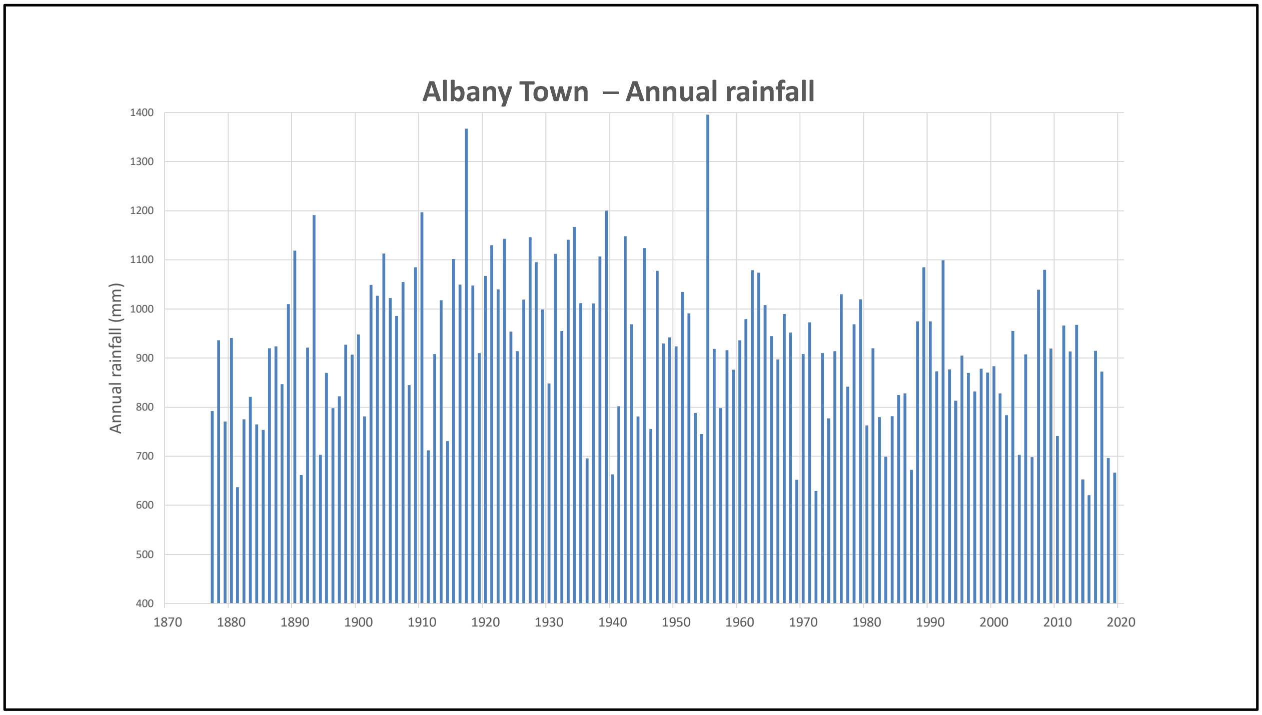


This presentation is about the research I have undertaken since 2016 into the effects of rainfall change across Australia using actual rainfall and flow data; not modelled or predicted data.

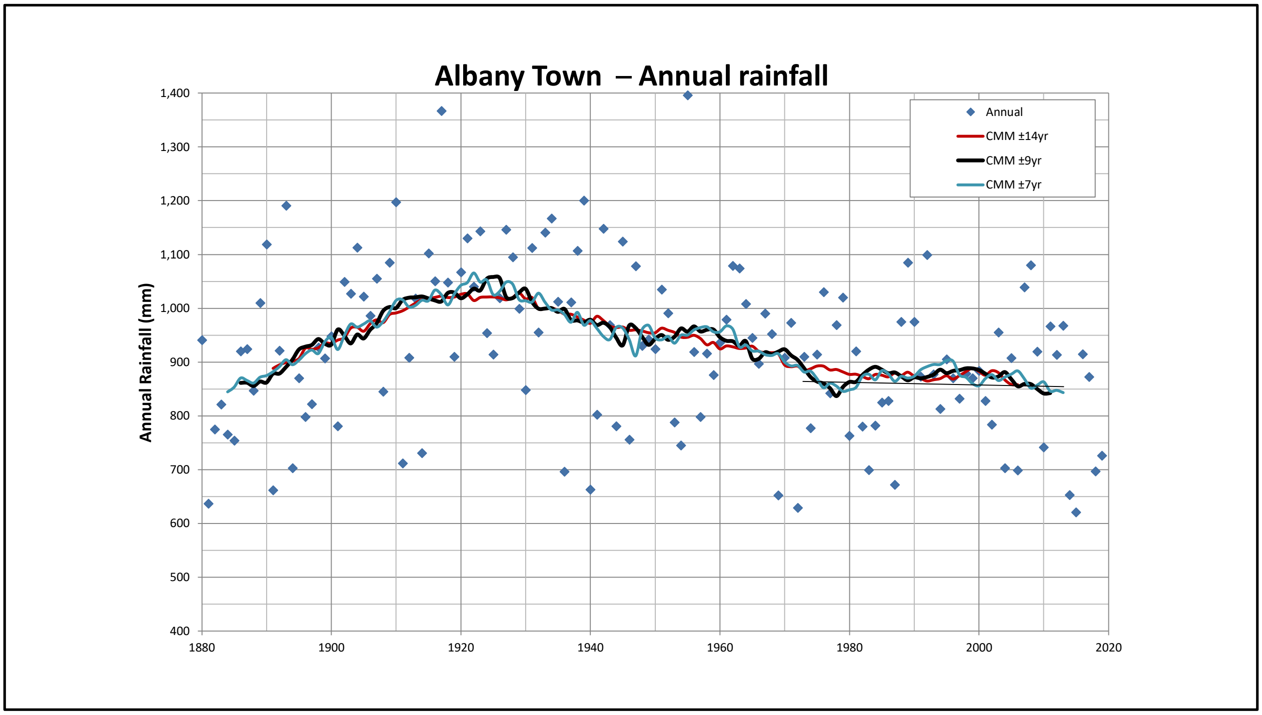
The work emphasises how a different presentation of these datasets more clearly shows when 'step-changes' in rainfall and flow have occurred at individual sites. For rainfall, these changes have then been congregated and presented spatially to more clearly show changes in rainfall. The relatively simple hydrology at the Muir-Byenup Ramsar System has been selected to show the influence of seasonal variability of rainfall and its resultant driver on streamflow.

The presentation then provides describes the far more complex Swan Coastal Plain and Darling Ranges climate and hydrology with a particular emphasis on the Peel Region.

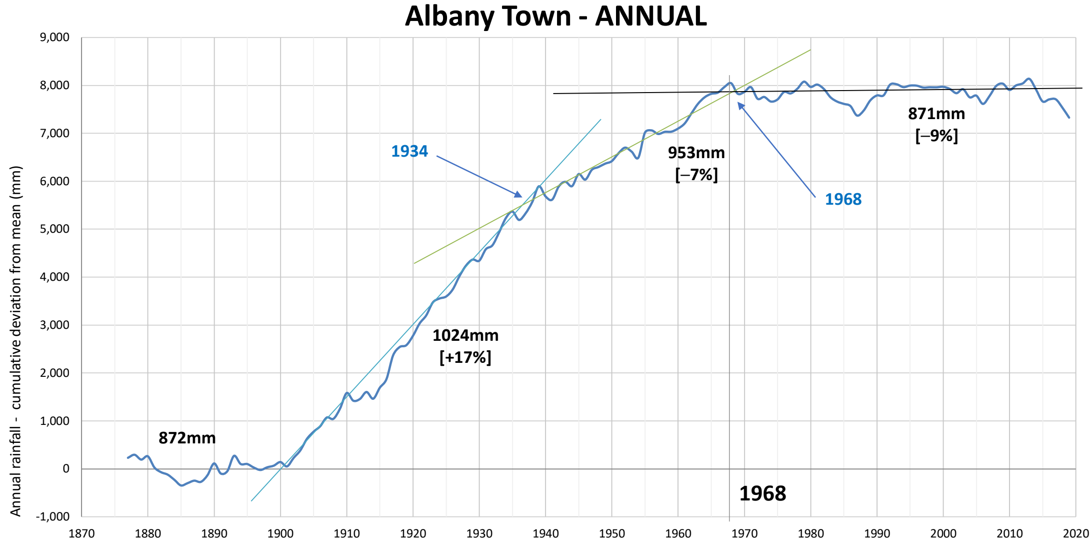


This is the ‘traditional’ presentation of rainfall variability at a site; basically a ‘scatter plot’. Annual data shown here is from Albany Town is from 1877 to 2019; a period of almost 150 years.

There is little than can be determined from this plot, with the only clear ‘trend’ being that it rains every year……



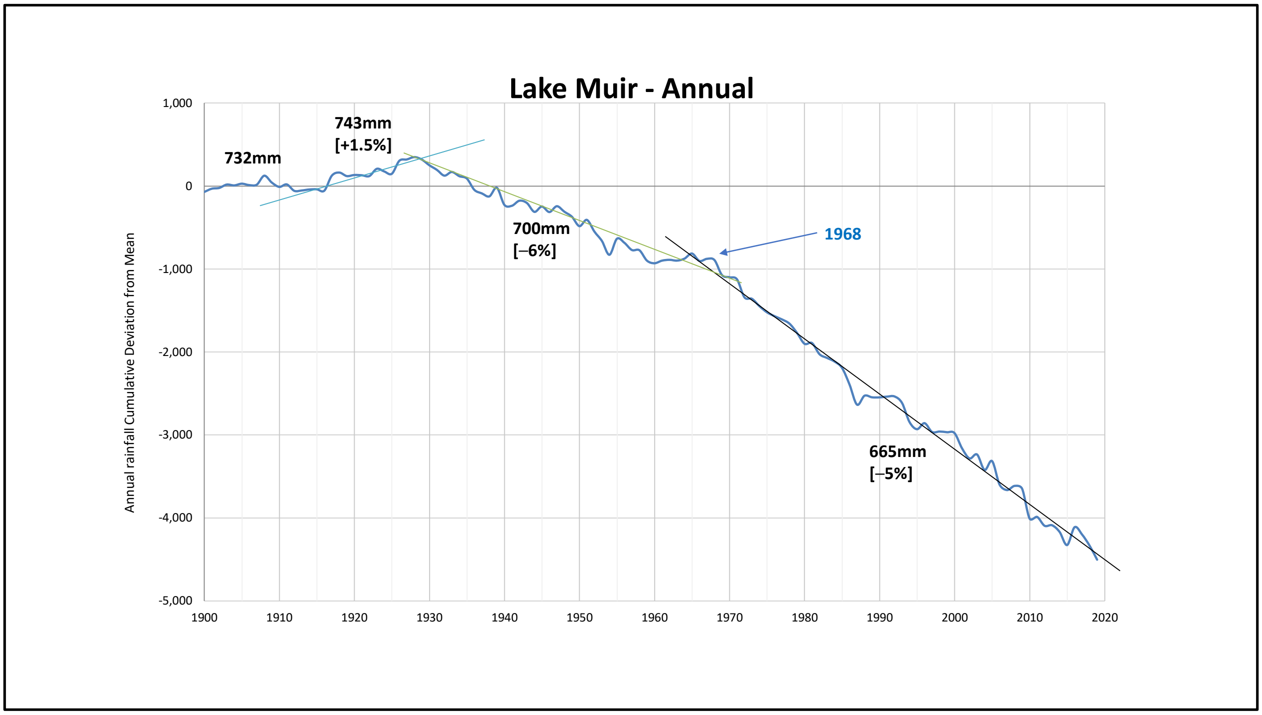
Here the same long-term **Albany Town** annual rainfall data is presented with the smoothed Central Moving Mean (CMM) averages of different periods.
It is very hard to determine WHEN changes have occurred due to the smoothing function of CMM which masks any steps. The CMM implies an increasing average rainfall during the late 1800's/early 1900's when the calculation of average rainfall each year includes more and more of the higher rainfall average between 1901 and 1934. It also implies little change in the latter period.



A more realistic understanding can be gleaned by cumulating the rainfall, then analysing for 'Cumulative deviation from Mean' (CDfM). With CDfM, there is no smoothing; and the slope of the line is the average rainfall for that period.

In this plot, the annual rainfall from Albany Town is again analysed and while there is some variability, it is clear that step changes in averages have taken place near specific years. Analysis of sites across WA show that the years these changes occur are consistent across regions.

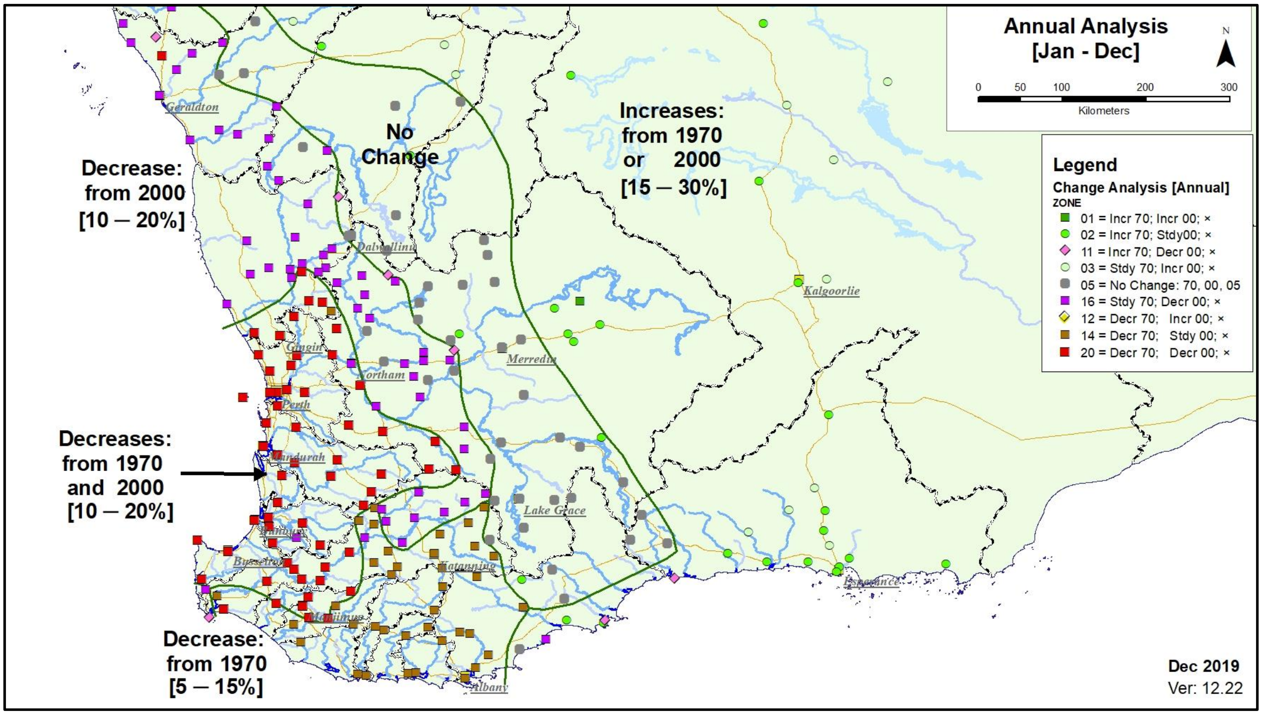
In recent times, since 1968, the average rainfall at Albany has been a consistent 871mm/a with only minor variability. The initial annual average rainfall over the 25 years between when rainfall records began in 1877 and 1901 was only 872mm/a; very similar to current annual rainfall average. Between 1901 and 1934, the average rainfall was 17% higher at 1024mm/a. In 1934 there was a decrease of 7% and there was a further decrease in 1968 of 9% to the current annual average of 871mm/a. Between each of these 'step-changes', there was natural rainfall variability.



Rainfall records from Lake Muir in the Muir-Unicup-Byenup wetlands, only began in 1980. Hence, data from nearby raingauges were and correlations developed to infer the monthly rainfall at the site. Note that prior to 1900, correlations are poor. This slide shows the annual rainfall variability at Lake Muir; note that again the annual average rainfall has not changed since 1968.

This curve has similar shape to Albany, but the data only begins in 1900, so does not show the increase in rainfall after the late 1800's.

What is very odd about the hydrology of the Lake Muir area is that since 2005 there has been a significant change in flow in streams in the area as well as a significant change in hydroperiod in local wetlands resulting in major water quality changes. The question is: how can there be a change in the streamflow if the annual rainfall does not change?



In WA, 360 rainfall sites have been analysed in this way (with a further 140 in the rest of Australia). By collating this data (grouping similar steps and trends), it is possible to present it spatially. By analysing data in this way, it was possible to clearly define where the various effects occurred and where similar step-changes occurred at a regional scale. What was also apparent, was the steps around 1914 (increase) and 1934 (decrease) which occurred in many (although not all) sites.

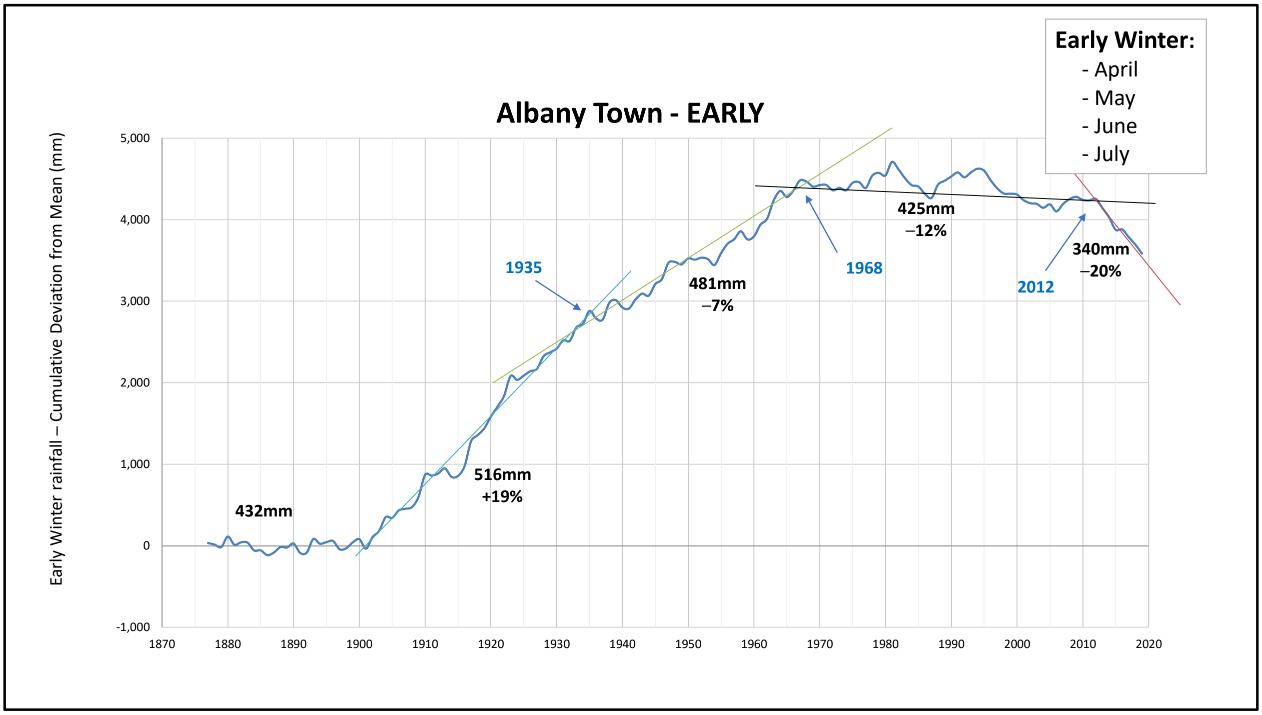
In SWWA, the area south-west of a line between Kalbarri to Kelleberrin to Cape Riche, there were considerable reductions of annual rainfall since 1960 which is consistent to other studies. At this stage of the research, only the post-1960 step changes have been represented spatially, in the current slide. What was also apparent were the specific regions in SWWA where similar step changes occurred in the rainfall datasets; these were not random, but could be grouped and spatially represented.
– The Brown squares in the map above were sites where there was a single step around 1970 and nothing afterwards.
– The Magenta squares show sites where there was a single step around 2000 and no change around 1970.
– The Red squares are where there was a reduction in BOTH 1970 and 2000.
– To the far East, there was increasing rainfall since 1960 and
– In Grey, there was a small band between the two trend directions where there was no recorded change at either time.

Note, for a change to be shown above, the change had to be 'Statistically Significant'; that is > 2x the standard deviation.

Analysing ANNUAL rainfall only gives part of the picture. It is not just the total annual rainfall that defines our Climate, but when that rainfall occurs. There have been numerous anecdotal comments around identifying the late starts to winter as a major contributor to reduced rainfall, while other anecdotal discussion identifies an increasing number of summer events.

To quantify the seasonal rainfall variability, the annual dataset was split up into three other periods:
- **Early Winter** rainfall: April, May, June & July
- **Late Winter** rainfall: August, September & October
- **Summer** rainfall: November to March

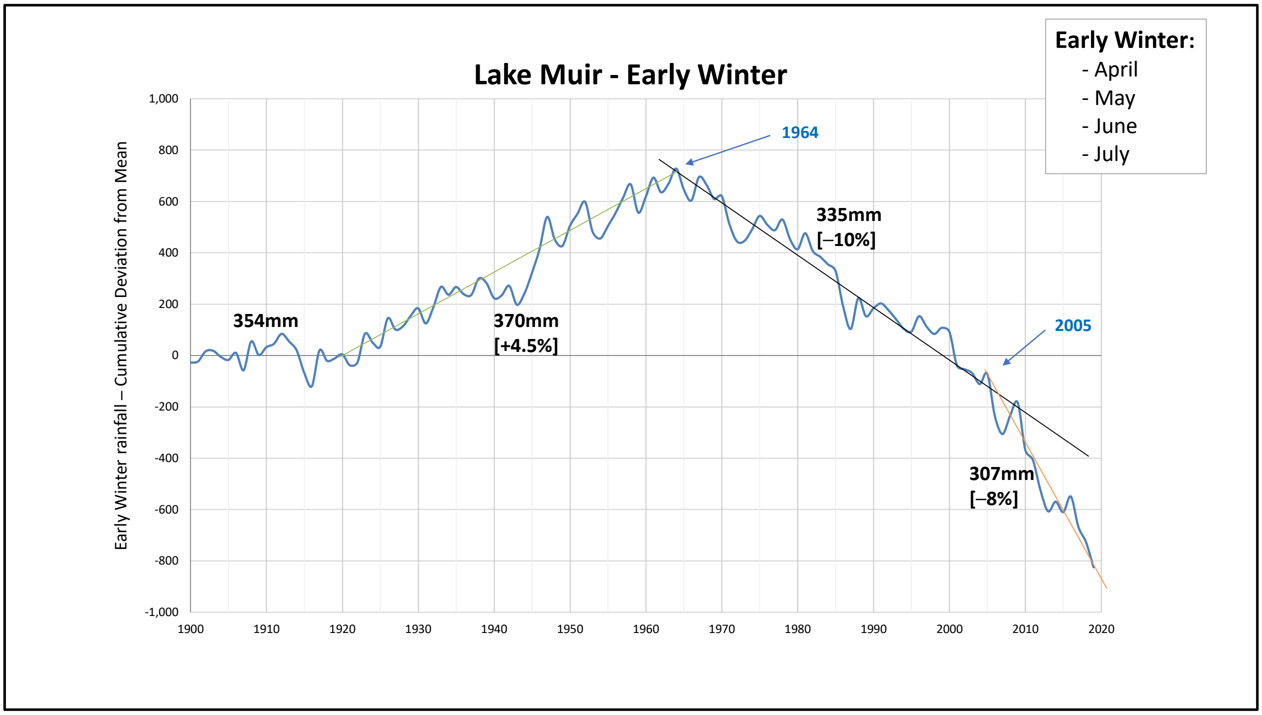
These datasets were analysed in the same way as for Annual Rainfall.



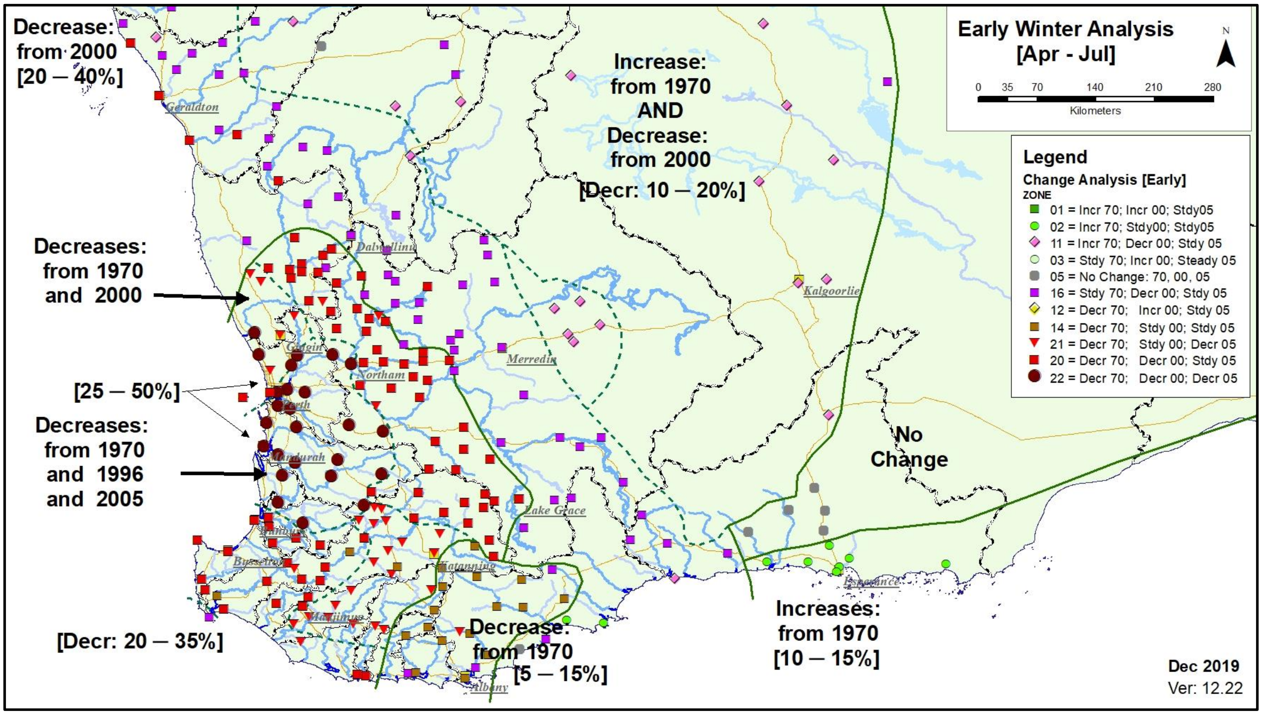
In this graph presenting Early Winter rainfall at Albany[009500], the dataset is also shown as CDfM rainfall. At this site, there are changes around 1902, 1935 and 1968 like in the annual dataset. What we do have in this Early dataset is an additional change in 2012 for Albany (and this occurs in Denmark as well).

Steps in the 2005 to 2010 period do occur at many sites in the Early Winter dataset. While the duration of the change is very short, the consistency of the change at so many sites indicates its 'Significance'. Interestingly, steps post 2000 only occur in Early Winter, but not in Annual, Late Winter or the Summer periods.

However, the 2012 change in the Early dataset at Albany and Denmark is different enough that it behaves more as an 'anomaly' than a 'significant' step change.



In this graph presenting Early Winter rainfall at Lake Muir [509394], the dataset is also shown as CDfM rainfall. At this site, there are changes around 1916 and 1965 like the annual dataset, but the change in 1934 is missing. What we do have in this Early dataset is an additional change in 2005. This 2005 step is unique to the Early period and shows up in many areas of the SWWA, but does not show in the Annual, Late or Summer periods.



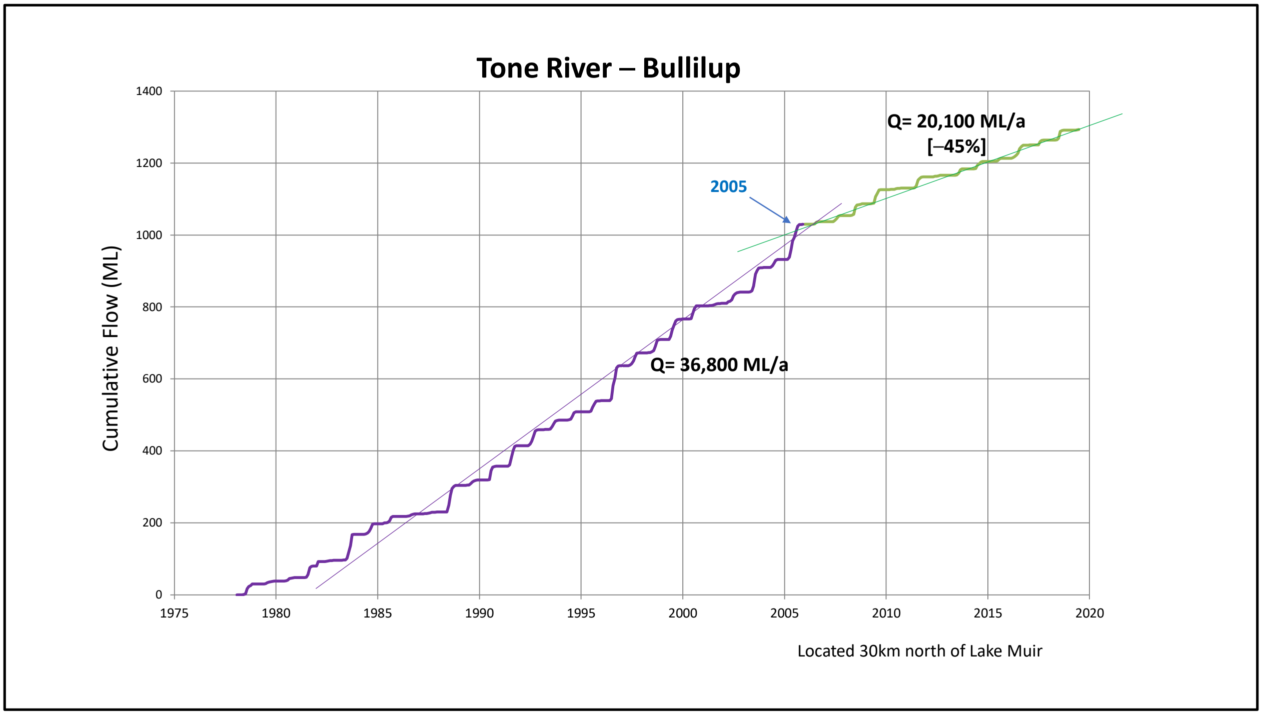
Presenting the Early Winter data spatially, shows a far more extensive impact of rainfall change; particularly in terms of percentage decreases.

The spatial extent of reducing rainfall in 2000 is far more extensive and runs from the Pilbara, Goldfields to near Esperance. The far Eastern part of WA has not had a change although little rainfall occurs in this area during this Early Winter period. Interestingly, the area around the Esperance coast has had a rainfall increase.

There is still an area on the South Coast (Brown) where there was only the single decrease around 1970, however this area is much smaller.
The Red area is much more extensive and includes rainfall reductions in 1970 and 2000 (Red Squares) and reductions in 1970 and 2005 (Red Triangles).
The area of Brown Circles are a triple ‘step’ decrease with the original 1970 change, the 2000 change occurring earlier around 1992-96 and a further decrease in 2005.

Early winter rainfall has fallen 25–50% in the SCP and Darling Ranges.

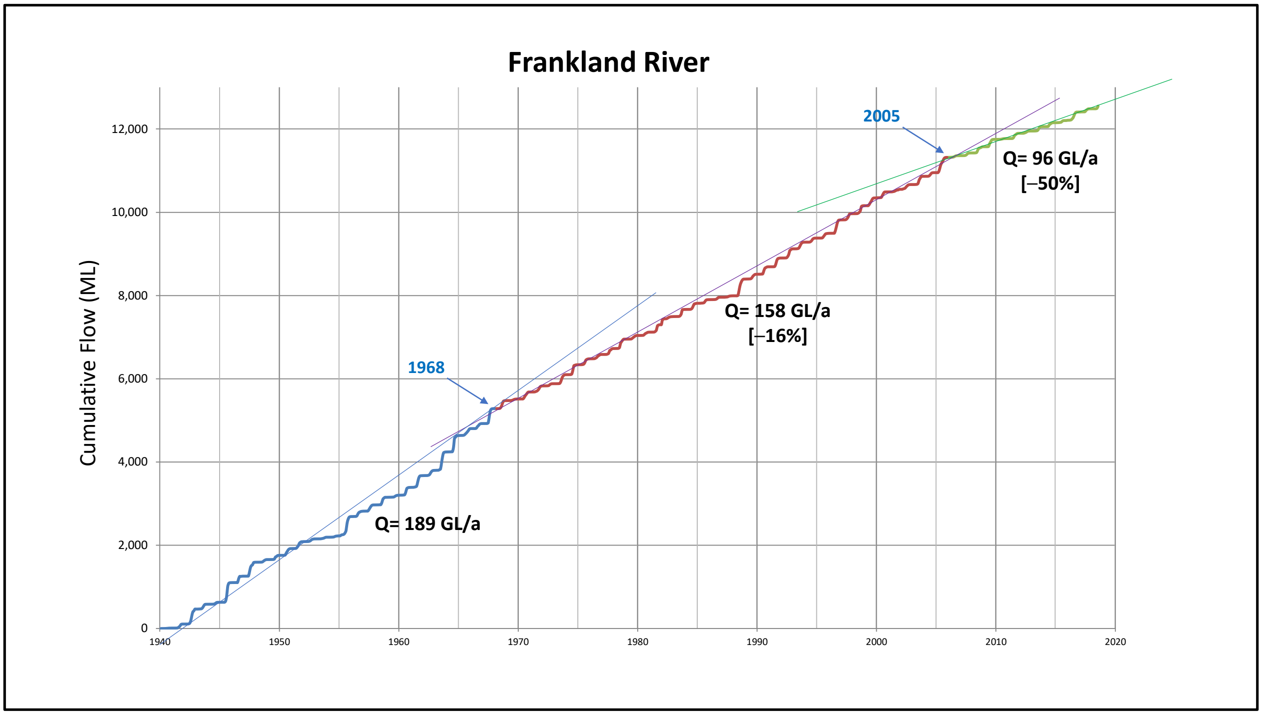
Now, presenting what the changes in rainfall are doing to the hydrology of both waterways and wetlands



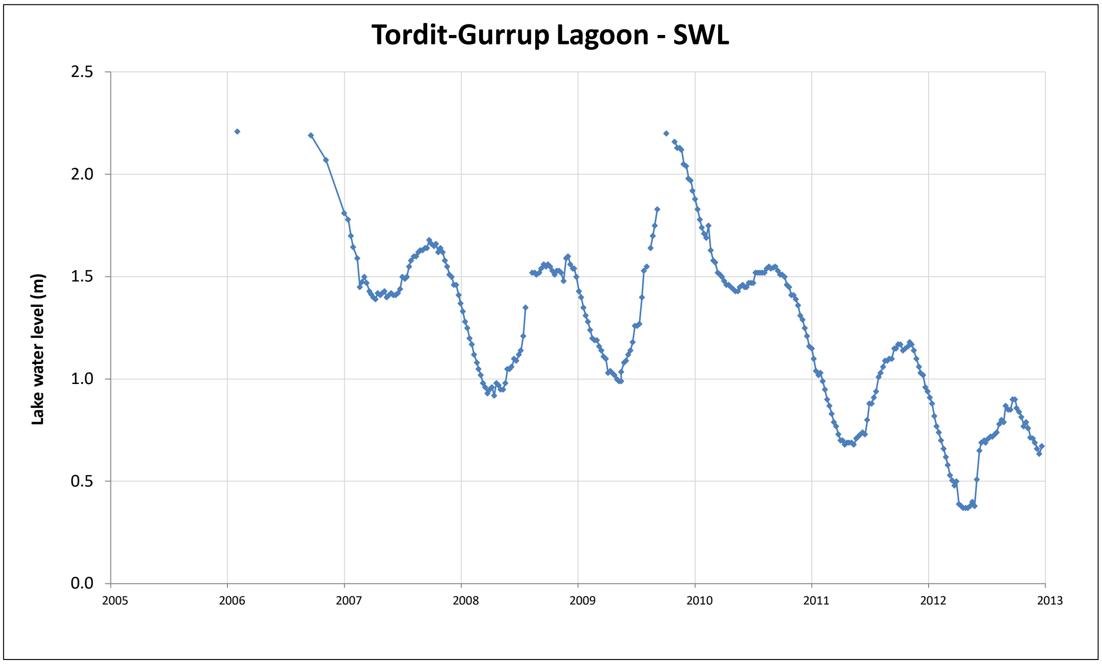
Reviewing hydrologic data for Muir-Byenup, there is no long-term data within the actual area with the earliest monitoring only commencing in 1978 under the SWWM Program (spring lake WL data only), before broader and more intense monitoring began in 2005.

However, DWER have operated a continuous surfacewater monitoring site on the Tone River (shown above) which also began in 1978. This data has been shown as cumulative flow with the averages for each period also calculated. It is quite clear that there was a significant change in average flows after 2005.

The annual rainfall in this catchment has not changed since around 1970, so the only driver could be the significant reduction in Early Winter rainfall which also occurred in 2005. So a Conceptual Model would be that when the Early Winter rainfalls do not occur, the catchment does not wet up early in winter and hence the flows are considerably reduced. The reduction in early winter rainfall at Lake Muir in 2005 was only 8%, however, this corresponded with a 45% reduction in annual flow in Tone River.



A larger catchment with longer dataset in the local area is the Frankland River. This shows the change in 1968 (driven by both Early Winter and Annual rainfall changes), and again a significant fall in flows in 2005.
Note the significance of a 50% drop in flow driven by a 8% drop in rainfall.

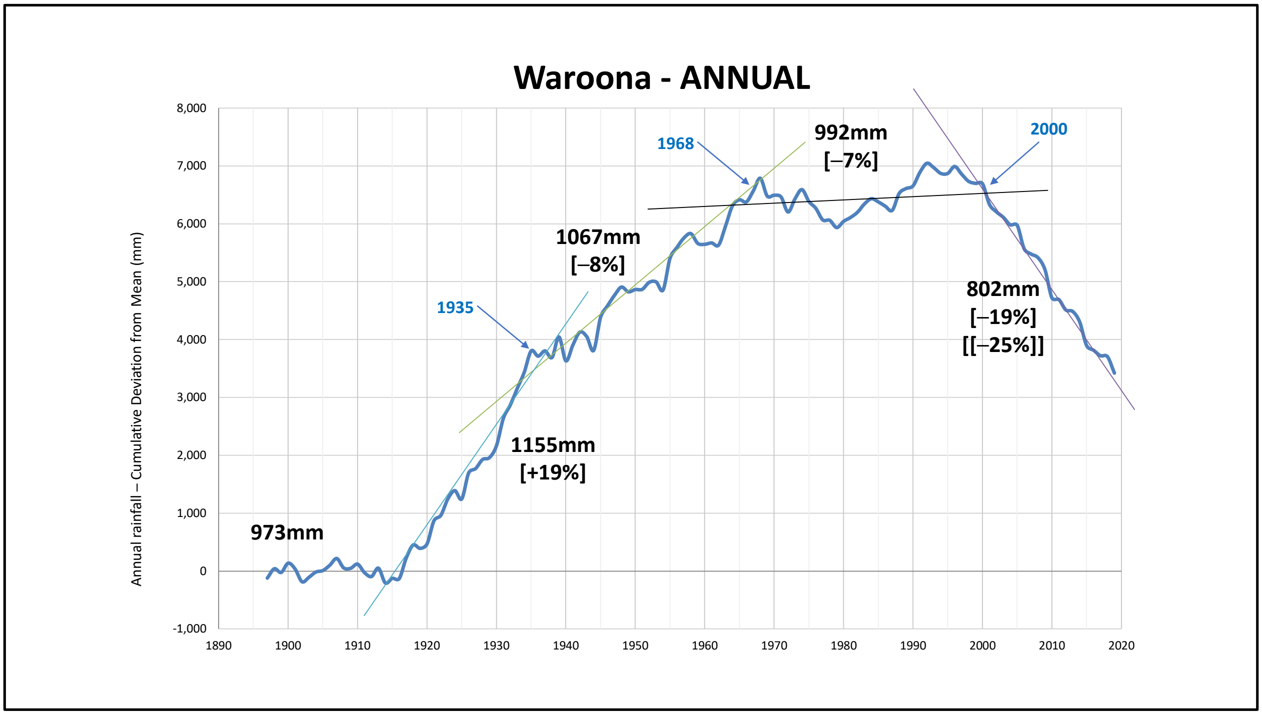


Data has been collected at Muir-Byenup Ramsar and Muir-Unicup NDRC since 1978 and with more regular monitoring between 2006 and 2012. The monitoring has been significantly reduced since then.
Water level data is shown here for Tordit-Gurrup Lagoon which has continued to fall since the rainfall change in 2005 and (while I do not have access to the WL data) it has been seasonally drying since 2012.

Incidentally, the pH in Tordit-Gurrup has also declined from a healthy average of 8.4 to a current level (2019) of between 2.5 and 3.1. Other lakesin the area which recorded some low pH readings in the 2005-2012 period were: Kulinilup, Kodjinup East, Cowerup, Bokerup and as shown here Noobijup. It is expected that other wetlands and waterways have also turned acid in the past few years and sampling on Kulinilup Long Swamp showed a pH reading of 4.8 on 28/08/2019.

The Muir-Byenup system is relatively simple; showing a simple cause-effect after analysing the lack of change to annual rainfall since 1968.

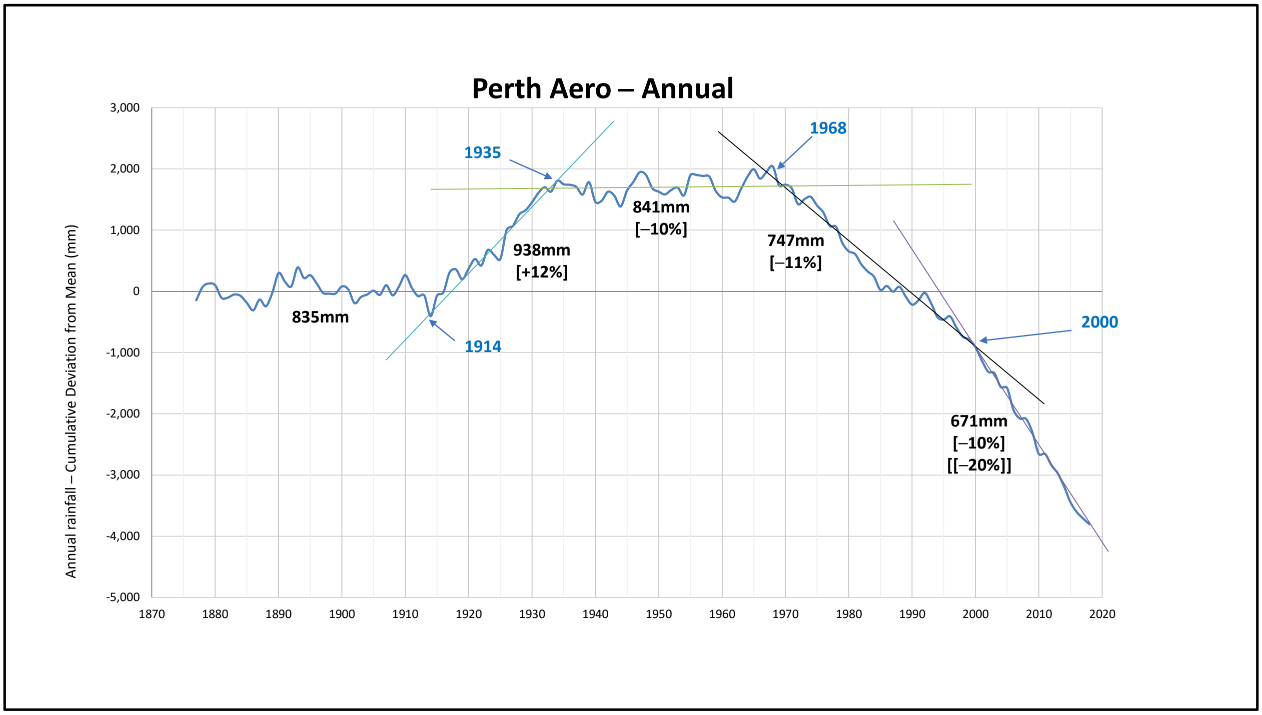
However, the area around Perth-Peel on the Swan Coastal Plain is far more complex.



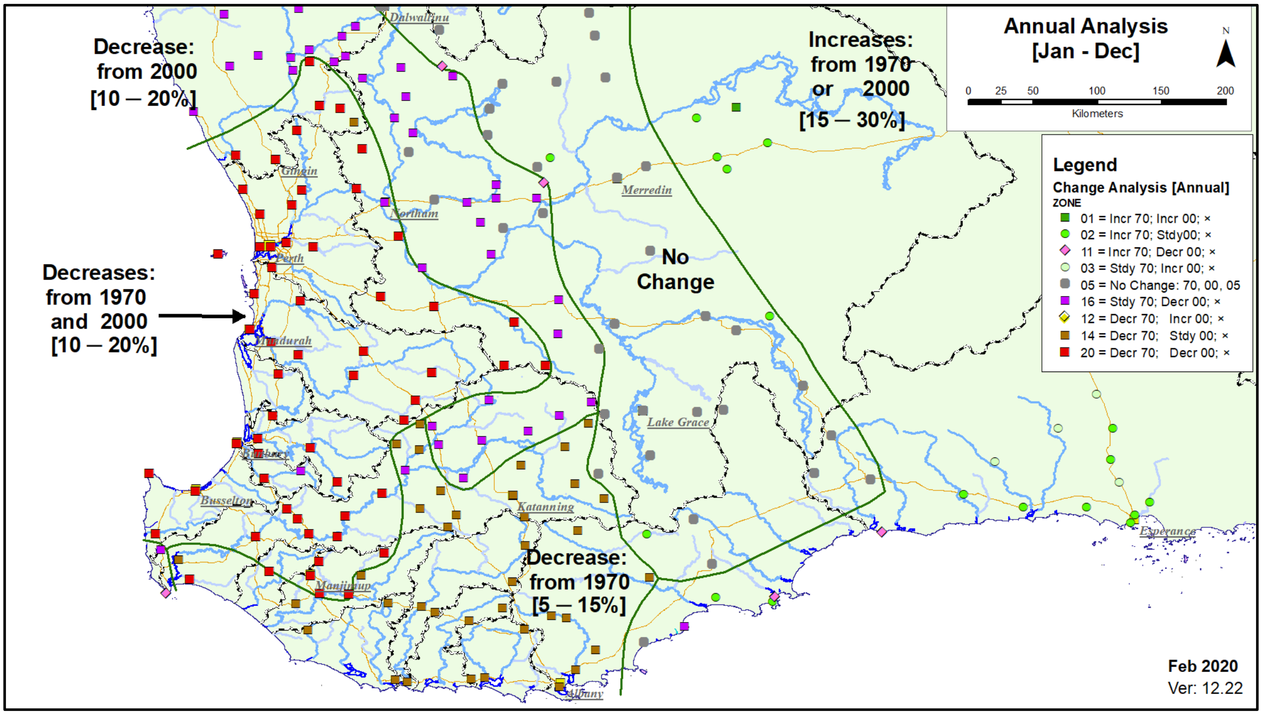
Unfortunately, key long-term raingauges in the Peel (Mandurah, Pinjarra and Waroona) have all had to move due to urbanisation. The site I have shown above closed in 2012, however, the correlation site started in 1983, so has a long period of comparison and matches statistically.

The steps seen here are consistent with Annual rainfall at other sites in the area (& much of SWWA). A big rainfall increase in 1914 followed by decreases in 1935, 1968 and 2000 with consistent average rainfall in the periods between (with some variability).

Note that the earlier steps are seen in most sites in SWWA, the year 2000 step is not seen at Lake Muir or the South Coast Regional sites.

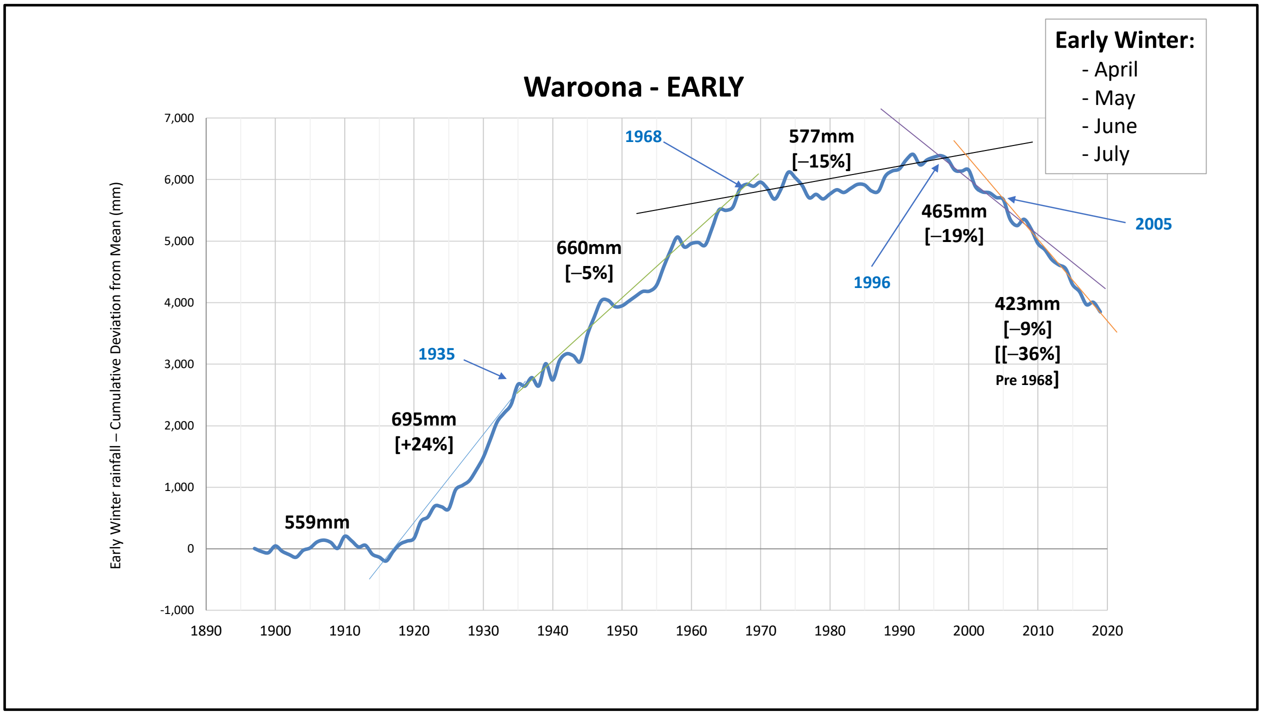


For comparison, the Perth Airport data is presented above. It shows similar steps to those seen at Waroona.

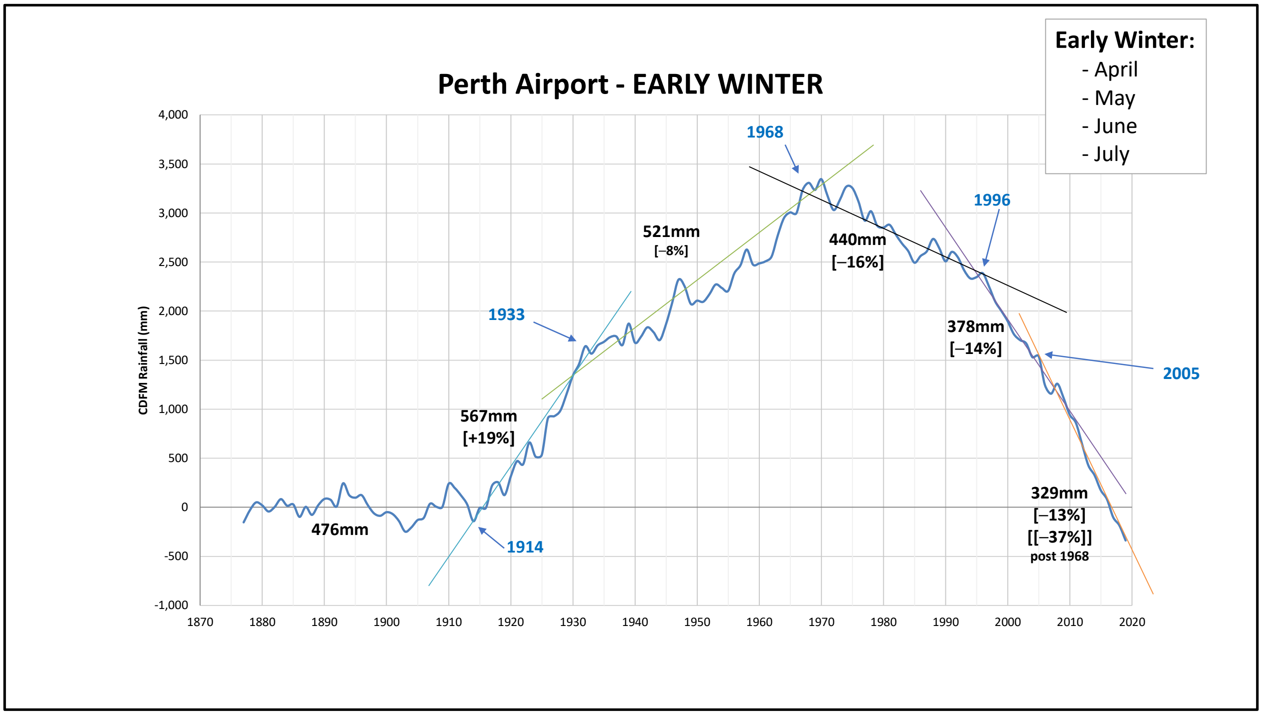


All rainfall datasets in the Perth-Peel area (including the whole Serpentine-Murray-Harvey catchments), all exhibit ‘double’ step-changes around the years of 1970 and 2000 similar to what is seen in the previous two slides. These changes equate to a reduction in rainfall of 10 – 20% compared to the period before 1970.

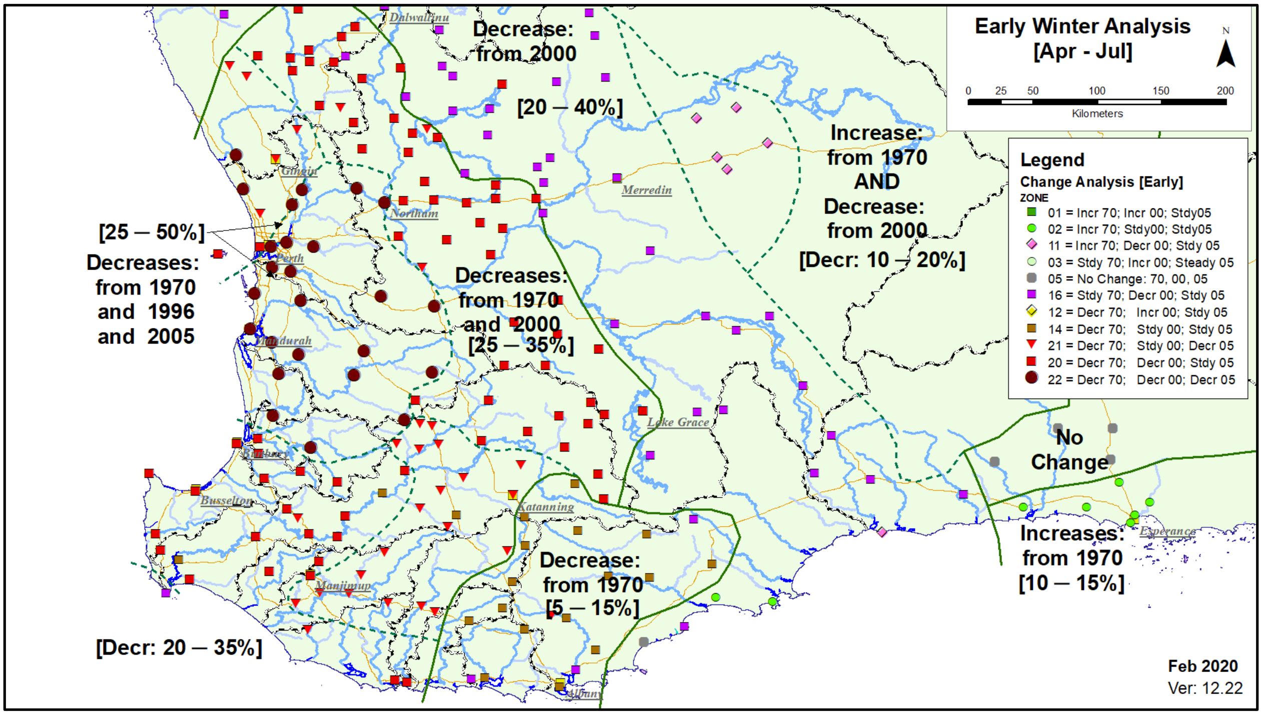
However, if the hydrological impact of what occurred around Lake Muir has a similar effect here, it is the Early Winter rainfall changes that are likely to be most indicative here too.



This is the Early Winter rainfall (Apr-Jul) plot for Waroona.
As expected, it shows the usual 1915 increase followed by decreases in 1935 and 1968. However, what can also be seen is reductions in 1996 and 2005. Note that the reductions total 36% from the average rainfall of 660mm before 1968.



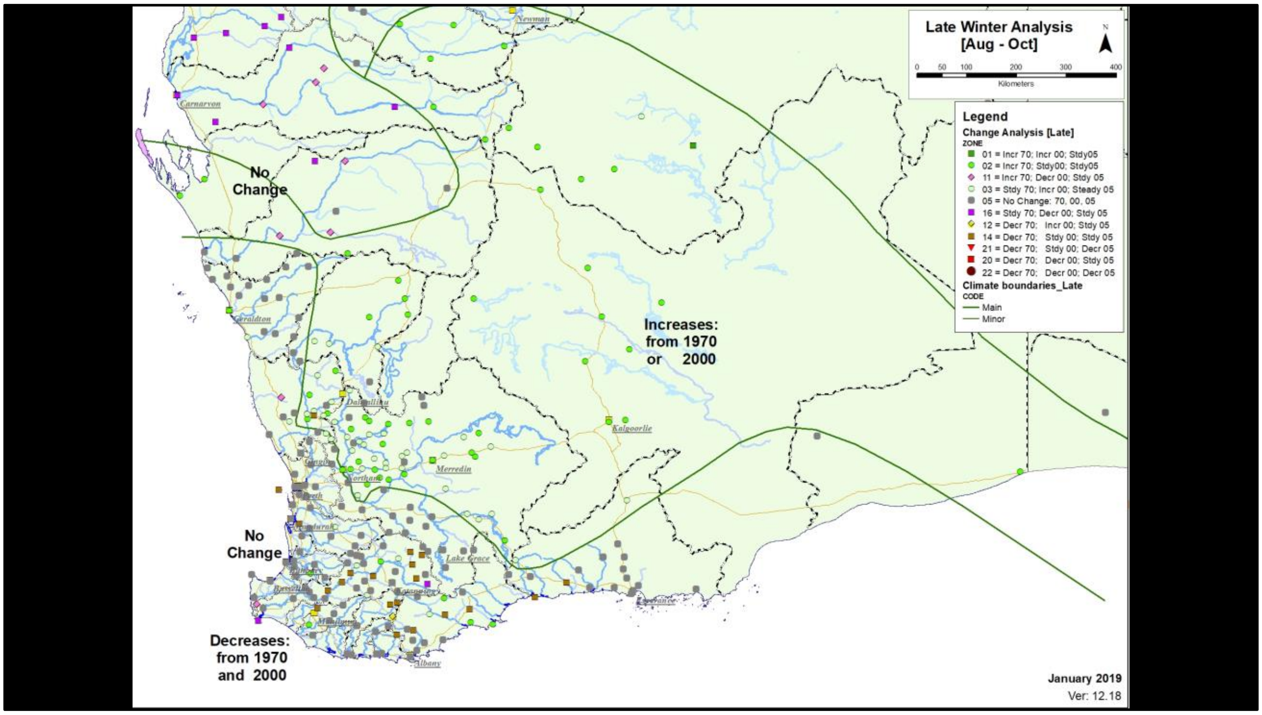
The Early Winter rainfall (Apr-Jul) plot for Perth Airport is shown in this slide. Again, it shows the usual 1914 increase followed by decreases in 1933 and 1968. And similar to Waroona, there are also reductions in 1996 and 2005 with the reductions totalling 37% from the early winter rainfall of 521mm post 1968.



And for the Early Winter series, the data shows consistent steps in 1968, 1996 AND 2005.

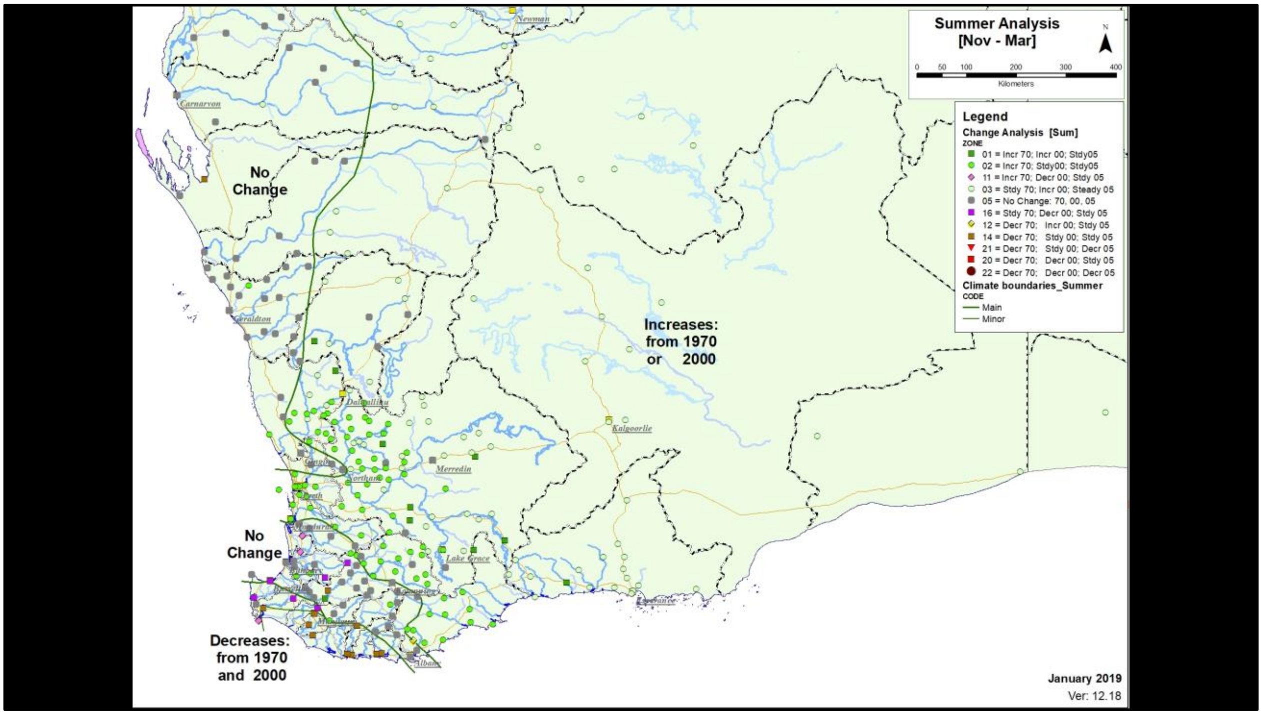
There are many influences in this SCP area that effect wetland and streamflow behaviour including abstraction and urbanisation; far too many to talk through now.

However, it is worth noting the work I presented on Lake McLarty at last years conference as to influences on lake water levels.
What is clear from that work is that there was a significant change in lake hydroperiod after 2005; yet no change in hydroperiod associated with the change in annual rainfall in 2000. So my take-home message today is that it is the influence in changes in Early Winter rainfall which are most significant and that the impacts of climate change are far more than changes in annual rainfall.



The **Late Winter** period was also very enlightening.

Much of the northern Wheatbelt, and Goldfields had increased rainfall. The West Pilbara had decreasing rainfall in 2000, while pretty well everywhere else in the state had no change at all, with only a few dataset anomalies occurring in the SWWA.

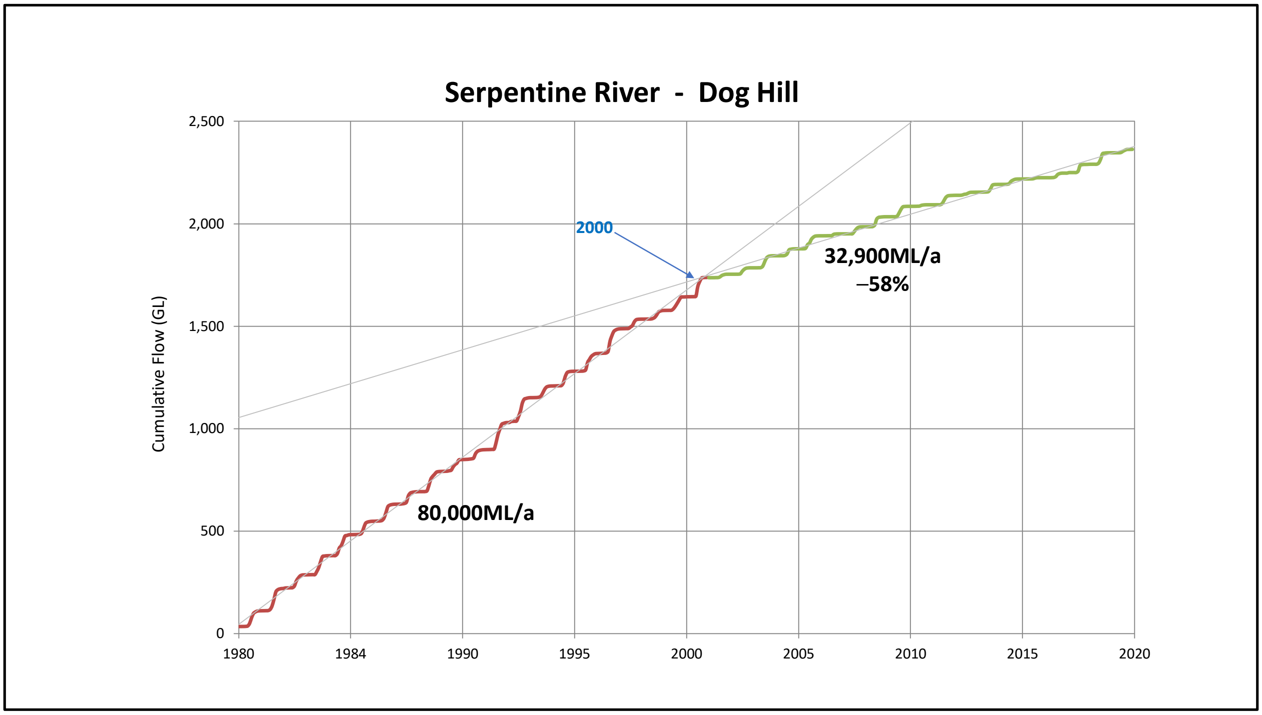


In **Summer** (November-March), the West Coast of WA mostly had no change, while the majority of the State had increasing rainfall.
Interestingly, a band south of a line from Busselton to Albany had decreasing rainfall.

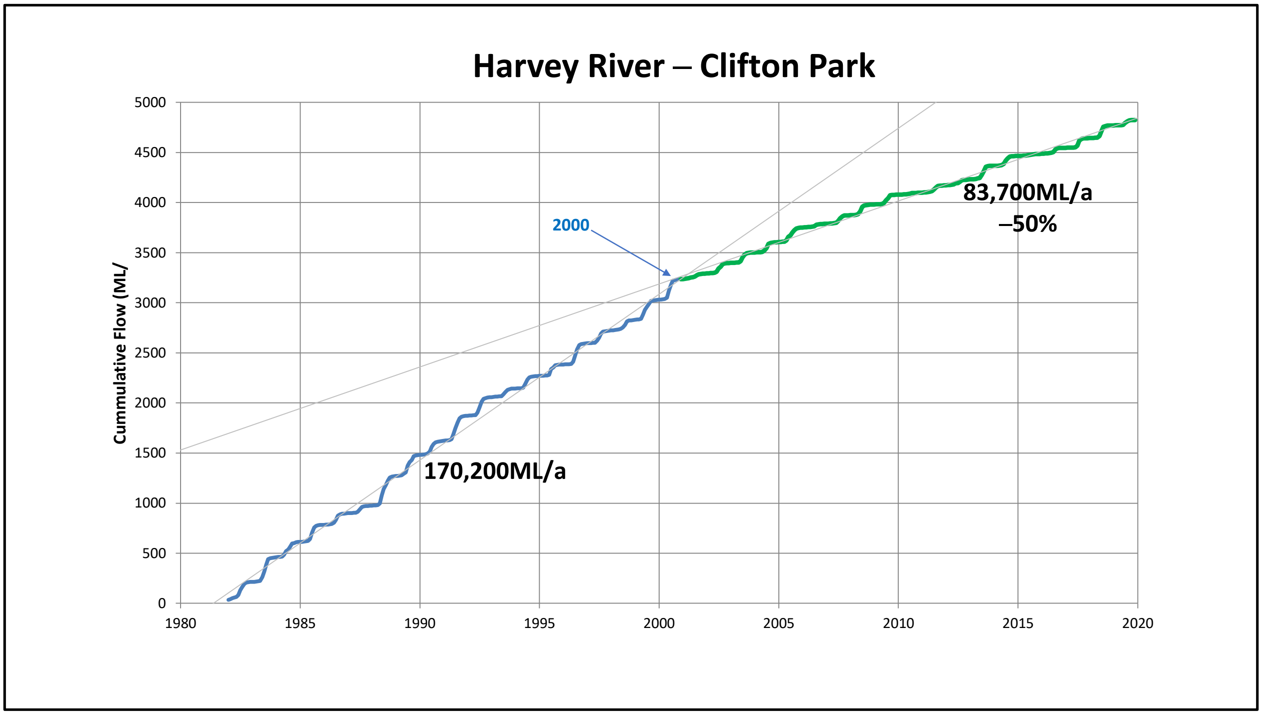
Now, moving to an area where many of us work…..

This area has very complex hydrology. The SCP has groundwater within 2m of the surface for 90% of the land area (and GW is at the surface during winter for 30% of the area). Yet in the hills, rainfall has reduced so much and groundwater levels have dropped so much that the behaviour of forested catchments has completely changed since the 1950’s and 60’s.

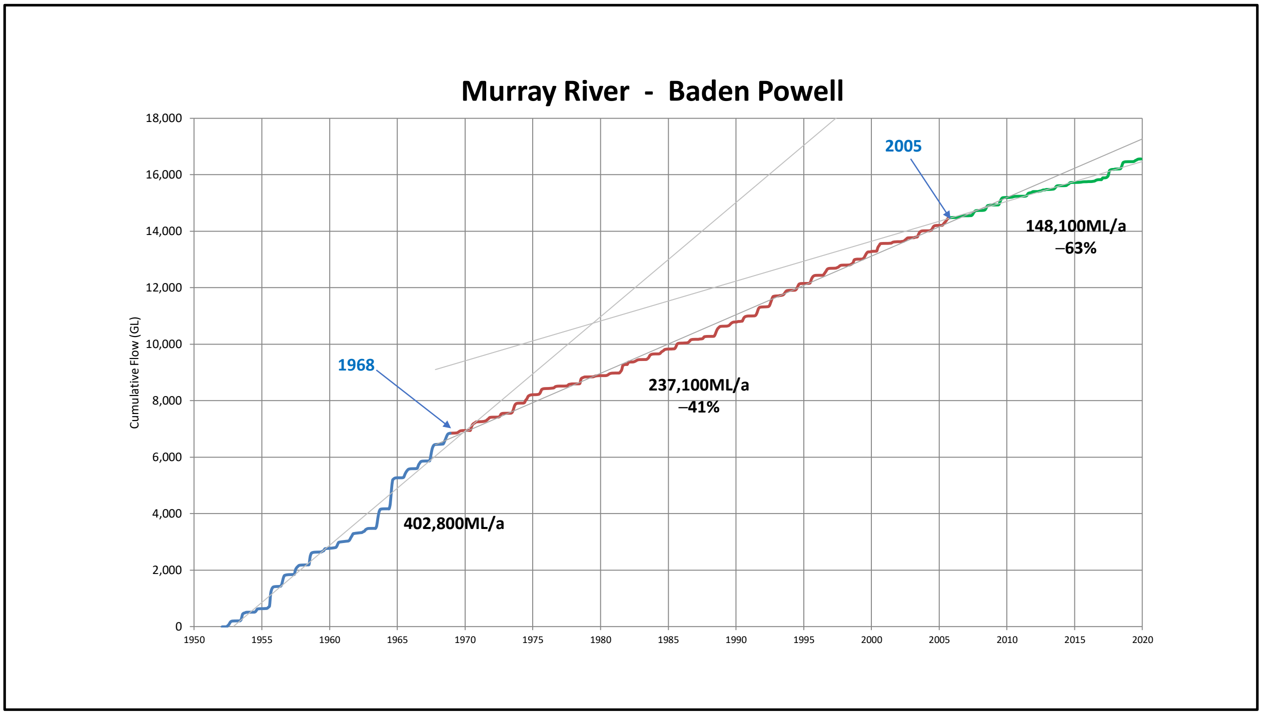
The three rivers are key to the inflow to the Peel-Harvey Estuary and together they account for 50% of the catchment inflow to it.



Firstly is Serpentine River which at Dog Hill is only a relatively small catchment and has little flow from Hills catchments. It had a significant reduction of flow after 2000.

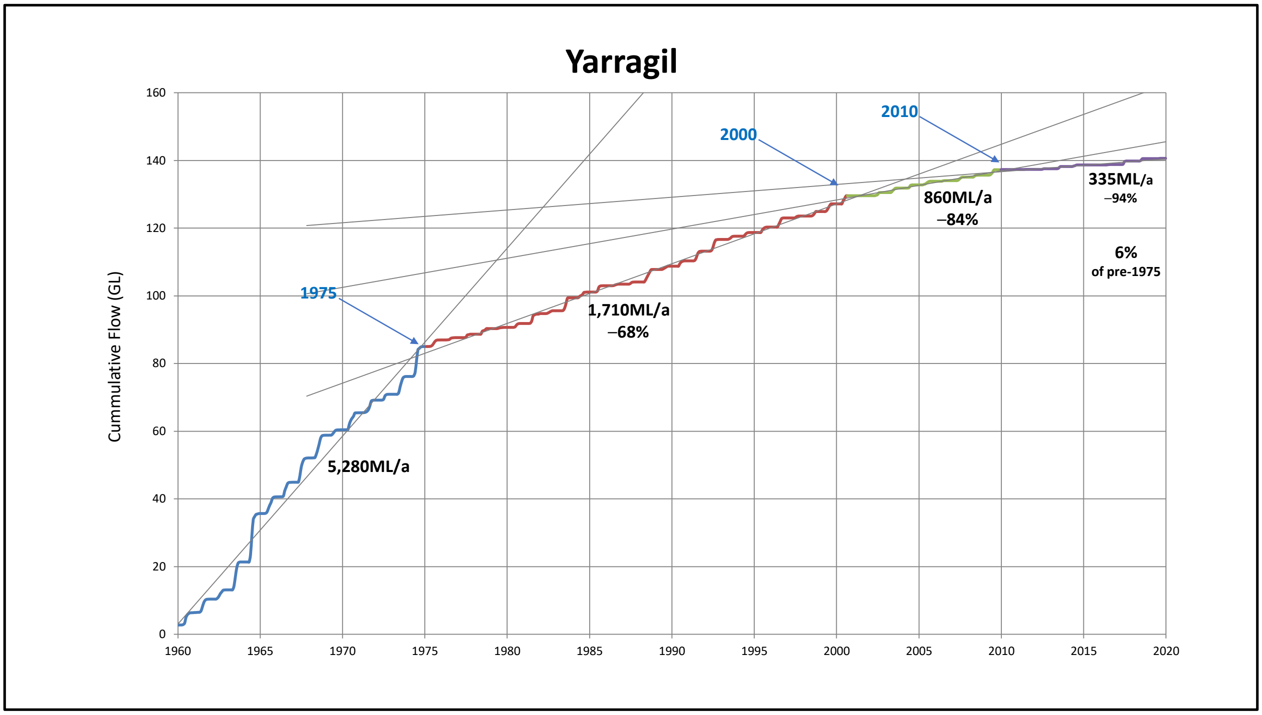


The second is the Harvey River, which mostly drains the SCP with only a few small tributaries sourced from the Darling Range. Again there was a similar reduction in flow post-2000.



The third river is significant and 90% of its catchment flow is recorded at the Baden Powell GS and 75% of the catchment is sourced from the Hotham and Williams Rivers in the wheatbelt.

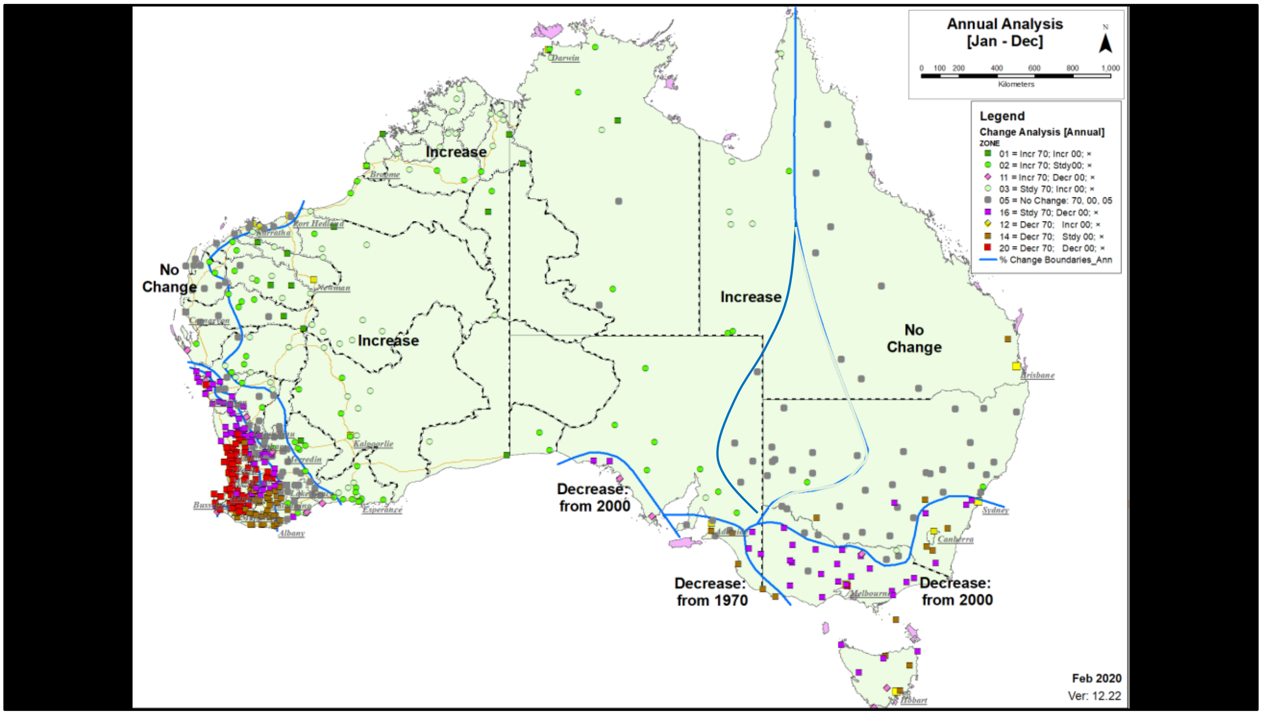
Note, that there has been a larger reduction in flows in just the Hills catchment areas (71% reduction post-2005).



A good example of the impact of reduced rainfall on flows in forested catchments is from the Yarragil catchment near Dwellingup. There is some correlation to changes in rainfall, however, it is also likely from other research that the influence of falling groundwater levels plays a big part in the flow reductions.

Recorded flow indrains on SCP has dropped about 50–60% from before 2000, however, at Yaragil the reduction of current flows to those recorded before 2000 is 80%. The reduction of flow since the 1960's is now 94%: so only 6% of the 1960's flows in this 72km² catchment reaches its outlet.

While we are very focused on what is happening in SWWA an Australian context is important.

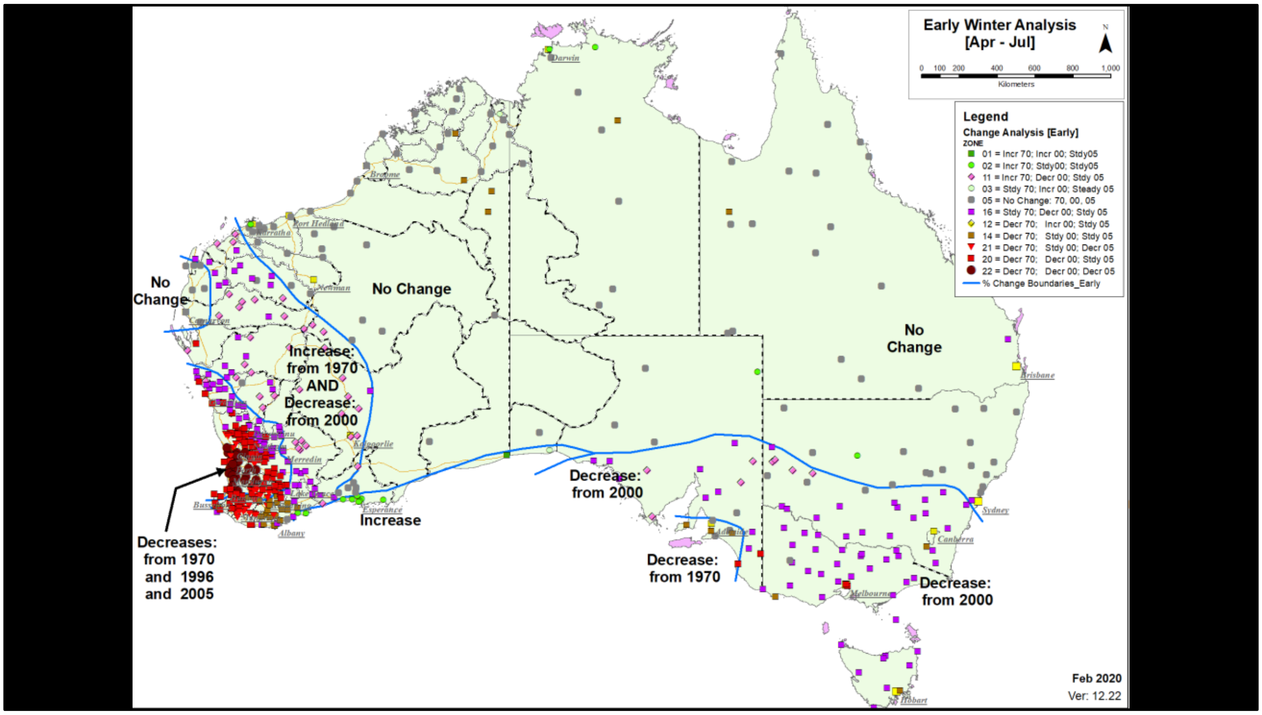


To put what is happening in SWWA in context, the same analysis is presented in this slide for the Annual Rainfall step changes across Australia.

Most of Australia has had increasing Annual rainfall, while the majority of NSW and Queensland has had no change of annual since before the 1970's. Only Victoria, SE NSW and Tasmania have had a single decreased in annual rainfall around year 2000. Coastal parts of South Australia have also had single decreases.

Yes, there is currently a very severe drought in many areas, but it is not a step-change in annual rainfall. Nor was the Millennium drought.

What is very apparent is the double-step in SWWA over such a large area of the most populous part of the state.



Changes in Early Winter rainfall are also quite apparent in SE Australia, but again mostly confined to a single decrease post-2000. In WA, the triple change around Perth has had a massive effect on both water supply and the ecology.


The
End