Australian Rainfall & Runoff

Revision Projects

Climate Change Research Plan Summary

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AUSTRALIAN RAINFALL AND RUNOFF
CLIMATE CHANGE RESEARCH PLAN

Summary

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1. Introduction

Australian Rainfall and Runoff (ARR) is a national guideline document for the estimation of design flood characteristics in Australia. With nationwide applicability and coverage of our varied climates, the information and the approaches presented in ARR are essential for policy decisions and projects involving:

- infrastructure such as roads, rail, airports, bridges, dams, and stormwater and sewer systems
- town planning
- mining
- developing flood management plans for urban and rural communities
- flood warnings and flood emergency management
- operation of regulated river systems
- estimation of extreme flood levels

There is now widespread acceptance that human activities are contributing to observed climatic change. Human-induced climate change has the potential to alter the prevalence and severity of rainfall extremes, storm surge and floods. Recognition of the risks associated with climate change is required for better planning of new infrastructure and mitigating potential damage to existing infrastructure (Taylor and Philp, 2010). Furthermore designers of hydraulic structures will need to base their decisions on up-to-date information from reliable sources. Thus the revision of the current (1987) edition of ARR was identified as a priority in the Council of Australian Governments' National Climate Change Adaptation Framework in 2007. In June 2008 the then Federal Department of Climate Change announced $2 million of funding to assist the revision.

There are many aspects about potential changes to the behaviour of extreme events for which knowledge is scant. For example, how will rainfall extremes (and in particular Intensity-Frequency-Duration relationships which describe these extremes) change as the atmosphere warms? How will antecedent moisture conditions in the catchment respond to increasing temperatures and changing rainfall regimes? Will the rainfall temporal patterns used for design flood estimation need to be modified? And how will compound extremes that are forced by more than one physical process change as various features of the atmosphere and oceans change? Answers to such questions will require careful research design, the application of innovative technologies, and a strategic approach to research investment and engagement. This will ensure that the research is fit for purpose and accessible to practitioners.

This document describes a five-year research plan for enhancing our understanding of how projected climate change may alter the behaviour of weather extremes relevant to ARR and for the incorporation of this knowledge in design guidelines. The plan draws on the expertise and experience of members of the Technical Committee for the revision of ARR as well as the Australian research community, and supports ongoing and new collaboration. It presents a vision for bringing research and practice together over the next 12 months (Stage 1) and the following four years (Stage 2).

2. Research Purpose

The strategic goals of the research plan are to:

- Facilitate a more coordinated and collaborative approach to extremes research.
- Develop a national research capability that is more focussed, and used more efficiently and effectively to achieve the best outcomes for the nation.
- Improve engagement between researchers and practitioners.
- Enhance access to information that is supported by the latest developments in climate change science.
- Encourage widespread use of the information and tools arising from the research described herein.
- Make a significant contribution to knowledge about the potential behaviour of future weather extremes and to the routine design of hydraulic structures.

3. Research Design and Integration with ARR

3.1. Overview

The ARR Climate Change Strategy (2011) identified six key themes for research:

- Historical rainfall trends.
- Rainfall intensity-frequency-duration relationships.
- Rainfall temporal patterns.
- Continuous rainfall sequences.
- Antecedent conditions and baseflow regimes.
- Simultaneous extremes.

Research in these themes will require a systematic application of knowledge from a range of disciplines including meteorology, climate science, hydrology and statistics. Research in each of these areas has been designed to build on the work that has been completed to date as part of the ARR revision project, such that any climate change aspects associated with flood estimation can fit in seamlessly with existing methodology and advice.

The research plan has been developed over a five year horizon, and has been divided into two distinct stages. The first stage has been designed to leverage off existing research on flood risk in Australia, and has an intended duration of 12 months in order to be included as part of the forthcoming revision of ARR. The second stage has been designed to address more fundamental scientific issues related to the implications of climate change on flood risk, as well as expand the domain of the research in the first stage to a larger geographic area. It is envisioned that this work will take a further four years.

3.2. Description of the Research Themes

3.2.1. Historical rainfall trends

Research objectives: The purpose of this theme is to evaluate the presence of trends in historical rainfall extremes, focusing on shorter (sub-daily) rainfall information which has thus far received less research attention. The basis of this research is the outcomes of several recent studies showing potential trends in rainfall at sub-daily timescales [Australian Bureau of Meteorology, 2010; Jakob et al., 2011; Westra and Sisson, 2011]. The first stage of this work will involve: (1) developing a database of high-quality continuous rainfall data; (2) identifying suitable statistical methods for trend analysis; and (3) re-examining the existing research on sub-daily rainfall trends in Australia based on this enhanced dataset. The second stage will involve a more detailed trend analysis of continuous rainfall extremes to evaluate the evidence of climate variability and change over the historical record.

Intended research outcomes: The outcomes of the first stage will comprise: (1) a database of approximately 50 to 100 high-quality continuous rainfall records from the Bureau of Meteorology and other sources, with sufficient meta-data to evaluate the implications of any systematic change in gauging technology; (2) the results of an interim analysis of any systematic change in sub-daily intensity and frequency based on re-examination of the studies by [Australian Bureau of Meteorology, 2010; Jakob et al., 2011; Westra and Sisson, 2011]; and (3) a literature review of 'state of the science' approaches to investigating the presence of trends in historical rainfall data. In the second stage, a report will be provided and will cover the evidence of climate variability and anthropogenic climate change on annual and seasonal sub-daily rainfall extremes, as well as the significance of climate variability and change on rainfall for a range of durations and exceedance probabilities of interest to ARR users.

Guidance to be provided to ARR users: The first stage will focus on developing the high quality database of continuous rainfall data which will support research in Themes 2, 3 and 4. Furthermore, outcomes of the interim analysis will complement advice on trends in daily rainfall data provided as part of the ARR Intensity-Frequency-Duration (IFD) revision project.

3.2.2. Rainfall Intensity-Frequency-Duration Relationships

Research objectives: This research theme aims to quantify possible changes and uncertainties in IFD data as a result of anthropogenic climate change. Furthermore, interim advice is to be provided to practitioners on how these changes should be included in design and planning decisions. Stage 1 will be restricted to the Greater Sydney region due to the ability to leverage off previous and current downscaling projects over this area. Furthermore, information will be provided on the feasibility of the methodology for understanding changes to IFDs resulting from anthropogenic climate change which can be used to inform subsequent work. Therefore an important part of the work will include a comparison of results from different General Circulation Models (GCMs) and Regional Climate Models (RCMs), as well as the evaluation of these results against historical (gauge- and radar-based) data. The second stage will extend this work to other population centres and regions, including Southeast Queensland, Melbourne, Adelaide, Northwest Western Australia and Southwest Western Australia.

Intended Research Outcomes: In the first stage, various simulation outputs will be generated using the Regional Atmospheric Modelling System (RAMS) and the Weather Research and Forecasting (WRF) models. Outputs from these models will be provided over the Greater Sydney region with temporal resolutions of rainfall down to five minutes. Radar data will also be reprocessed by removing inhomogeneities introduced by changes in processing algorithms. Based on these results, IFD curves for current and future climates will be generated at gauged and ungauged locations (< 5 km resolution) within the region encompassing Sydney-Wollongong-Newcastle-Canberra. Furthermore, Depth-Area (DA) curves for a nominated catchment will be calculated under current and future climatic conditions. Finally, results will be compared to out-of-sample validation sites, and the results from different approaches will be evaluated and compared.

In the second stage, the RAMS-based simulations will be extended to Southeast Queensland, Melbourne, Northwest Western Australia and Southwest Western Australia for current and future climates. Furthermore, 10 km WRF-based simulations will be run over the Southeast Australian domain, while 2 km resolution WRF-based simulations will be run over Melbourne, Brisbane & Adelaide. Radar data will be calibrated to rain gauge records, and this information will be used to understand the spatial extent of extreme rainfall events to evaluate the performance of downscaled projections of rainfall extremes. Finally, IFD curves for current and future climates will be developed based on linking spatial statistical models of pluviograph data to multiple high-resolution simulations (models yet to be determined) of current and future climates.

Guidance to be provided to ARR users: In the first stage, the results of the different methods will be synthesised and an assessment of the methods for calculating IFDs in the greater Sydney region will be conducted. Uncertainty will also be quantified, based on comparisons between the models as well as a comparison with radar/gauged data. This project is expected to lay the foundations for the development of design rainfall estimates at high temporal and spatial resolutions as required by key stakeholders in the greater Sydney region. The second stage will extend this work to a larger geographical domain, as well as provide more detailed information on uncertainty due to the different modelling approaches.

3.2.3. Rainfall Temporal Patterns

Research objectives: As part of the revision to ARR, a new method of determining rainfall temporal patterns based on observed rainfall data is being prepared by ARR Project 3. The proposed method will create temporal patterns based upon the dominant extreme rainfall-producing mechanisms (i.e. frontal, convective etc) under historical climate assumptions. The objectives of this climate change research theme are therefore to: (1) apply this revised method on downscaled reanalysis data to determine if the modelling methodologies reproduce the observed temporal patterns; (2) determine if there are likely changes in the frequency distribution of these temporal patterns projected for the future; and (3) identify the underlying changes in the mix of storm types which might cause temporal patterns to change.

Intended Research Outcomes: The outcome of this theme will be an estimate of how climate change will affect the temporal patterns of rare rainfall events, which is to be used for design purposes. This includes an investigation of the change to the mix of storm types (e.g. east coast low, frontal) and also how some of the key statistics are likely to change (e.g. the percentage of front, middle and back loaded storms). Ensembles of temporal patterns for key durations and frequencies will be developed that can be tested using an industry standard runoff routing model. The work in this theme will use the outcomes of the work in Theme 2, and therefore the first stage will focus on the greater Sydney region while the second stage will cover the other domains to be analysed in Theme 2.

Guidance to be provided to ARR users: The updated ARR method will use an ensemble of temporal patterns for design flood estimation; therefore it will be necessary to produce either new ensemble patterns or sufficient information about likely changes to alter the ensemble mix.

3.2.4. Continuous Rainfall Sequences

Research objectives: The objectives of this theme are to develop and test approaches for continuous rainfall generation for a future climate, which will be suitable for use with continuous rainfall-runoff models. In the first stage this will include development of a methodology for generating daily sequences of rainfall using a stochastic downscaling framework, followed by a disaggregation algorithm which provides information on sub-daily sequences at a six minute resolution. A detailed characterisation of uncertainty, including the influence of different GCMs and predictor sets, will also be considered. In the second stage, the downscaling algorithm will be adjusted to use the higher-resolution outputs from WRF and CCAM, and a detailed comparison of different approaches will be undertaken.

Intended Research Outcomes: The research will produce a procedure for generating daily rainfall sequences at ungauged locations with a focus on extremes, given GCM simulations of relevant atmospheric variables suitably corrected to impart low-frequency variability. Furthermore a procedure for formulating continuous (sub-daily) rainfall sequences given the daily rainfall for gauged and ungauged locations will also be developed. Finally, this information will enable derivation of both IFDs and the pre-storm antecedent rainfall characteristics, and thus provide an alternative approach to event-based estimation of design floods.

Guidance to be provided to ARR users: It is expected that ARR users can be given tools to generate continuous rainfall sequences at locations of interest, and advice will be provided on how to use these sequences to ascertain the resulting design flood and associated confidence intervals.

3.2.5. Antecedent Conditions and Baseflow Regimes

Research objectives: To provide guidance on changes in assumptions about baseflow and antecedent rainfall for design flood applications in a warmer climate.

Intended Research Outcomes: In the first stage, climate change simulations available through past studies (e.g. the Murray Darling Sustainable Yields Project, the Western Australia climate change study) will be used to assess changes in: (1) baseflow preceding extreme daily rainfall events; (2) antecedent rainfall and soil wetness prior to the extreme daily rainfall events; and (3) the extension of the method to other parts of Australia. In the second stage, the continuous sequences generated as part of Theme 4 will also be used to better relate the extreme rainfall with the antecedent conditions.

Guidance to be provided to ARR users: Advice will be provided about the distributional changes in both antecedent and baseflow characteristics under assumed climate change scenarios.

3.2.6. Simultaneous (joint) extremes

Research objectives: Many damaging floods arise when extremes are caused by the simultaneous (or near-simultaneous) occurrence of multiple physical forcings. In this project, two approaches are proposed, based on statistical modelling and direct analysis of data products using typological classification methods. The aim is to model and describe simultaneous forcings such as extreme rainfall and storm surge that are frequently responsible for flooding. Stage 1 will provide an initial assessment, based on synoptic typing, of potential impacts of climate change on the simultaneous occurrence of severe rainfall and coastal sea levels. It will also include a component of exploration and development of statistical methodology for modelling coincident extremes through the analysis of climate models, together with hydrodynamic models that downscale the results of climate models. Stage 2 will refine and broaden the scope of these assessments by including extreme rainfall and riverine flooding. It will also characterise other contributions to extreme coastal sea levels arising from tides and longer term climate variations.

Intended Research Outcomes: Outcomes from the first stage will include: (1) identification of the key weather features that are responsible for coincident extreme rainfall and sea level events for selected locations along the Australian coastline; (2) quantification of possible changes in closed-low frequency, intensity and size for the Australian region; (3) evaluation of changes in the magnitude and seasonality of extreme sea levels as well as the identification of changes associated with meteorology; (4) evaluation of whether statistical dependence varies as a function of synoptic meteorology under a historical climate, which would provide a foundation for understanding how dependence might change as the synoptic drivers change in the future; and (5) a review of statistical methods which can account for non-stationary dependence parameters.

Outcomes in the second stage will include: (1) quantification of possible changes in frontal frequency of occurrence and intensity for the Australian region; (2) climatologies showing the influence of the tides and interannual variability on sea levels at tide gauges around Australia; (3) qualitative assessment of the changes in extreme sea levels due to the changes in tropical cyclones along a populous stretch of tropical coastline; (4) quantitative assessment of changes in frequency and amplitude of extreme sea level events associated with rainfall along mid-latitude stretches of coastline; (5) statistical characterisation of dependence under a future climate; and (6) guidance on methodology to incorporate any changes in joint dependence into flood estimation practice.

Guidance to be provided to ARR users: Guidance will be provided in ARR on the following issues:

1) Quantification of changes in closed-low frequency of occurrence, intensity and size for the Australian region, and an assessment of uncertainty related to these projections;
2) Quantification of possible changes in frontal frequency of occurrence and intensity for the Australian region and an assessment of uncertainty related to these projections;
3) Quantification of changes in extreme sea level events and their associated uncertainties and meteorological causes.
4) Information on joint dependence parameters to use along the Australian coastline, and methodological guidance on using these parameters to estimate flood quantiles.

3.3. Relationship between Climate Change Research Themes and the ARR guidelines

The abovementioned themes have been developed to integrate with existing ARR research projects which have been undertaken under the assumption of a stationary historical timeseries of rainfall bursts. The relationship between the climate change research themes proposed here and the existing ARR research projects is described below:

3.3.1. Historical rainfall trends

This project will draw heavily from the data collected as part of ARR Project 1. In particular, work in ARR Project 1 involves collation of data from the Bureau of Meteorology and other sources, together with significant data quality control. This project will take advantage of this data, but will focus on analysing the data to detect possible changes due to the climate change and variability that have occurred to date.

3.3.2. Rainfall intensity-frequency-duration (IFD) curves

ARR Project 1 involves developing IFD relationships across Australia for a range of storm burst durations and exceedance probabilities. This has involved a significant data collection effort, together with the development of statistical methodology to estimate the IFD curves. The outcome of this project will be a set of IFD maps, representing historical climate conditions.

The work proposed here will involve dynamical modelling of rainfall extremes under historical and future climates, to determine how extreme rainfall will change as a result of global warming. It is likely that information will need to be provided relative to a climatological ‘baseline’, and the IFD curves provided as part of ARR Project 1 can be used to provide this information.

3.3.3. Rainfall temporal patterns

The updating of temporal patterns under historical conditions is being addressed as part of ARR Project 3, and will provide an important ‘baseline’ against which future changes in temporal patterns can be measured. The outcomes of ARR Project 16 (Storm patterns for use in design events) will also be relevant for this research.

3.3.4. Continuous rainfall sequences

The use of continuous rainfall sequences for flood modelling represents one of the primary methods by which catchment antecedent conditions can be included in flood estimation. ARR Project 4 involves a detailed comparison of several methods for continuous rainfall simulation under a historical climate. The method proposed here represents an extension to one of the methods developed as part of ARR Project 4, except that the continuous rainfall sequences are to be based on future climate.

The use of continuous rainfall-runoff models to convert the continuous rainfall sequences into flood estimates is being considered as part of ARR Project 8. This research will also be useful to form the basis for analysing continuous rainfall sequences generated for future climate conditions.

3.3.5. Antecedent conditions and baseflow regimes

An alternative approach for including information about antecedent catchment conditions into flood modelling is through event-based rainfall-runoff models with information on the expected antecedent moisture values, often parameterised through 'loss' parameters. Furthermore baseflow can be an important component of the flood hydrograph for smaller in-bank floods, or for over-bank floods in regions such as southwest Western Australia, and thus may need to be explicitly considered in the flood modelling. Research into these topics under historical climate conditions is being conducted through ARR Projects 6 and 7.

The research proposed here will involve examining how future changes to catchment conditions (such as a possible drying out of catchments) can be accommodated into these models, and therefore will make significant use of the research of the abovementioned ARR projects.

3.3.6. Simultaneous (joint) extremes

ARR Project 18 addresses the interaction of coastal processes and severe weather events under historical climate conditions, and the implications of such interaction on coastal flooding. A pilot study has been completed recently as part of ARR Stage 2, focusing on the interaction of storm surge and extreme rainfall under a historical climate at several trial locations. Continuation of this research is proposed as part of ARR Stage 3, together with the development of case studies to apply this knowledge for the estimation of flood risk.

The work proposed here will draw heavily on the methodological outcomes of Project 18. However the emphasis will be on how the interaction of different atmospheric drivers of flooding will change in the future due to climate change. This will require additional innovation of statistical techniques that can account for such non-stationarity, as well as research into the physical processes which lead to joint extremes.

3.3.7. Other interactions with ARR

There are other ARR projects that will need to account for the outcomes of the climate change research described herein. For example, Project 12 (*Selection of an Approach*) will need to provide guidance on which approaches will be suitable for simulating floods under a future climate. Similarly, climate change means that flood risk is now expected to change over time, and therefore this issue will need to be discussed as part of Project 20 (*Risk Assessment and Design Life*).

Finally, several chapters of ARR would be expected to remain valid irrespective of whether flood modelling represents historical or future conditions. For example, ARR projects covering the hydraulic aspects of flood modelling such as Projects 9 (*Urban Drainage System Hydraulics*), 11 (*Blockage of Hydraulic Structures*), 15 (*Two-Dimensional Simulation in Urban Areas*) and 10 (*Appropriate Safety Criteria for People*) are all expected to be independent of the climate sequences used in other parts of the flood estimation process.

Funding for First Stage of Climate Change Research

In August 2012, Geoscience Australia advised Engineers Australia that $5.15 million will be made available over the next three years for Stage 3 of the ARR Revision Project. A large proportion of this funding will enable the first stage of the climate change research identified in Theme 2 (rainfall IFD curves) and Theme 3 (rainfall temporal patterns) to be included in the ARR revision publication.

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List of Acronyms and Abbreviations

ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
CMIP	Coupled Model Intercomparison Project
CSIRO	Commonwealth Scientific and Industrial Research Organisation
IOCI	Indian Ocean Climate Initiative
RAMS	Regional Atmospheric Modeling System (see, e.g., http://rams.atmos.colostate.edu/rams-description.html)
UNSW	The University of New South Wales
WRF	Weather Research and Forecasting Model (see, e.g., http://www.wrf-model.org/index.php)

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