Journal of Hydrology 496 (2013) 31–46

Contents lists available at SciVerse ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Studying reach-scale spatial hydrology in ungauged catchments

J.N. Callow[a,*], G.S. Boggs[b]

[a] School of Earth and Environment, The University of Western Australia, 35 Stirling Highway, Crawley, WA, 6009, Australia
[b] School for Environmental Research, Charles Darwin University, Darwin, NT 0909, Australia

ARTICLE INFO

Article history:
Received 29 October 2012
Received in revised form 24 April 2013
Accepted 11 May 2013
Available online 23 May 2013
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief

Keywords:
Remote sensing
Flood hydrology
Ecology
Dryland river
MODIS

SUMMARY

Dryland regions are home to some of the most poorly gauged rivers on Earth. Consequently, these regions lack a detailed understanding of the hydrology, are associated with underdevelopment and significant socio-economic disadvantage, though there is increasing pressure to develop the water resources in these areas. However, this is often limited by a lack of data from which to understand regional hydrology and water-dependent processes and make informed water resource management decisions. This paper presents a novel approach to directly map, from remotely sensed imagery, the five flow types and six hydrological metrics defined as the most significant determinants of ecological condition of dryland rivers (*Flow* (duration of flow), *Amplitude* (last maximum depth), *Pulse Shape* (duration of rising limb and falling limb), *Duration* (present length of inundation), *Connection* (duration of present downstream connection)).

At fourteen "virtual" gauging stations in two rivers (Newcastle Creek and Playford River) on the Barkly Tablelands, northern Australia, daily classified Moderate Resolution Imaging Spectroradiometer (MODIS) imagery was used to map flow types and metrics at 250 m resolution, across 1996 km^2. The performance of the "virtual" gauging stations is validated against traditionally gauged data at two locations and confirms that hydrological data significant for ecology can be extracted from daily flood mapping using remotely sensed MODIS imagery. Results found a pronounced downstream trend in flow characteristics from more ephemeral uplands to seasonally-inundated lowlands. Significant between reach variability in the *Duration* and *Connection* is also noted, which is related to cross section morphology and river position. It is suggested that this approach could be applied to other poorly or ungauged large, dryland rivers, where the requirements, including limited cloud cover, long (weeks to months) flood pulses, inundation widths of greater than 2 km, and lateral floodplain gradients of less than approximately 0.005 m/m are met. This novel approach for the measurement of ungauged basins offers significant potential to allow research relevant to hydrology and water-dependent processes where traditional approaches to dryland river hydrology are limited by the lack of gauging infrastructure, or by complex multi-channel and low-gradient geomorphology.

1. Introduction

The hydrology of floods in remote, large dryland rivers and their role in dependent processes such as geomorphology, ecology and ecohydrology remains poorly understood (Bauer et al., 2006; Larned et al., 2009; Tooth, 2000). Drylands are characterised by climatic extremes, suffering long periods of drought punctuated by occasional torrential rains making floods an important aspect of the flow regime of dryland rivers. Drylands support up to 40% of the World's population, but have typically been less developed due to the high levels of socio-economic disadvantage (Karim et al., 2012), and the unpredictability of climate and water availability. Consequently, they are characterised by a dearth of stream gauging infrastructure to capture data describing dryland river flow patterns. This basic information is vital to further our understanding of dryland river hydrology and water-dependent environmental and economic processes, opportunities and constraints, and from which to make sound water resource planning and allocation decisions.

The distribution of gauging stations in Australia highlights the challenges of undertaking hydrological research in dryland landscapes. Australia is approximately 7.2 million square kilometres, and contains 6342 active and closed gauging stations (BoM, 2009). Once gauging stations that drain to the coast are excluded, there are only 101 active and closed gauging stations to quantify hydrology across an area of 3.2 million square kilometres (an area equivalent to India), or 44% of the Australian continent (BoM, 2009) (see Fig. 1). The challenges facing hydrologists, ecologists, water management planners and others in dryland regions are emphasised by conclusions of the Northern Australia Land and Water Science Review:

* Corresponding author. Tel.: +61 (8)64881924; fax: +61 (8)64881037.
E-mail address: nik.callow@uwa.edu.au (J.N. Callow).

0022-1694/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jhydrol.2013.05.030

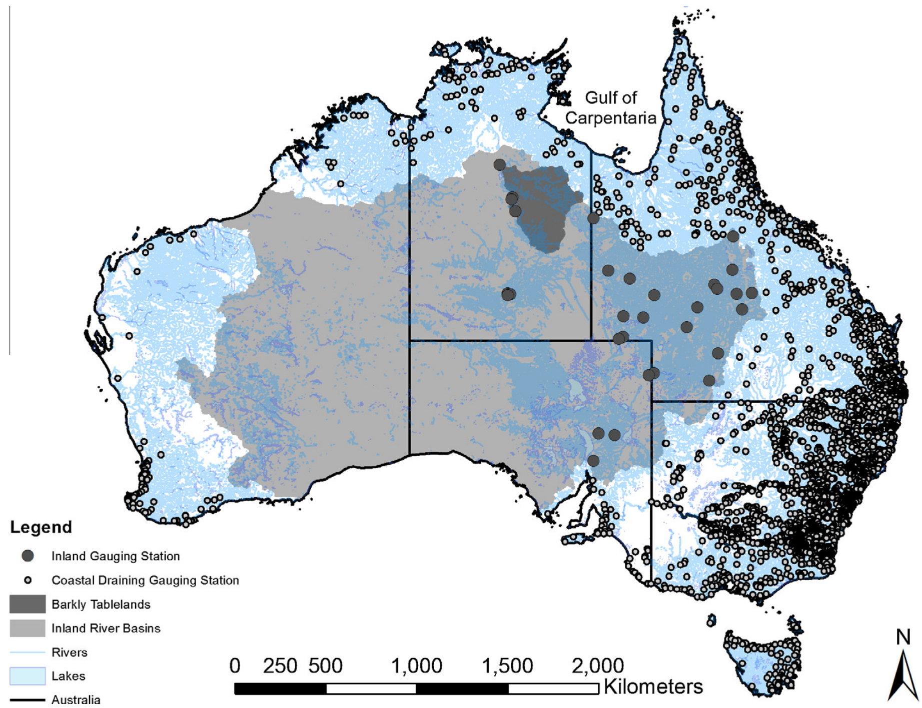

Fig. 1. Location of the Barkly Tablelands (Northern Territory) study site, with the location of the 3111 open gauging stations in coastal (light grey circles) and the 31 gauging stations in inland draining catchments (darker grey circles on shaded catchment boundary).

> "*Northern Australia comprises >1.2 million km*^{2} *of highly variable landscape. Understanding its form and function at the scale required to identify the impacts of specific uses of land or water (i.e. certain types of development) is beyond the scope of this report. It is, as we show, also beyond the current capability of any report. Northern Australia cannot currently be understood at a detailed, site-specific scale – the raw observational data required for such understanding simply doesn't exist*." (Stone, 2009, p. 10)

Modelling using process-based models or empirical and regionalised relationships is commonly used to build an understanding of dryland hydrology. Costelloe et al. (2006), for example, modelled flood wave movement through a 330 km reach between two stations along the Diamantina River (Australia), and highlighted the challenges in quantifying flood wave velocity, flood inundation footprint and other aspects of the flood and hydraulic regime using a coarse (28 km^2 or 0.05° × 0.05° cell) hydrological model. Understanding dryland hydrology at the reach-scale from traditional approaches is therefore challenging and is inherently compromised by the limited availability of data and the resolution at which processes can be accurately represented by modelling approaches in such large catchments.

The challenges of research on hydrology and water-dependent processes in drylands and other data-poor landscapes are profound. Their irregular but flood-dominant regime (Knighton and Nanson, 2001), together with the inaccessibility and high width of floodplains means that much of the limited infrastructure that does exist has poor rating curves or data are simply not recorded due to equipment failure because of inadequate maintenance, or simply due to the nature of such an ephemeral and extreme environment that can result in destruction or damage of hydrographic equipment during these occasional flood events. Furthermore, in many low-gradient dryland systems the channel planform often exhibits complex multi-channel geomorphology which makes direct measurement and quantification of the hydrology particularly challenging in these landscapes. These issues mean that there are only limited and sparse locations (e.g. geologically-controlled constructions) where hydrographic data for the rivers and streams exists, and consequently many dryland regions are ungauged or data-poor.

Previous studies have shown that there are key hydrologic components that drive the geomorphic and ecologic function of dryland river systems. The duration, frequency, depth, timing, regularity, magnitude and extent of flooding are well accepted as the most important influences on ecological communities and on river and lake geomorphology (Junk et al., 1989; Kingsford and Auld, 2005; Powell, 2009). Building on work by Puckridge et al. (1998), Sheldon et al. (2002) identified six flow types and eleven hydrologic metrics that were the best descriptors of river ecological condition in dryland regions:

- *Flow* – duration of flow, duration of the previous flow and the one before that (one and two "removes"), duration of present cessation of flow, duration of cessation of previous flow).
- *Pulse Shape* – (duration of present rising limb, duration of present falling limb).
- *Duration* – (present length of inundation).
- *Amplitude* – (last maximum depth).
- *Connection* – (duration of present downstream connection).
- *Permanence* – (relative frequency of drying).

Sheldon et al. (2002) found strongest correlations between these six flow types and eleven metrics with observed patterns of species diversity, richness, biodiversity (Shannon evenness), channel and floodplain habitat and function, and wetland ecology.

Water resource development and river regulation have traditionally been more concentrated in temperate-zone rivers, though more recently the under exploited drylands have come under increased pressure for development (Callow and Clifton, 2011; Tooth, 2012; Vorosmarty et al., 2010). The data paucity in these regions (e.g. Stone, 2009), means that very few data are available to make sound water resources management and development deci-