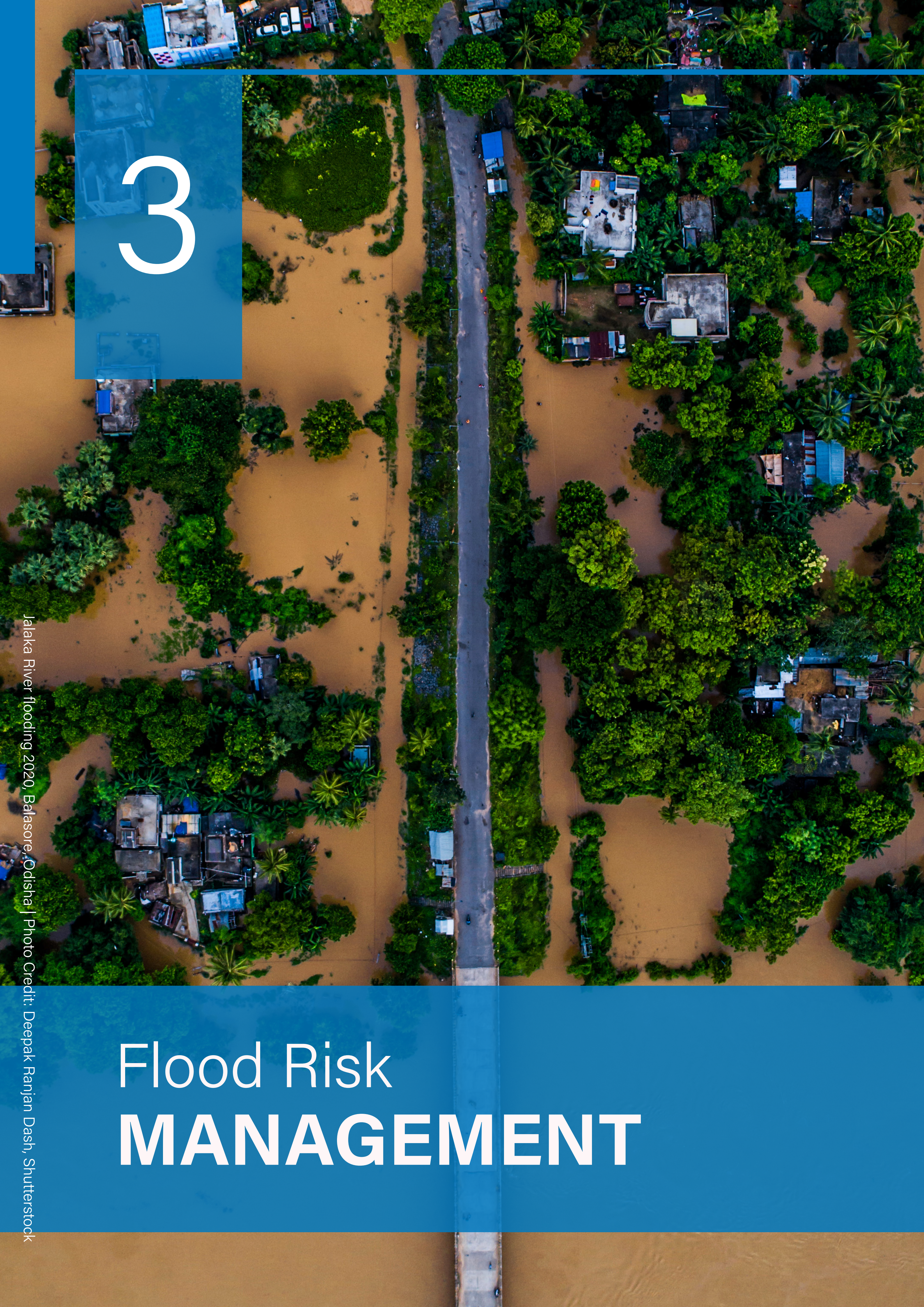
3

Flood Risk **MANAGEMENT**



Jalaka River flooding 2020, Balasore, Odisha | Photo Credit: Deepak Ranjan Dash, Shutterstock

GLOBALLY, FLOODS are the most common of all natural disasters. They lead to loss of life, extensive disruption and major economic impacts. Flood risk is expected to increase in the future because of changes in extreme weather patterns caused by long-term climate change. According to the UN Office for Disaster Risk Reduction, India has experienced an average of 17 floods per year over the period 2000 to 2019, affecting approximately 345 million people (UNDRR 2020). Estimating the risk and severity of floods both now and in the future is vital for the design and management of infrastructure such as flood management schemes, dams, hydropower projects and irrigation systems. Flood frequency estimates are also a key source of information for flood risk maps and insurance applications. The key challenge is closing the gap between research and practice in design flood estimation in India. This chapter introduces new statistical and modelling techniques for generating spatially consistent flood frequency estimates, moving away from simple regional equations. These new techniques are flexible, robust, and can easily be applied to local data. A particular advantage of the combined approach is that it has the potential to incorporate projected changes in climate, and thus to establish the likely effects of these changes on flood frequency. Here, the application of these methods to river catchments in the State of Maharashtra is shared, but the approach has the potential for national application in hydrological design and flood risk assessment throughout India.

3.1 Flood hazard estimation in India

India's high risk and vulnerability to flooding are highlighted by the fact that about 12% of its total area of 3.29 million km^2 is prone to floods, with 75,000 km^2 affected every year (National Disaster Management Authority 2008). In 2020 alone, heavy rainfall and flood-related incidents claimed over 600 lives from different parts of the country during the pre-monsoon, monsoon and post-mon-

Better understanding of regional flood hazard through combined statistical and modelling approaches can improve hydrological design and flood risk assessment.

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soon seasons, including 50 lives lost in the State of Maharashtra (IMD 2021). It is, therefore, very important to understand the flood hazard arising from multiple sources throughout India. Although urban floods from surface water are an increasing problem throughout the world, the focus of this chapter is fluvial floods. The standard approach to flood prediction in India is to apply regional equations based on catchment area and other basic characteristics of the river basin derived from a limited number of gauging stations. As a result, not all hydrological regions have specific estimation equations associated with them. Furthermore, updating these equations is an expensive undertaking. Altogether, this makes estimating design floods, especially at ungauged sites, a major challenge in India.

Recent research has indicated that extreme rainfall events in India have been increasing since 1950 (Roxy et al 2017) and it is expected that a warming climate will continue to increase the frequency and severity of extreme rainfall and floods throughout the world. This, together with continuing land-use change and urbanisation, presents the additional challenge of quantifying the effects of environmental change on changes (or **non-stationarity**) in flood frequency, as standard methods assume no change (**stationarity**) over time in flood regimes.

3.2 Design floods and why they are needed

Design floods are estimates of peak river flow that are assigned a particular probability or **return period** in years, for example the 100-year flood. These estimates are fundamental to the design of hydraulic structures such as bridges, dams, culverts and flood management schemes. They are also used in the design and planning of irrigation and hydropower projects, in flood risk assessments for new developments, and in the insurance sector. Understanding flood risk provides decision-makers and planners with the knowledge required to plan effectively and protect people, livelihoods, economies and ecosystems.

River Godavari flooding, Nashik in 2019. Photo credit: REUTERS, Alamy Stock Photo.

3.2.1 Estimating design floods in large river basins

To address the issue of ungauged sites, land-use change and possible non-stationarity in design floods, research conducted by the authors and their team has explored the application of **statistical frequency analysis** to catchments in Maharashtra State, together with the use of **continuous hydrological modelling** to simulate peak river flows at ungauged sites. This combined approach has the potential to use climate model projections to explore the potential impacts of climate change on peak flows.

Current practice in the UK makes use of the national standard suite of methods of design flood estimation as set out in the Flood Estimation Handbook (FEH; IH 1999) and subsequent updates (e.g. Kjeldsen 2007). The underlying philosophy of the FEH is the use of all the available data, including peak river flows and the hydrological characteristics of river basins, to derive robust design flood estimates at any location on the river network, whether it is gauged or ungauged.

Improved methods of **statistical flood frequency analysis**, including the index-flood and region of influence methodologies, together with the availability of longer peak flow records offer an improved, flexible approach to design flood estimation. Using simple software, analyses can be made at both gauged and ungauged sites. The same approach can be applied to Indian river catchments. These generalised methods take advantage of recent increases in the quality and length of available flood peak records, such as the India Water Resources Information System (India-WRIS[1]), and offer a standardised approach suitable for national application to a range of hydrological design problems.

A parallel approach to flood frequency estimation applies **rainfall-runoff modelling of sub-catchments in continuous mode** to simulate long series of river flow. The largest peaks in each year (annual maximum values) can then be used in a statistical frequency analysis to derive flood estimates. This method has several advantages, particularly where gauged records are short or incomplete, and where an understanding of the complete flood hydrograph is required, for example, in the design of hydraulic structures such as dams. The **continuous modelling approach**,

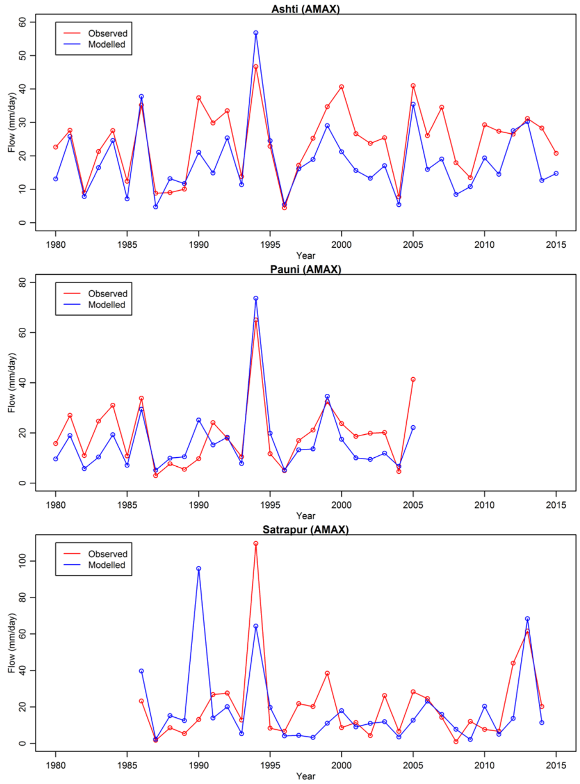


FIGURE 3.1 Observed and modelled (conceptual rainfall-runoff) hydrographs for sub-catchments of the Wainganga Basin, Maharashtra State, India. River flow data from CWC accessed via India-WRIS.

using gridded rainfall and evapotranspiration data as input to a conceptual rainfall-runoff model, has been shown to perform well in reproducing peak flows in a number of test catchments in Maharashtra State (**Figure 3.1**).

This type of research is fairly complex and inaccessible to those who need the information generated. To close this gap between research and practice, user-friendly, **interactive applications** can help, as they enable a wider audience to engage with complex research[2]. The SUNRISE Flood Frequency Estimation App, being trialled, demonstrates the methods, and provides the user with the combined data for their catchment of choice. This functionality can aid hydrological practitioners, who may not be statistics or technical programming experts, in the design of hydraulic structures and the assessment of

1 https://indiawris.gov.in/wris/

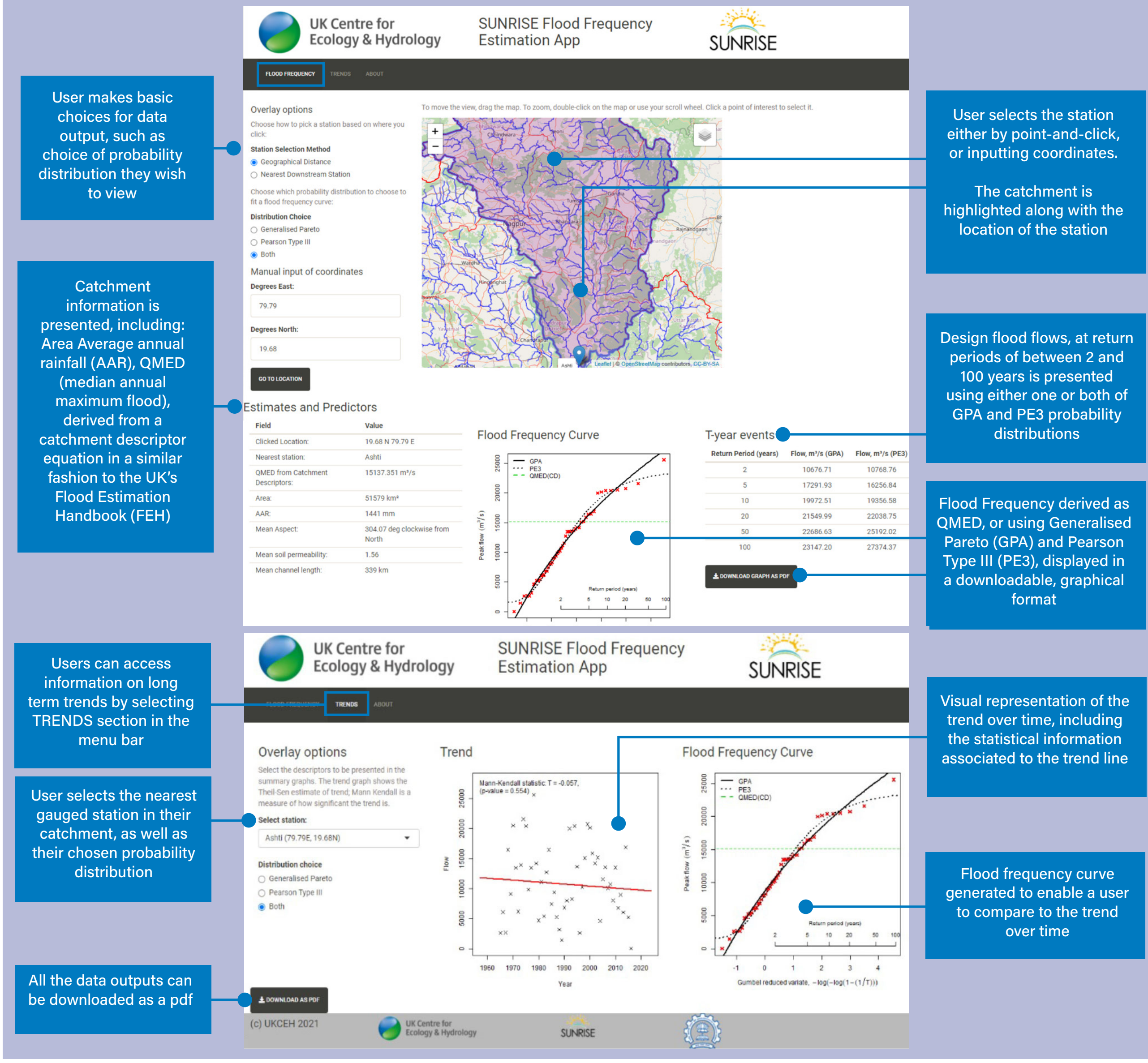
2 See Chapter 4 for another example of the use of interactive applications, this time for drought management and mitigation.

BOX 3.1 Applying the Combined Method to Maharashtra

The Godavari and Krishna river basins in Peninsular India regularly experience monsoon-related extreme floods. The Wainganga basin, which is in eastern Maharashtra State, is a very rural sub-catchment of the Godavari River. It is naturally prone to flooding, with floods being recorded every 5 to 7 years, for example in 2001, 2004, 2007 and 2013. However, it has seven gauging stations, including one at Ashti, the base of the Wainganga, making it a perfect case study site. Flood-peak data and physical/climatological catchment properties (catchment descriptors) can be combined to derive flood frequency curves for both gauged and ungauged sites. The '*SUNRISE Flood Frequency Estimation App*'[1] provides users with varying statistical and technical programming skills the opportunity to interact with data from partially gauged catchments to understand their potential flood risk over the next 2 to 100 years. The app also gives the user the ability to explore trends in recorded data and provides downloadable statistics from which a user can compare these trends with the flood frequency curve generated for the catchment. This is critical, for example, when designing engineering projects. If a station shows significant trends, then it highlights the need to account for future changes in engineering projects.

Interacting with the app is relatively straightforward, as illustrated below, and enables a user, for example a hydraulic engineer or planner, to download easily the flood frequency curve for use in project documentation, and to review or verify design calculations.

1 https://shiny-apps.ceh.ac.uk/mah-flood-frequency



catchment flood risk. The app provides simple visualisations of flood frequency estimates derived using the methods outlined above, from the available gauged data and pre-computed catchment descriptors (for more on the App see **BOX 3.1**).

In general, using the combined methods, a flood frequency curve can be constructed for a pre-defined set of river flow gauging stations within a selected catchment. This can be presented alongside estimates of peak river flow for key return periods between 2 and 100 years. For Indian peak flow data, our research shows that the Generalised Pareto (GPA) and Pearson Type III (PE3) probability distributions are the most appropriate, and these have been adopted in the App.

3.2.2 Non-stationary methods

With floods expected to increase in frequency and severity in the future, as the projected effects of climate and land-use change are experienced, the adoption of methods of design flood estimation that can take non-stationarity into account becomes vitally important. The latest hydrological science uses several different approaches to estimate how flood frequency might change in the future. The **exploration of trend in long records of peak flow data** can be used to identify non-stationary time series and non-stationary frequency models can then be applied. Continuous simulation models also have the potential to be used with climate change projections to evaluate non-stationary design flood estimates, and this remains a key area of ongoing research.

3.3 Towards improved flood design

A key component of robust design flood estimates is the extent of data available in the form of observed flood peaks from gauging station networks, and hydrological descriptors that characterise the relevant features of river catchments. As the length of records of peak flow in Indian catchments increases and data are made freely available to download, the aspiration of developing a national system of generalised flood frequency estimation relevant to both gauged and ungauged sites in India becomes more attainable. As presented here, research is showing that it is feasible to derive spatially consistent design flood estimates from applying both statistical and modelling approaches in major river catchments. In developing such systems, it will be important to consider how floods are expected to change in the future, both as a result of climate change and changes to the catchment land use, such as urbanisation.

Ongoing research in many countries is investigating several approaches to non-stationarity in design flood estimates (Kalai et al 2020). Current practice in the UK is to apply climate change adjustments to conventional (i.e. stationary) flood frequency estimates. These adjustments are derived from hydrological modelling of future changes to peak flows using climate change projections (e.g. Kay et al 2020), and a similar approach could be developed for Indian catchments. In the UK, current research on non-stationary flood frequency is focusing on further development of regionalisation methods that consider trend in the fitting of extreme value distributions. In addition, the use of continuous simulation modelling approaches to flood frequency estimation has been an important component of the FEH research programme for some time and this has the potential to allow for non-stationarity in generalised flood estimates (Formetta et al 2018) in the near future.

3.4 References

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Painted Stork, Ranganathittu Bird Sanctuary, Karnataka. Photo credit: Nihal M Maka, Shutterstock.