# DEVELOPING PRIORITISED RESTORATION PLANS FOR NSW ESTUARIES

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## Abstract

Identifying sustainable estuarine management opportunities requires a detailed understanding of community needs and broad acre estuarine processes. However, in many cases management actions are focused on the most vocal proponents (i.e. the squeaky wheels). To overcome short-term reactionary management, a holistic evidence-based approach is required. This is particularly important when assessing complex estuary wide water quality issues involving various spatial and temporal scales such as acid sulfate soils.

In this paper an applied research approach is outlined that results in prioritized action plans for all acid sulfate soil affected sub-catchments within an estuary. The action plans provide detail remediation goals for each sub-catchment based on a range of data including:

- Acid Risk (including soil chemistry and hydro-geologic factors)
- Surface Water Dynamics (including catchment characteristics and acid flux factors)
- Sensitive Receivers (including proximity to environmental factors)
- Asset Condition (based on field assessments)

Action plans, including forecasted costs, are developed for the immediate and longer term timeframe depending on the resource availability and sea level rise implications. Implementation strategies are developed following community input.

A case study of the Shoalhaven River floodplain is provided to highlight the input steps, data requirements, example action plans and implications of sea level rise. The Shoalhaven River floodplain is an ideal case study as it is a recognized acid sulfate soil hotspot with over 30 sub-catchments identified. The highest priority action plans are currently being implemented using a range of remedial strategies. Recent numerical modelling of the estuary and detailed field investigations have calibrated the applied research approach.

## Introduction

Acid sulfate soils (ASS) lie beneath the majority of eastern Australia's coastal floodplains. The construction of deep (> 0.5 m) drainage systems on coastal floodplains increased the generation and export of acidity from ASS (Johnston et al., 2003). The discharge of acidic and deoxygenated runoff is exacerbated by floodgates, which prevent tidal waters from inundating low-lying areas of the floodplain (Glamore, 2003). Floodgates also maintain low drain water levels, creating a strong hydraulic gradient between the groundwater and the drain. This results in the transport of acid from the groundwater to the drainage channel and onwards to the estuary.

Within estuaries, the tide, salinity and freshwater flows change daily. During dry times, acidic plumes are naturally neutralised, or ‘buffered’, by bicarbonate ($HCO_3^-$) diffusing into the estuary from the ocean. However, rainfall events can flush the estuary of salinity and bicarbonate. During these periods, acidic runoff contaminates the estuary, often resulting in fish and oyster kills. At these times, individual acidic plumes from separate drains can join to form larger plumes in the estuary. The size and impact of the individual plumes is dependent on local topography, rainfall and soil acidity (Rayner, 2010).

Acid sulfate soil drainage has been identified as a significant contributor to poor water quality across NSW (Sammut and Melville, 1994; Pease, 1994; Blunden, 2000; Glamore, 2003; Morgan et al., 2005; Winberg and Heath, 2010). This process has resulted in impacts to the local shellfish, prawning and fishing industries (Winberg and Heath, 2010; Nash and Rubio-Zuazo, 2012). To date, remediation of ASS drainage has largely involved ad-hoc or opportunistic remediation projects focused on landholder willingness and short term planning.

The Shoalhaven River floodplain contains extensive areas of acid sulfate soils, with the Broughton Creek floodplain nominated as an acid hotspot (DECC, 2008) (Figure 1). According to the acid sulfate soil risk maps described by Naylor et al. (1995), approximately 6,600 hectares of land in the Lower Shoalhaven River floodplain has a high risk of acid sulfate soil. Broad scale management options for selected areas of the Shoalhaven region were previously proposed, however further technical scoping and assessment of remediation benefits on a catchment wide scale have not been investigated.

In this paper, a multi-criteria analysis is proposed to prioritise acid sulphate soil affected floodplain sites. The analysis process takes into consideration the major issues associated with upland drainage, acid content, on-ground hydraulics, asset management, groundwater discharge, sensitive receivers and climate change. For each prioritised site Action Plans, including immediate and long-term remedial works. are then developed and resources can be strategically allocated. A case study of the the Shoalhaven and Crookhaven River floodplains (Figure 1) is provided to highlight the applicability of the analyses.

## Multi-Criteria Analysis

Multi-criteria analyses (MCA) are often applied to risk based assessments. Previous MCA assessments have been applied to fire risk (Vadrevu et al., 2010; Chen et al., 2003), flood risk (Meyer et al., 2007; Raaijmakers et al., 2008; Meyer et al., 2009), landslides (Abella and Van Westen, 2007), earthquake vulnerability (Rashed and Weeks, 2003), and a wide range of other environmental decision applications (Kiker et al., 2009). In NSW, DPI (2007) prioritised floodgate modification across NSW based on upstream channel length and habitat. To date, limited MCA has been undertaken to assess broadacre remediation of floodplains impacted by acid sulphate soils.

Designing an objective and evidence based plan relies on identifying key parameters for assessment and identifying objective field based parameters. Results from the MCA ensure the greatest environmental benefit and most cost effective outcome. In the Shoalhaven and Crookhaven floodplain there are 38 Council maintained flood mitigation drains and one non-Council floodgated drain (upper Crookhaven Creek). Each drain has a range of factors that contribute to its ability to generate and produce acidic discharges. Following research recently undertaken by Glamore et al. (2012), key parameters were identified as mechanisms for acid impacts. These factors are:

- Drainage
- Catchment hydrology
- Asset condition
- Groundwater (hydraulic conductivity)
- Water quality
- Acidic Soils


**Figure 1. Location of major flood mitigation sub-catchments in Broughton Creek and Crookhaven River.**

For this study, sufficient field data was gathered for each factor to generate a risk matrix. This information was then normalised to compare and rank drainage sites against each other. A summary of the risk as applied to each factor is outlined in Figure 2. Other factors not directly related to acid generation were also considered. Additional issues which were incorporated when designing short and long-term of remediation strategies were:

- Sensitive Receivers
- Climate change
- Landholder support

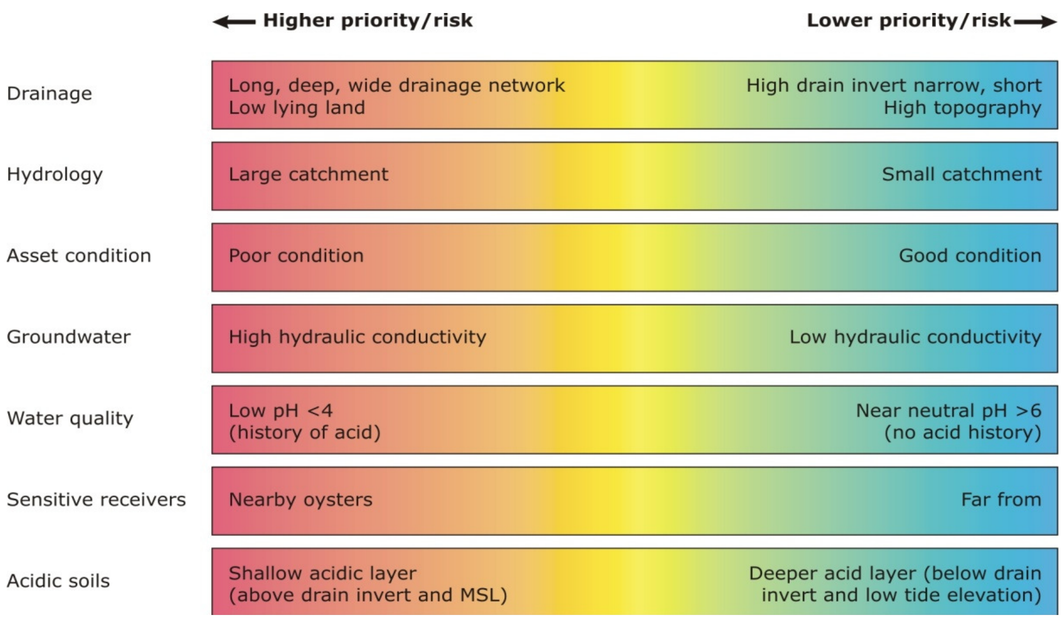


**Figure 2: Factors influencing the risk of environmental impacts (adapted from Johnston et al. 2003)**

A brief description of how each parameter was incorporated into the MCA is detailed below. A full description of each parameter and the assessment process is provided in Glamore et.al. (2014).

### *Drainage*

The extent and capacity of drainage across a sub-catchment influences the acid export potential of an area. The longer the total network of drains across a floodplain, the greater the potential for acid sulfate soils to be drained and oxidised. This is referred to as the 'drainage density'. A higher drainage density results in increased risk and subsequently a higher priority ranking.

Drain dimensions (width and depth) are also critical factors with respect of acid oxidation and mobilisation. A wide drain that is deeply incised into the acidic soil layers (AASS and PASS) poses a greater potential environmental impact than a narrow drain with a higher invert.

### *Catchment Hydrology*

The quantity of acidic water discharged from a drain is determined by the drainage catchment area. The greater the drained catchment area, the greater the flow in comparison to other drainage areas. Flow, in combination with poor water quality, provides the pollutant flux (flux = discharge x concentration) from a drain. Generally speaking, a drain with a higher flow has the potential to discharge a higher pollutant flux, having a greater impact on the environment.

Catchment flows for this study were generated using the Australian Water Balance Model v2002 (AWBM) (Boughton, 2004). The catchments for Broughton Creek and Crookhaven River floodplains were divided into steep catchments and flat floodplain catchments. Each drain sub-catchment was delineated using LIDAR data and divided into steep and flat where appropriate. The 5 m AHD contour was used to divide steep and flat areas. An area of catchment currently gauged by the NSW Office of Water was used to calibrate the AWBM model for steep catchments. Auto-calibration was used for the low, flat floodplain areas of the catchments. Ninety-nine (99) years of daily rainfall data at Berry was used to create a prediction of daily discharge for each drain. Daily flows were analysed to produce percentile exceedance statistics for each drain to enable a normalised ranking. The 98$^{th}$ percentile exceedance flows were used to rank each drain.

### *Asset Condition*

The condition of Council's flood mitigation assets was surveyed by Shoalhaven City Council (SCC) between 2010 and 2011. Both drain and structure condition was included in the survey. Asset condition was summarised as:

- Good;
- Fair;
- Poor; or,
- Very Poor/Missing.

When assessing floodgate structures, condition reporting was only undertaken on the ability of a floodgate to restrict tidal intrusion and maintain efficient drainage. If a floodgate had been previously modified for an auto-tidal gate, the condition of the auto-tidal gate was not surveyed. A survey by SCC and WRL-UNSW in July 2013 showed that all auto-tidal gates except P3D5G1 installed in Broughton Creek are no longer functional, or were never commissioned or are in poor/very poor condition.

### *Landholder Willingness*

Landholder willingness is a major component of the prioritisation processes. Although interim (short-term) remediation strategies are aimed at minimal disturbance to the landholder and agricultural practices, the majority of long-term remediation strategies involve changing of current land use practices of a portion or all of a drainage area. A willing landholder greatly influences the potential remediation strategy that is achievable, particularly in the long-term.

Existing land productivity also influences potential future land management strategies. Some areas have high soil salinity from previous natural tidal inundation resulting in poor agricultural yields. Other agricultural areas are extremely low lying (below 0 m AHD) and have a history of poor drainage and extended inundation. These areas are candidates for changing land use practices whereby poor quality land is utilised for wet pasture management or transformed to a natural wetland or saltmarsh system. Future risk to climate change and sea level rise may also influence landholder willingness to vary existing land use management strategies.

A survey of landholder knowledge regarding acid sulfate soils and willingness to adopt various remediation strategies was undertaken using a survey distributed in October 2013. Full results of the landholder survey are not presented in this report due to protection of privacy. Statistical analysis of survey results was undertaken, finding that further education is required to fully inform landholders about acid sulfate soil remediation. Landholders were generally opposed to remediation strategies that impact their existing agricultural practices.

### *Groundwater*

The ability of water to flow through the soil matrix is known as the hydraulic conductivity (K) of a soil. A high hydraulic conductivity implies a greater potential groundwater flow rate. On the Broughton Creek and Crookhaven River floodplains, a high soil hydraulic conductivity increases the potential for acid to be transported from the soil into drainage channels and the estuary. Areas with a high hydraulic conductivity are subsequently assigned a high priority. Overall, hydraulic conductivity data is spatially sparse across both floodplains.

### *Water Quality*

Acid discharge events occur after large wet weather events. During dry periods, drain water quality is an indicator of potential acid event discharges, however the measurement of actual wet weather flow, and acid discharge is preferred. Measurement of post-flood discharge and water quality enables the total acid flux of a drain and the contribution of each drain to overall estuarine water quality to be determined.

Following the 1991 and 1992 acid events on Broughton Creek, an intensive water quality monitoring campaign was initiated with regular monitoring at major drains on Broughton Creek until 2001. Since 2001, a reduced number of monitoring locations are maintained.

Wet weather pH measurements were used where possible to rank drain water quality for prioritisation. Where wet weather data was unavailable, dry weather drain or groundwater pH data was used. Catchment modelling was used to determine when wet events occurred and which pH value corresponded to wet weather discharge. A higher acid risk and ranking was applied to larger drainage areas with measured low pH discharges. As pH is a logarithmic measure of hydrogen protons ($H^+$), pH values were converted to $H^+$ concentrations to ensure the acidity of each measurement was correctly included into the priority risk assessment.

### *Sensitive Receivers*

The proximity of each drainage area to sensitive environmental receivers is an important factor to consider when assessing the benefits of remediation. The

Shoalhaven River estuary contains significant environmental and economic values that are impacted by poor water quality and acidic discharges. Some sensitive receivers, such as commercial oyster leases and seagrasses, are located adjacent to the discharge point of several drains and are subsequently highly susceptible to poor water quality.

A range of stationary sensitive receivers in the Lower Shoalhaven River estuary were identified as part of this study including:

- Oyster leases
- Macrophytes
- Endangered Ecological Communities (EEC)
- Riverbank stabilisation projects

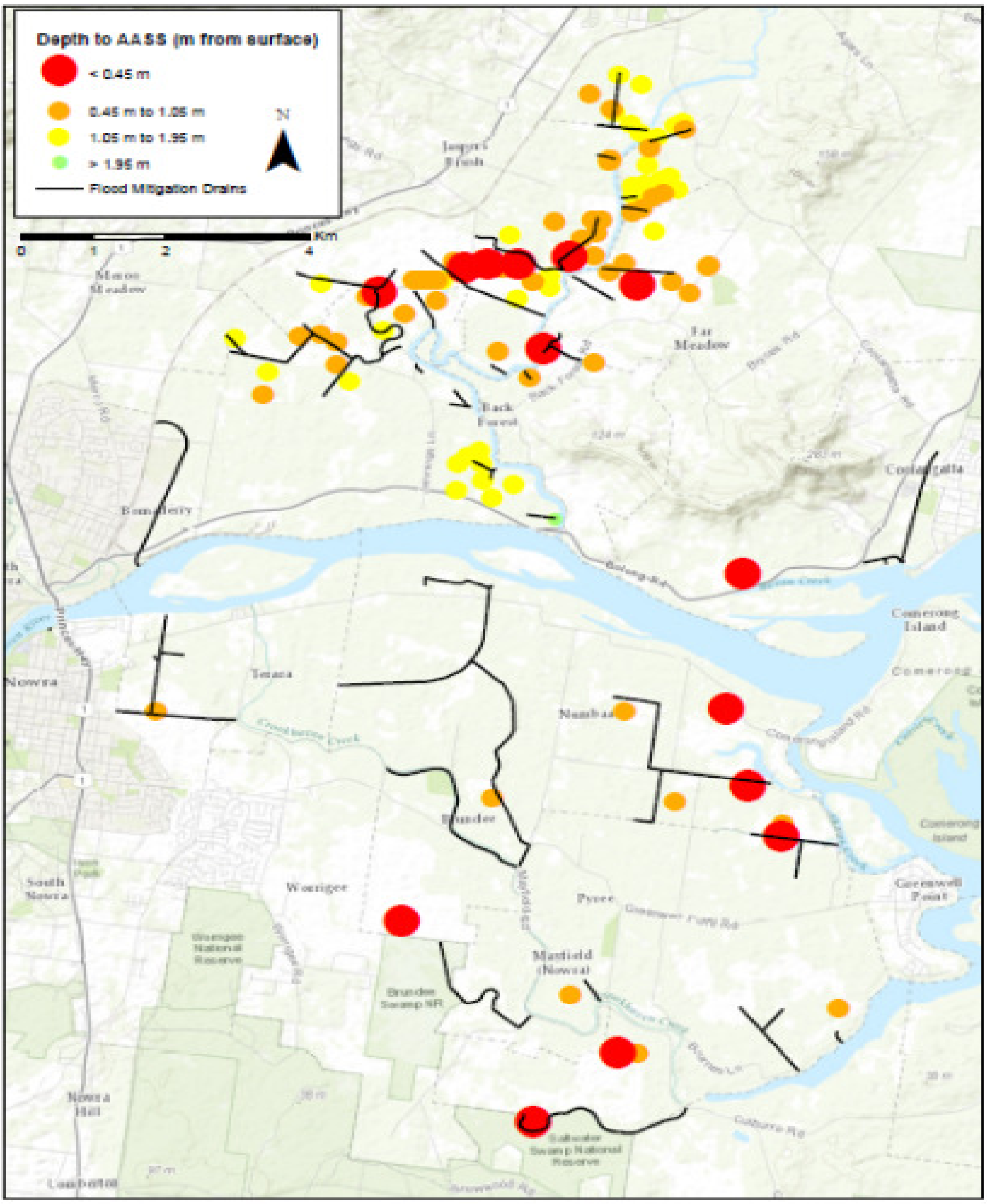


**Figure 3. Depth to Active Acid Sulphate Soil Layer Across Study Site**

These sensitive receivers were mapped and the proximity to each drain determined.

Potential aquatic habitat contained within each drainage area was also considered as part of each remediation strategy. Winberg and Heath (2010) identified that floodgates eliminate natural fish and invertebrate life from tributary habitats and reduce overall primary production in the lower estuary. Tributaries function as key fishery nursery habitat and contribute to the overall population of fisheries in estuaries (NSW DPI, 2007; Winberg and Heath, 2010).

### *Acidic Soils*

The extent of acidic soils across the Broughton Creek and Crookhaven River floodplains is a key component of the priority assessment. The depths to the actual and potential acid sulfate soil layers (AASS and PASS) are critical in identifying acid sources and the potential acid production of drainage areas (Figure 3). Relating acid layer depth to drain invert elevations enables high risk drains to be identified. A drainage area, which is deeply incised into the acidic layers, poses a higher risk for acid generation and mobilisation than a shallower drain constructed through the same acidic layer. Furthermore, the AASS and PASS layer elevation in relation to the low drain water elevation determines the potential acidic groundwater hydraulic gradient. The drain prioritisation process also considered drain width and length when assigning priority rankings based on soil acidity, as a long, wide drain has a greater acid generating potential compared to a short, shallow drain.

### *Climate Change*

Climate change in the Shoalhaven River estuary is likely to affect land use and flood mitigation management over the next 10 to 50 years. Sea level rise predictions indicate 0.4 m rise in average water levels by 2050 (DECCW, 2009). The impact of sea level rise was assessed across the Broughton Creek and Crookhaven River floodplains as part of this study. As long-term tidal levels increase, individual drainage areas become connected at higher elevations (Figure 4). Subsequently, climate change was assessed on management areas where the interconnectivity of future sea levels is predicted.

The elevation of existing infrastructure (levees, headwalls, and floodgates) was incorporated into the climate change assessment. The headwall elevation of existing structures is generally the lowest point on the Shoalhaven River banks and is the first point of overtopping in many drainage areas. Areas identified as being highly susceptible to sea level rise were given a higher priority for implementation of a long-term remediation strategy. Drainage areas that are likely to be unaffected by climate change in the short to mid-term (10 to 20 years) are logical candidates for implementation of interim remediation strategies.

Although increased high tide elevations are likely to impact the floodplain in the long-term, the major short-term impact will be reduced drainage. This is particularly relevant to low-lying areas where prolonged periods of inundation following wet weather events are expected by 2050. The Crookhaven River floodplain is likely to be worst affected by reduced drainage, with low-lying areas in Terara, Numbaa, Saltwater, Brundee and Greenwell Point. The backswamp areas of the Broughton Creek floodplain at Jaspers Brush Swamp, Back Forest and Far Meadow Swamp will also experience reduced drainage and increased inundation.

Climate change was incorporated into this study by considering both short and long-term impacts on each drainage area. The susceptibility of areas to both saline inundation and reduced drainage was assessed to guide the final remediation action plans. The impact of climate change was applied by characterising climate change susceptibility as:

- High = Significantly reduced drainage
- Medium = Saline inundation/overtopping and/or reduced drainage
- Low = General reduced drainage


**Figure 4. Implications of Sea Level Rise on Floodplain Management**

## Results

The results from the MCA were used to develop a prioritised list of sub-catchments based on acid risk impacts (Figure 5). This information was then used to develop short and long-term drain remediation Action Plans for all flood mitigation drains on the floodplain. Climate change implications were assessed at each of the drainage sub-catchments.

A total of 39 drainage areas were identified and assessed. Broughton Creek was identified as the worst affected area, containing the top 13 acid affected drains. Particularly, the Far Meadow, Jorams Creek and Berry areas were found to be the highest risk sub-catchments. Some areas of the Crookhaven River floodplain were found to be a potential acid risk, however the overall impact of the Crookhaven sub-catchment is low.

The priority list generated from the MCA provided an interesting series of observations about acid impacts in the Shoalhaven/Crookhaven region, namely:

- The highest priority areas are located predominately in the mid-Broughton Creek region;
- The top 6 priority sites contain 80% of the floodplain risk;
- Climate change, and particularly sea level rise, will influence drainage in the region but the largest impact is associated with the new elevated low tides, with lesser impacts from the proposed new elevated high tides.

A full description of the prioritised sub-catchments, action plans and implications of climate change is provided in Glamore et al. (2014).

## Summary

To date, remediation plans for ASS affected floodplains have been focused on individual drains, not catchment wide/floodplain characteristics. On-ground remediation works have largely been undertaken on an ad-hoc or opportunistic basis with limited catchment wide planning or multi-criteria analysis.

In contrast, this study assessed historical evidence and designed plans for each sub-catchment drainage area based on a multi-criteria evidence based assessment including drain characteristics, acid contributions and sensitive ecological receivers using field data. This strategic approach to floodplain planning enables key sites to be targeted now and into the future. An important component of the approach is the development of Action Plans for each sub-catchment, including immediate and long-term actions required onsite to mitigate and remediate previous legacy issues.

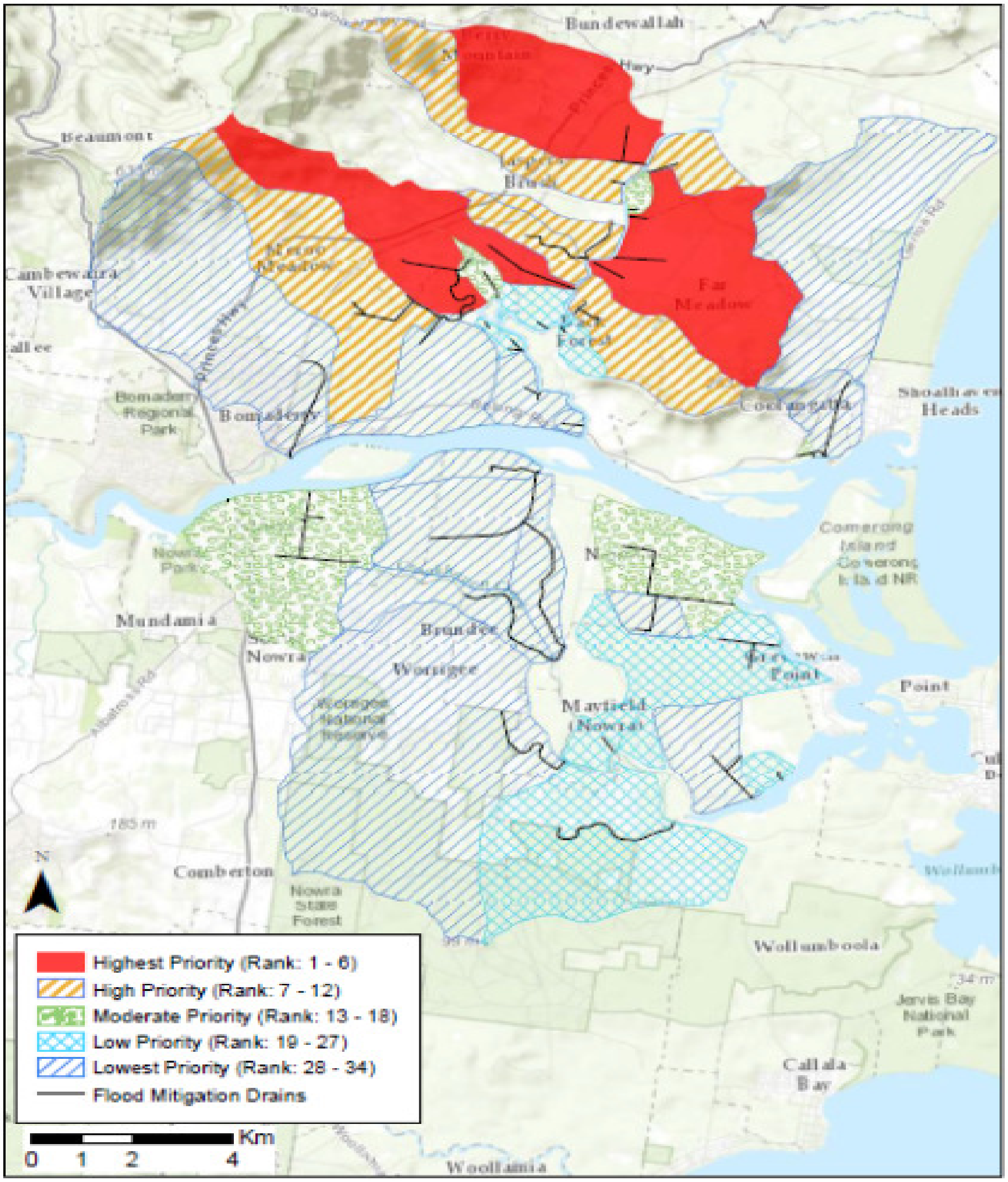


**Figure 5. Priority Rankings Based on Multi-Criteria Analysis**

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