FLOOD RISK MANAGEMENT AND FLOOD DEPENDENT ECOSYSTEMS – LOW FLOW, HIGH FLOW AND EVERYTHING IN BETWEEN

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Introduction

Floods can be of significant benefit to the community by delivering water to flood dependent ecosystems (AIDR, 2017). Flood dependent ecosystems, in the context of the Guide to Best Practice Flood Risk Management in Australia (AIDR, 2017), are referenced largely around rural floodplains and their associated ecosystems. These ecosystems include large scale forested areas, such as the River Red Gums and Woodland Forests of the Riverina Bioregion (Natural Resources Commission, 2009).

However, there are also many instances of flood dependent ecosystems in more urbanised coastal floodplains (peri-urban floodplains and floodplains with pockets of remnant vegetation). In these environments, the types of ecosystems that would be considered to be flood-dependent are generally described by ecologists as groundwater dependent ecosystems (GDEs). For such GDE’s, the process of flooding, as defined by floodplain managers (i.e. where water exceeds the banks of a river or stream), is just one mechanism through which soil moisture is replenished and groundwater that the ecosystem is reliant upon (i.e. an aquifer) is recharged.

The specific eco-physiological water characteristics, requirements and tolerance levels of most flood/groundwater dependent ecosystems are not well understood, particularly where the catchment and floodplain has been modified and the original flooding and drying processes altered (with associated adaptation or die-back of certain species within the ecosystem). These characteristics, even if somewhat understood, are often not considered in detail (or at all) in floodplain risk management studies or plans, particularly those in urbanised or peri-urban areas that often contain remnant floodplain or freshwater wetland ecological communities. These include those protected as threatened ecological communities in NSW under the NSW Biodiversity Conservation Act 2016 and at a national level under the Environment Protection & Biodiversity Conservation Act 1999.

For many ecological communities, the specific flood requirements (in terms of ‘design’ flood events, being those that are defined by a recurrence interval) is rarely if ever quantified in a manner that allows for the correlation between ecological requirements and hydrological assessments that are conducted in accordance with Australian Rainfall and Runoff (either Pilgrim (Ed), 1987 or Ball et al, 2016). This is the case for both regularly occurring events (such as the 12 Exceedances per Year (EY) event) or major design events (such as the 1% Annual Exceedance Probability (AEP) event).

In some Floodplain Management Plans for inland systems, there is a correlation requirement of actual flooding events and the protection of ecosystems by maintaining the extent of flooding that was known to have historically occurred (e.g. in the Gwydir Valley Floodplain Management Plan, 2016, made under the Water Management Act, 2000).

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This lack of knowledge means that apart from information gathered from historical events, floodplain managers and ecologists rarely have a common position to be able to effectively manage remnant ecosystems within the floodplain concurrently with the range of ‘human’ uses.

This paper seeks to provide foundational understanding of the ecological issues that are in play when considering the concept of flood-dependent ecosystems, provide an overview of current practice (where relevant) and address some of the issues associated with attempts to consider the correlation between hydrological assessments and ecological assessments with reference to some relevant floodplain ecological communities, with a focus on coastal river floodplains of NSW. The paper also provides comments on ways in which floodplain risk management assessments can better consider the requirements of these dependent communities.

AIDR (2017) Guidance on Flood Dependent Ecosystems

Managing the floodplain: a guide to best practice in flood risk management in Australia (AIDR, 2017) contains a number of references to the provision for flood dependent ecosystems. These include:

- How to use this handbook This handbook applies to the management of floods in urban and rural areas, including water flowing overland through urban areas to waterways. Its use in different locations should consider the different issues that need to be considered. For instance, in rural floodplains, the scale of flood-dependent ecosystems means that environmental issues and maintenance of flow to these areas is important and needs additional consideration.
- Section A It should also be remembered that floods can be of significant benefit to the community by delivering water to flood dependent ecosystems, improving soil moisture contents for agriculture and providing inflows to water supply dams. Management of flood risk is essential to limiting the impacts of flooding on the community in balance with maintaining the benefits of occupying the floodplain to society and the benefits of flooding to the environment.
- Chapter 1 Best practice requires the consideration and management of flood impacts to existing and future development within the community. It aims to improve community flood resilience using a broad risk management hierarchy of avoidance, minimisation and mitigation to:
  - limit the health, social and financial costs of occupying the floodplain
  - increase the sustainable benefits of using the floodplain
  - improve or maintain floodplain ecosystems dependent on flood inundation.
- Chapter 2 Floods have both positive and negative impacts. Positive impacts include inflows to water supplies, sustaining flood-dependent ecosystems and improving soil moistures and fertility for farming.
- Section 6.3 Floods can be beneficial to the environment by providing water to flood-dependent ecosystems, depositing fertile silt on farmland and increasing soil moisture content. The study of the consequences of floods on the natural environment is an important and specialist area not covered by this handbook. Impacts of flooding on the natural environment can be an important element in the development of a floodplain management plan for a rural area or it may be more effectively considered as part of integrated catchment management which is considered in the development of a management plan.
- Section 7.1.2 Maintaining the flood function of the floodplain is essential to ensure that the floodplain can perform its natural functions of flow conveyance and storage. Understanding (Chapter 5) and maintaining these natural functions...
(Section 8.1) are essential to effective management. Maintaining flood function involves encouraging:

- maintenance or improvement of the capability of the floodplain to perform its natural function of conveying and storing floodwater
- land uses that are compatible with the flood function of the specific area of the floodplain
- maintenance of the capability of the floodplain to supporting floodplain ecosystems dependent on inundation
- floodplain and catchment management practices that are ecologically sustainable.

Figure 1 shows how the AIDR (2017) envisages the breakdown of flood function, inclusive of the definition of flood dependent ecosystems.

Figure 1 Flood Function Breakdown Example Showing Areas of Flood Dependent Ecosystem (Source Figure 5.1 of AIDR, 2017)

**NSW Floodplain Development Manual (2005) and Associated Guidelines**

The Floodplain Development Manual (NSW Government, 2005) includes general high level reference to ecosystems that the floodplain sustains. These references include:

- Foreword *The manual is concerned with the management of the consequences of flooding as they relate to the human occupation of the floodplain for both urban development and agricultural production. It addresses flood risk in full recognition of the fact that management decisions taken in respect of the human occupation of the floodplain need to satisfy the social and economic needs of the community as well as being compatible with the maintenance or enhancement of the natural ecosystems that the floodplain sustains.*

- Section 1.1.2 - *The NSW Flood Prone Land Policy provides for…Recognition of the need to consider ways of maintaining and enhancing riverine and floodplain ecology in the development of floodplain risk management plans.*
Section 1.6 - The policy and manual use a broad risk management hierarchy of avoidance, minimisation and mitigation, as discussed in Appendix B, to… Improve or maintain floodplain ecosystems dependent on flood inundation.

Section E5.2 Environmental Studies and Plans –

The natural attributes of floodplains are very important to both the NSW economy and the natural environment. Clearing for agriculture, urban development and flood mitigation, drainage and irrigation works has extensively modified the environment of most floodplains.

Depending on the characteristics of the environment where the management study is being undertaken, analysis of the riverine and floodplain environment, including the identification of key habitat areas and the importance of a natural flooding regime to surrounding areas, needs to be considered.

The environmental characteristics of the floodplain needs to be considered in most management studies, especially in areas where there are flood-dependent ecosystems such as freshwater wetlands or river red gum forests or in areas with acid sulfate soils.

These considerations should ensure compatibility of floodplain management measures to the relevant environmental issues.

There may be a range of relevant data already available that need to be considered in management studies. Native vegetation and water management planning undertaken by CMAs (now LLS) and DIPNR (now OEH and DPE) need to be considered through reference to both.

There are no current or proposed floodplain risk management guidelines prepared by the NSW Office of Environment and Heritage (OEH) that deal with flood dependent ecosystems. However, there are many guiding documents that deal with this matter with respect to the management of the Murray Darling Basin system, including the preparation of Floodplain Management Plans to fulfil the requirements of the Water Management Act, 2000 and the preparation of Water Resource Plans (WRPs), which are a key requirement of the Commonwealth Basin Plan 2012. WRPs will set out arrangements to share water for consumptive use. They will also establish rules to meet environmental and water quality objectives and will take into account potential and emerging risks to water resources (DPI, 2017). WRPs are understood to be currently in preparation and will be published for consultation in the near future (i.e. after June 2018).

This paper does not seek to consider in detail flood dependent ecosystems for inland rivers as there has already been and continues to be a significant effort in this space.

Hydrological Processes

From a water resources perspective, creek/river systems and adjacent aquifer systems are commonly interlinked, noting this is highly dependent on the soils and geology of the system.

During periods of low or no rainfall, the majority of flow in the creek/river is derived from inflows from the adjacent groundwater systems (where a hydraulic gradient exists). Rainfall that has infiltrated into the upper and adjacent catchment areas flows slowly toward the creek/river and forms the baseflow in the system. Once the flow has reached the creek/river it then flows faster in the open channel toward the receiving water (e.g. lakes, sea, etc). Processes such as evapotranspiration and transpiration of vegetation draw water from the groundwater system and the levels alter in response to these
During periods of higher rainfall (and substantial rainfall), the majority of flow in the creek/river is initially derived from runoff from the catchment. Creek/river flows increase until the bankfull level is exceeded and flows spill to the floodplain. The extent of spilling is dependent on the cross section of the creek/river and downstream conditions (such as constrictions) which control the rate and volume of flooding of the floodplain. Flows from the creek to the floodplain then infiltrate into the soils until such time as the soils are saturated and then floodwaters rise above the ground level. After the peak flood level is reached, flood waters then recede depending on the available space in the channel. Floodwaters then infiltrate to the groundwater below and recharge groundwater in this way. After a flood, the processes discussed above for the periods of low or no rainfall occur.

Figure 1 shows a simple river and floodplain cross section in low flow (day to day no or low rainfall conditions) and high flow (flood) conditions.

![Figure 1 Cross Section Schematic of Low Flows and High Flows and Floodplain Forest Community in an Urbanised Area (Dimensions representative)](image)

Figure 1 attempts to simplify a range of complex processes and show where water is coming from and that a floodplain community (for example, a floodplain forest community) may depend on. Floodplain forest is typically set low within the landscape, adjacent to the river or creek main channel. What is important to note is that the groundwater level for the area adjacent to the creek is largely related to the level in the river/creek. As the creek level rises and falls (and where there is a relatively constant baseflow and regional groundwater is flowing toward the stream (referred to as a ‘gaining’ stream), the floodplain community has a source of water that it can rely on which is largely associated with the groundwater but which is inter-related to the river/creek.

Periodically, the river/creek banks are exceeded and floodwaters flow across the floodplain forest community. Depending on the gradient of the land on which the floodplain community is located and any restrictions or controls downstream, the floodwaters will recede back to the stream but will leave behind water in the soils which will tend to flow into the groundwater below or will be taken up by the vegetation.

Typically, many streams in coastal NSW will have a bankfull capacity of up to a 2 year average recurrence interval (ARI) (0.5 EY event) and so the exceedance into the floodplain area may occur on average approximately only once every two years (which would equate to a rainfall depth of approximately 45 mm over a 2 hour period in the Sydney area using ARR2016 IFD information). However, this will vary depending on the catchment and floodplain (e.g. it might be a 6EY or 1EY).

It is important to note that the water that the floodplain community is primarily dependent on is the groundwater in the first instance during day to day conditions. However, the...
groundwater fluctuations are linked to the inundation by flooding. The question is therefore, what is a suitable amount of exceedances and are there too many or too few that will alter a floodplain community in such a way that constitutes a key threatening process, particularly for floodplain communities that are endangered. ‘Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands’ is a key threatening process listed under the Biodiversity Conservation Act 2016 (Office of Environment and Heritage 2018 Saving Our Species – Key Threatening Processes Strategy).

Ecological Profile – Swamp Sclerophyll Forest on Coastal Floodplains

One coastal floodplain community considered to be ‘flood dependent’ that is present in a number of coastal local government areas (LGA’s) in NSW is Swamp Sclerophyll Forest on Coastal Floodplains (SSFCF). This community is present in at least 25 LGAs including Tweed, Byron, Lismore, Ballina, Richmond Valley, Clarence Valley, Coffs Harbour, Bellingen, Nambucca, Kempsey, Hastings, Greater Taree, Great Lakes and Port Stephens, Lake Macquarie, Central Coast, Hornsby, Northern Beaches, Liverpool, Bayside, Randwick, Sutherland, Wollongong, Shellharbour, Kiama and Shoalhaven (NSW Scientific Committee, 2011).

The NSW Scientific Committee determination (2011) states that Swamp Sclerophyll Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions is the name given to the ecological community associated with humic clay loams and sandy loams, on waterlogged or periodically inundated alluvial flats and drainage lines associated with coastal floodplains. Floodplains are level landform patterns on which there may be active erosion and aggradation by channelled and overbank stream flow with an average recurrence interval of 100 years or less (adapted from Speight 1990). Swamp Sclerophyll Forest on Coastal Floodplains generally occurs below 20 m (though sometimes up to 50 m) elevation, often on small floodplains or where the larger floodplains adjoin lithic substrates or coastal sand plains in the NSW North Coast, Sydney Basin and South East Corner bioregions. The structure of the community is typically open forest, although partial clearing may have reduced the canopy to scattered trees. In some areas the tree stratum is low and dense, so that the community takes on the structure of scrub. The community also includes some areas of fernland and tall reedland or sedgeland, where trees are very sparse or absent. Typically these forests, scrubs, fernlands, reedlands and sedgelands form mosaics with other floodplain forest communities and treeless wetlands, and often they fringe treeless floodplain lagoons or wetlands with semi-permanent standing water.

The composition of Swamp Sclerophyll Forest on Coastal Floodplains is primarily determined by the frequency and duration of waterlogging and the texture, salinity nutrient and moisture content of the soil. Composition also varies with latitude.

A key threat to this community is change to hydrological regimes, the final determination (NSW Scientific Committee, 2011) refers to increased and decreased periods of inundation and changes to salinity. Changes would result from flood modification works including levees and dykes; filling and anything that results in altered inundation conditions.
Quantifying How Much Flow is Required and How Often

For the purposes of floodplain planning and in accordance with guiding documents such as the Floodplain Development Manual (NSW Government, 2005) and the national Handbook 7 (AIDR, 2017), the floodplain is most commonly defined as the extent of the Probable Maximum Flood (PMF). However, ecosystems that rely on periodic inundation will obviously need inundation more frequently than once every 10,000 or 1 million years (being the likely return period for the PMF) for ecological processes.

Local stream gauging upstream and downstream of the creek/river and the gauging of a transect of bores through the floodplain forest community over a period of years and ideally decades would be the most appropriate way of properly defining how often the banks might be exceeded and how the overall system operates from a water resources perspective. However, in coastal areas the network of stream gauges is relatively limited compared to the extent of remnant floodplain vegetation.

A literature review conducted to inform the preparation of this paper revealed that there have been limited or no research investigations into the frequency, duration and depth of inundation that is characteristic of particular floodplain species or coastal floodplain communities in NSW. It is highly likely that the requirements will vary depending on local conditions, however, even a starting point of some data would be useful for the purposes of providing a reference point, compared to no useful data at all.

Any stream gauging or local data collected needs to be cognisant of the condition in which the catchment/floodplain is in, those that have been modified may present a false representation of the original inundation patterns. Ideally benchmark values representative of undisturbed (or as close to as possible) floodplain communities are required to allow more useful comparisons. Ecological communities may have adapted to altered conditions or may still be adapting where changes are ongoing. Reconstructing pre-clearing vegetation and catchment patterns (e.g. Rose, 2014 for the Clarence River) and endeavouring to establish hydrological and hydraulic models that are representative of pre-clearing/pre-modified catchments may be a means of determining how much flow is required and how often it is required (by running longer duration simulations).

The following case study seeks to offer an example of a method used to try and evaluate inundation patterns in a data scarce situation and identify some of the pitfalls and shortcomings.

**Case Study – Evaluating Potential Creek Rehabilitation Designs for their Effect on Inundation Patterns of SSFCF**

The Warriewood Valley Urban Land Release is an area within the Northern Beaches Local Government Area where development of previously rural land uses to urban land uses commenced in the late 1990’s. Planning controls identified that an area of SSFCF was present and that flooding and drying processes needed to be considered as part of any development of the land (Pittwater Council, 2001).

Preliminary investigations conducted as part of creek rehabilitation investigations for the portion of Narrabeen Creek (a tributary of Narrabeen Lagoon) where the SSFCF is present on the floodplain (notably within the extent of the 1%AEP) involved the consideration of potential design options for their effects on inundation patterns.

High flow analysis for design flood events (such as the 5%AEP and 1%AEP) was conducted using two dimensional (2D) flood modelling but initially, this did not consider flooding and drying mechanisms and was confined to considering impacts on flood levels.
to ensure no effects on adjacent properties or changes to flood hazard that may alter risk
to life for events such as the PMF.

Investigations of more frequent events were conducted. It became apparent that using
the 2D flood model unaltered and merely running alternate design intensity-frequency-
duration information in the associated hydrological model was not directly applicable as
the more frequent events involved different losses.

A stream flow gauge was identified downstream of the SFFCF area and further
investigations were made of this stream flow data to better understand flooding and
drying behaviour. This included analysis of water level data collected over the period
1998-2010 (approximately 11 years in total of reliable data) and conversion to stream
flow at a gauge approximately 200 m downstream of the community. The analysis
involved identifying the peak monthly flow and using this to conduct a rudimentary
monthly exceedance probability analysis.

However, it became clear that there was no real baseline information of what was
acceptable for the SFFCF community (including no local information on the current
fluctuation of water level within the community itself via groundwater level monitoring).
This was particularly relevant when detailed surveys of vegetation were completed,
identifying a range of species, some of which might not be as tolerant of extended periods
of inundation as others. In this case an extended period of inundation would suffocate
the root systems of the plants (including canopy species) and most likely result in
dieback. Conversely, extended periods of no or ineffective inundation during drought
years can also threaten particular species.

Monitoring of groundwater in an adjacent SFFCF community (less than 1 km away) for
a short two month period in 1998 (MHL, 1998) revealed a substantive range in levels
(noting that approximately a 10 -20 year ARI event occurred during the monitoring period
(April 1998 flood event). A much longer period of data is key to understanding the range
of fluctuations that occur within a system.

The key outcome of the investigations identified the need for the following data:

- Comprehensive survey of the ecological community and adjoining communities
including species composition and condition
- Comprehensive ground survey to understand where low points are present,
identify the banks and bed of the creek adjacent and to provide a base data set
for inundation modelling – this type of survey can generally not be captured by
LiDAR and traditional field survey is required
- Long time series (ideally years or decades) of groundwater levels within or
immediately to the community
- Long time series (ideally years or decades) of creek levels and stream gauging
- Local rainfall gauge operating concurrently with the level recordings
- Soil moisture sensors to monitor the soil moisture for key species within the
community.
- Repeated transect surveys through the community to monitor vegetation health
and changes in species composition and dominance over time and correlate this
with inundation.

The data can then be used to establish a conceptual or numerical model to understand
the water cycle such that limits can be set to benchmark requirements for changes to the
floodplain or catchment.
Approach to Incorporation of Requirements in Floodplain Risk Management Studies and Plans

Based on the discussion above a preliminary approach for defining flood/groundwater dependent ecosystems within the flood function mapping for flood risk management studies and to be incorporated in management actions for Floodplain Risk Management Plans in coastal areas of NSW is provided below.

- Overlays of 10%AEP and 1%AEP design flood extents on remnant ecological community mapping as a starting point. Most local government authorities hold extensive and up to date ecological mapping for their area. Where this is not available, OEH offers mapping through the environment data portal. Field verification of mapping is essential. This overlay will assist with a first pass analysis of where flood dependent communities are present.

- Identify groundwater dependent ecosystems – these have been mapped by the Bureau of Meteorology (Doody et al, 2017) and are also discussed in Kuginis et al (2012). Studies of the ecosystems and/or data to assist evaluating their hydrological characteristics may have already been undertaken.

If an area is identified as a flood dependent ecosystem, then the assessment of these may need to include:

- Modelling - More detailed low flow analysis of impacts, including additional hydrological modelling for frequent rainfall events with alternate design losses (or no losses) to those recommended in ARR2016 (Ball et al, 2016)
- Economics – need to be able to assign a value of a FDE/GDE in traditional annual average damage calculations to ensure that the value is captured in cost: benefit analysis and/or multi-criteria matrix analysis used to evaluate various floodplain management options.
- Property options – an additional flag on a Section 149 certificate may be required to identify a property that has a flood dependent ecosystem located on it. However, this approach would need extensive consultation to determine how it could be implemented and whether it would be practical.

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