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Hydrologic Reference Station Selection Guidelines

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1 Hydrologic Reference Station selection guidelines

The aim of the hydro-climatic and seasonal prediction services of the Extended Hydrological Prediction (EHP) section is to enhance the knowledge of water availability and aid the development of sustainable water resource management decisions. A part of that service is to improve the prediction of the impact of climate variability and change on water availability across Australia. Prediction services require streamflow gauging stations in catchments with minimal water resource development and land use disturbances, which are sensitive to hydrologic changes resulting from climate variability and change. Networks of hydrologic reference stations have been developed in the United Kingdom (National River Flow Network – NRFN), Europe (Environmental Water Archive – EWA), the United States of America (Hydro-Climatic Data Network – HCDN)) and Canada (Hydrological Basin Network – HBN). Previously, such a network had not been developed in Australia.

This document outlines the development and application of selection guidelines to identify streamflow stations that form a network of hydrologic reference stations across Australia. The Australian Network of Hydrologic Reference Stations (HRS) will provide a foundation for expanding future long-term and seasonal prediction services. It will also provide government, research and management sectors of the water industry with a set of living gauges from which to investigate the impact of climate change and variability on long term streamflow availability.

In 2010, the Bureau of Meteorology engaged Sinclair Knights Merz (SKM) to develop guidelines to select hydrologic reference stations (SKM, 2010a) based on 18 criteria (Table 1). In 2011, we applied the guidelines to all river networks in Australia. The order and approach of applying the guidelines was redefined to suit the simultaneous investigation of multiple streamflow stations in multiple catchments. The full adaptation of the guidelines in summarised in Section 6. This document outlines the application and development of the guidelines into four key phases:

1. Development of a preliminary list of hydrologic stations in unregulated catchments with a long term streamflow series.
2. Stakeholder consultation and the prioritisation of catchment impacts and hydrological quality of each streamflow station.
3. Land use change analysis and data reporting.
4. Identifying the hydro-climate region of each hydrologic reference stations.

The limitations or additional criteria added to the original SKM (2010a) guidelines within the process of applying the guidelines will be discussed.

Table 1. Reference station selection guidelines (SKM 2010a)

Criteria		Discussed in Section
1	Identify all streamflow gauges within a river basin from the Bureau's water resources station catalogue (http://www.bom.gov.au/hydro/wrsc/). Extract information on the station number, river name, station name, latitude, longitude and catchment area. Where the catalogue identifies sites with duplicate numbers but a different suffix, separately list each site and suffix, because this may indicate a change in location of the site or a significant gap in the period of record at the site.	2
2	Check this list of gauges against state agency lists to ensure that all available streamflow gauges are covered. Fill in any gaps about the period of record and catchment area of streamflow gauges where they are readily available from state agency lists.	2
3	Exclude any sites clearly identifiable as drains, channels, outfalls, lakes or other non-river sites.	2
4	Exclude any sites clearly identifiable as affected by tidal movement.	3
5	Identify the approximate period of record at each streamflow gauge from the Bureau's water resources station catalogue and state agency lists after excluding sites in previous steps above.	2
6	Identify the most downstream flow regulating structure upstream of the gauge. Determine the area upstream of the structure and calculate the proportion of the gauged catchment that is regulated. If the area upstream of the structure is more than 10% of the gauged catchment area, then the site is considered regulated over the period for which the structure was in place. For each site considered to be regulated, determine whether there is any data available prior to the construction of the structure or after its decommissioning by comparing these dates with the period of record from Step 5. Exclude any sites where all data at the site is considered to be regulated.	2
7	Estimate the mean annual flow at each streamflow gauge	3
8	Estimate the volume of any point source discharges upstream of the streamflow gauges. A site is not considered suitable if the average annual volume of point source discharges upstream of the gauge is more than 10% of the mean annual flow. If annual volumes of discharge are low but there is considered to be a significant shift in seasonality or low flow characteristics of streamflows due to the discharges, then the site may be excluded.	3
9	Estimate the volume of diversion licences upstream of streamflow gauges. A site is not considered suitable if the average annual volume of licensed diversions upstream of the gauge is greater than 10% of the mean annual flow. Groundwater licences should be included in the total licensed diversions in areas where groundwater volumes are high and are considered to potentially deplete stream baseflows.	3
10	Combine the data records of any duplicated streamflow gauges corresponding to a single site and note any changes in location for a given streamflow gauge which could create a discontinuity in the data.	4
11	Determine the proportion of missing data over the period of record. Only retain sites which have at least one continuous period of 15 years with not more than 5% of days with missing data.	4
12	Determine the proportion of data above the highest gauged streamflow or below the lowest gauged streamflow. The highest	4

Criteria		Discussed in Section
	and lowest gauged values can be obtained from rating tables and may vary over different parts of the flow record if rating table versions change over time. Only retain sites which have not more than 20% of data outside of the range of gauged data.	
13	As an alternative to the previous step, calculate the uncertainty associated with all streamflow data collected at a site using Australian Standard ASA 3778.2.3. Only retain sites which have not more than $\pm$10% average uncertainty in flow data over the period of record.	4
14	Collect and report on land use change data for each selected site. This includes the percentage of urban area over time, the percentage of forest cover over time, the volume of small catchment dams over time, the area of forest plantations over time, a list of historical bushfire events and a history of coops logged in the catchment. Coops are the named areas logged at any given time.	5
15	Check the spatial and temporal representativeness of high quality streamflow sites and consider relaxing the constraints if needed to be able to identify a site with slightly lesser quality but with the potential to become a high quality site in the future. Assign a climate region and classify sites according to whether they have at least 15 years of data with not more than 5% missing in each climate phase. Check the list against those used in previous studies.	2, 5
16	Plot a daily flow-duration curve for each site and visually inspect a plot of the daily time series data to ensure that there are no data anomalies or unusual flow patterns which are potential indicators of poor quality data. Also prepare double mass curves of streamflow relative to other candidate high quality streamflow sites in the same region. This step should be undertaken by an experienced hydrologist.	4
17	Present the list of selected high quality sites to a State agency representative to ensure that there are no other factors influencing the streamflow data at these sites which could cause them to be considered not high quality	3
18	Document other supporting information, such as preparing a catchment map, identifying any high quality rainfall sites located within the catchment and presenting the elevation of the gauge.	5

2 Phase 1: Preliminary list of hydrologic reference stations

Phase 1 identified 246 potential hydrologic reference stations. The criteria from SKM (2010a) that were used to identify hydrologic reference stations in unregulated catchments with a long term streamflow series are outlined in Table 2. Datasets were collated that enabled the concurrent investigation (in ArcGIS) of five key areas:

Location of streamflow stations with a catchment - The water resources station catalogue (WRSC) provided the foundation for the preliminary selection of streamflow stations. Supplementary data sources also included: Pineena (NSW Office of Water Surface water information catalogue), Northern Territory Natural Resources, Environment, the Arts and Sport (NRETAS) surface water monitoring network, the Victorian data warehouse (Department of Sustainability and Environment database), the Queensland Department of Environment and Resource Management (DERM QLD) water monitoring data portal and the South Australia Water Connect portal (Government of South Australia, Department for Water, Surface water monitoring network).

Data availability - The Bureau of Meteorology hydstra database was used to investigate data availability for each streamflow station in all catchments across Australia. A station was considered in the preliminary list if it had a rating curve together with a depth and streamflow series available.

Data series length - A hydrologic reference station must be active and have a minimum start date from 1975 onwards. The Bureau of Meteorology hydstra database, the WRSC and web portals of state and territory agencies were used to identify the potential hydrologic reference station with an active long term streamflow series. SKM (2010a) noted that there should be a minimum of 15 years in each climate phase within a region. In the application of the guidelines this was not considered a priority over a minimum start date of 1975.

Location of dams in the upstream catchment – the Australian dam and dam wall spatial layers were used to identify the location of regulatory structures upstream of potential hydrologic reference stations.

Benchmarking studies – spatial layers of streamflow stations that have been included in previous studies including also provided a foundation for identifying potential unregulated catchments with minimal land use (Stewart *et al.* 1991, Peel *et al*. 2000, and Viney 2010).

Table 2. Phase 1: Preliminary list of hydrologic reference stations

Phase	Aim	Criteria applied to achieve aim	SKM (2010a) Criteria
1	To collate a list of potential hydrologic reference stations	1.1 Identify all streamflow gauges within a river basin	1
		1.2 Check state agency lists to cover all gauges	2
		1.3 Not clearly identifiable as a drain, weir or non-river site	3
		1.4 No dams, weirs or irrigation infrastructure upstream	6
		1.5 Long-term time-series (Minimum of 1975 onwards)	5
		1.6 Minimum 15 years continuous data in each climate phase (dependent on series length)	15
		1.7 Used in previous benchmarking studies	-

3 Phase 2: Stakeholder Consultation and prioritising hydrologic reference stations

A large volume of information and data is required for criteria that determine the impacts of water resource development, land use change and streamflow gauge maintenance/monitoring on potential hydrologic reference stations across multiple catchments. A stakeholder consultation program provided an avenue to access information and data to quantify impacts across each state and territory. The on-ground knowledge of stakeholders provided invaluable insight into each catchment and improved the rigour of the hydrologic reference station selection process. Seventy stakeholders from sixteen organisations across Australia (Table 3) were asked fourteen questions (Table 4), to:

1. Identify any sites that have not been considered in the preliminary list of high quality streamflow reference stations, and
2. Identify any impacts within the upstream catchment of the potential hydrologic reference stations that could compromise the quality of monitored streamflow.

The stakeholder consultation program identified an additional 116 potential hydrologic reference stations across Australia. Further information on the stakeholder consultation program can be found in Turner and Bari (2011).

Table 3: List stakeholders in different Jurisdictions

Jurisdiction	Organisation	Number of Participants
New South Wales	New South Wales Office of Water (NOW)	3
	Sydney Catchment Authority (SCA)	5
ACT	Actew AGL	1
Victoria	Department of Sustainability and Environment (DSE)	6
	Melbourne Water	7
Queensland	Department of Environment, Resources and Management (DERM)	15
South Australia	South Australia Department for Water	6
	SA Water	2
	NRM Board	1
Northern Territory	Northern Territory Natural Resources, Environment, the Arts and Sport (NRETAS)	1
Western Australia	Department of Water	2
	Water Corporation	1
Tasmania	Department of Primary Industries, Parks, Water and Environment	4
Murray-Darling Basin	Murray-Darling Basin Authority	5
	Commonwealth Environmental Water Holder	1
	Department of Sustainability, Environment, Water, Populations and Communities (SEWPaC).	10
Total		**70**
*Additional consultation was also carried out with the Bureau of Meteorology RHMs		

Table 4: Phase 2: Stakeholder consultation questions

Phase	Aim	Criteria applied to achieve aim	SKM (2010a) Criteria
2	Undertake stakeholder consultation to identify and understand impacts in upstream catchments that may impact on the quality of the streamflow reference stations	2.1 Are there minimal farm dams in upstream catchment (capturing <10% of runoff)?	14
		2.2 Does the list provide adequate representation of reference stations located on unimpacted reaches in the region?	2
		2.3 Are there any reference stations that are not currently included but would be more relevant?	2
		2.4 What is an estimate of the volume of diversions occurring upstream of the selected reference station?	9
		2.5 What is the likelihood of the volume of diversions increasing in the future?	9
		2.6 Are there any regulatory structures upstream of the reference station?	6
		2.7 If a coastal region, is there any tidal influence on the reference station?	4
		2.8 Are there any point source discharges upstream of the selected reference station?	8
		2.9 Have there been any significant land use changes that would impact on catchment hydrology? Land use practices could include farm dams, clearing, forestry, urbanisation, bush fire and water resource development	14
		2.10 Are there any land use practices likely to increase in the future?	14
		2.11 Does the reference station have a particularlimportance, for example, water supply or ecological?	-
		2.12 What is the hydrological data quality of each reference station?	11, 12, 13
		2.13 Is the rating curve sensitive to all facets of the flow regime?	12
		2.14 Is there any uncertainty related to the streamflow series?	13

A classification system was developed following stakeholder consultation. The station classification system provided a basis on which to assess, rank and prioritise streamflow stations consistently across all jurisdictions. Based on the type of feedback that was provided during stakeholder consultation the classification system provides a summary of station quality and the next step required in the application of the guidelines.

A site classification was assigned to each streamflow station on the preliminary list developed in Phase 2. The ranking of sites was sent back to each jurisdiction to assess if the interpretation of feedback was correct and to confirm they agreed with the classification of station quality and actions required for its inclusion into the Australian Network of Hydrologic Reference Stations.

Table 5. Streamflow stations ranking classification system developed based on stakeholder feedback

Category	Definition	Action
1. Pristine	A station with an unimpacted catchment upstream.	Do data reporting/time-series check. Land use and farm dam coverage will be checked[1] but not expected to be an issue.
2. Good site	A station with minimal impacts in the upstream catchment.	Do data reporting/time-series check[2]. May be some land use impacts but are considered stable. Land use and farm dams will be checked but not expected to be a problem.
3. Good site	Currently minimal land use impacts. However, there is potential for future impacts in the upstream catchment.	Do data reporting/time-series check.
4. Reasonable site	May be some land use impacts or some issues of hydrological quality.	Need to confirm land use change and farm dams. Do data reporting/time-series check.
5. Suggested by stakeholder	Good site recommended for inclusion by the stakeholder. Minimal land uses are impacts expected.	Land use and farm dams coverage will be checked but not expected to be a problem. Do data reporting/time-series check.
6. Suggested by stakeholder	Site recommended by stakeholder. However, possible land use impacts also flagged by stakeholder.	Land use impacts need further investigation. Do data reporting/time-series check.
7. Flag for seasonal use only	Good site is located in a relatively unimpacted region. Unable to use for long-term trend analysis as time-series is too short. But the site could be useful for seasonal streamflow predictions.	
8. Remove (Category A)	Good site but unable to use due to planned closure.	Remove station from list.
9. Remove (Category B)	Site impacted by land use or has a poor rating curve history.	Remove station from list.
10. Remove (Category C)	One of multiple sites in a region of similar condition.	Remove station from list.

1. Land use and farm dam coverage will be checked – spatial analysis of land use change from 1972 to 2005 will be combined with a landuse history (where required) to confirm land use history in the upstream catchment.
2. Do data reporting/time-series check – this refers to criterion in the data reporting category of the guidelines. This step will be carried out prior to trend analysis at each HRS

Based on feedback from the stakeholder consultation process (Table 5) we ranked and prioritised 362 streamflow stations (Figure 1). The prioritization of stations provided three groups:

Group 1: 128 streamflow stations that are considered a) pristine, b) a station with minimal land use impacts or c) a site with currently minimal impacts but potentially further impacts in the future. These stations were used in phase 3 of the project.

Group 2: 131 streamflow stations that are in catchments where landuse impacts need to be investigated further being included in analysis.

Group 3: 103 streamflow stations that should be removed from consideration because of: a) impacts of land use change in the upstream catchment or poor hydrological

quality, b) high quality stations that are planned for closure or c) stations in a cluster of stations of similar quality and land use impacts.

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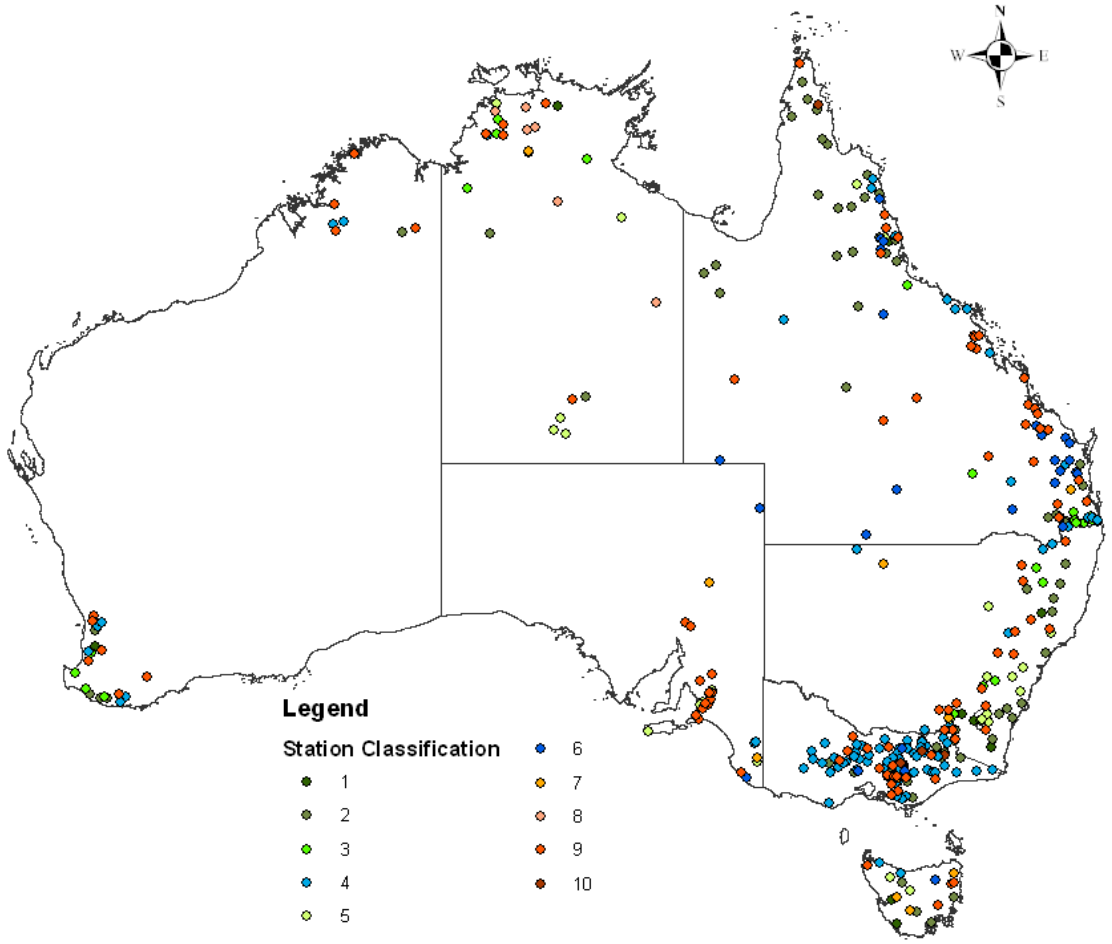

Figure 1. Classification of streamflow reference stations (see Table 5 for classification definition).

4 Phase 3: Quantifying land use change and hydrological data quality

Phase 3 analysis quantifies the impact of land use change and quality on the streamflow series, including its completeness and measurement (Table 6).

Table 6. Phase 3 Criteria: Quantifying land use impacts and hydrological quality

Phase	Aim	Criteria applied to achieve aim	SKM (2010a) Criteria
3	Quantify land use changes and hydrological quality of streamflow series	3.1 Is there <10% land use change in the catchment upstream from the streamflow station	15
		3.2 Is there minimal missing data (< 5% over the period of record)?	12, 16
		3.3 Is the rating curve sensitive to all facets of the flow regime?	13
		3.4 Minimal data outside the gauging limits	13
		3.5 Minimal data anomalies and unusual flow patterns	17

Land use change within an upstream catchment can change the hydrological character of downstream sites. Land use activities include farm dams, clearing, forestry, urbanisation, fire, water resource development and increases in, or alteration of agricultural practices. SKM (2010a) set out criteria to achieve an objective of having less then 10% of land use impacts within the catchment upstream of a hydrologic reference stations. We adopted those criteria in the following way.

Farm Dams

One megalitre of farm dam volume equates to a one megalitre reduction in mean annual flows (SKM 2004, SKM 2010a). The volume of farm dams in an upstream catchment was discussed as part of the stakeholder consultation process. Information on the impact of farm dams within a catchment was available from either the opinion of stakeholders or as data. For example, of the 91 stations categorised as a 4, sixty-five percent of those stations are located in Northern Victorian catchments where demand for surface water, and therefore farm dam volume is very high. The impact of farm dams on these stations (group 2); will be investigated further in 2012-2013 before confirming their inclusion into the Australian Network of Hydrologic Reference Stations.

Diversions and regulatory structures

The impact of water resource development in the upstream catchment of potential hydrologic reference station was discussed as part of the stakeholder consultation process. Any streamflow stations with upstream diversions contributing to >10% change in runoff were not retained in the selection process.

Bushfires

The removal of vegetation by bushfire can significantly alter evapotranspiration rates and subsequent runoff rates in a downstream catchment (SKM 2010b). A recent bushfire impact modelling study in Victoria found that the maximum average annual reductions in runoff were between 0 and 1ML/ha/yr, with an average impact of 0.4ML/ha/yr (40mm/yr) (SKM 2010b). The occurrence of bushfires in the catchment of each streamflow station was discussed during the stakeholder process. Catchments potentially impacted by bushfire were flagged and the station was added to the Group 2 list for further analysis in 2012-2013. Spatial layers of the coverage of bushfire (2003, 2006, 2007 and 2009, available from DSE), will be used in the 2012-2013 period to analyse the area and impact of bushfires in Victorian catchments.

Urban Areas, Forestry, Clearing for agriculture

A number of organisations were consulted in the investigation of resources and methodology development to quantify land use change in each upstream catchment of the hydrologic reference stations. These included: the Department of Climate Change, Environment and Energy Efficiency (DCCEEE), the Department of Primary Industry (DPI Victoria), Bureau of Rural Sciences (BRS), Australian Bureau of Agricultural and Resource Economics (ABARE) Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology Geofabric Team.

The area of forest cover was chosen as an indicator of land use change that would be sensitive to changes in urbanization, clearing for agricultural practices and forestry. Catchment boundaries for each potential hydrologic reference station were derived by the Bureau of Meteorology's Geofabric team. The DCCEEE provided spatial analysis of the changes in the area of forest and non-forest cover between 1972 and 2010 in each catchment.

Analysis of the 128 streamflow stations identified in group 1 showed that 63 hydrologic reference stations had <5% missing data over the period of record and <10% land use change from 1972 to 2010. Criteria 3.2, 3.3 and 3.4 (Table 6), which are the remaining hydrological quality criteria, will be quantified in 2012-2013. Discussions with stakeholders identified any potential hydrological data quality issues. Streamflow stations were not retained in the selection process if any issues of hydrological quality were identified, including: ineffective maintenance, irregular gauging, unstable controls and inadequate representation of low or high flows.

The 63 hydrologic reference stations were used in the first round of analysis of long-term trends in streamflow availability across Australia. They also provided a foundation for the development of a web portal to house the Australian network of hydrological reference stations and associated station information, catchment data, key streamflow stations and trend analysis results (Turner *et al.* 2012).

5 Phase 4: Identify hydro-climatic region

Spatial variability of reference stations across hydro-climate regions is important to verify climate variability and change across Australia (Table 7). The long-term temporal variability in climate drivers of hydrology, i.e. temperature and precipitation, will differ between hydro-climate regions. Selecting hydrologic reference stations in multiple hydro-climate regions will aid the investigation of long-term trends in streamflow availability across Australia. The selected reference stations are not equally distributed across all hydro-climate regions (Figure 2) as station selection was also dependent on the existing streamflow gauge network in Australia.

Table 7. Phase 4 Criteria: Köppen Climate Classification region

Phase	Aim	Criteria applied to achieve aim	SKM (2010a) Criteria
4	To identify climate region	4.1 Köppen climate classification region	16

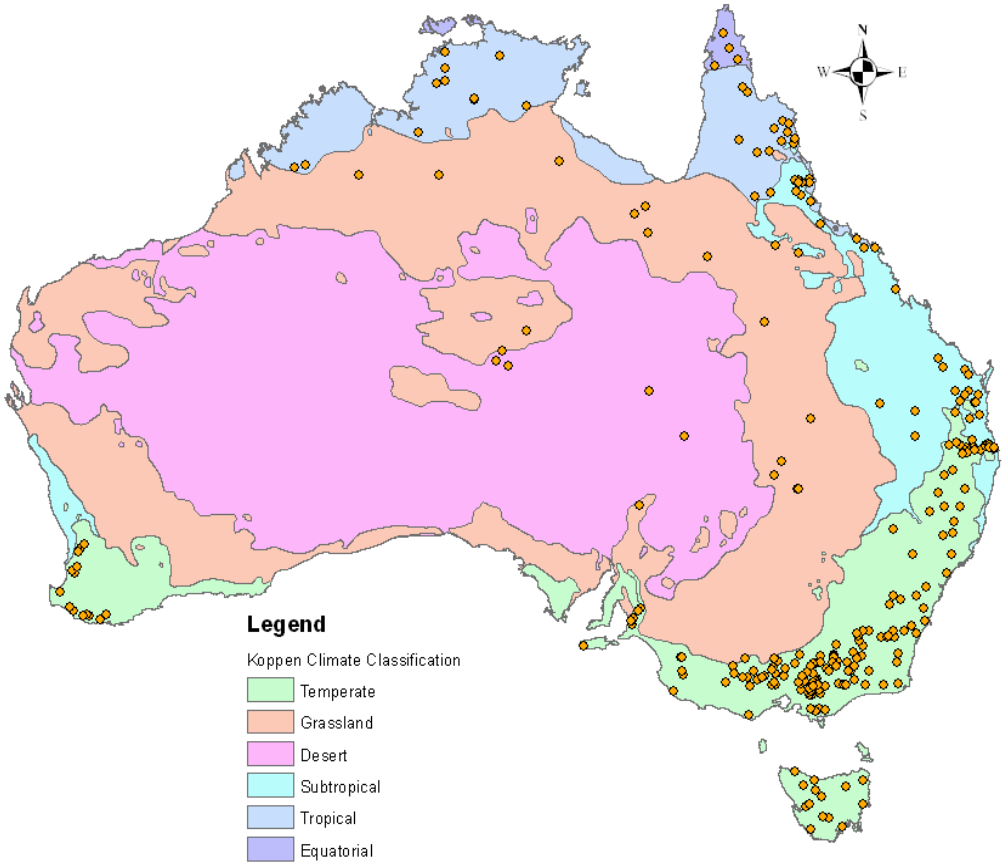

Figure 2. Distribution of Hydrologic Reference Stations across Australia's climate regions.

6 Summary of Streamflow Station selection guidelines

A set of guidelines were developed in 2010 to select hydrologic reference stations to expand long-term and seasonal forecasting services (SKM 2010a). Since then, these guidelines have been applied to develop the Australian Network of Hydrologic Reference Stations (Table 8). During the application of these guidelines they have been adapted for efficiencies for application on a national scale (Table 8).

Steps to complete the development of the HRS include:

1. Confirm impacts in upstream catchments hydrologic reference stations identified in Group 2.
2. For group 1 stations with >5% gap over the whole series - explore the completeness of streamflow series in each climate phase
3. Quantify the hydrological data quality criteria 3.3, 3.4 and 3.5 at all stations
4. Provide stakeholders with further opportunities to critique the quality of the Australian Network of Hydrologic Reference Stations.

Table 8. Guidelines to develop the Australian Network of Hydrologic Reference Stations[1]

Phase	Aim	Criteria applied to achieve aim
1	To collate a list of potential hydrologic reference stations	1.1 Not clearly identifiable as a drain, weir or non-river site 1.2 No dams, weirs or irrigation infrastructure upstream 1.3 Long-term time-series (Minimum of 1975 onwards) 1.4 Minimum 15 years continuous data in each climate phase (dependent on series length)
2	Undertake stakeholder consultation to identify and understand impacts in upstream catchments that may impact on the quality of the streamflow reference stations	2.1 Are there minimal farm dams in upstream catchment (capturing <10% of runoff)?
		2.2 Does the list provide adequate representation of reference stations located on unimpacted reaches in the region?
		2.3 Are there any reference stations that are not currently included but would be more relevant?
		2.4 What is an estimate of the volume of diversions occurring upstream of the selected reference station?
		2.5 What is the likelihood of the volume of diversions increasing in the future?
		2.6 Are there any regulatory structures upstream of the reference station?
		2.7 If a coastal region, is there any tidal influence on the reference station?
		2.8 Are there any point source discharges upstream of the selected reference station?
		2.9 Have there been any significant land use changes that would impact on catchment hydrology? Land use practices could include farm dams, clearing, forestry, urbanisation, fire and water resource development
		2.10 Are there any land use practices likely to increase in the future?
		2.11 Does the reference station have a particularly importance, for example, water supply or ecological?

Phase	Aim	Criteria applied to achieve aim
		2.12 What is the hydrological data quality of each reference station?
		2.13 Is the rating curve sensitive to all facets of the flow regime?
		2.14 Is there any uncertainty related to the streamflow series?
3	Quantify land use changes and hydrological quality of streamflow series	3.1 Is there <10% land use change in the catchment upstream from the streamflow station
		3.2 Is there minimal missing data (<5% over the period of record)?
		3.3 Is the rating curve sensitive to all facets of the flow regime?
		3.4 Minimal data outside the gauging limits 3.5 Minimal data anomalies and unusual flow patterns
4	To identify climate region	4.1 Köppen climate classification region

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End of document

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