Hydrologic Reference Stations to Monitor Climate-Driven Streamflow Variability and Trends

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Abstract

The Australian network of Hydrologic Reference Stations (HRS) embraces 221 well-maintained river gauges with high quality, long periods of streamflow records managed by Commonwealth, State and Territory water agencies. The HRS attempts to monitor and assess the streamflow variability and trends in 221 catchments reflecting the diversity of Australian flow regimes. Detecting the streamflow changes in the HRS network focuses on unregulated catchments with minimal effects of water resource development and land use change, which enables observed trends to be distinguished from direct anthropogenic impacts. Trend analysis identifies inter-annual, seasonal, decadal variability, long-term linear trends and step change in streamflow. Trends are characterised for annual total flow, base flow, seasonal flows and four daily flow quantiles. The results suggest a varying pattern of spatial and temporal variation in streamflow across different hydroclimatic regions in Australia. Most of the stations in New South Wales and Victoria show a significant decreasing trend in annual streamflow, while increasing trends are observed in Northern Territory and the northern parts of Western Australia and Queensland, and no significant trend visible for stations in the central regions of Australia. The findings in trend analysis of annual total streamflow show evidence of hydrological response resonating with observed climate changes over past decades. Overall, the HRS stations serve as 'living gauges' for streamflow monitoring and climate change detection. A wealth of freely downloadable hydrologic data are provided in the HRS web portal including annual, seasonal, monthly, daily streamflow data, trend analysis products, and relevant site data.

1. INTRODUCTION

Many studies have been undertaken to investigate the trends in Australian climate data, particularly temperature, rainfall and other key climate variables. The Australia Bureau of Meteorology produces an extensive range of regular climate products from daily basis to annual reports. Figure 1 gives an example showing an updated summary of long-term rainfall trends. Higher temperature and changes in precipitation or other climate variables impact on the rainfall-runoff process directly, and indirectly causing changes in flora, relief and soil erosion. Changes in catchment characteristics, either naturally or under human influence such as farm dams, can also have an important influence on water flow. Moreover, hydrologic data generally have strong natural variability, subject to data availability and quality. All factors make it challenging to detect changes or trends in streamflow data. Even if a trend is identified, it is difficult to attribute changes to any specific cause, as global warming and other changes are contributing to the hydrologic process.

Numerous studies have analysed Australia streamflow data to detect hydrologic non-stationarity under changing climate. Chiew and McMahon (1993) examined trends in annual streamflow of 30 sites across Australia and no clear evidence of changes was suggested in streamflow resulting from climate change. Haddad et al. (2008) reported a decreasing trend in many Victorian stations of annual maximum floods particularly after 1990. Tran and Ng (2009) also showed a consistently decreasing trend among 9 streamflow statistics of 14 stations in a Victorian region, but indicated the result was not able to relate the effect of global climate change with the decreases in streamflow. Durrant and Byleveld (2009) analysed post-1975 flow record at 29 sites across south-west Western Australia; they indicated the majority of sites show a consistent regional reduction in streamflow. Silberstein et al. (2012) further computed simulations of runoff from 13 major river basins in south-western Australia. They found that the reduction in runoff for the study region is likely to continue under projected future climates. Pui et al. (2011) detected changes in annual maximum flood data of 128 stations in NSW according to multiple climate drivers. Ishak et al. (2010, 2013) presented trend analysis in annual maxima flood series data from 491 stations in Australia, and suggested much of the observed trend may be associated with the climate modes on annual or decadal timescales.

Many of the above investigations were focused on certain regions in Australia, or limited to some particular aspects of flow data such as flood risk. While hydrologists are trying to get a comprehensive image about recent changes in river flows over the continent, there was a gap in data providing services of quality continuous hydrologic time series data covering the main river gauges in Australia. The Australian network of Hydrologic Reference Stations (HRS) was developed by the Bureau of Meteorology to fulfil the requirement of providing a range of water data. The HRS embraces 221 well-maintained river gauges with high quality, long periods of streamflow records managed by Commonwealth, State and Territory water agencies. The HRS will facilitate monitoring and assessment of the streamflow variability and trends in a large number of catchments reflecting the diversity of Australian flow regimes. Detecting the streamflow changes in the HRS network focuses on unregulated catchments with minimal effects of water resource development and land use change. It attempts to address the issue of streamflow variability or trend that is most likely driven by climate changes and with minimum impacts from direct anthropogenic influences. This paper presents the methods involved in the development of HRS, including station selection criteria, database description, trend detection techniques, and data visualisation on the web portal. It ends with summary results of trend analysis and key product examples on HRS web portal.

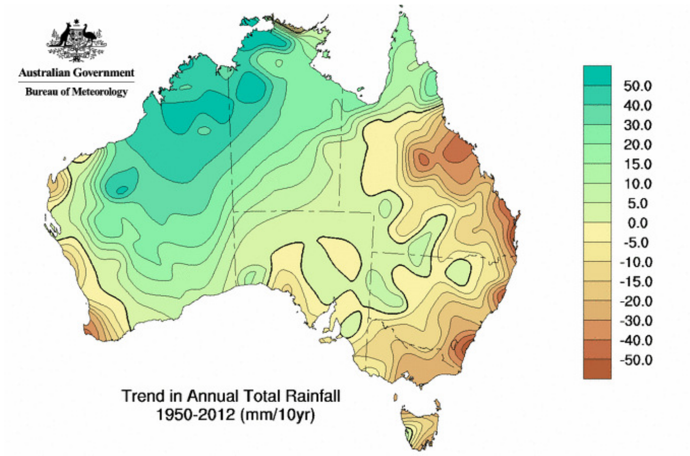

Figure 1 Trend in annual total rainfall in Australia 1950-2012. Source: www.bom.gov.au/climate/change/

2. METHODS AND DATA

2.1. The Hydrologic Reference Stations (HRS)

When attempting to select stations suitable for identification of streamflow variability and trends, a selection guideline (SKM, 2010) was followed mainly with four criteria: 1) Record length – a station must have a long period of record with more than 30 years starting from 1950 or later, and will have continuous data in the future; 2) Data quality – minimum gap-filled data were assessed based on knowledge of quality of primary data to ensure that high quality streamflow data were included in network; 3) Intervention of human activities in basin – only stations were selected with no dams, weirs or irrigation infrastructure in the upstream area, and with minimal land use change; 4) Spatial representativeness – stations were included in the network that spatially covers different hydro-climate regions to represent the diversity of Australian flow regimes.

221 stations were selected from a preliminary list of potential streamflow stations across Australia according to the selection guideline (Turner et al., 2012). The study to detect streamflow variability and trends was performed on the collected data from the HRS network of unregulated rivers in Australia. Figure 2 shows the location of each hydrologic station in the HRS and illustrates the climatic zones. The geographical distribution of the 221 HRS stations in the map reveals that the HRS network has covered all the climatic zones and Australian jurisdictions. Limited to the data availability, most of the selected stations were located along coast, while only a few were in the central regions.

All stations have a minimum 30 years of streamflow record length with good data quality and minor anthropogenic influences that allow detection of climate change impacts. The average record length is 45 years and all data used for trend analysis start from 1950 or later. Catchment areas range from 4.5

to 232,846 km^2 with a mean size of 3,108 km^2. Table 1 summarizes the data statistics of HRS stations in each Australian jurisdiction or region. One or two climate zones are found in each region, except Queensland where multiple types of climate classifications in Australia are presented.

Table 1. Data characteristics of the 221 HRS stations in different regions

Regions	Number of HRS stations	Main climate zones	Average Catchment area (km^2)	Average data length (years)	Average gap filling (%)
NSW	35	Temperate	1828	53	2.39
VIC	72	Temperate	431	43	1.38
QLD	60	Equatorial, Tropical, Subtropical, Grassland, Temperate	1661	44	4.82
SA	10	Temperate, Desert	35471	38	2.03
WA south	13	Temperate	356	44	4.78
WA north	3	Tropical	815	39	2.21
TAS	12	Temperate	332	49	2.57
NT	16	Tropical, Desert, Grassland	7899	42	4.56

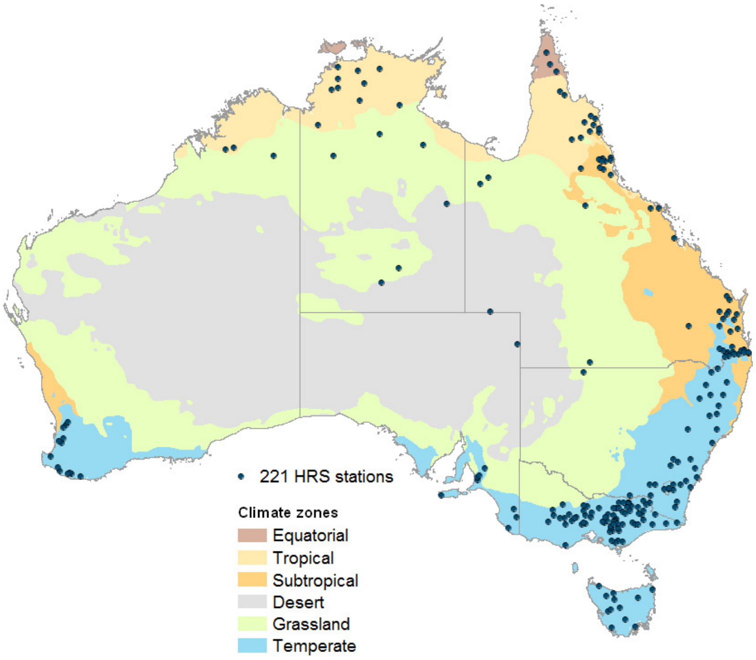

Figure 2 Location of the 221 high quality streamflow reference stations in the HRS network.

2.2. Trend detection methods

Climate change can have an impact on water flow in numerous ways: patterns can be seen by visual assessment on observations, gradual or abrupt changes, or in a more complex form that may affect various aspects of data. A good way to improve the understanding of changes in streamflow is to gather as much information as possible, including basic catchment features, hydraulic station status, local climate and streamflow records over a long-term period. In the effort to monitor streamflow variability and detect climate-driven trends, the HRS network has included the most up-to-date river flow data and relevant catchment or station information. Daily streamflow records were aggregated as monthly, seasonal and annual time series for further analysis.

There are multiple ways on the HRS web site to depict the streamflow changes: observed streamflow records, anomaly analysis with moving average windows, flow duration curves, flow events analysis, and trend tests. The combined analysis identifies the inter-annual, seasonal, decadal variability, long-term trends and step changes in streamflow. Trends are characterized for annual total flow Q_T, base flow Q_{BF}, four seasonal flows and four daily flow quantiles, namely the daily maximum flow in annual time series Q_{Max}, the 90th percentile daily flow Q_{90}, the 50th percentile daily flow Q_{50}, and the 10th percentile daily flow Q_{10}. Base flow component was separated from daily total streamflow using a recursive digital filter given by Nathan and McMahon (1990).

The rank-based non-parametric Mann-Kendall test (Helsel & Hirsch, 2002) was used to assess the significance of monotonic trend in the selected flow variables. The magnitude of trend was calculated from ordinary least squares regression. The Rank-Sum test (Chiew & Siriwardena, 2005) was used to identify the presence of a step change in median of two periods, with the distribution free CUSUM method (Chiew & Siriwardena, 2005) providing the year of change. Values are reported for sites with Mann-Kendall or Rank-Sum test at higher than 0.1 significant levels for statistically significant monotonic trend or step change.

2.3. The HRS web service

A HRS toolkit was developed for data aggregation of daily flow time series, statistical analysis of streamflow data, and graphical products generation. The toolkit was run for all 221 stations and generated graphical products and related tables of statistical tests results. After the quality control of the graphical products and cross checking of trend analysis results, the HRS toolkit and all the graphical products were incorporated into a web portal. The fully-functional web portal was released on Bureau's public website as an operational service to provide comprehensive streamflow information from the 221 HRS stations. The information on the HRS website will be updated and reviewed every two years. The HRS stations will be considered as priority sites for ongoing data collection on long term water availability across Australian water supply catchments.

3. RESULTS

3.1. Spatial distribution of trends

Maps were created showing the results of Mann-Kendall test for each variable. Figure 3 illustrates spatial distribution of the trend detection results for annual total streamflow. Presented is the location of HRS stations identified with trends that are significant at the 0.1 significance level and other stations with no significant trend at the 0.1 significance level. The stations with significant trends are divided into two groups by the direction of trend as increasing trends and decreasing trends.

Among the 221 stations, the number of stations showing increasing and decreasing trends are 9 (4%) and 78 (35%) respectively. A definite spatial pattern can be seen from the map (Figure 3). Stations displaying a decreasing trend are found mostly in the south-eastern Australia, including Victoria, New South Wales, South Australia, Tasmania and southeast part of Queensland. Similar patterns appear in the southwest of Western Australia. In contrast, increasing trends are noted in the northern regions of the continent, mainly in the northern part of Northern Territory.

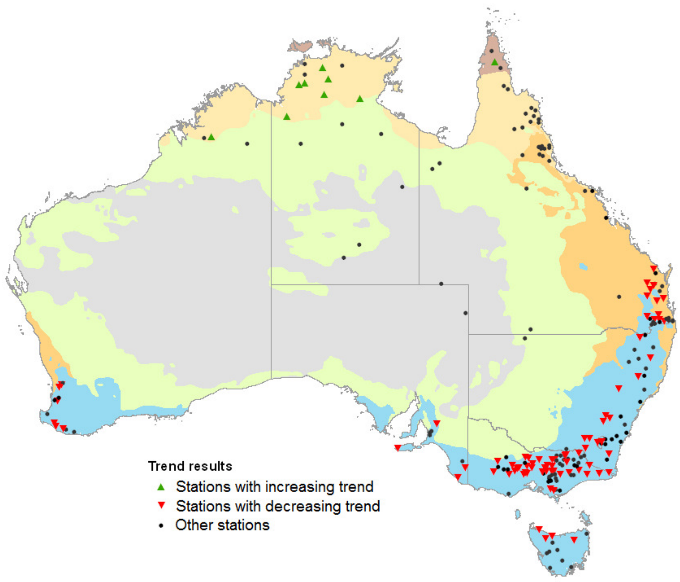

Figure 3 Results of Mann-Kendall trend analysis of annual total streamflow.

The identified trend patterns in annual total streamflow are spatially consistent with trends in annual total rainfall as shown in Figure 1, where most of eastern and south-western Australia has experienced substantial rainfall declines since 1950; while north-western Australia has become wetter over this period. This similarity implies that hydrological variability is closely related with changes in rainfall patterns.

3.2. Results of other streamflow variables

Figure 4 summarizes the results of the trend test on the selected 10 streamflow variables. It describes the percentage of stations with an increasing or decreasing trend in each region. The total number of stations showing significant trends varies among different flow variables, with predominant decreasing trends. For the two annual flow variables Q_T and Q_{BF}, the same proportion of gauges (4%) show increasing trends. Q_T is noted to have stronger results towards decreasing trends than Q_{BF} in both terms of percentage of stations and trend significance. A consistent increase in percentage of stations is present in positive and negative trends in flow variables Q_{10}, Q_{50} and Q_{90}. Among the four seasonal flows, the largest number of stations showing increasing or decreasing trends is found for summer flow Q_{sum} and winter flow Q_{win} respectively. Winter is noted as the only season where no stations show an increasing trend (Figure 4).

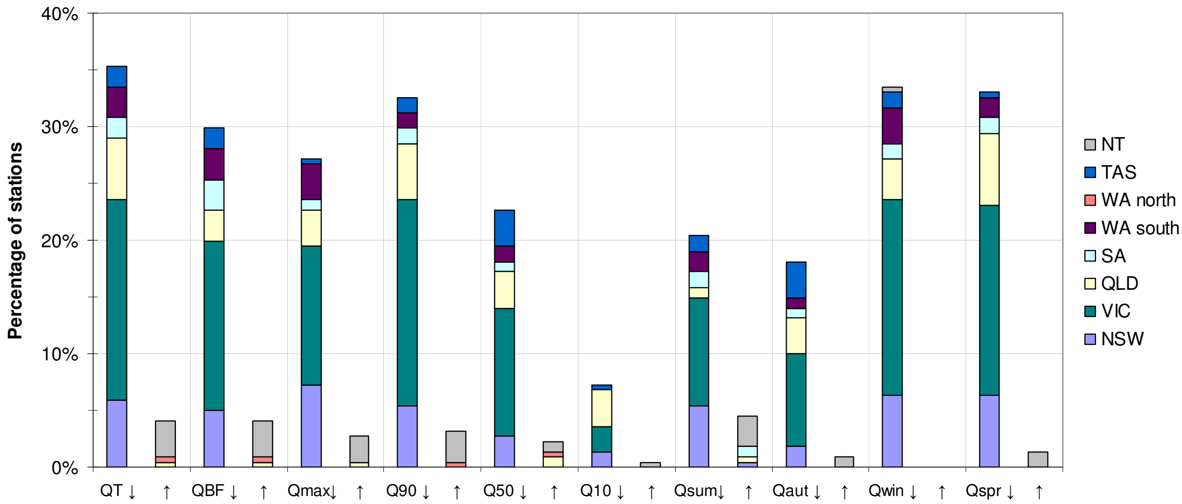

Figure 4 Percentage of stations showing significant decreasing and increasing trends in all selected flow variables in different regions.

Across all the eight regions investigated in this study, most of the regions located in southern part of the country display a consistently decreasing trend in the 10 streamflow variables. These regions include Victoria, New South Wales, South Australia, Tasmania, and southern Western Australia. Exceptions are found in summer flow: three stations near the central region of Australia, two in SA and one in NSW, which show increasing trends, though the identified trends are rather weak. Combined patterns of decreasing and increasing trends are detected in Queensland, which has the most diverse climatic conditions. Northern Territory and north of Western Australia are the regions where increasing trends are found in most of the streamflow variables.

3.3. Key product examples on HRS web portal

The HRS web portal was developed and implemented as one of Bureau's standard operational services to provide water data and analysis products of Hydrologic Reference Stations. The web portal has two main components. One is project information that contains details on the station selection process, feature stations, stakeholder consultation, analytical methodology, and FAQ. The other is product pages for data access and analysis results. The product pages consist of three parts – snapshot, data explorer and trend explorer – where all the data and graphical products are nested under. A reference station locator and selection tool based on geographic filters (jurisdiction basin and station name) is located on every product page. To illustrate the architecture from a user's prospective, the three product pages and key product examples are now described.

Snapshot (Figure 5) is the entry page of a selected gauge station on the HRS web portal. The chart type presented on the graphic panel of snapshot page is annual time series of streamflow anomalies over the period of record. It gives a direct visual impression of changes in streamflow variations compared to the annual mean value. The users are able to download data related to the graphs and daily observed streamflow data. All original data, results of analysis and graphical products are gathered in a data download page to facilitate downloading multiple products at one location.

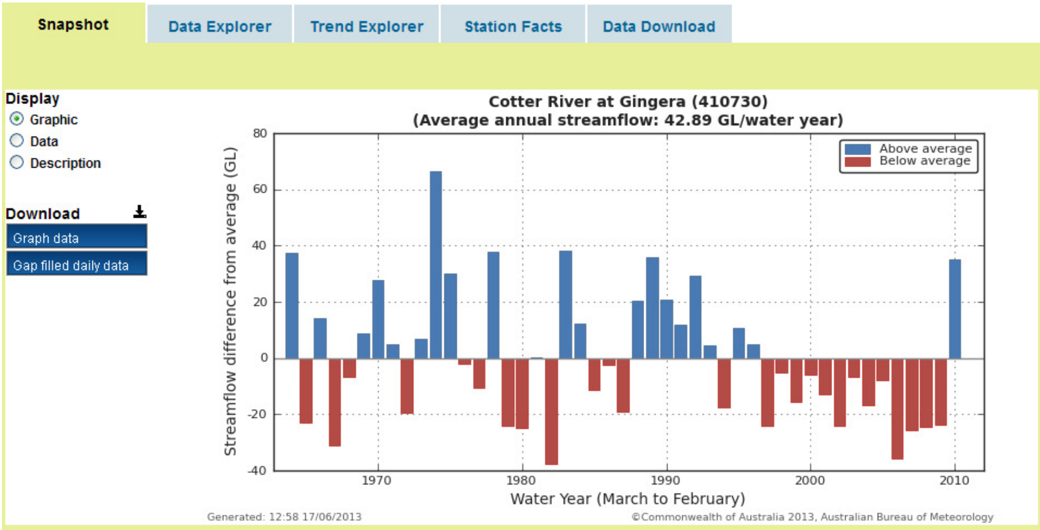

Figure 5 Snapshot example graph – anomalies of annual total flow in Cotter River at Gingera.

Data explorer (Figure 6) expands data analysis to annual, seasonal, monthly and daily streamflow statistics under four tabs respectively. The anomaly and total annual streamflow are clustered in the 'Annual' tab as chart options, where the user will be able to select and update the displaying graph. 'Seasonal' and 'Monthly' tabs have a similar function to present graphs for four seasons and twelve months. Moving average analysis with 3, 5 11 years are provided for annual variables. 'Daily' tab includes daily time series plots, a grid plot describing the quality of the daily streamflow data, and flow duration curve. As shown in Figure 6, the flow duration curve can reveal decadal variations of daily streamflow magnitude.

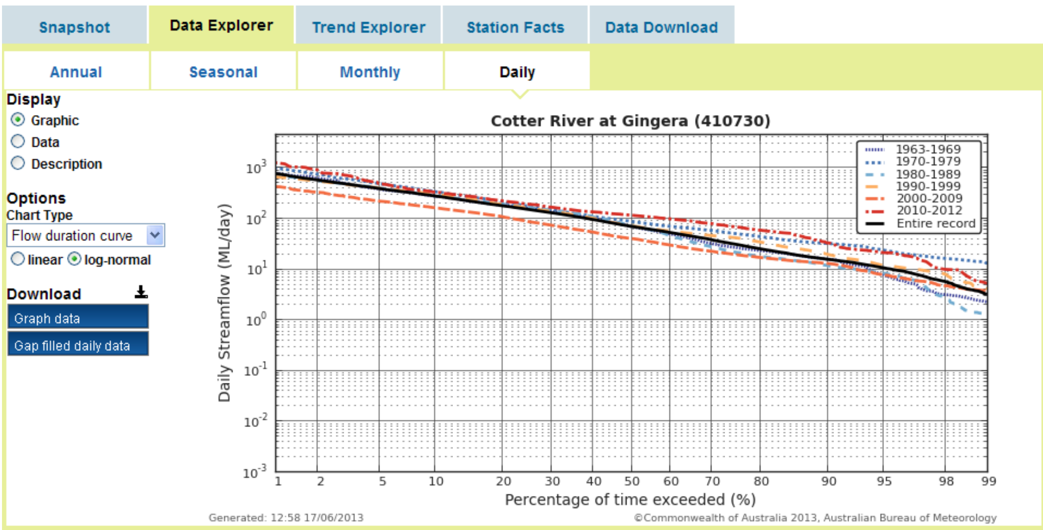

Figure 6 Data Explorer example graph – daily flow duration curve for different decades in Cotter River at Gingera.

Trend explorer (Figure 7) expands the streamflow variables and provides user the facilities to conduct analysis of long-term trends in streamflow at the Hydrologic Reference Stations. Users can apply statistical test to identify long term streamflow trend (Mann-Kendall trend test) and step changes

(Distribution Free CUSUM and Rank-Sum tests) in the streamflow series. An example is shown in Figure 7, with a significant trend and a step change identified in the spring flow of the Cotter River at Gingera. The linear regression trend line and the identified step change equation are plotted on the time-series, with key statistic values presented. Other than the trend analysis results of ten streamflow variables that were grouped into corresponding tabs, the variability in seasonal and monthly flows was investigated with boxplots showing changes in flow distribution among seasons or months. All three product pages - snapshot, data explorer and trend explorer – were built upon each other to facilitate users searching the web portal dependent on their needs and particularly the level of information that they require.

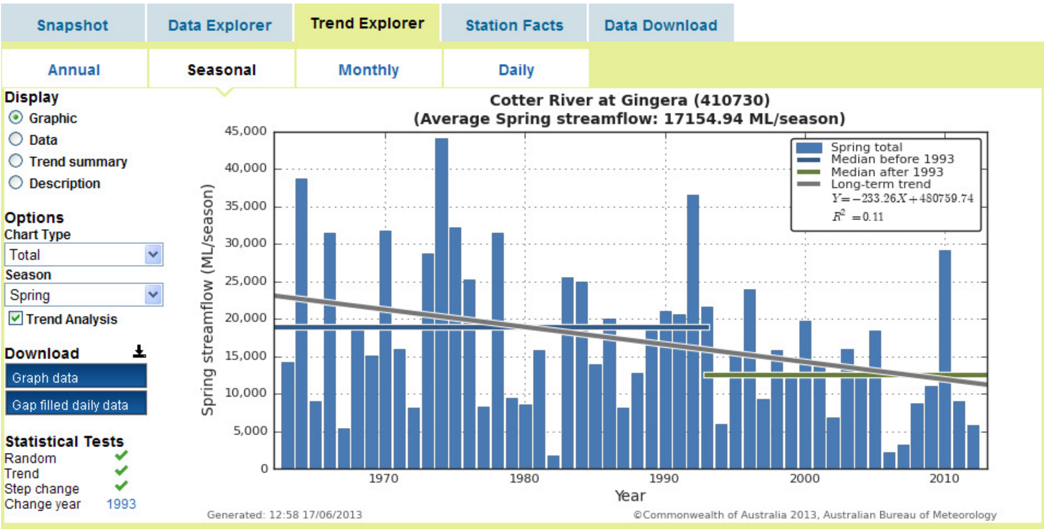

Figure 7 Trend Explorer example graph – trend test of spring flow in Cotter River at Gingera.

3.4. Future steps

The reference stations included in the network will be reviewed and updated every two years, along with updated analyses of streamflow data. Some stations have been used for seasonal and short term streamflow forecasting. The Bureau will make a nationwide comprehensive statement about the probable impact of climate change on future water availability of the HRS stations using the latest IPCC AR5 climate change projection data set.

4. CONCLUSIONS

To monitor long term streamflow variability and to identify climate change signature in river flow data is an important scientific issue. It is also fundamental for water planning and adaption of future water management. The Hydrologic Reference Stations provides comprehensive streamflow information from 221 stations to identify trends and detect long-term variability and change in Australian streamflow. This study gives an overview on how streamflow patterns have been changed with regards to global climate change. Trend tests for ten streamflow variables and other data analysis were applied to all HRS stations to identify inter-annual, seasonal, decadal variability, long-term linear trends and step change in streamflow. The results suggest a varying pattern of spatial and temporal variation in streamflow across different hydroclimatic regions. In general, most of the stations showing decreasing trends were found in the south-east and south-west regions, while stations with increasing trends were in the northern part of Australia. The trend patterns in annual total flow are consistent with those identified for precipitation. Overall, the HRS stations serve as 'living gauges' for streamflow monitoring and climate change detection. It provides useful information for both scientific research and water resources management. A wealth of freely downloadable hydrologic data are available in the HRS web portal including annual, seasonal, monthly, daily streamflow data, trend analysis products, and relevant site data. Future work will address the issue of long term streamflow projection of climate variability and change.

5. ACKNOWLEDGMENTS

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