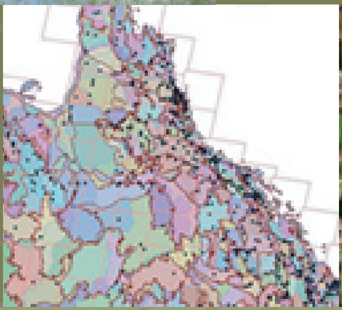
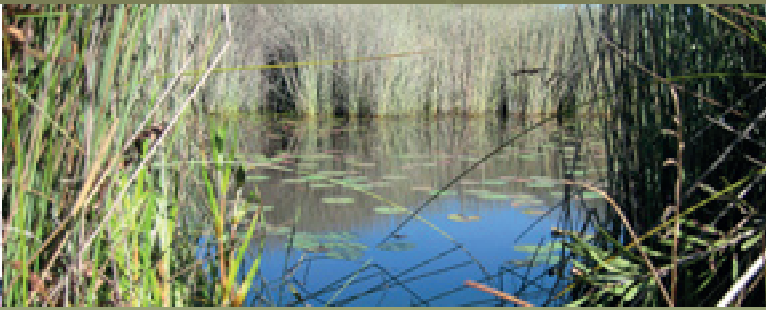
Hydrological Characterisation for Wetlands and Wetland Imagery

A method to attribute and evaluate hydro-climatic conditions for the Queensland wetland mapping





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This document forms one part of the three-part tool Hydrological Characterisation for Wetlands and Wetland Imagery that includes a user guide, methodology and frequently asked questions.

Contents

List of Figures

List of Tables

1 Introduction and Background

The Queensland Wetlands Program's Wetlands Mapping and Classification (WMC) methodology was reviewed by four eminent wetland scientists in 2005. The review recommended that the hydro-climatic conditions represented through annual flow/rainfall regimes be provided for the imagery used for inundation mapping.

This information provides a more accurate and meaningful way to convey hydro-climatic conditions relative to historical records and natural variability across landscapes and imagery, using common terminology such as probability of exceedence and hydrological regimes.

Research and development in ecology and hydro-climatology has increased rapidly over the last decade, such that a new field, ecohydrology, has emerged (Manfreda et al. 2010). Ecohydrology integrates concepts of land and water pattern, process, and interactions within and between ecosystems and species, so that the manner in which aquatic systems are organised in space and time and across scales may be better understood. Therefore the hydrological attribution methods build as much capacity as possible to explain the patterns and timing of inundation for different wetland types and ecosystems across the state of Queensland, benefiting their management.

To achieve this, the reporting of hydro-climatic conditions is assessed within physiographic zones with similar climatic or hydrological conditions and physical geographic context. These zones are defined by ecoregions (sub-bioregions) and sub-basins: 120 sub-bioregions with similar vegetation, landform pattern, elevation, geology and rainfall, for application of climate data, and 253 potentially assessable sub-basins within sub-bioregions for application of stream gauge data. The interrupted nature of flow data and its discontinuous spatial distribution over most of Queensland limited the capacity to model the data deterministically and systematically with locally meaningful parameters. To address this, the project applied a non-parametric stochastic approach that could evaluate periods of record magnitude-recurrence information.

The method described in this report provides probability of exceedence information for spatially interpolated rainfall and modelled run-off and for gauge-station normalized discharge and gauged stage (i.e. stream) height within their respective zones for assessment for up to 118 years of data. The method provides daily zonal index data, annual metadata and reference quantile-probability information. The data is profiled through three annualised regimes: lowest 5 per cent dry conditions, 50 per cent median conditions, and upper 95 per cent wettest conditions, and 90 per cent confidence intervals are provided to identify the precision of the median series. Each regime is provided at five temporal scales: daily, weekly and one, three and six months, whilst annual totals are provided for yearly scales of assessment. This reference information defines hydro-climate variability per year between drought (e.g. baseflow), 'normal' and wet (e.g. flood) conditions. Specific seasonal data profiling was not attempted due to the contrasting variability in seasonal conditions across the state and the decrease in precision this would impose on assessment methods. Instead seasonal data and their representation in different hydro-climatic regimes may be obtained by retrieving information from the source zonal index data.

This approach meets the requirements for the WMC project whilst building additional capacity for ecohydrological assessments through characterisations of inundation regimes for different wetland types at different reference time scales for different hydro-climatological processes. The method does not include ground water processes, and whilst this is a major deficiency, it should be noted that the potential interaction of surface and ground water processes can sometimes be inferred from the pattern and timing of mapped inundation relative to the observed regimes and noted human disturbance.

The zonal assessment approach imposes some limitations on the suitability of the information for different applications. This is due to the creation of centralized values that are not exactly representative of conditions across a zone. The statistical profiles and time series produced are valuable for interpretation of ecological processes but are not applicable for water resource planning (see Section 8).

The WMC project intends that this attribution facility be used in conjunction with wetland mapping, wetland classification, wetland inventory and typological information. By enabling this integration, new insights into ecological processes and conditions are expected, and this in turn will lead to updates in the hydro-climate information and its delivery.

This report describes the methods and tools provided to profile the magnitude and variability of rainfall, run-off, stream flow (discharge) and stage height at different time scales to identify hydrological conditions, and the representativeness of conditions, and to search data archives. This report provides the performance requirements, examines key components of data types and the collection, spatialisation and integration of information, the production of statistics, the assessment and management of variability in the data, and potential applications and the limitations of the information.

2 Purpose

The requirements for the method are listed below:

- provide information to identify the hydro-climatic conditions contributing to the inundation of all wetland types for the full period of usable data records
- provide quantile-probability of exceedence information at different reference time scales (at least daily, weekly, monthly and yearly) in a manner that can be linked to observations of wetland inundation whilst accommodating variation in hydro-climate observations
- provide reference statistics that identify annual and within-year variability of conditions and the precision of median annual series, and provide reference quantile-probability series for dry, median and wet annual conditions
- use this information to attribute the hydro-climatic conditions at the satellite scene scale to inform the interpretation of the representativeness of classified water bodies obtained from imagery, and
- provide the information through Wetland*Info* to interpret wetland mapping and satellite imagery.

This report identifies how these requirements are met for appropriate applications. Appropriate applications include:

- characterising the wetness or dryness of the environment at a Landsat scene scale
- characterising the variability of hydro-climate data and identifying the representativeness of inundation information within an assessment area
- characterising the sources of water for wetland inundation through incorporation of water source, timing, magnitude and duration
- use of benchmark and reference statistics to manage the evaluation of change in time series data.

The method provides tools described in the Users Guide (DERM 2011 Hydrological Characterisation for Wetlands and Wetland Imagery: Users guide to attribute and evaluate hydro-climatic conditions using the Wetland*Info* tools for hydrological characterisation for wetlands and wetland imagery, Version 1.1.) to define the temporal scope of hydro-climatic conditions and facilitate time series evaluation of seasonal state and annual trend. The tools convey this information using maps, imagery, bar charts, data extraction, and benchmark references and reference curves that are scaled by probability of exceedence. Metadata are provided to facilitate the quality control of data use and interpretation.

The tools are provided by the Queensland Wetlands Program to support the assessment, evaluation and management of Queensland wetlands for government, scientific institution, natural resource management, education and general public applications. The tools use simple evidence based methods to characterise hydro-climatic conditions and behaviour and are not intended to support prescriptive or specific diagnostic applications.

3 Data Collection

The inundation of wetlands depends on local hydro-climatic and physical-geographic context, including the paths for flow and water cycling (Winter et al. 1998, Brodie et al. 2007b). Flows may follow defined or dispersed pathways, or may be wholly dependent on rainfall or ground water contributions. Inundation may be very ephemeral, responding to infrequent events, it may change gradually over months due to the slow progression of floods sourced from catchments thousands of kilometres away, or inundation may be permanent due to human modification of flow regimes combined with reliable groundwater and runoff inputs.

In addition, catchments and landscapes present a diversity of land covers, land uses and conditions, which impose spatial and temporal structure or non-linear responses in flow and runoff processes, and these effects are often heterogeneously distributed (Gottschalk et al. 2006, Goetz & Fisk 2008, Smakhtin & Batchelor 2005, Detenbeck et al. 2005, Linsley et al. 1982, Moliere et al. 2006).

To cater for this diversity across Queensland (an area of approximately 1.9 million km^2 spanning latitudes 9.5 to 29.15 degrees south), the full period of record for 0.05 degree grid interpolated rainfall from 1889 to 2006 and simulated run-off (surplus flow to stream) (1890 to 2006) was captured (from SILO and AussieGRASS systems <www.bom.gov.au/silo/> and <www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/project.html>). In addition, all stream gauge data spanning 1 to 100 years from 1900 to 2005 at daily time steps (from Hydsys systems <www.derm.qld.gov.au/water/index.html>) were used.

The rainfall and runoff grids were processed in ESRI ArcGIS in ASCII format using ArcObjects processing. The data were treated as point observations allocated to grid cells. In comparison the stream gauge data is point data representing discontinuous spatial and temporal observations from up to 1191 stations distributed unevenly across the state with a coastal bias. The rainfall and runoff data were quality assured by the suppliers and the grid information was spatially co-registered. In comparison the stream gauge data were provided with quality codes but required quality control before the data could be spatialised and integrated, so the data were managed in an S-PLUS ® 8 data base through the use of scripted programs.

4 Spatialisation and Integration

It is a license requirement to use the data for ecological applications in a way that does not reproduce the data structure or make source data available to third parties. The requirement for annualised statistics to profile historical conditions depends on the provision of samples with sufficient information content to provide representative diagnostic information.

The geographical variability and uncertain precision of data values combined with the issue of irregular and biased distribution of stream gauge data, and the requirement to model data in an ecologically meaningful manner up to the scale of Landsat scenes (circa 32 000 km^2) dictated that some form of stratification and integration of the source data occur. This was achieved through the derivation of zonal statistics within ecoregions defined by similarity of ecological and hydro-climate characteristics.

It is acknowledged that the use of zonal statistics results in the loss of locally relevant information, but it enables the provision of temporally dynamic and representative information over suitably selected areas. The imposition of a spatial scaling effect is not normally desired, and the loss of cause and effect relationships between hydro-climate variables produces challenges for most assessment models, especially numerically intensive bottom-up models. This tradeoff in information content and application potential is accommodated by applying top-down stochastic modelling techniques that robustly characterise hydro-climate regimes at different temporal scales and provides interpretive tools that combine zonal observations and regime reference information. In either case, whole of catchment rainfall to run-off to yield routing across the State was unachievable and unrealistic given the nature of variability observed and lack of assessment, calibration and computational capacity for the many unrouted catchments.

Zones were selected using ecohydrological principles (Pusey et al. 2009, Schroder 2006, Poole et al. 2002), whereby target wetland ecosystems could be expected to operate with some similarity due to similarity in climate, hydrology and physiographic settings. The effect of annualisation and zonation is to statistically smooth and centralise data signals to create less biased and more precise estimates of sub-regional conditions to better inform management decisions at an appropriate scale for wetland systems across Queensland. Expected applications for zonal data included the characterisation of wetland ecosystem processes and functions including aquatic connectivity. Zonation should provide an intermediate scale that enables lumping to the scene scale whilst interpolation to the local area (e.g. 5 km scale) for wetland characterisation requires calibration with time series information. Appropriately selected zones are required to facilitate consistent decision making for resource management (Acreman & Dunbar 2004, Agarwal et al. 2002), and scale effects are largely a matter of conceptualisation that are defined through observation and stochastic testing (e.g. Kondolf et al. 2006, Newson 2010, Agarwal et al. 2002, Overton et al. 2009, McGill 2010, Muneepeerakul et al. 2008).

Zones were selected to maximise the interdependence of hydrological and terrestrial ecosystem processes, which is reasonable given that wetland classification depends on terrestrial ecosystem classification and rainfall, run-off, flow and storage characteristics are strongly influenced by landform, land cover and surface conditions. Sub-bioregion zones used in regional ecosystem mapping are defined on the basis of similarity between rainfall, geology, landform pattern and elevation, and vegetation communities and their distribution (Sattler & Williams 1999). In Queensland sub-bioregions facilitate the assessment and management of regional ecosystems (Howell et al. 2008) and are strongly correlated with ecohydrological characteristics (Pusey et al. 2009). In addition, the data for rainfall and run-off (surplus rainfall) is spatially interpolated from distributed observation using spatial smoothing and forcing functions that account for topographic and soil type effects (Jeffrey 2006, Jeffrey et al. 2001, Rayner 2004, Carter 2007), so it is conservative and practical to estimate centralised rainfall and runoff values in this context, and this regionalisation was applied to rainfall and runoff data.

In comparison, the interdependence of flow observations is determined by the similarity of rainfall, run-off, detention, concentration and chanelised flow processes within the previous landscape constraints. This requires drainage observations from similar catchments driven by similar rainfall processes to be assessed (Linsley et al. 1982). Given that the routing and reporting of stream flow is constrained within sub-basins, it is logical to combine stream flow observations within sub-basins intersected

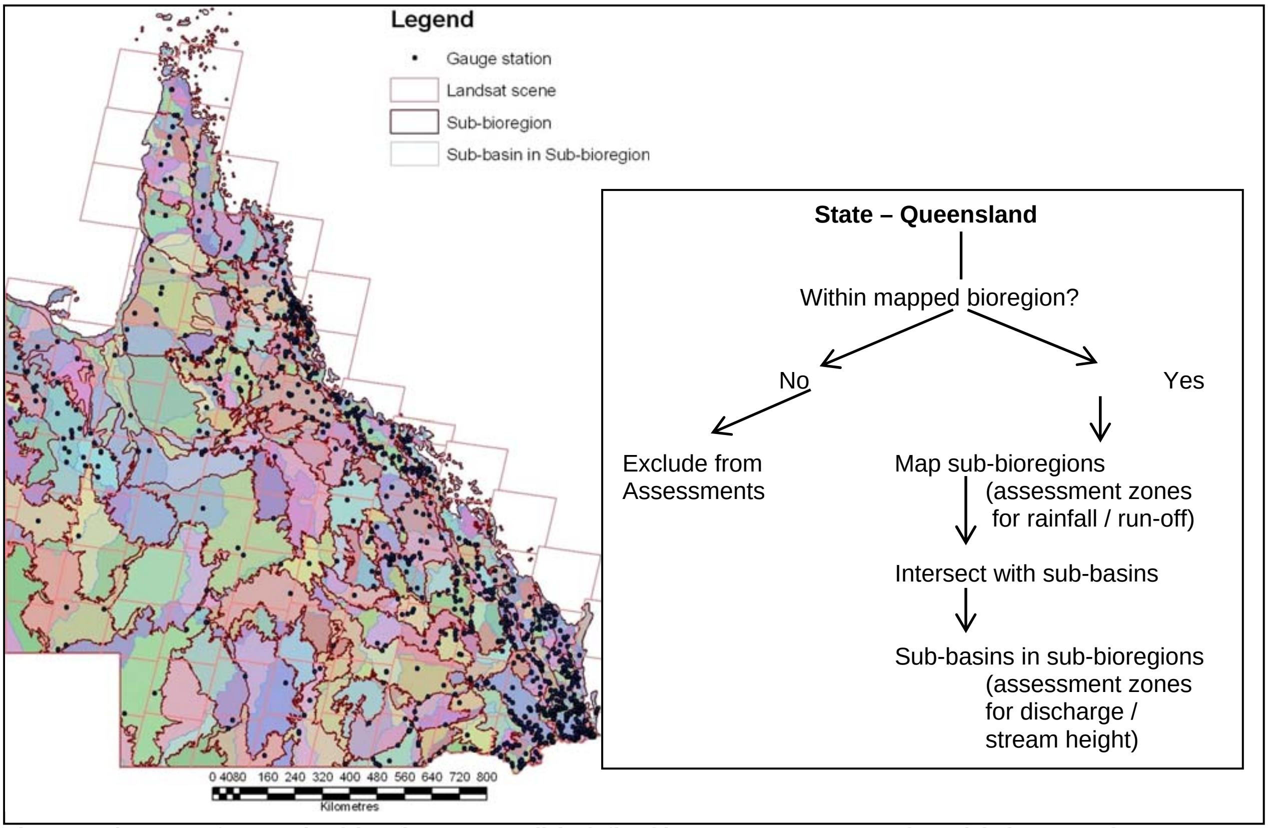


Figure 1. The state of Queensland (north-east Australia), defined by assessment zones and overlain by 87 Landsat scene footprints. The derivation of assessment zones is illustrated on the right.

with sub-bioregions. This results in more drainage zones with smaller areas (e.g. 253 zones with a mean of 4580 km^2 (range of 45 505 km^2)) than the rainfall and runoff zones (120 zones with a mean of 14 120 km^2 (range of 68 795 km^2)). Figure 1 illustrates the distribution of assessment zones with stream gauge stations and Landsat scenes

Landsat TM and ETM+ imagery were used to identify the occurrence of open water bodies and water-vegetation complexes. The method used seven dry season and non-cloudy images per scene area (multi-temporal imagery) and a wet scene between 1986 and 2005, selected by expert opinion, showing water extent in flow recession following flood conditions. The dry scenes indicate water permanence and are representative of most normal conditions in inland areas whilst the wet scenes indicate maximum water extent and help to identify flood plains and the association between flood flows and permanent, periodic or intermittent wetlands. Imagery was provided by the Department of Natural Resources and Water Statewide Land and Trees Study (SLATS) group for 87 scene areas. Imagery was systematically and consistently corrected for radiometric, sensor and spatial registration variations (<www.derm.qld.gov.au/slats/meth.html>). Refer to Knight et al. (2009) for the image classification methods for water bodies. The imagery is principally used for vegetation audits and land cover mapping. This coincidence between vegetation and wetland mapping imagery is important because the wetland mapping is a component of regional ecosystem classification and mapping conducted by the Herbarium, and both mapping processes are subject to accuracy assessments and biennial reporting, with useful synergies being produced for resource management.

The SLATS image template (shown in Figure 1) was intersected with assessment zones to identify zones contributing to imaged conditions. Zones with assessable data were related to scenes in a look-up table with areal weights assigned to designate the proportion of assessable zone area to the total zone assessable area within each scene. These weights are used to aggregate (lump) zonal information to the scene scale (Figure 2). A separate look-up table listing the dates scenes were imaged was provided to coordinate data retrieval for scene assessments.

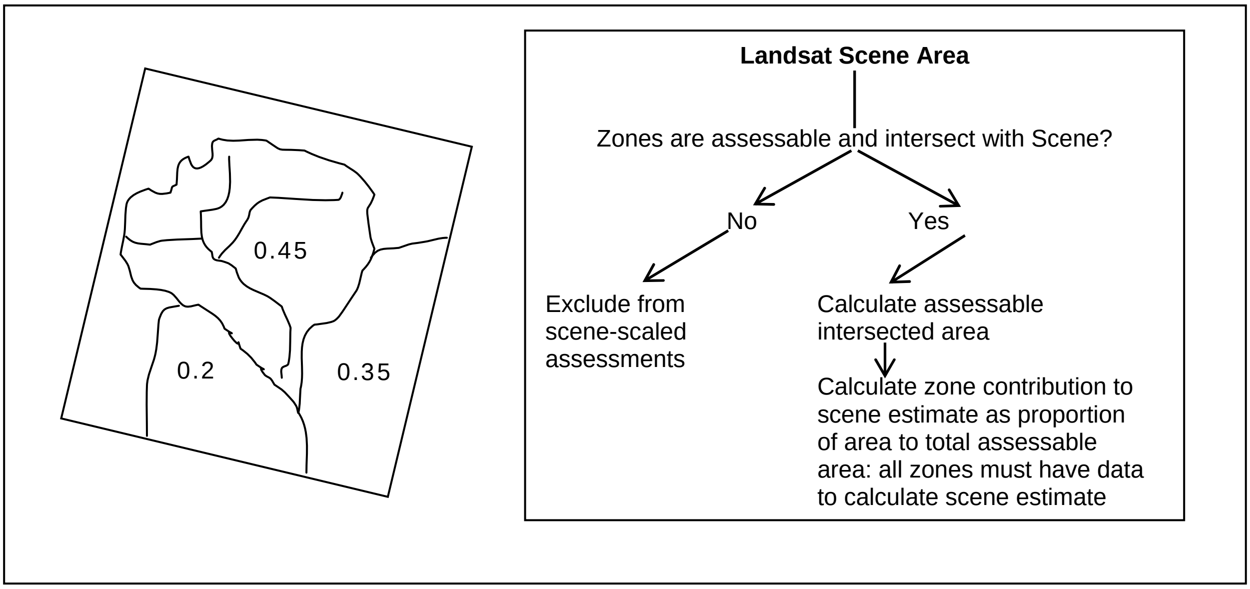


Figure 2. Relationship between assessment zones (shown on left), assessable records and calculation of scene-wide estimates (shown on right) through zone area weights (shown in bold on left).

A master shapefile was created to depict the distribution of zones and to provide a framework for relating zones to stream gauge points. Using a majority rule on a pixel by pixel basis, 0.05 gridded rainfall and runoff data were allocated to zones. Gauge station points were identified in the corresponding 0.05 grid cell-to-zone registrations and were allocated accordingly through spatial joins (of attributes) to the master file. Allocations in the master shapefile data base and look-up tables are related by gridcodes. These look-up files and data base were imported to the Wetland*Info* Oracle data base to coordinate queries linking scenes, assessment zones, dates, zonal data etc.

Zonal statistics are calculated on a per-observation basis rather than a per area basis, which means per pixel or gauge station within a zone provides central statistical estimates of values on a daily basis (arithmetic mean, standard deviation etc.). The use of zone extents, defined by gridded SILO data and constrained by sub-bioregion and sub-basin distribution for each data type, ensures spatial consistency in the assignment of zonal statistics. Rainfall or runoff observations that fall outside of sub-bioregion zones are excluded from zonal analysis. Likewise sub-basin extent and sampling is constrained within sub-bioregion extents. The AussieGRASS runoff data set has a smaller extent than the rainfall data in the Torres Strait and some other coastal areas such as Fraser Island. Zonal statistics identify these conditions through counts of observations.

The derivation of source daily zonal statistics was obtained using ArcGIS (for rainfall and runoff grids) and S-PLUS (stream flow and stage height). The simple data collation methods assume the significance / influence for each observation is the same and that the arithmetic average adequately represents the most likely state for the zone. This method works well for the spatially smoothed rainfall and runoff data, but is amended for the stream flow data, which have inherent non-linear variations in space and time. No control on the contribution of each gauge station’s data to the zonal estimate is made, as routing information that explains distributed storage contributions over space and time was generally not available.

The local terrain and catchment characteristics determine flow accumulation and storage movements. Scaling to each station’s long-term flow or stage height mean is used to normalise these environmental factors between stations before zonal statistics are calculated (e.g. Detenbeck et al. 2005). It should be understood that some non-linear effects persist because drainage characteristics change through time due to land use and land cover changes, changes in stream profile and roughness and due to upstream water capture in off- or in-stream reservoirs. The use of smaller zones for drainage processes than for the pre-smoothed rainfall data helps to ensure increased proximity between related gauge stations and therefore greater similarity in stream observations through time.

Rainfall and runoff data were analysed directly for the 120 zones using a sub-bioregional mask that allocated statistics to zonal vectors across the State and then used direct Arc object statistic calls to calculate sample size, minimum, maximum, range, sum, mean and the sample standard deviation.

Stream flow and stage height data were more difficult than rainfall and runoff data to model because of their irregular distribution of observations in space and time, the variable quality of observations and the localised nature of drivers for stream flow characteristics. The following criteria were used to improve the quality control of stream flow data during the data collation process.

- Quality assurance flags must have acceptable levels and not exceed a Hydsys value of 150 (i.e. remove suspect or unavailable data).
- Gauge stations are required to have flows exceeding .01 m^3/s over the full period of record, or .01 m stage height.
- Following collation of station data, irrespective of individual station dates for operation, at least 95 per cent of days within a year must be assessable and no more than two consecutive days are allowed to have missing data.
- For stage height data (only), negative observations are not representative of most observations and are not comparable for most stations or assessable using percentile-quantile relationships or many post-hoc models (e.g. log-regressions) and stations with these values are excluded. Reasons for negative values include change in rated conditions, the appropriateness of the height datum, and gauge placement in tidal zones. Inland stations may show a long-term trend downwards in minimum heights into the negative domain and these observations are inconsistent with other stations and cannot be ‘normalised’ away.
- At later steps of data analysis (percentile-quantiles), zones with less than four years of data are not assessable but the time series data is maintained for perusal.
- Many stations do not have data for the water body classified period of 1990 to 2005, but their incomplete data is recorded to provide some historical reference.
- Not all stations provide both flow and stage height data, but all assessable data is utilised to provide zonal estimates.

A maximum of 237 zones (out of 253) were assessable for stream flow with one zone lost to percentile analysis due to a short time series. A maximum of 222 zones (out of 253) were assessable for stage height with an additional 25 zones lost to percentile analysis due to short time series.

S-PLUS scripts were used with look-up-tables to allocate stations to zone, to provide quality controlled zonal period of record data sets, to identify annual precision and variability, and normalise station data prior to zone averaging. Inversion of zonal means of normalised daily data multiplied by the raw zonal mean provides a daily scalar of the station-corrected zonal mean, which is later averaged within and across years to provide a long-term zonal scalar to expand all normalised source zonal data to a meaningful scale. Zonal statistics include station count, minimum, maximum, range, and sum, mean and sample standard deviation of raw and normalised data.

Rainfall and flow events will never be uniform within any zone and the number and quality of source observations varies at a daily time step. Usual probability of exceedence assessments that assess continuous periods of records for a specific temporal assessment scale (e.g. daily) are more likely to bias zonal probability estimates to the prevailing conditions. This bias is reduced by this method by segmenting the data series annually and profiling the zonal statistics within-year to produce probability of exceedence series comprised of statistics from contributing years (Vogel & Fennessey 1994).

Therefore whilst low magnitude quantities may be prevalent it is reasonable to assume that the probability of these observations is accurately represented by a sufficient number (e.g. less than or equal to 20) of annualised assessments. Rainfall distribution and flow/storage variations can also be smoothed by performing assessments at different temporal scales. For example a daily scale of flow may be representative for fast changing systems along a coastal hinterland, whilst a week, month or three month scale may be more appropriate for large coastal systems, inland and channel country systems. In these cases integrating information through time consolidates the influence of contributing processes. This may be particularly important for the characterisation of different wetland types (e.g. palustrine versus lacustrine) with different flow paths and regimes.

5 Statistics

The method selected to provide yearly quantile-probabilities information is based on the annualisation of daily data over the number of assessable years at different temporal scales (daily, weekly, monthly, three monthly and six monthly) for different prescribed regimes (Figure 3). Annual (totalled) data are provided, though with less metadata because it forms a period-of-record series collated at an annual scale and not profiled within a larger temporal scale, such as decades (Linsley et al. 1982).

The non-parametric profiling approach enables the derivation of confidence intervals for median quantiles and the identification of consistently wet and dry regimes within the sampled data (Vogel & Fennessey 1994). This climatology approach is suitable to profile the variability and representativeness of conditions in a robust and unbiased fashion, but it does not provide causal mechanisms to predict or link physical processes except through temporal correlations within sampling zones. This was considered an acceptable trade-off because most landscapes and catchments are unrouted and the accuracy and precision of data may be poorly defined.

All annual statistics are calculated in S-PLUS in a similar manner except for more indicators of variability in stream gauge data, the scaling up of normalised stream gauge data, and the conversion of flow data (m^3/s) to discharge (m^3) for each reference time scale (Table 1). Stage height data are accumulated across time scales like discharge but are presented as daily equivalents for web-based tools. Missing data (an issue only for stream gauge data) are excluded from index calculations.

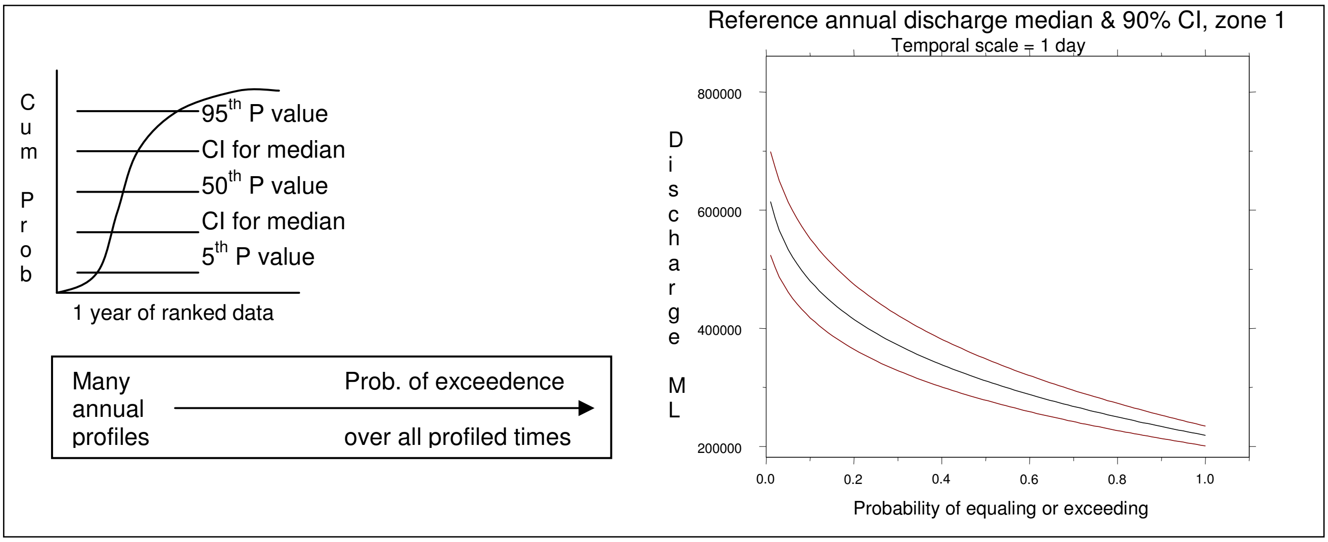


Figure 3. Profiling annual quantiles by probability provides the data for the reference percentile-quantile series / regimes at daily to six monthly time scales. The median annual discharge series with 90 per cent confidence intervals is illustrated on the right. The 0.95 regime (shown on the left) has larger quantiles (wetter conditions) and the 0.05 regime the smallest quantiles (drier conditions). Note: 'Cum prob' = cumulative probability.

Table 1. Description of key common items across data types for benchmark (across year) statistics and annual statistics, for each reference time scale* and zone.**

Benchmark statistics	Annual statistics
Number of pixels, or maximum number of stations assessable across years and the minimum and maximum number of stations assessable at a daily time step (d,w,1 3 6m,y)	Year (d,w,1 3 6m,y)
Start year (d,w,1 3 6m,y)	Number of daily/weekly/monthly records (d,w,m)***
End year (d,w,1 3 6m,y)	Average index value (scaled up from normalised index values for discharge and height) or total value (observed quantity) for annual reference scale (d,w,1 3 6m,y)
Number of assessable years (d,w,1 3 6m,y)	Ratio of average (or total) to long-term average of values (d,w,1 3 6m,y)
Long-term index average (scaled up from normalised index values for discharge and height); (d,w,1 3 6m,y)	Arithmetic average of spatial coefficient of variation (d)
Arithmetic average of annual standard deviations (d,w,1 3 6m) or actual standard deviation of yearly totals (y)	Temporal coefficient of variation for values within-year (d,w,1 3 6m)
Arithmetic average of annual spatial coefficient of variation (d)	Temporal standard deviation for values within-year (d,w,1 3 6m)
Arithmetic average of annual temporal coefficient of variation (d,w,1 3 6m) or actual temporal coefficient of variation across years (y)	Variance of logged values (d,w,1 3 6m)
Arithmetic average of annual variance of logged values (d,w,1 3,6m)	Ratio of annual variance of logged values to their long-term equivalent (d,w,1 3 6m)+
	Quantiles of the 95th, 50th, and 5th percentile profiled regimes (d,w,1 3 6m), 50th upper confidence interval, 50th lower confidence interval (d,w,1m)

* d (daily), w (weekly), 1 3 6m (one, three, six monthly), y (yearly)

** Some of these items may be unavailable for website access

*** Number of sample points determines precision of confidence interval allocation, though only the variation in daily values is significant

\+ Ratio of annual to long-term variances of logged normalised stream data or climate data. Assess significance using F-test; degrees of freedom of year to long-term state = number of time intervals in year – 1; degrees of freedom for number of years = number of years – 1. Assumes logarithms are normally distributed (Zar 1984).

The non-parametric S-PLUS quantile function profiled annual records to provide the 95 per cent, 50 per cent and 5 per cent quantiles whilst the 90 percent confidence intervals for the 50 per cent series was obtained through determination of rank positions through binomial theory for each sample size (Conover 1980). Yearly scaled totals are observed period of record quantities and are not profiled. Ninety per cent confidence intervals for the observed yearly totals are provided for general information using jackknife estimation (S-PLUS ® 8 2007) with no repeated knots (quantities), and these intervals are not comparable to exactly profiled intervals obtained from within-year series. All annual and annualised stream flow data (daily averages in m^3/s) are presented as an index of discharge (m^3) scaled directly to the time reference period (daily, weekly etc.) assessed. Similarly height data is aggregated but are converted to an index of daily equivalents for extraction through web tools.

Reference quantile-percentile series are derived consistently across all annualised data types when at least four years of records exist. The S-PLUS quantile function is used to provide look-up series defined by:

- reference probabilities (e.g. 0 to 100 at one per cent increments) with linearly interpolated quantiles obtained from the annual values for each regime
- actual observed annual quantities with linearly interpolated probabilities, along with some benchmark indicators and estimated annual recurrence intervals for each regime value and probability of exceedence (Table 2).

No regime series are provided for annual totals and 90 per cent confidence intervals are not calculated for three and six monthly data due to their small sample size.

Table 2. Description of key common items* derived for observed and reference quantile-percentiles across data types for each reference time scale and zone.**

Reference percentile-quantiles	Observed annual quantiles and estimated percentiles
Reference percentile (d,w,1 3 6m,y)	Year (d,w,1 3 6m,y)
Interpolated index quantile for 95th percentile (d,w,1 3 6m)	Observed 95th percentile index quantile (d,w,1 3 6m)
Interpolated index quantile for 50th percentile (d,w,1 3 6m)	Observed 50th percentile index quantile (d,w,1 3 6m)
Interpolated index quantile for 5th percentile (d,w,1 3 6m)	Observed 5th percentile index quantile (d,w,1 3 6m)
Interpolated quantile for 50th percentile upper confidence interval (d,w,1m)	Observed upper confidence quantile for the 50th percentile quantity (d,w,1m)
Interpolated quantile for 50th percentile lower confidence interval (d,w,1m)	Observed lower confidence quantile for the 50th percentile quantity (d,w,1m)
Interpolated index quantity from annual totals (y)	Interpolated percentiles for the above quantiles obtained using the reference percentile-quantile series for scales as previously marked
	Estimated annual recurrence intervals for the interpolated percentiles, obtained as 1/interpolated percentile for scales as previously marked. Extreme events moderated by quantile smoothing using a 0.9999 multiplier.
	Observed index total (y)
	Interpolated percentile for observed total using associated reference series (y)
	Upper jackknife fitted confidence interval for observed total (y)
	Lower jackknife fitted confidence interval for observed total (y)

* Some of these statistics may not be available on the website, and some statistics may be estimated using reference data at appropriate time scales. Comparable yearly scaled recurrences cannot be derived because the data is not annualised. The user may produce recurrences using yearly data at own risk.

** d (daily), w (weekly), 1 3 6m (one, three, six monthly), y (yearly)

It should be noted that the 50 per cent (median) regime is sensitive to high frequencies of occurrence of zero-valued states. In very seasonal or dry environments the median regime, its lower confidence interval, and especially the 5 per cent regime may have a high occurrence of zero states within a normal year. However the confidence intervals accurately and representatively indicate the range of hydro-climate variation around the median and should guide evaluations of median conditions. The 5 per cent and 95 per cent regimes are particularly useful for the identification of low or high flow/rainfall within-year conditions, and when observations (quantities) persistently register close to the 50th percentile for these regimes then those time series observations may be said to have membership with those lower or higher hydro-climatic conditions. Repeated membership of annual data with these regimes may also indicate transitions in membership from median (1 in every 2 year conditions) to drier (1 in 20 years drier than the median) or wetter (1 in 20 years wetter than the median) regimes. Such transitions may be correlated with expectations for climate change. The evaluation of exceedence probabilities and their relationship with reference regimes for increasing temporal periods for aggregation (e.g. monthly to six monthly) will inform the detection of climate transitions because the longer duration time scale assessments become less variable and more stationary and often more like the yearly totals. Estimated confidence intervals for annual totals are provided as indicators of potential year-scaled variability, and because they are not exact, estimates may fall below zero levels, and these should be ignored.

6 Evaluation and Management of Variability

Hydro-climate data that are collated into zonal statistics combines multiple flow/rainfall duration processes that are measured or estimated at specific points within a region. This regionalisation approach is required to spread the best and longest records of information available across the large number of ungauged catchments in Queensland to enable the behavior of wetland inundation to be characterised in its many forms. The method does not attempt to make predictions in ungauged basins but seeks to characterise hydro-climatic conditions across different temporal scales within ecoregions experiencing similar variability in hydro-climatic processes.

Traditional hydrological methods aim to compare and distribute point measures using shared probability functions based on the similarity of parameters of probability functions, and seek to ensure that variability in the form of spatial heterogeneity or statistical heteroscedasticity is sufficiently managed to enable regional flow frequency analysis (e.g. regional flood risk or regional low flow analysis) across similarly behaving catchments (e.g. L-moment techniques (Abida & Ellouze 2008), sometimes including spatial correlation analysis of randomness (Modarres 2008)). A goal for these methods is to overcome spatial and temporal scaling factors that influence measures due to differences in flow accumulation and transfer processes (e.g. Gottschalk et al. 2006). These methods are sometimes improved by the stratification of basins by similarity in rainfall or runoff processes and terrain, and by catchment areas, but the methods usually ignore these factors by demonstrating that the assemblage of records used show similarity in statistical properties, which can be enhanced by normalising point flow (gauge station) data to its long-term mean (Gottschalk et al. 2006, Detenbeck et al. 2005) and by data quality control and parameter optimisation (Bardossy and Singh 2008).

The problem for the investigation of ecological problems, such as the evaluation of wetland inundation processes, is that these mechanisitc methods for information management diminish:

- the ability to generate ecologically relevant information and characterisations across large areas of contrasting processes (e.g. non-floodplain dependent processes)
- the ability to investigate hypotheses for wetland processes, especially when spatial connectivity cannot be determined.

Indeed mechanistic bottom-up methods assume that specific outcomes and information constraints are desirable to provide predictable reference information (Savenije 2008). Ecological sciences cannot readily engage with this determinism because biological processes, including population dynamics dependent on hydrologic connectivity, is influenced by a multitude of factors, such as water quality, timing and duration of flows and modes for dispersal across many guilds of species and life forms (e.g. larval versus winged adult invertebrates, flighted birds versus fish versus crustacean dispersal) for different wetland filling processes (run-off versus ground water versus rainfall versus overbank flow), so determinism for flow predication is often not helpful or readily developed.

In these circumstances, such as for methodology of this report, to characterise regional wetland filling characteristics, targets for reference information is not determined, but instead ecoregional similarity is sought, gauge station data is scaled to its long-term mean, independence through annualised sampling for different time scales is used, and a spectrum of regionalised probability curves is provided to characterise temporal variabilty and membership of observations with different rainfall, run-off, discharge and stage height processes (see also Smakhtin and Batchelor 2005, Schroder 2006). Rich temporal information is required to explain biological processes, and to identify the most tractable reference probability information if hydro-climatic heterogeneity/heteroscedascity is a problem, thereby enabling a ‘tuning’ or thresholding of assessments for resource assessment or management (e.g. Belmonte et al. 2010, Detenbeck et al. 2005, Hunger and Doll 2008, Tetzlaff et al. 2007).

This type of empirical multi-temporal generation of probability information promoted by Vogel and Fennessey (1994) provides reference information that when combined with spatial observations of wetland filling provides the capability to characterise wetland filling processes by their probability or quantity, which is similar to the spatial connectivity indicators of Michaelides and Chappell (2009) but applied temporally within a defined assessment zone. This stochastic top-down characterisation process when applied consistently across data types allows comparison of hydrological processes across temporal scales without the need to explicitly account for specific process mechanisms. As Michaelides and Chappell conclude, ecological applications require inputs that explain emergent hydrological behavior rather than hydrological complexity (see also Tetzlaff et al. 2007, Savenije 2008).

This method does recognise the potential influence of rainfall, runoff, discharge and stage height heterogeneity on observed processes and statistics and the resultant characterisation and interpretation of wetland filling processes. Method design handles these issues elegantly in multiple ways.

1. Data is sampled within ecoregions which show similar characteristics and variations in topography, geology, rainfall and drainage and terrestrial ecosystems.
2. The data is averaged at a daily time-step across zone, with gauge station data normalised to long-term means prior to zonal averaging. Gauge station data is quality controlled prior to daily collation. Due to the nature of the spatio-temporal construction of the time series data, including scaling to larger time scales, hydro-climate statistics should be considered indices of zonal rainfall, run-off, discharge and stage height.
3. Regime reference statistics are obtained by independently profiling percentile-thresholded regimes annually (e.g. Figure 3), thereby minimising the effects of serial correlation (bias) in observations which is prevalent in period-of-record methods.
4. The empirical 90 per cent confidence intervals are obtained from the probability distributions for each median regime. These illustrate the statistical variability / precision of the median (1 in 2 year) assessments, directly revealing the amount of uncertainty in the separation of dry, median and wet regimes.
5. Within-year variability is directly indicated by the dispersion of regime quantities for any given probability, whilst between-year variability is depicted by the range of quantities per regime across all probabilities of exceedence (Figure 4). When evaluated together, heterogeneity in the processes observed for each regime becomes apparent such as in the Diamantina Basin in the Diamantina Plains sub-bioregion (see Users Guide), and the effect of increasing temporal scale on the reduction of heterogeneous hydrological conditions becomes apparent.
6. Reference and benchmark information is provided to identify anomalous values, recalling that anomalies may be due to decadal variations (e.g. El Nino) or unusual seasonal conditions as much as changes in the quality, quantity or representativeness of the underlying data. Statistics for comparison against time series zonal data include the long-term mean, the mean, median and regime statistics for the year assessed, and the coefficient of variation for the year and its long-term mean, and the ratio of the variance of logged zonal statistics to the long-term mean of annual variances. The coefficient of variation and ratio of variances are important indicators to evaluate unusual within-year relative dispersion of values, and potentially significant differences in variability between years which could be caused by heterogeneity, statistical heteroscedacity or anomalous hydro-climatic conditions. The Users Guide demonstrates the application of the F-test statistic on variance ratios in the Diamantina Basin to discriminate and interpret domains of problematic variability. The tools provided enable not only the identification of anomalous annual periods but the investigation of that year's data to characterise the temporal patterns of variation and the identification of the potential benefits of temporal scaling to minimise the effect of variability on within-year assessments that utilise reference regime statistics.

The method thereby provides the tools (e.g. techniques 4 to 6 above) to explicitly evaluate and manage the effects of variability within the data within ecologically meaningful regions. These tools are consistent with regional hydro-climate modelling methods and for ecological applications to characterise emergent behavior including aquatic ecosystem connectivity (e.g. Schroder 2006, Tetzlaff et al. 2007, Michaelides and Chappell 2009, Sorrano et al. 2010).

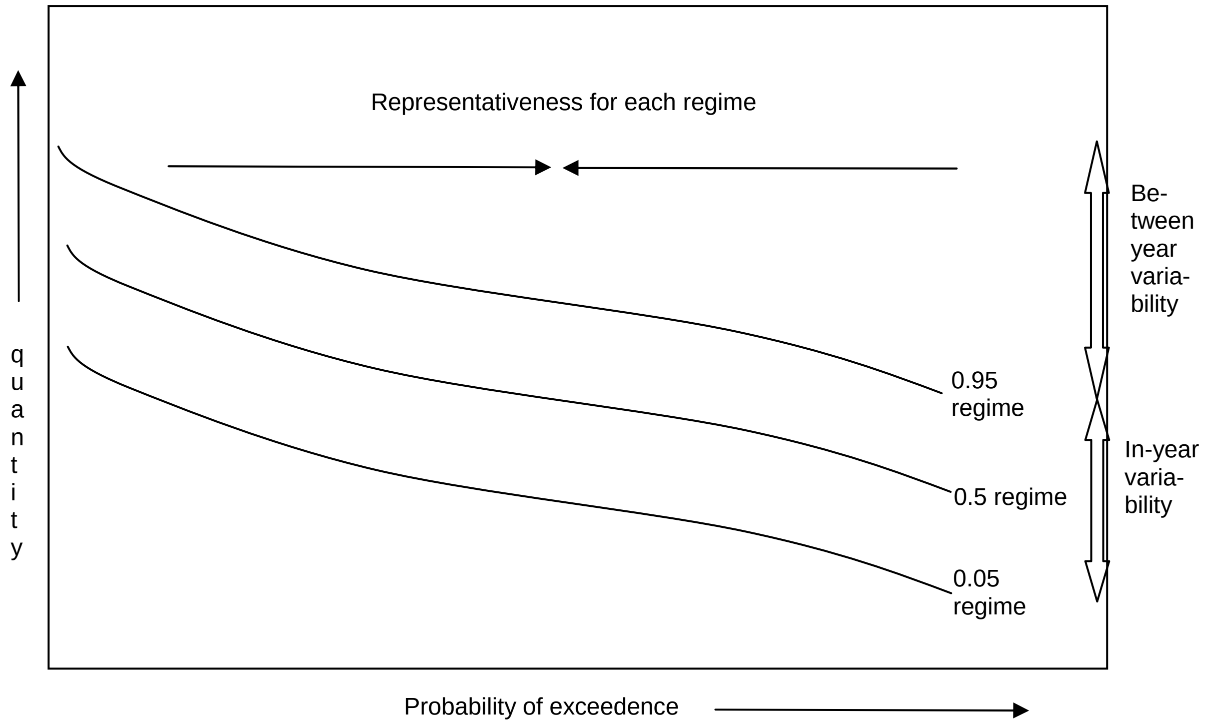


Figure 4. Idealised example of variability and representativeness of data values characterised by reference probability of exceedence series for each hydro-climate regime and reference time scale. Curves with a larger range of quantities represent conditions of greater inter-annual variability whilst the degree of within-year variability is indicated by the separation between regimes.

7 Potential Applications

The potential applications for the tools should be used with regard to the Departmental disclaimers for these tools. Users should download data and model it as required in spread sheet or statistical analysis or similar software.

Below are several examples of potential application.

- The tools may be readily accessed to query time series for a specific date. This is useful to evaluate the hydro-climatic conditions that may represent what is depicted by a particular Landsat image and the mapping of inundation for the associated date. For example the wet scene in Figure 5b (5 March 1991) is quite different from the dry scene in Figure 5c (5 October 2005). Extraction of quantile and probability of exceedence information for run-off (a surrogate indicator for stream discharge for the scene dates) at weekly to monthly scales clearly shows the differences in potential inundation processes for these desert channel wetlands (Table 3).

In addition, once a general relationship between event size and extent is understood, the time series data could be filtered by event size using different time scales to identify dates that may present flood conditions suitable for image selection and mapping. This could be used to improve the representation of different hydro-climate regimes and their effect on the distribution of inundation.

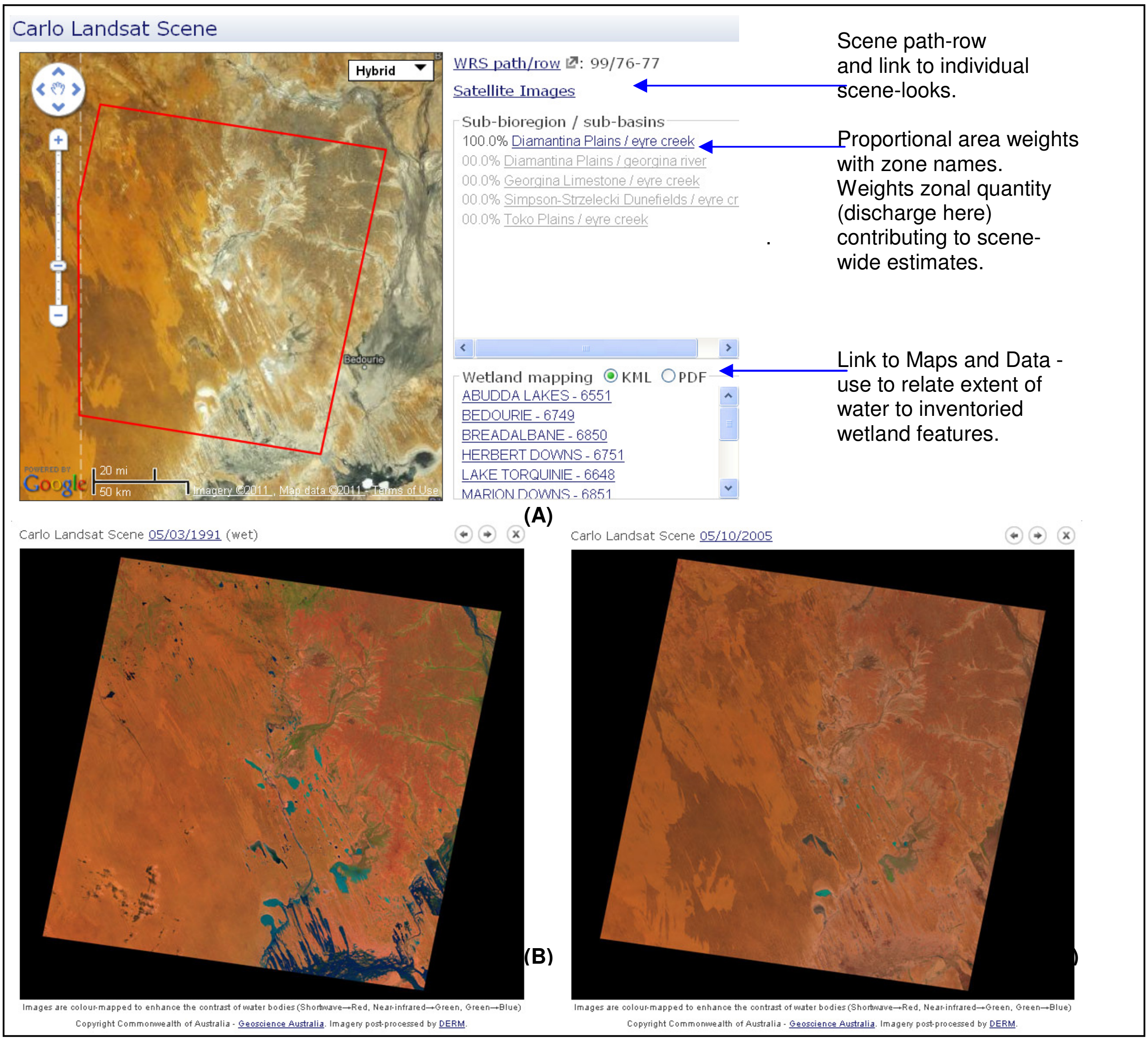
The 'Landsat Scene' interface provides a link to the wetland mapping (figure 5a). This link may be used to view the geographic context of wetland features and relate inundation event characteristics to mapped wetland extent, wetland type and frequency of imaged inundation. Refer to the 'Users Guide' for additional information about the link to wetland maps.

Table 3. Runoff quantities observed for the Carlo scene and key sub-bioregion (Diamantina Plains), with interpolated probabilities of exceedence obtained from the sub-bioregion for the 95 per cent regime (wet assessment) and 5 per cent regime (dry assessment) statistics relative to image dates for wet and dry image and reference time scales*.

Three month period preceding 5 March 1991, Wet Carlo scene				**Three month period preceding 5 October 2005, Dry Carlo scene**			
Scene Wide (run-off, mm)		Sub-bioregion (probability of exceedence)		Scene Wide (run-off, mm)		Sub-bioregion (probability of exceedence)	
Week	Month	Week	Month	Week	Month	Week**	Month**
0.0004	0.0004	0.75	0.997	0.0	0.0	≤1	≤1
0.0	15.05	0.75	**0.06**	0.0	0.0	≤1	≤1
0.0	44.16	0.75	**0.0**	0.0	0.0	≤1	≤1
0.0		0.75		0.0		≤1	
12.12		**0.007**		0.0		≤1	
0.8842		**0.312**		0.0		≤1	
2.045		**0.0134**		0.0		≤1	
1.476		**0.02**		0.0		≤1	
42.68		**0.0**		0.0		≤1	
0.0094		0.557		0.0		≤1	
0.0003		0.75		0.0		≤1	
0.0		0.75		0.0		≤1	

*The final cell in each column is equivalent to the end date (e.g. 5 March) up to which the preceding time values are assessed. Periods that may be associated with flooding due to regional run-off have probabilities highlighted in bold. For monthly values the final month listed is February or September. It is the user's responsibility to include the current/end/target month if weekly values indicate the need for it.

**All reference quantiles are zero for the 5 per cent regime and zero states are certain to occur every year and effectively for all of the year if the 5 per cent (drought) regime prevails through a year.



Carlo Landsat Scene

WRS path/row: 99/76-77

Satellite Images

Sub-bioregion / sub-basins

100.0% Diamantina Plains / eyre creek
00.0% Diamantina Plains / georgina river
00.0% Georgina Limestone / eyre creek
00.0% Simpson-Strzelecki Dunefields / eyre cr
00.0% Toko Plains / eyre creek

Wetland mapping ● KML ○ PDF

ABUDDA LAKES - 6551
BEDOURIE - 6749
BREADALBANE - 6850
HERBERT DOWNS - 6751
LAKE TORQUINIE - 6648
MARION DOWNS - 6851

Scene path-row and link to individual scene-looks.

Proportional area weights with zone names. Weights zonal quantity (discharge here) contributing to scene-wide estimates.

Link to Maps and Data - use to relate extent of water to inventoried wetland features.

Carlo Landsat Scene 05/03/1991 (wet)

Carlo Landsat Scene 05/10/2005

Images are colour-mapped to enhance the contrast of water bodies (Shortwave→Red, Near-infrared→Green, Green→Blue)
Copyright Commonwealth of Australia - Geoscience Australia. Imagery post-processed by DERM.

Images are colour-mapped to enhance the contrast of water bodies (Shortwave→Red, Near-infrared→Green, Green→Blue)
Copyright Commonwealth of Australia - Geoscience Australia. Imagery post-processed by DERM.

Figure 5. The Carlo scene area selected by the web-tool (A) to view its hydro-climatic conditions for specific dates for wet (B) and drier (C) imagery.

- The provision of reference quantile-probability of exceedence data sets can be used to convert between quantiles and probabilities. This can be achieved either through simple linear algebraic interpolation between points that straddle a query value or through the use of statistical functions in appropriate software to interpolate values. This enables the user to convert a quantity to a probability or probability to a quantity, which facilitates data exploration and the comparison of contemporary and historical data. For example, a user may have a contemporary value but would like to determine the relative position of that value in each historical flow regime to optimise a search of historical time series data. This can be obtained through interpolation of quantity against probability by regime to determine probability and data spread in a regime series.
- The shape of reference series is an outcome of regional hydro-climate processes i.e. the persistence of flow sources, and their variability and magnitude for different regimes. The confidence intervals for the median series indicate the historical variability of values representing conditions that are similar to the median. A loss of precision in median series at low flows indicates much greater variability in the frequency of occurrence of low flows in normal years,

and likewise for divergence at high flows. Conversely more uniform and elevated levels of flow are indicative of consistent elevated inflows of source water due to high and persistent rainfall across years (for specific regimes) or due to flow augmentation from reservoirs or irrigation outflows up-stream. Users should interpret hydro-climate indices or data in the context of these process effects for each regime assessed (e.g. Assani et al. 2010, Brodie et al. 2007a, Bunn et al. 2006, Wong et al. 2007, Sheldon and Thoms 2006, Sanz and del Jalon 2005, White et al. 2008, Frazier and Page 2006).

- In addition to the above, users may convert probability of exceedence for annualised data into annual recurrence interval equivalents. For example, a probability of one per cent (0.01) is equivalent to a 1 in 100 year event for the regime assessed (1/0.01 = 100). This may assist with the communication of events noted or selected in time series analysis and related to specific regimes. It should be noted that probabilities and recurrence values have a random element and only characterise historical conditions. It is quite probable that events occur more than once in their expected return interval due to the natural spatio-temporal variability of climatic conditions and the inability to incorporate this variability into the zonal statistics.
- Many ecological field surveys or monitoring activities depend on the sampling of conditions influenced by specific/representative hydro-climatic conditions. By characterising landscape or wetland conditions spatially through satellite images for particular dates and hydro-climatic conditions and relative to previously sampled data, ecologists could monitor contemporary hydro-climate data to trigger/schedule surveys based on the relationship between event recurrence intervals and imaged/previously surveyed conditions.
- Expectations for wetland functions are characterised by wetland typologies and survey data (e.g. Wetland*Info* <www.derm.qld.gov.au/wetlandinfo/site/WetlandDefinitionstart/WetlandDefinitions/Typologyintro.html>). The processes for wetland inundation (inflow and outflow) and the relationship between inundation, wetland connection and biological response differ between wetlands, even when they share the same typology due to different geographical or biological contexts (Catford et al. 2007). The hydro-climate tools provided here may facilitate the characterisation of local wetland system inundation processes by profiling and analysing the suite of available data, calibrating the data to known local observations and interpreting this information in a landscape context using digital elevation models etc.

Using the above techniques, time series data and hydrological indices could be evaluated to identify disturbance to wetland filling processes post development of water infrastructure or landscapes. For example the persistence of aseasonal flows may increase and overall flow magnitude may increase. Apply this information to evaluate potential change in values of environmental assets.

8 Limitations of the Information and Potential Applications

These tools are provided for general information and their application is at the users own risk. Some potential limitations to applications are identified here. Users are requested to read the product disclaimers provided at the website before proceeding with applications.

The stochastic zonal information provided is not suitable for deterministic (causal) predictive modelling. For example persistent zero-flow regional estimates may restrict percentile-quantile application at a local scale where other sources or processes of water movement may be important. Users should not assume either independence or interdependence between different data types for the purposes of modelling. The implication of this is that the information is suitable for statistical classification and characterisation activities at a zonal scale but not for precisely identifying, determining or predicting conditions at any point within a zone. The output is therefore most applicable to associative, decision rule (e.g. decision tree) or time series based modelling rather than predictive parametric modelling that use mixtures of (multi-variate) data types (rainfall, run-off, flow, stage height) unless these are calibrated to local observations.

Particular details to be aware of include:

1. Fitness of the data for specific applications is a matter for the user to judge after understanding the general associative nature of the data and the limitations imposed by zone summarisation. The representativeness of zonal statistics varies in space and time. In particular the combination of non-similar hydrographic properties may cause significant within-year variation. This method accommodates this variation by normalising each gauge stations data to its long-term mean before collation of zonal statistics. The resulting zonal statistic is a mean of normalised values, which at a daily time step is centered on 1.0. The normalised values are later scaled up by the estimate of zonal long-term daily discharge (or height) data. This means that:
    - zonal values will never be exactly related to any single point of observation over time although variation around associated exact values should be consistent
    - discontinuities in zonal values will occur at zone boundaries.
2. Rainfall and runoff statistics are derived from rainfall modelling through a 0.05 degree grid. The interpolation method used (Jeffrey 2006, Jeffrey et al. 2001, Rayner 2004) imparts some bias where meteorological data is sparse and in mountainous or rain-shadow areas. Sub-bioregion zones help to reduce some of this bias, but some undesirable effects will persist. If these anomalies or discontinuities are an issue, users should seek to relate time series or reference series values to 'exact' values to calibrate zonal statistics to local observations. This will impart some improved accuracy although precision will still be as variable as the underlying factors (e.g. variability in gauge station contribution) and will not account for climate change or changes occurring largely outside of the period of time sampled by the zonal statistics.

   Rainfall and runoff data is comprehensive in time and space for the period of record. Stream gauge data is distributed unevenly across the state with station operation often being for limited durations or episodic. This is why zonal statistics are required to spread information across large areas when sparse or unreliable information exists. Each gauge station's contribution was quality controlled before collation, but whole years are required to produce annualised statistics. Therefore many zones do not have discharge or stage height information at all or for a significant number of years. At least four years of data are required to estimate reference curves, but at least 15 or 20 years of records are recommended to provide information that is representative of most annual and seasonal conditions.
3. Quantiles with repeating recurrences, such as a value of zero occurring 60 to 100 per cent of the time in a regime series may cause some confusion: e.g. a quantity that spans 40 per cent of all expectations (e.g. from a probability of 0.6 to 1.0) means that that quantity is likely to occur in any year and the associated conditions would be expected to not occur in a year with a probability of (1–0.6) or 40 per cent of the time for that regime, data type and time scale (e.g. Wong *et al.* 2007). This is particularly common for runoff estimates. If all quantiles are zero then in a regime series there is '100 per cent certainty' (relative to the historical archive

accessed) of zero states for a full year period for the temporal scale (e.g. daily), regime and data type assessed. No average recurrence (annual) interval can be calculated for these no-flow state conditions because they represent a persistent condition within and between years. Sensitivity to low flow conditions may be reduced by increasing reference time scales, for example shifting from daily to monthly estimates.

4. The 0.05 and 0.95 percentile-quantile series are useful to profile near-maximum and near-minimum hydro-climate scenarios for a zone, but they do not necessarily incorporate the maximum or minimum observations from a zone sample. Extreme observed quantities will lie outside of the assessable zonal range. In addition to this the rainfall and runoff data is already spatially and temporally smoothed and cannot be expected to correspond to specific observations at specific rainfall or stream gauge observation sites.
5. Zone statistics as output by this work should be assessed for the extent of the zone selected with the variation of values referenced to the annual and long-term benchmark statistics. Lumping of within-scene zone statistics provides an estimate of scene-wide conditions but these may not be realistic or available when limited within-scene data is available or the information is concentrated within a small number of zones (e.g. the effects of localised storms). Even within a zone it is possible that a user may observe the effects of a localised storm which is not logged by the Bureau of Meteorology and which does not influence stream gauge observations. Spatially and temporally the statistics may be ‘out of phase’ with local observations due to time lags involved in the concentration and drainage of water, due to the absence of ground water data, due to the distribution of actual observation points, and due to any biases in the observations, such as interpolation effects in source rainfall / runoff data, or changing gauge station height datum and effects of different gauging conditions (e.g. locations in reservoirs versus in streams). Zonal statistics are discrete for a whole zone and except for the confidence intervals for the median regime, do not provide a range of values per statistical outcome. Archived reference statistics of precision and variability can be used to indicate the range of underlying levels but not the distribution of these levels. Calibration of zonal statistics to local observations may improve the reliability of applications.
6. If time series data are filtered to select candidate dates for which satellite scenes may have imaged inundation representative of particular hydro-climatic conditions the user must be aware that other factors must be considered in the image selection process. The user should download and evaluate metadata about the atmospheric conditions (especially cloud cover) and solar elevation and zenith and review any issues specific to the satellite sensor of interest (e.g. line drop outs, sensor calibration etc.). The user should always view quick-look summary images for each date and sensor before ordering an image.
7. The lumping of zone statistics to a scene scale using zone within-scene weights requires the use of specific SILO gridded templates. No support is provided for the estimation of exact zone to scene conversions. In addition the delineation of zones is subject to change due to mapping update, and the Landsat scene areas are defined by non-standard frames as determined by SLATS.
8. Assessment of scene quantities for stream gauge data is problematic because the aggregation of data to scene totals requires observations from all assessable zones. No dynamic allocation of zones to scenes occurs, and even if it was available, the results would not be comparable between dates due to differences in contributing areas. This means that for most scenes and dates no scene wide aggregation can occur due to variation in data availability. In these situations the user must select a key zone of interest and compare hydrological conditions over time in it rather than at the scene scale, or select a surrogate climate item (rainfall or run-off) that does span all zones and times for evaluation (e.g. Table 3). In addition, no interpolation of probabilities can occur at the scene scale for any item as no reference quantity-probability series exist at that scale. Interpolation of probabilities can only occur at the zone scale using zone reference quantile-probability series.
9. Stream gauge stations may fall close to a zone boundary and users should compare the hydro-

climatic conditions of adjacent zones when conditions along a zone boundary are of interest.

10. Ground water is not explicitly modelled in any of the zonal statistics. Various models exist to identify ground water contributions to stream flow through analysis of stream flow recession and baseflow curves when stream storages are noticeably augmented by soil interflow and ground water flows. Local calibration of normalised stream gauge values in conjunction with ground water assessment methods (e.g. Brodie et al. 2007a, 2007c) might enable the modelling of ground water contributions although this is at the users own risk, realising that zonal information may span different ground water aquifers and flow accumulation processes.
11. While exact confidence limits are provided for (annualised) daily through to monthly data scales, no comparable confidence intervals can be provided for three and six monthly time scales, and the exact confidence limits are not directly comparable with the jackknifed annual quantile confidence limits for yearly totalled (period of record) data.
12. Stream flow data have limited periods of recorded history. Contemporary observations may or may not be suitable for comparison with the historical context sampled. However some context is better than none and it is the user's responsibility to note the period of record archived and the number of sample points (i.e. gauge stations) contributing along with statistics that benchmark variability in the data. At least four years of data are required for the provision of percentile-quantile series, but 20 or more years are recommended for percentile-quantile interpretation to ensure the estimates are adequately representative of historical conditions.

    In addition the re-scaled output from normalised zonal flow data series may appear poorly scaled to local observations due to the size of the estimated long-term zonal average used to scale up normalised values (which are centred on a value of 1), and if this is a modelling issue it is the responsibility of the user to calibrate the scaled values to observed local conditions.
13. An alternative seasonally focused approach to percentile-quantile analysis is to compile statistics at the temporal scale desired but only for the specific day, week, month, three or six month period of the calendar year. This approach increases the capacity to identify season specific phenomenon such as El-Nino effects but it requires many more years of data to provide sufficient precision for assessment, and confidence intervals can only be estimated through parametric regressions or through resampling (e.g. jackknife) techniques. These types of period-of-record assessments do not include climate regime modelling unless multiple within-day (or time-frame) observations are available. Multiple within-day observations may be available for some stream gauge data but not for the spatialised rainfall and runoff data referenced by this report, and the base time scale used in all assessments is the daily scale. Using these tools seasonal conditions can be assessed by extracting time series data for the season or period of interest. Repeated extractions of seasonal information can be assessed through different climate regimes to profile seasonal variations and the representativeness of particular seasonal conditions. At this stage of product development seasonal data extraction and interpretation is the user's responsibility.
14. Violations occurred for some zonal statistic calculations in the source data (e.g. due to missing data or due to division by zero). These violations are indicated by character codes (e.g. N, M, I) or as blanks. For example where less than four years of data occur the non-calculation of percentile information is indicated by blanks.

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