1.

2. Climate Impacts Relevant to Flood Risk

As described in the previous section, the

6) Models are consistent in finding that

maximum flood records of length between 30 and 97 years found approximately 30% of stations with a statistically significant trend at the 10% significance level, which are in a downward direction in southern parts of the Australian continent and an upward direction in the northern regions [*Ishak et al.*, 2010], although this study did not evaluate the contribution of natural or anthropogenic causes to these observed changes.

9) The IPCC [2007] report recently provided sea level rise projections for 2090-2099 relative to 1980-1999 of between 0.18 and 0.59m, excluding dynamical changes in ice flow, with an additional 0.1-0.2m assuming the contribution of ice flow from Greenland and Antarctica increases linearly with temperature. It is generally considered likely that this report has underestimated likely sea level rise, with a recent summary of the literature on behalf of the Sydney Coastal Councils group providing estimates ranging from 0.18m through to 1.4m [*Preston et al.*, 2008], and another recent review of the literature projecting sea level rise until 2100 likely to be at least twice as large as the IPCC [2007] estimates, with an upper limit of 2m [*The Copenhagen Diagnosis*, 2009].

10) Several studies of the implications of storm surge along the east Victorian co0TDalong0Tc<0003>Tj/T,T21Tf.22950T

character of precipitation can have

Changes in ocean levels and joint probabilities of

and dynamical methods have been developed to account for these issues, and rate of change of extreme precipitation varies continuously as a function of both the temperature and the percentile, leading those authors to caution that the Clausius-Clapeyron relation may not provide an accurate estimate of the temperature relationship of precipitation at any temporal resolution.

Statistical downscaling

Statistical downscaling involves the development of statistical relationships between large-scale climate variables and local-scale weather [*Maraun et al.*, 2010], and is used to develop projections for a range of hydrological processes which are at a finer scale than the relevant general circulation model (GCM) resolution. In some ways statistical downscaling can be viewed as an extension to the temperature scaling approach described above, except that for statistical downscaling, rather than conditioning only on land-surface (or sea-surface) temperature, a much larger set of (usually atmospheric) variables can be incorporated. Furthermore, by using GCM-derived projections of the atmospheric variables in a future climate, factors such as large-scale circulation changes, meridional changes to relative and specific humidity, differential warming between the ocean and land surface and a diversity of other processes, can be implicitly accommodated.

Although a large range of statistical downscaling methods are currently available [for recent reviews see *H J Fowler et al.*, 2007; *Maraun et al.*, 2010], methods developed specifically for the simulation of hydrological extremes are less common, with calibration of statistical models to mean conditions not necessarily being appropriate for handling extremes [*Wilby et al.*, 2004]. Furthermore, statistical downscaling models that have been developed to simulate sub-daily precipitation are limited, with only a few attempts described in the literature [*Marani and Zanetti*, 2007].

The most common statistical approaches for simulating extremes are based on extreme value theory [*Abbs and Rafter*, 2009; *Katz*, 2010; *Rafter and Abbs*, 2009], which represents the natural statistical theory for addressing the tail end of the distribution. Other methods which have been used to provide projections for extremes in Australia, such as the multi-site modified Markov model by Mehrotra and Sharma [2010], have simulated the full range of precipitation magnitudes including both dry and wet spells, and have evaluated the performance of the model in that context, rather than in the context of whether the physical processes leading specifically to extreme rainfall are correctly simulated.

There are at least three conceptual approaches for predictor selection in statistical models [*Maraun et al.*, 2010]. Arguably the most common is the identification of predictors based on an evaluation of the fit between the historical predictors and observed precipitation. The second approach, advocated by [*Charles et al.*, 1999b; *Charles et al.*, 2007; *Johnson and Sharma*, 2009], involves selection of predictors based on the capacity of GCMs to simulate these variables. Thus, a strong predictor variable in the historical climate may not be useful in simulating future change if that variable exhibits low skill in GCM simulations. A related approach involves using metrics of GCM performance as a basis for selecting downscaling predictors [*Perkins and Pitman*, 2009]. The third approach considers whether the key physical drivers of change in extreme precipitation are captured in the statistical model [*Charles et al.*, 1999b; *Wilby et al.*, 2004]. For example, as discussed in Section 2, it is likely that in Australia specific humidity will increase even as relative humidity decreases, whereas the high dependence between these variables in historical climate might lead to only one of these predictors being selected.

evaluation of whether the downscaling approach is able to simulate the presence or absence of historical modelling for extreme precipitation

Finally, in addition to simulating precipitation extremes, there are various other applications which are well suited to

Table 2: Summary of present understanding of likely changes, and outstanding questions and issues

Flood variable	Current understanding	Key issues and questions
IFD relationships (daily or longer durations)	Limited evidence of change can be observed in historical annual maximum data. The extent to which future change can be inferred based on the historical record is uncertain, however given an increase of 0.9°C in Australia since 1950, this may provide a constraint on short time-horizon projections. Large-scale climate modelling projections for extreme daily rainfall (defined using different metrics) are already available are[6.4012850TD-0016TcricalÇ	

2010], with this

Antecedent conditions	Antecedent moisture conditions appear to be changing based on observational work on average annual rainfall, evapotranspiration and soil moisture. It is unlikely that the trend detection results on annual maximum streamflow by [*Ishak et al.*, 2010] can be explained without some reference to antecedent moisture. Some projections on future antecedent moisture are already available, such as changes in average seasonal rainfall and temperature

4. Australian and overseas guidance on estimating flood risk under a future climate

In this final section a brief overview of guidance information in Australia and event recurrence interval. For detailed assessments, the methodology of modifying the shape and scale parameters from a Gamma distribution described in [*Semenov and Bengtsson*, 2002] is recommended [*New Zealand Ministry of the Environment*, 2008b]. Information on accounting for sea level rise and storm surge is provided in [*New Zealand Ministry of the Environment*, 2008a], and further complementary information on flood estimation in climate change has also recently been provided [*New Zealand Ministry of the Environment*, 2010].

Recently, NIWA has developed a framework for assessing the impacts of climate change on river flow and floods using precipitation outputs from a dynamically downscaled model (bias corrected using a quantile mapping approach) to develop continuous sequences of daily precipitation of 30-year durations for the periods 1970-2000 and 2070-2100. The long-term objective is to use outcomes from this study to develop national projections of climat[illegible]

5. Conclusions and future research needs

This discussion paper has addressed a range of issues related to accommodating climate change estimates of various flood-related variables into flood estimation practice. The focus of this discussion paper has been on reviewing the science linking climate change to flooding as

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