Water Research Laboratory

Gumma Gumma Swamp Hydrologic Investigation

WRL Technical Report 2013/03
July 2013

by
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Water Research Laboratory
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1. Introduction

Gumma Gumma Swamp is located on the south bank of the Nambucca River, approximately 9 km upstream from the ocean entrance (Figure 1.1). Comprising a catchment of approximately 1,350 hectares (13.5 km^2), Gumma Gumma Swamp is characterised by high surrounding hills draining to the low-lying floodplain of the Nambucca River Estuary (Figure 1.2). The wetland itself is approximately 130 hectares (1.3 km^2) of SEPP 14 classification with a history of high-risk acid sulphate soils (WetlandCare Australia, 2012). Gumma Gumma Swamp experiences flooding from local catchment inflows as well as backwater flooding from the Nambucca River. Following wet events, the wetland is drained through Gumma Gumma Creek into the Nambucca River channel.

The wetland has a long history of hydrologic modification. In the early 1900s, Gumma Gumma Swamp was zoned for potential agricultural development and subsequently drained via a set of 10 floodgated culverts at the mouth of Gumma Gumma Creek. These one-way floodgates, in conjunction with extensive floodplain drainage channel construction, ensured low water levels were maintained and limited saline intrusion to the wetland. Following stakeholder concern of tidal intrusion through the dilapidated floodgates, a drop-board weir was constructed in 2005 approximately 1.4 km upstream from the Nambucca River/Gumma Gumma Creek confluence. In 2006, the dilapidated floodgates were replaced by a single span bridge (WetlandCare Australia, 2012).

The drop-board weir was constructed to allow landholders to manually remove drop-boards during flood periods to increase wetland drainage, whilst keeping drop-boards in place during dry periods. With drop-boards installed, saline intrusion is limited and elevated groundwater levels are maintained, thereby minimising acid export. Since installation, the mid-north coast has experienced extended periods of wet weather and the site has been subject to frequent flooding in excess of 2.0 m AHD (Australian Height Datum). Stakeholders have raised concerns that the current drop-board structure limits drainage, producing extended periods of paddock inundation. Telfer and Birch (2009) identified that the drop board structure does not control drainage from the wetland, with a natural barrier located approximately 50 m upstream controlling site drainage.

Key objectives for Gumma Gumma Swamp (as outlined in the project brief) include:

- Rapid drainage of the wetland following flooding;
- Limit saline intrusion to agricultural land;
- Limit acid sulphate soil scalding and acid runoff events (i.e. improve water quality);
- Improve fisheries; and
- Restore the ecological values of the wetland.

A basic understanding of wetland/catchment hydrology is required to correctly address these issues. WetlandCare Australia commissioned the Water Research Laboratory (WRL) at the School of Civil and Environmental Engineering of the University of New South Wales (UNSW) to develop a conceptual hydrological model and water balance model of the site.

Key to developing a conceptual model of site hydrology and water quality is:

- Identification of flow controls (drain, levees, structures etc.);
- Identification of acid export mechanism;
- Identification of acid sources;
- Water movement/drainage and residence time on the wetland; and
- Site drainage following a flood.

This report provides a description of WRL's interpretation of site hydrology and the resultant water balance. For this investigation WRL developed a conceptual hydrologic model where available data permitted, and identified data gaps that limit hydrological understanding at Gumma Gumma. In conjunction with review and collation of available data (Section 2), WRL undertook a two-day site inspection to ground truth LiDAR data, investigate groundwater characteristics and inspect key site topography (Section 3). A desktop review and assessment was then undertaken to develop a conceptual model of wetland hydrology (Section 4, Section 5 and Section 6).

2. Existing Data

A range of existing data was supplied by WetlandCare Australia, Nambucca Shire Council (NSC), Manly Hydraulics Laboratory (MHL), Bureau of Meteorology (BoM), and also sourced from other available literature.

Datasets collected were:

- Macksville water level timeseries (MHL);
- Raw LiDAR survey point cloud (NSC);
- Annual tidal planes (MHL, 2012);
- Water level and water quality timeseries at the drop-board structure (Greenspan-Pentair, 2013); and
- Historical aerial photographs (1942, 1967, 2004, 2010).

Historical aerial photographs are presented chronologically in Figures 2.1 to 2.4. Historical photos show natural and man-made drainage channels across the site. Between 1942 and 1967 the distribution of rush and reed species diminished, being replaced by swamp oaks (*Casuarina glauca)* and swamp paperbarks (*Melaleuca quinquenervia and Melaleuca stypheliodes*). Comparison with the later 2000's imagery shows extensive coverage of oak and paperbark. Furthermore, increases in aquatic weeds since 2004 are visible in previously open water areas covered in *Jancus usitatus* and *Salvinia molesta*.

Natural and man-made drainage channels currently concealed by dense vegetation can be identified from historical photos. Key structures and levees were identified from the LiDAR data and previous reports (Telfer and Birch (2009); WetlandCare Australia (2012)). These features are summarised in Figure 2.5.

Analysis of LiDAR data in conjunction with field knowledge of existing and historical drainage channels enabled a schematic of site connectivity to be constructed (Figure 2.6). At low water levels, (approximately 1.0 m Australian Height Datum (AHD) and below), each pond is essentially disconnected. Conversely, higher water levels of approximately 1.3 m AHD and greater result in full connectivity between ponds.

3. Site Investigation

WRL staff completed a two-day site inspection of Gumma Gumma Swamp on January 17^{th}-18^{th}, 2013. During the two days, the site was inspected by vehicle and on foot with a portion of the wetland surveyed using RTK-GPS. During the site inspection WetlandCare Australia staff were trained to undertake groundwater testing, acid sulphate soil testing and water quality measurements. A large area of the site was accessible due to the prolonged dry conditions preceding the field investigation.

3.1 LiDAR Ground-Truthing

LiDAR is the large-scale surveying of topography using airborne laser. Whilst the accuracy of LiDAR is usually provided in the metadata file, vegetation and open water influence the accuracy of the laser return signal locally where these occur. LiDAR poorly penetrates dense vegetation or water, providing false-positive readings for a ground level at standing water locations. Desktop assessment of aerial photography showed significant open water and ponded areas covered in aquatic vegetation. Subsequently, the accuracy of the survey must be verified.

To ground-truth the dataset, land not typically inundated (i.e. paddocks) was surveyed using RTK-GPS techniques and compared to LiDAR data to determine accuracy across sparsely vegetated areas (Figure 3.1). Areas typically underwater were also surveyed where on-ground access and satellite connection permitted. The supplied LiDAR dataset indicated readings of approximately 1.0 m AHD for large areas of the swamp. Wetland bathymetry elevations at the same locations were surveyed with the RTK-GPS and were observed to vary between approximately 0.0 m and 0.3 m AHD. These survey points were used to create the bathymetry for the areas underwater at the time of LiDAR data collection (Figure 3.1).

3.2 DEM Construction

Based on the ground-truthing exercise noted above, the area of the wetland underwater at the time of LiDAR data collection was removed from the interpolated Digital Elevation Model (DEM) (Figure 3.2). Survey points taken in open water areas were extrapolated across the entire area to create a revised estimated bathymetry. The revised bathymetry was merged with the surrounding LiDAR data to create a new DEM (Figure 3.3). This DEM was constructed specifically for the purpose of calculating storage relationships and assessing pond connectivity. It should not be used for any other purpose.

3.3 Bulk Hydraulic Conductivity (Ksat)

Water quality discharging from Gumma Gumma Creek has been highlighted as a significant issue affecting local stakeholders (Kemsley (1997); Telfer and Birch (2009); WetlandCare Australia (2012)). Poor water quality at Gumma Gumma has been attributed to the presence of acid sulphate soils at shallow depths and long residence times of floodwaters (Telfer and Birch, 2009). Advection and diffusion of acid sulphate soil leachate into drainage channels following flooding events results in low pH, and highly soluble iron and aluminium being discharged into the Nambucca River.

The importance of the groundwater flux (hydraulic conductivity) to acid export at Gumma Gumma Swamp can be tested using the methodology outlined by Johnston *et al*. (2003). This method comprises the excavation of a shallow pit, extraction of standing groundwater and measurement of the rate of infilling. This technique provides a rapid, semi-quantitative assessment of saturated hydraulic conductivity (K_{sat}).

WetlandCare Australia staff were trained by WRL to undertake the groundwater assessment. A total of 7 locations were sampled across the wetland over the two-day field investigation (Figure 3.4). Two pits (1 and 4) did not produce water within the required 0.5 m to 0.75 m depth. Testing of groundwater by Kemsley (1997) during a dry period identified the level of the water table to be between 0.4 m to 1.0 m below the soil surface for the south-eastern extent of the wetland. Testing by WetlandCare Australia noted average groundwater depths between 0.3 m to 0.4 m below ground surface. The K_{sat} results for the pits are presented in Figures 3.5 to 3.9.

During the pit excavation, a soil sample was extracted using a gauge auger and tested using 30% hydrogen peroxide (H_2O_2) to assess potential acid sulphate soil risk (Table 3.1). The pH, EC and salinity of the soil were also measured for the samples that produced the greatest H_2O_2 reaction (Table 3.2).

Table 3.1: Acid Sulphate Soil Reaction Results

Depth Below Surface (mm)	Pit 2	Pit 2a	Pit 3	Pit 3a	Pit 4a
0 – 100	1	2	1	3	1
100 – 200	1	2	1	3	1
200 – 300	1	2	1	3	1
300 - 400	1	3	1	2	1
400 – 500	1	3	1	2	0
500 – 600	1	3	1	1	0
600 - 700	2	-	-	-	-

Note: A result of 0 = no reaction/low ASS content to 5 = violent reaction/high ASS content

Table 3.2: Soil pH and Groundwater Quality

Pit	pH	EC (ms/cm)	Salinity (ppt)
1	Dry*		
2	4.78	-	-
2a	5.53	25.07	12.51
3	4.64	25.20	12.61
3a	3.97	23.56	12.00
4	Dry*		
4a	6.55	-	-

* No groundwater located within 0.7 m of surface

Groundwater testing results indicated that groundwater transport at Gumma Gumma is a potentially significant source of acid, iron and aluminium and a major contributor to poor water quality discharging to Gumma Creek. All pits with shallow groundwater were observed to have moderate to high hydraulic conductivity (Figures 3.5 to 3.9). Furthermore, low soil pH was observed at the majority of test locations. Moderate acid sulphate soil content was recorded for Pits 2a and 3a.

Importantly, the K_{sat} and pH soil results provide an indication for a limited number of discrete locations. The acid sulphate soil tests did not indicate high sulphur content. Further investigations of acid sulphate soil extent are required to adequately delineate acid sources. Additional discussion on acid sulphate soils is provided in Section 5.

3.4 Existing Flow Control Structure

The existing drop-board structure was surveyed during the field investigation (Figure 3.10). The crest of the structure was observed to be at + 0.9 m AHD with the invert at - 0.1 m AHD. The structure was designed to prevent saline intrusion during spring tide events and control acid groundwater discharge from upstream. The site inspection confirmed that the structure does not control drainage from the site, as also noted by Telfer and Birch (2009). Approximately 30 m to 40 m upstream of the structure, the channel thalweg (lowest part of the channel) is higher than the structure crest. The mangroves and sediment in the drainage channel create a natural barrier and appear to control drainage/tidal flooding of the eastern portion of the site. This natural barrier is likely to promote wetland drainage via the eastern drains/structures that are more hydraulically efficient.

The crest of the weir structure was observed to be approximately 0.5 m below the elevation of the levee surrounding Gumma Gumma Creek. This suggests that drainage above approximately 1.4 m to 1.5 m AHD is controlled by the Nambucca River levels. Drainage at levels below 1.5 m AHD is controlled by the natural barrier located upstream of the drop-board weir, and the channels/structures draining to the east of Gumma Gumma Creek. The middle and western areas of the wetland are poorly connected to the eastern drainage channels and are likely to drain inefficiently once water levels reach (or fall below) approximately 1.0 m AHD.

4. Flooding

Gumma Gumma Swamp experiences frequent inundation from local catchment, tidal, and backwater effects from the Nambucca River. Evidence of high flood levels was observed across the wetland with flood debris present in trees and fences across the lower-lying areas of the site. These fences were surveyed to be above 2.0 m AHD. Evidence of saline inundation of the site was observed with salt remaining on the dry circular pond adjacent to Gumma Gumma Swamp. Further, stands of mangroves were observed up to 200 m upstream of the drop-board structure, indicating a potential saline connection with the eastern portion of the site.

Development of a stage-volume relationship from the modified DEM is vital in assessing the flooding response of the site. The stage-volume relationship indicates the volume of water below a certain elevation. This volume was extracted for the site using the DEM (Table 4.1 and Figure 4.1). The DEM indicates some connection in the south-western portion of the site at elevations above 1.5 – 2.0 m AHD, however drainage of this area is predominantly north via the East Street Drain and was not included in the catchment analysis and stage-volume relationship.

Note that since the majority of the wetland is below 1.0 m AHD, was underwater at the time of aerial surveying, the stage-volume relationship below this elevation should be considered an estimate only.

Key hydrological features of the site (as noted on Figure 4.2) as floodwater elevations increase are:

- Minor tidal inundation of elevation below 0.75 m, primarily contained to the eastern extent of the swamp.

- Above approximately 1.0 m AHD, a connection between the middle and eastern ponds occurs with the western area of the swamp connecting at a water level above approximately 1.3 m AHD (as indicated in Figure 1.2). An elevation of approximately 1.0 m AHD represents the extent of regular inundation. This elevation is approximately where vegetation changes from paddock grass species to aquatic vegetation and water/salt tolerant species.

- Inundation of land above 1.0 m AHD indicates catchment based wet events. A substantial increase in inundated area occurs between 1.0 m and 1.25 m, with an 80% increase in storage volume.

- Above approximately 1.5 m AHD, the levee surrounding the semi-circular pond is fully inundated and connected to Gumma Gumma Creek. Water elevations in excess of 1.5 m AHD are likely to occur due to backwater flooding from Nambucca River or an extreme local catchment flood event.

- At elevations above 1.75 m AHD, the main Gumma Gumma wetland connects to the western boundary of the East Street drainage catchment.

Table 4.1: Gumma Gumma Swamp Stage-Volume Relationship

Elevation (m AHD)	Approximate Volume Below (m^3)
0	50
0.25	3,000
0.5	120,000
0.75	531,000
1	1,260,000
1.25	2,249,000
1.5	3,452,000
1.75	4,880,000
2	6,478,000
2.25	8,221,000
2.5	10,077,000
2.75	11,999,000

4.1 Tidal Planes

Tidal planes for Macksville are presented in Table 4.2. Mean ocean tidal levels at Macksville are generally elevated, indicated by a mean sea level (M.S.L) of 0.23 m AHD. The peak tidal water level at Macksville of 0.959 m AHD experienced in 2009-10 is just above the crest of the drop-board structure. Historical peak tidal level averages are generally below the crest of the structure (Figure 4.2).

Table 4.2: Tidal Plane Analysis at Macksville (m AHD) (MHL, 2012)

Tidal Plane*	2005-06	2006-07	2007-08	2008-09	2009-10	Annual Average (1990 – 2010)
H.H.W.S.S	0.827	0.732	0.841	0.938	0.959	0.858
M.H.W.S	0.538	0.447	0.534	0.611	0.617	0.544
M.H.W	0.484	0.397	0.742	0.552	0.542	0.483
M.H.W.N	0.429	0.347	0.410	0.493	0.466	0.422
M.S.L	0.229	0.154	0.205	0.251	0.191	0.203
M.L.W.N	0.30	-0.039	0.001	0.008	-0.084	-0.016
M.L.W	-0.025	-0.089	-0.062	-0.051	-0.159	-0.076
M.L.W.S	-0.080	-0.139	-0.124	-0.110	-0.234	-0.137
I.S.L.W	-0.285	-0.342	-0.343	-0.343	-0.478	-0.361

*Expanded tidal plane acronyms are as follows:
H.H.W.S.S – High high water spring solstice
M.H.W.S – Mean high water springs
M.H.W – Mean high water
M.H.W.N – Mean high water neaps
M.S.L – Mean sea level
M.L.W.N – Mean low water neaps
M.L.W – Mean low water
M.L.W.S –Mean low water springs
I.S.L.W – Indian spring low water

Tidal coverage across the site was estimated by applying global tidal elevations to the modified DEM (Figure 4.3). This methodology indicates significant coverage of tidal water across the wetland. However, observed saline inundation was limited to the eastern quarter of the wetland as indicated by mangrove distribution and dried salt residue.

Further assessment of vegetation coverage allows a conceptual tidal inundation extent to be established. Freshwater species such as *Salvinia molesta* were observed in the middle and western portions of the site. Since the vegetation does not align with the tidal plane assessment, applying a "bathtub" approach to assessing tidal inundation at Gumma Gumma Swamp should be treated with caution. A revised conceptual saline inundation map is presented in Figure 4.4.

Saline inundation of the western half of the wetland is limited due to the drainage control being located approximately 50 m upstream of the existing drop-board structure. Sedimentation around dense stands of mangroves and associated root system has created a barrier at a higher elevation than the crest of the control structure. Unfortunately, dense canopy coverage around the natural barrier limited satellite connection to the RTK-GPS and subsequently the elevation of this natural barrier was not surveyed.

4.2 Local Catchment Flooding

To understand the magnitude of a rainfall event that would be required to fill Gumma Gumma Swamp, a simple desktop assessment was undertaken. Annual Recurrence Interval (ARI) rainfall for Macksville was utilised to assess the filling of Gumma Gumma Swamp from a level of 0.0 m AHD to 1.0 m AHD, a volume of approximately 1,260,000 m^3. The ARI rainfall for Macksville (Table 4.3) runoff was combined with a catchment area of approximately 13.5 km^2 to characterise rainfall events (Table 4.4). It was assumed losses would be 2 mm/hour.

Table 4.3: Rainfall ARI Curves for Macksville (mm/hour)

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins		135	170	191	218	254	281
6Mins		127	160	179	205	239	265
10Mins		104	132	148	170	199	221
20Mins		75.8	97.3	110	127	149	166
30Mins		61.8	79.8	90.5	105	123	138
1Hr		42.1	55	62.6	72.7	86.1	96.4
2Hrs		27.8	36.6	41.9	48.7	57.9	65
3Hrs		21.6	28.6	32.7	38.2	45.4	51.1
6Hrs	10.8	14.1	18.6	21.4	25	29.9	33.6
12Hrs	7.07	9.24	12.3	14.2	16.7	20	22.5
24Hrs	4.71	6.18	8.32	9.64	11.3	13.7	15.4
48Hrs	3.12	4.1	5.59	6.51	7.7	9.31	10.6
72Hrs	2.37	3.13	4.29	5.01	5.93	7.2	8.19

Table 4.4: Theoretical Event Inflow as a Percentage of Required Volume to fill Gumma Gumma Swamp from Dry to 1.0 m AHD

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins		12%	15%	17%	19%	23%	25%
6Mins		13%	17%	19%	22%	26%	28%
10Mins		18%	23%	26%	30%	35%	39%
20Mins		27%	34%	39%	45%	53%	59%
30Mins		32%	42%	48%	56%	65%	73%
1Hr		43%	57%	65%	76%	91%	102%
2Hrs		56%	75%	86%	101%	121%	136%
3Hrs		63%	86%	99%	117%	141%	159%
6Hrs	57%	78%	107%	126%	149%	181%	205%
12Hrs	66%	94%	133%	158%	190%	233%	265%
24Hrs	70%	108%	164%	198%	241%	303%	347%
48Hrs	58%	109%	186%	234%	295%	379%	445%
72Hrs	29%	88%	178%	234%	305%	404%	481%

Flooding from local catchment runoff at Gumma Gumma has the potential to inundate pastoral land and discharge water to the Nambucca River. Table 4.4 shows that a 2 year ARI, 24 hour duration rainfall event will fill the wetland from a dry state. Further, frequent small events have the potential to maintain high water levels in Gumma Gumma Swamp. The wetland, however, does not appear susceptible to 'flashier' flood events (i.e. high frequency, short duration). Ongoing catchment based flooding is exacerbated by poor site drainage.

Larger catchment flood events of long duration produce significantly more runoff volume than the wetland storage. These events would result in pond connection across the wetland and discharge to Gumma Gumma Creek. Large events are likely to result in flooding across the Nambucca River catchment and subsequently produce high river levels. Under this scenario, backwater flooding of the wetland would combine with local catchment flooding, producing elevated water levels across the wetland.

4.3 Backwater Flooding from Nambucca River

The Nambucca River is the primary source of major flooding for Gumma Gumma Swamp. When the Nambucca River experiences high water levels (i.e. greater than approximately 1.0 m AHD), floodwaters from the main river channel inundate the Gumma Gumma Swamp. To assess the impact of this flooding, the water level record for Macksville was sourced from MHL. This record provides hourly (at least) records from April 1983 to February 2013 (Figure 4.5). Water levels prior to this were noted to be available by NSC (2007), however they could not be located by the time of publication. Further, a longer timeseries of water levels does not necessarily provide increased benefits to this study as the 20 year, 50 year and 100 year ARI flood levels were provided in NSC (2007) and are listed in Table 4.5.

Table 4.5: Design Flood Heights at Macksville (NSC, 2007)

Annual Exceedence Probability (AEP)	Average Recurrence Interval (ARI)	Level at Macksville (m AHD)
5%	20	2.95
2%	50	3.35
1%	100	3.55

Since 2007, the Nambucca River has experienced frequent flood events in excess of 2.0 m AHD, resulting in regular inundation of Gumma Gumma Swamp. The State Emergency Service (SES, 2008) lists 2.10 m AHD as a Moderate flood level. Analysis of the past 30 years of water level data (Figure 4.5) shows that this level is exceeded approximately every 5 years. Figure 4.6 shows the extent of inundation from floodwaters at Gumma Gumma Swamp for moderate (2.10 m AHD) and major (2.95 m AHD) flood levels.

4.4 Draining

Flooding of the wetland from high river levels such as those experienced regularly since 2007 is unavoidable given the low-lying topography and levees on the site. WetlandCare Australia (2012) notes that the wetland experiences extended periods of inundation (weeks to months) following flood events. Recent field assessment of existing structures, levees, pond connectivity and drainage channels, suggest that drainage from the swamp is inefficient.

To confirm that poor drainage efficiency across the wetland causes extended periods of floodwater inundation, the time for the Nambucca River to reach a level of 0.5 m AHD following a flood event was extracted from the Macksville water level record (Table 4.6). Slow falling river levels would hold water within the wetland. Rapidly falling river levels would indicate that poor drainage efficiency across the wetland is the cause of extended inundation.

Table 4.6: Drainage Times Following Flood Events

Year	Peak Flood Level (m AHD)	Time till 0.5m AHD reached (hours)	Time till 0.5m AHD reached (days)
1985	2.16	30	1.25
1988	1.79	96	4.0
1989	1.98	48	2.0
1999	2.12	77	3.2
2001	2.33	66	2.8
2009	2.26	45	1.9
2009	2.18	67	2.8
2009	2.20	43	1.8
2011	2.51	79	3.3
Mean	2.17	61	2.6

Table 4.6 shows that river levels following minor to moderate flooding fall rapidly from peak levels to a level of 0.5 m AHD. Under these conditions, drainage from the site is no longer controlled by the river levels and is a function of internal hydraulic connectivity and efficiency. This analysis confirms the hypothesis that drainage from the site is controlled by the flat topography, poor pond connectivity, poor drainage connectivity, and existing structures and levees.

5. Discussion of Acid Sulphate Soils

Understanding how acid is generated and exported from Gumma Gumma Swamp is crucial to determining appropriate and effective remediation strategies. Acid sulfate soil (ASS) is the common name of soils and sediments containing iron sulfides, the most common being pyrite (DERM, 2009). Pyrite is formed by sedimentation of sands and muds during the last major sea level rise period approximately 6,500 years ago during the Holocene period. Deposition occurred in low-lying coastal zones characterised by low energy environments, such as estuaries and coastal lakes. Pyrite is predominantly located within 5 m of the surface and is found extensively on Australia's coastline (DERM, 2009).

When pyrite is exposed to air, the iron sulfides react with oxygen to form sulfuric acid and numerous iron compounds. ASS that remains in an anaerobic state are termed Potential Acid Sulfate Soils (PASS), with oxidised soils deemed Actual Acid Sulfate Soils (AASS). The problem is exacerbated by the acid breaking down fine clay particles, causing the release of soluble aluminium (Al^{3+}) and Iron (Fe^{3+}). Potential ASS are oxidised to form Actual ASS through the clearing of coastal land for agriculture, including extensive drainage resulting in a subsequently lower groundwater table, introducing gaseous oxygen from the atmosphere to the soil matrix.

Acid flux is the mass of acid discharged from a system and can be characterised by equation 3.1. As such, a system that produces a large volume of higher pH (but still acidic) water may be worse than a system that discharges a small volume of low pH water.

$$\text{Acid Flux} = \text{Volume of discharge (Q) x Acidity (pH, } Al^{3+}, Fe^{3+}) \qquad (3.1)$$

Acid can be exported from the groundwater by three common mechanisms:

1. Advection (or physical movement) due to a difference in groundwater and surface water levels (i.e. low drain levels and high groundwater levels); and,
2. Diffusion (or chemical transport) from high acidity groundwater to lower acidity surface water.
3. Mobilisation of monosulfidic black oozes (MBOs).

Advection of acidic groundwater occurs due to the construction of deep (> 0.5 m) drainage systems on coastal floodplains (Johnston *et al*. 2003). The discharge of acidic and deoxygenated runoff is exacerbated by the installation of one-way tidal floodgates on drainage channels (Glamore, 2003), installed to prevent floodwaters and tidal brackish water from inundating low-lying areas of the floodplain. Floodgates act to maintain low drain water levels, creating a strong water level gradient between the drain and surrounding groundwater, resulting in the efficient transport of acidic and deoxygenated ASS leachate from groundwater to the drainage channel.

Advective transport is likely to occur on the far eastern extent of Gumma Gumma Swamp where deep drains are combined with one-way flood gates. Acid generated from this process is usually exported 5 to 14 days following a flood event, once downstream water levels have returned to normal. Acid generated from this process is often highly acidic. The volume of acid water generated is a function of the area of land drained and the hydraulic conductivity of the soil.

Diffusion of highly acidic groundwater to near neutral surface water can occur when the hydraulic conductivity is very low or the residence time of standing surface waters is significant. This process involves molecular diffusion of H^+ protons through pore water to the surface over a longer period of time (i.e. weeks to months) coupled with evaporation resulting in the accumulation of acid salts. This process could occur at areas of Gumma Gumma Swamp where limited drainage results in long residence time for floodwaters. This acidic reservoir can then be exported following the next rainfall event, with high volume, moderately acidic water being discharged from the site. This acid export process generally leads to more infrequent acid runoff events with lower acid export rates (Johnston *et al.* 2003). Acid production by this method can be detected by monitoring of the first flush of surface water runoff after an extended dry period (Telfer and Birch, 2009).

Kemsley (1997), Telfer and Birch (2009) and Greenspan-Pentair (2013) assessed water quality, or its causes, at Gumma Gumma Swamp. Kemsley (1997) investigated acid sulphate soil content in the south-eastern extent of the wetland. Acid sulphate soils were detected within 0.5 m of the surface, providing pH readings between 3.1 and 5.6 indicating that the eastern extent of the site maybe a potential source of acid. Telfer and Birch (2009) included Gumma Gumma Swamp in a wider study of Lower Nambucca Estuary Water Quality and identified Gumma Gumma Swamp as a high priority subcatchment for action to address poor water quality. Two floodgates draining the eastern extent of the site and the main channel drop-board weir were monitored before and after a flood event (21/5/09 – 28/5/09). The pH and titratable acidity results recorded by Birch and Telfer (2009) showed pH levels greater than 6, however the eastern drains produced slightly worse result. Birch and Telfer (2009) suggested that lower pH readings are likely due to long surface water residence times on the wetland, however further investigation and monitoring was recommended.

In response to the findings and recommendations of Birch and Telfer (2009), Nambucca Shire Council contracted Greenspan-Pentair (2013) to install long-term water quality and water level monitoring equipment at the downstream extent of the drop-board weir structure. Comparison of pH, salinity and water level observations at the structure show consistent pH readings of approximately 6.7 during dry periods with low acid events of approximately pH=4 occurring following a minor to moderate flood event. Greenspan-Pentair (2013) observed an initial drop in pH followed by a slow recovery of pH levels. This suggests that the middle and western extents of Gumma Gumma Swamp produce acid by acid diffusion.

Reviews of previous water quality and groundwater data, in conjunction with groundwater assessment undertaken for this study, are inconclusive in identifying the source(s) and export mechanism(s) of acidic water from Gumma Gumma Swamp. Further investigation of groundwater and soil stratigraphy is recommended to determine the sources of acid. Ongoing and event based monitoring of all structures on Gumma Gumma Creek would enable the mechanism and contribution of the site to be determined.

6. Summary of Conceptual Model

The site inspection, data analysis and flooding calculations presented in this report suggest that Gumma Gumma Swamp can be characterised by:

- Poorly connected and inefficient drainage channels;
- Catchment and river based flooding both contribute to floodwater inundation;
- Poor water quality due to a number of mechanisms;
- Moderate to high saturated hydraulic conductivity in the soil;
- Presence of acid sulphate soils at shallow depths; and
- Uncertainty regarding acid discharge.

Currently, the natural drainage of the wetland is limited by connectivity at low water levels. Natural and man-made barriers limit tidal inundation of the wetland except for some areas directly adjacent to Gumma Gumma Creek. Water movement during dry periods is dominated by evaporation for the majority of the wetland with limited tidal flushing influencing water levels (Figure 6.1). Drainage of the site is also limited during dry periods by a flat gradient (west to east) in conjunction with high surface roughness generated by thick vegetation, both aquatic and otherwise. The western and middle ponds are separated by roads/levees and only connect during wet periods. Floodgates and deep drains connecting the eastern extent of the site to Gumma Gumma Creek provide more efficient drainage and potentially lower groundwater levels.

During a flood event, local catchment runoff fills the site and combines with river floodwaters flowing initially upstream into the wetland (Figure 6.2). As the floodwaters subside, site drainage is characterised by high volume, moderately acidic water being discharged (Figure 6.3). Drainage in the weeks following a flood event may result in highly acidic (low pH) water being discharged at relatively low flow from the eastern drains (Figure 6.4). Inefficient drainage at the western extent of Gumma Gumma results in prolonged releases of poor water quality from Gumma Gumma due to long residence times. Analysis of river level records at Macksville showed that river levels recede quickly following minor to moderate flood events, indicating that drainage is controlled by onsite factors.

Acid export from the site is potentially caused through two mechanisms. Firstly, advection of acidic groundwater to low surface water due to deep drainage channels is exacerbated by the installation of one-way floodgates that maintain low drain water levels. This process is most likely to occur across the far eastern extent of the site. Acid exported by this process occurs most commonly 5 to 14 days following a flood event when river levels have returned to normal. Secondly, diffusion and evaporative processes resulting in the accumulation of acid products and MBOs on the surface are likely to be the main acid generating process across the remainder of the site. Long floodwater residence times resulting from poor drainage exacerbate this process. These processes usually results in the export of acid during the first flush of a rainfall event. The contribution of each process to poor water quality discharging from Gumma Gumma Swamp is currently unknown.

7. Conclusions and Recommendations

This report aimed to characterise the hydrology of Gumma Gumma Wetland. Understanding the interaction of acidic groundwater and surface waters is crucial to determining how poor water quality is generated and exported from the site. Analysis showed that current site topography limits drainage of floodwaters, producing extended inundation.

Reduction of floodwater residence times would result in improved agricultural productivity (i.e. reduce paddock inundation). This could be achieved by increasing hydraulic connectivity across the site by:

- Installation of wide and shallow drains (or culvert) to connect the eastern and western sections of the site; and,
- Removal of vegetation/sediment that limits discharge through the top of Gumma Gumma Creek.

Increasing drainage efficiency should be viewed with extreme caution as this has the potential to increase acid advection and acid concentration. These remediation options should only be considered following further site investigations and monitoring.

Determination of acid production mechanisms and acid sources is currently inconclusive. WRL recommends further groundwater investigations and monitoring including:

- Monitoring of eastern floodgates to determine acid flux (volume x acidity);
- Monitoring of drop-board weir to determine acid flux from main wetland ponds;
- Further delineation of acid sulphate soils and saturated hydraulic conductivity; and
- Monitoring of water levels and quality in the main ponds of the wetland.

7.1 Event Based Monitoring

Determination of acid discharge sources/mechanisms from Gumma Gumma Swamp should be undertaken by manual monitoring of rainfall events by suitably qualified personnel. Recent long term data collection at the drop-board structure has been prone to instrumentation failure, with quantification of acid flux and acid sources being inconclusive. On-ground manual monitoring of flows and water quality ensures collection of reliable data. Monitoring of an acid discharge event requires measurement of pre and post-event discharge and water quality. As predicting an acid event is difficult, a dry snapshot of the wetland allows ‘normal’ conditions to be characterised. Ideally this would be undertaken following a 4 to 8 week period of limited rainfall. During a dry snapshot, water quality, levels, and discharge from the site area are assessed over a number of consecutive days.

Monitoring of acid discharge from Gumma Gumma Swamp should be undertaken following medium to large rainfall events (> 60 mm/day). Measurement at key drains/structures of flow, water quality and collection of water samples for laboratory analysis should be undertaken. Ideally this would occur during ebb tide (falling water levels in Gumma Gumma Creek) to ensure periods of high acid discharge are captured. Water quality in the main wetland should also be monitored daily to help determine acid export mechanisms and transport dynamics. Monitoring of discharges daily at the end and immediately following the rainfall event is recommended. Increasing monitoring and sampling to multiple times per day as pH decreases is recommended. Monitoring should be ongoing until discharge has returned to normal quality. Ongoing monitoring of Gumma Gumma Swamp discharge following an event is dependent on discharged water quality and the time between monitoring can be increased as water quality improves.

Surface water grab samples during the event should be obtained from the Nambucca River and Gumma Gumma Creek. Surface samples both upstream and downstream of the entrance to Gumma Gumma Creek would provide an indication of the far-field impacts of the acid plume on the immediate receiving water area. This sampling would provide standard water quality parameters (pH, EC, Temp, DO) as well as laboratory analysis of contaminants (Fe, Mg, Mn, Al, As).

7.2 Ongoing Site Monitoring

To complement targeted event based monitoring, ongoing monitoring of water levels across the site is recommended using water level loggers. This enables drainage and connectivity of different ponds across the wetland to be assessed as well as saline intrusion. Logger installations are recommended to be discretely located to minimise tampering. Monitoring at four (4) locations is recommended:

- Gumma Road bridge;
- Upstream of eastern floodgates in one drain;
- Upstream of the drop-board structure in open water pond; and
- West of Holsworths access road.

Further assessment of acid sulfate soil distribution and hydraulic conductivity using the pit test methods outlined by Johnston *et al.* (2003) is also recommended.

7.3 Preliminary Remediation Options

Although further monitoring and investigation is required, works that could be undertaken to minimise acid export from the site involve modification of the eastern floodgates and improvement of site connectivity to reduce floodwater residence on site. Modification of the eastern floodgates to promote tidal exchange within the channel would maintain higher drain water levels and minimise the gradient between groundwater and surface water. This remediation option has been successfully applied to other acid sulphate soil affected sites in NSW and QLD, however investigation of potential impacts to landholders is required.

These remediation options, in conjunction with stock and vegetation control are in line with the recommendations detailed by Telfer and Birch (2009).

8. References

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Glamore, W.C. (2003) "Evaluation and Analysis of Acid Sulphate Soil Impacts via Tidal Restoration", PhD Thesis, Faculty of Engineering, University of Wollongong

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Johnston, S., Kroon, F., Slavich, P., Cibilic, A. and Bruce, A. (2003) "Restoring the Balance: Guidelines for Managing Floodgates and Drainage Systems on Coastal Floodplains", NSW Agriculture, Wollongbar, Australia

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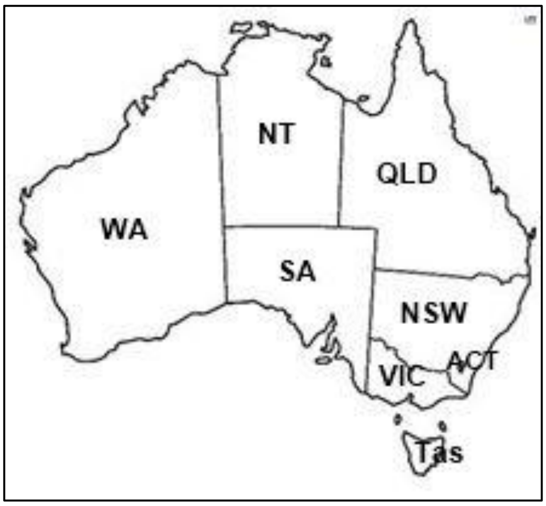
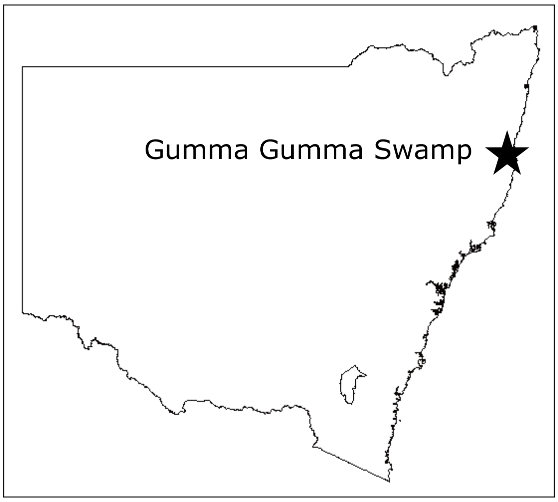
State Emergency Service (SES) (2008) *Floodsafe Macksville*

Telfer, D. and Birch, M. (2009) *Lower Nambucca River Estuary Water Quality Study*

WetlandCare Australia (2012) *Gumma Gumma Wetland - A Brief History*





Study Location

Gumma Gumma Swamp Topography and Catchment

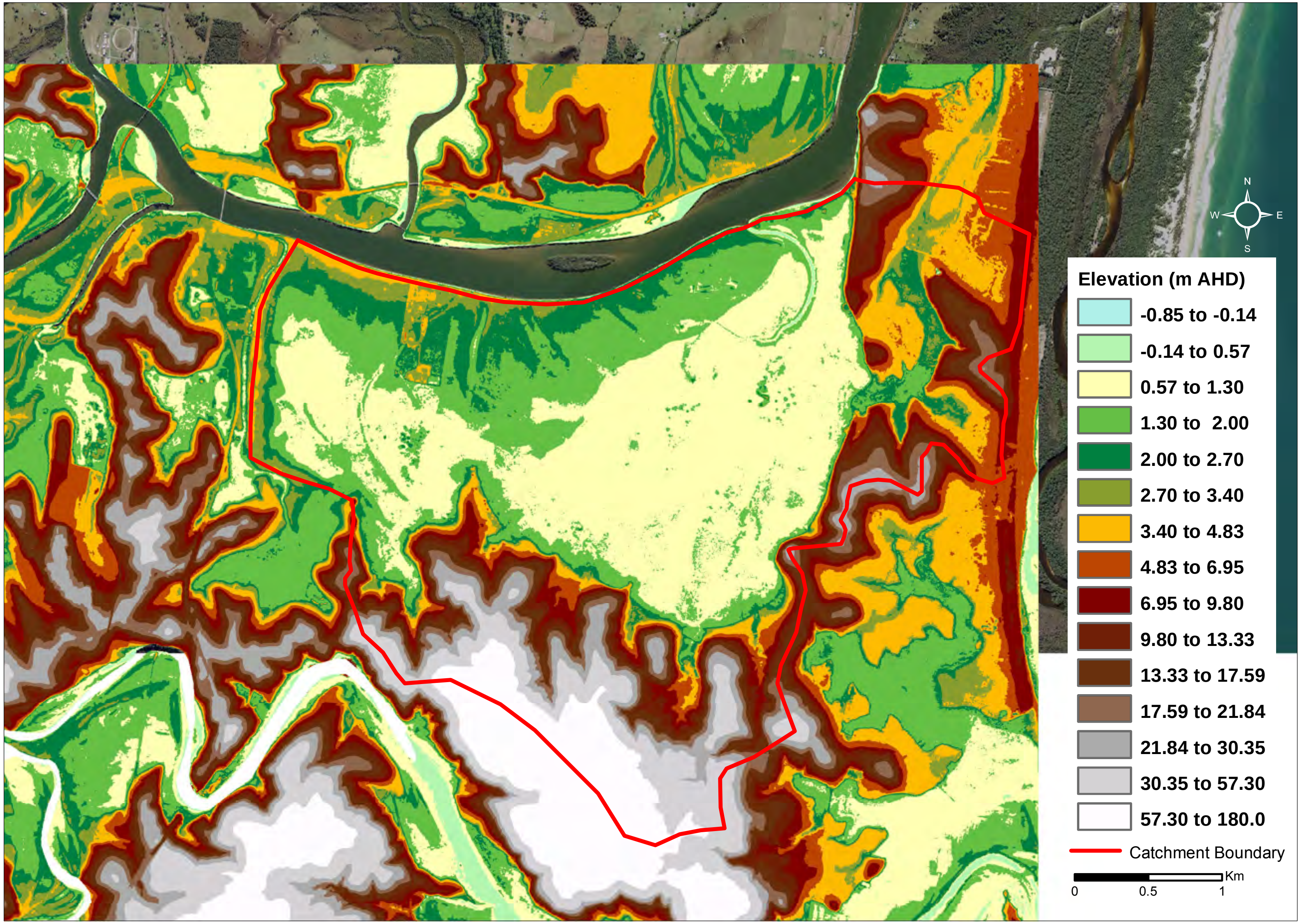


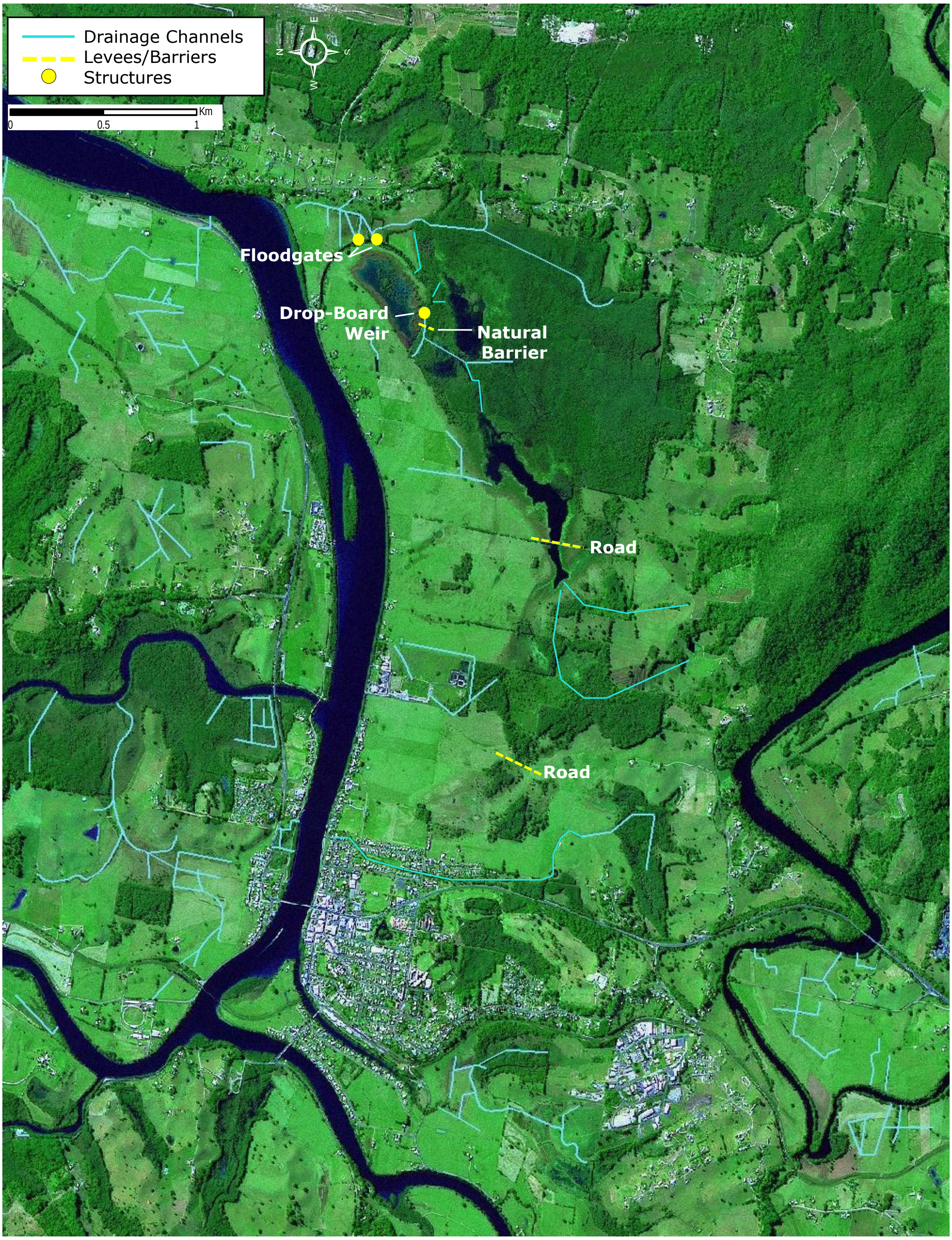
Figure 1.2

Aerial Photo 1942

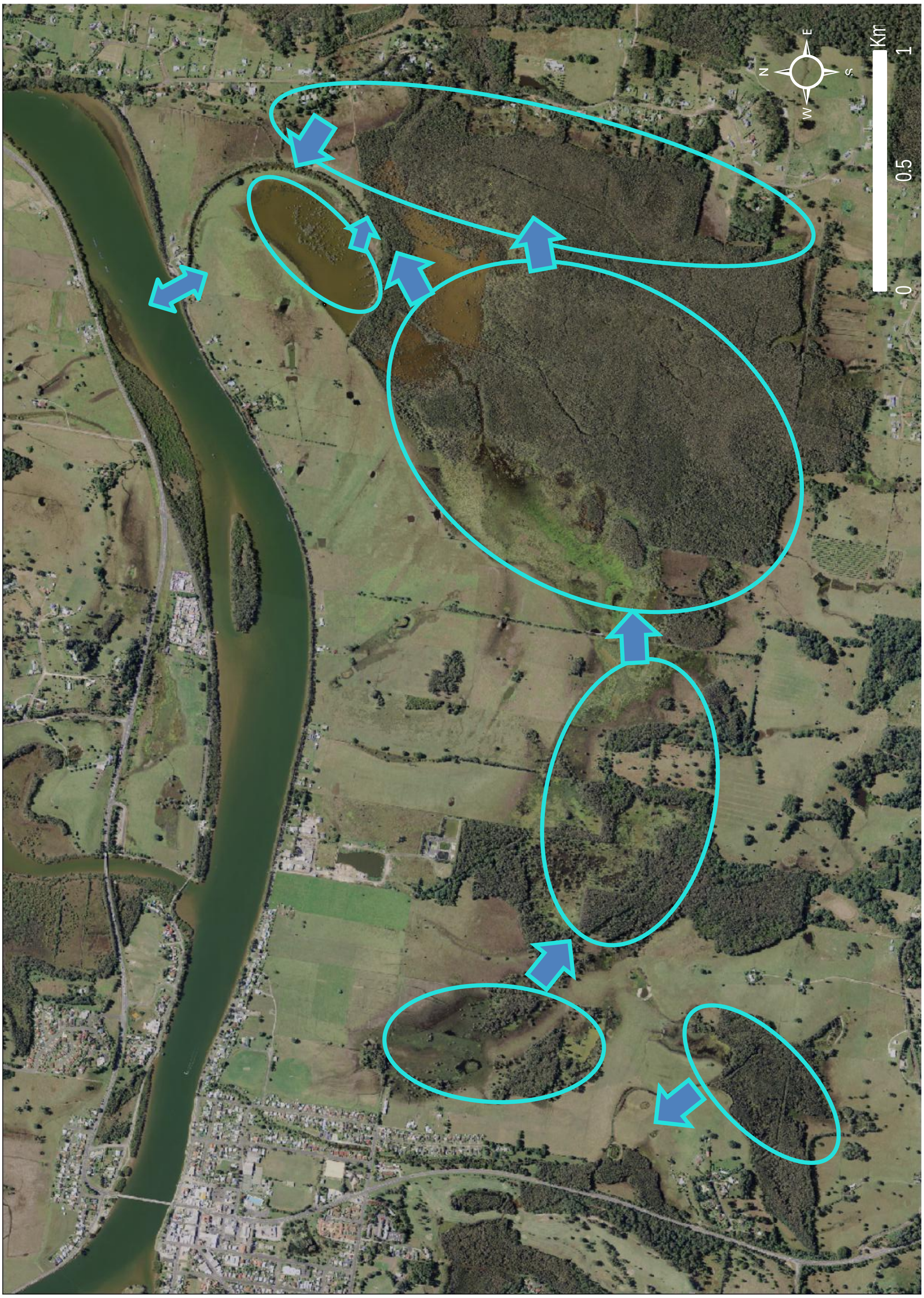
Aerial Photo 1967

Aerial Photo 2004

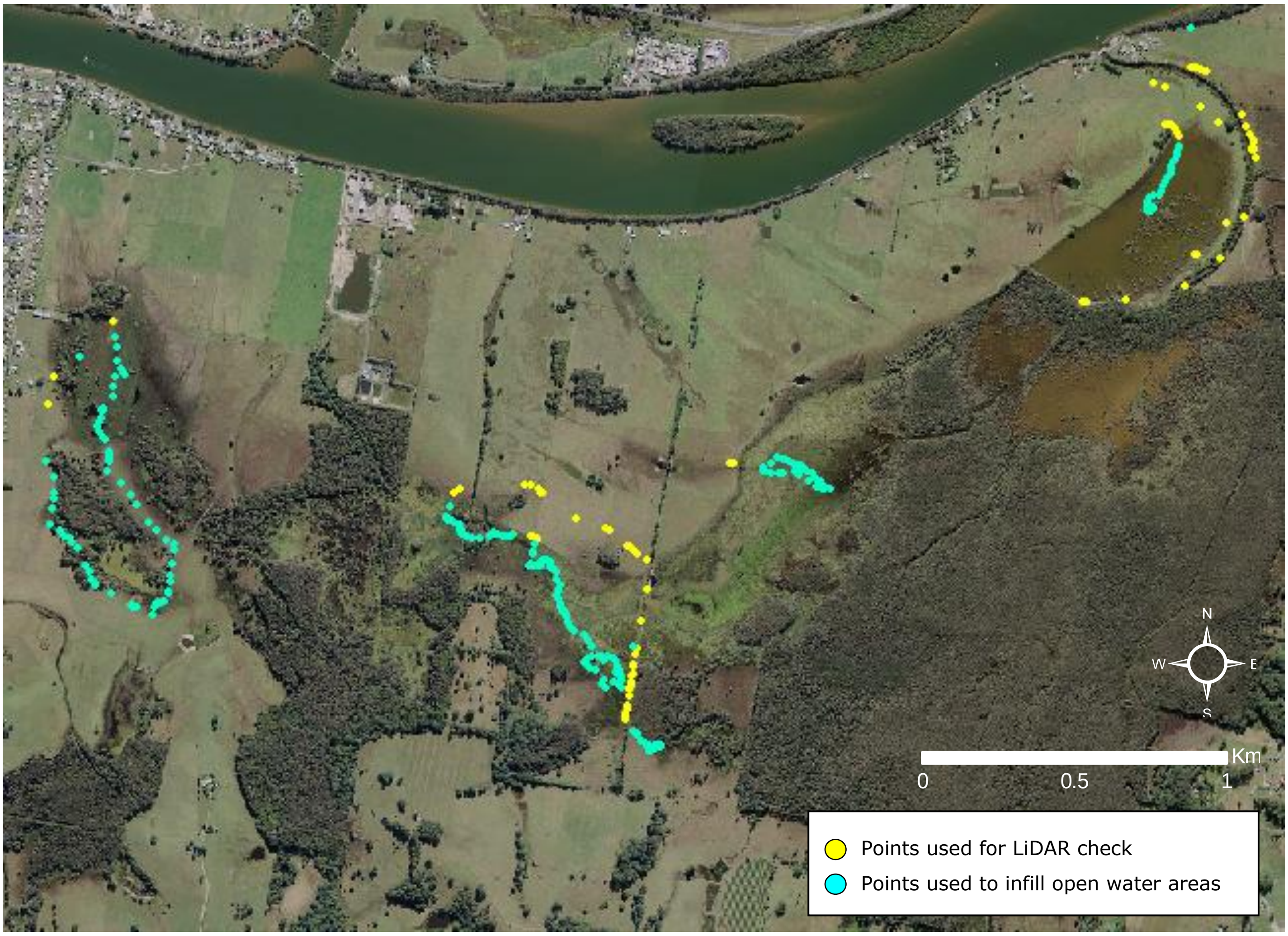
Aerial Photo 2010

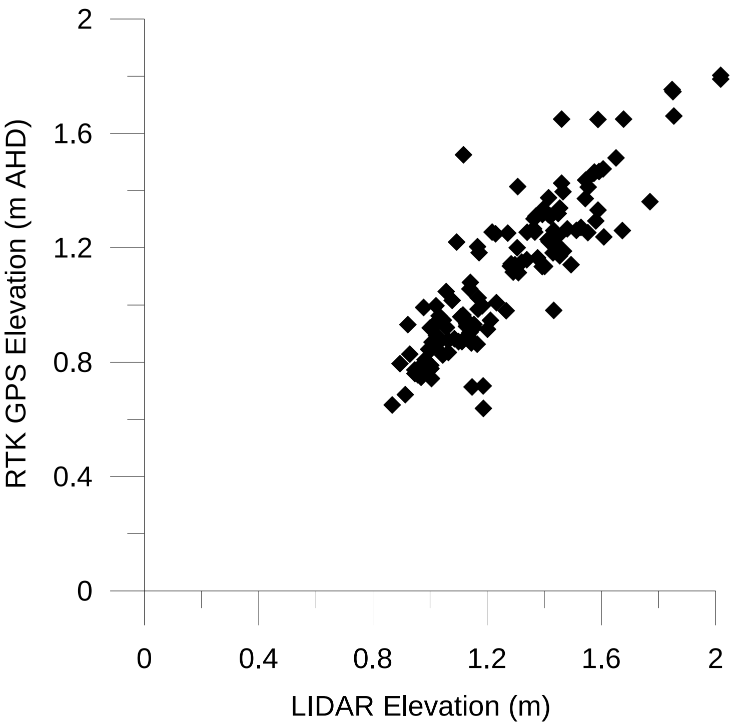


Key Site Features

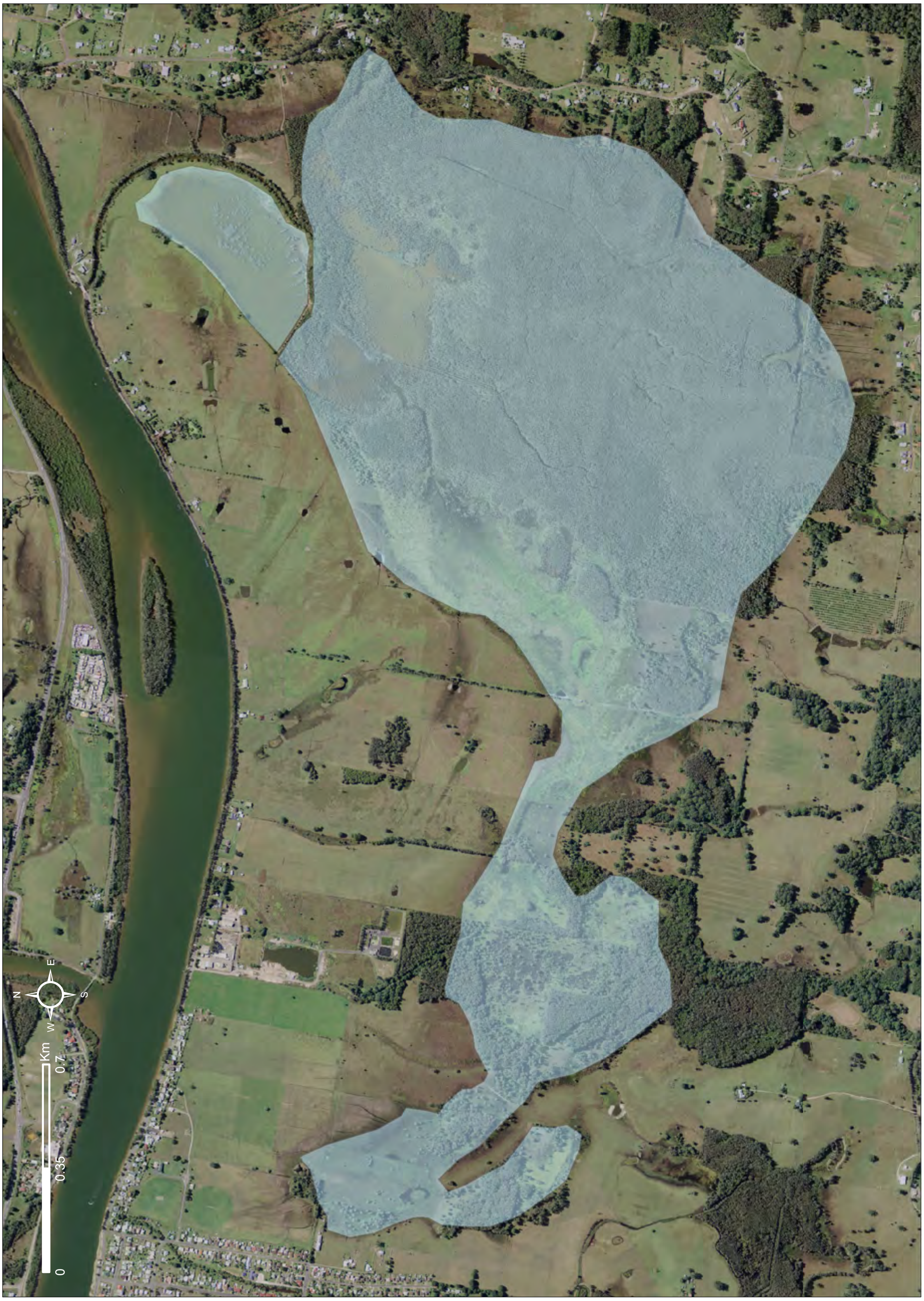


Site Connectivity Schematic





Site Survey and LiDAR Ground-Truthing



Areas of Gumma Gumma Swamp LiDAR Data Modified Based on Field Survey (Underwater at Time of LiDAR Survey)

Detailed Topography of Low Lying Gumma Gumma Swamp Catchment
(Modified DEM for Elevations Below + 2.0 m AHD)

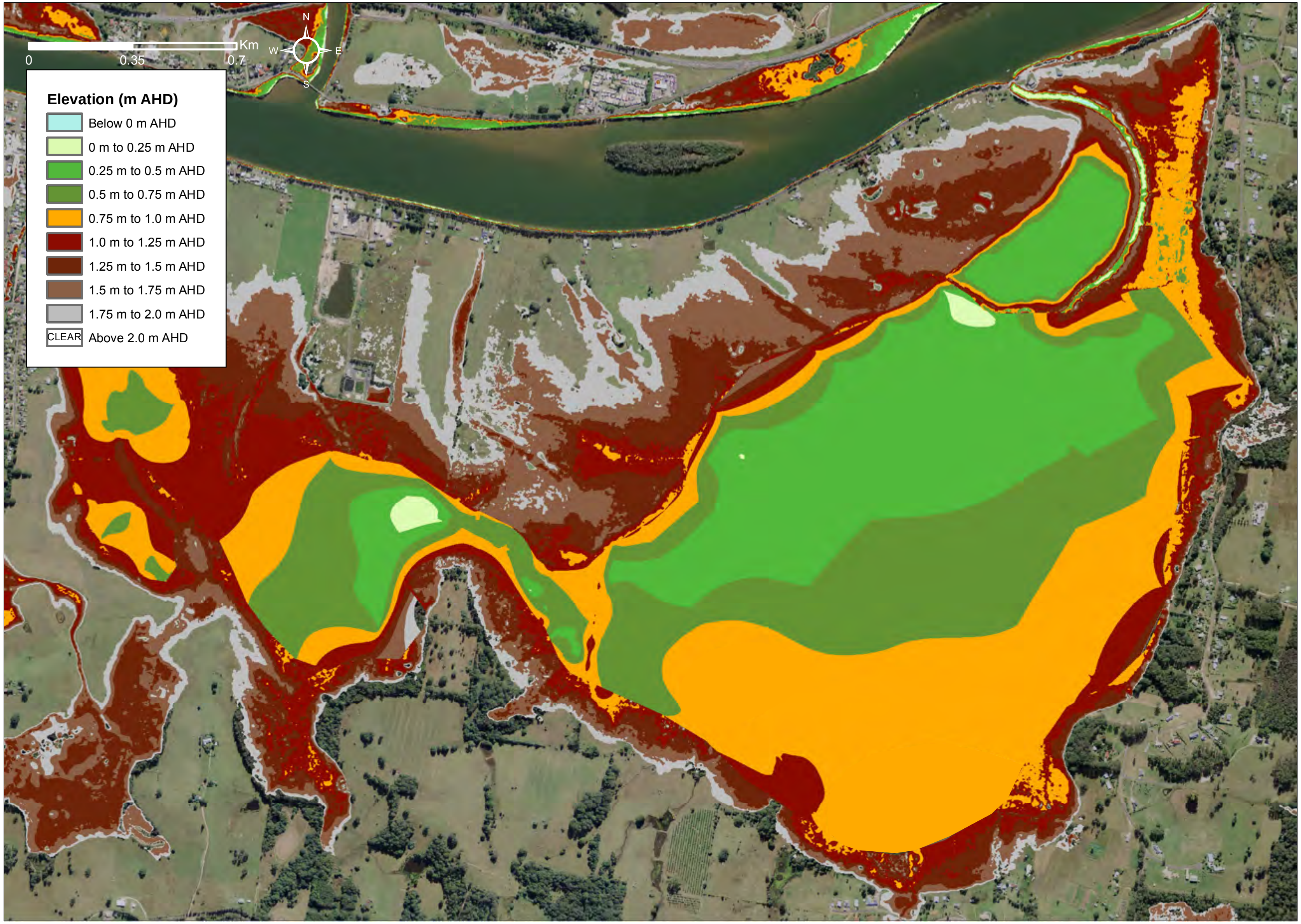
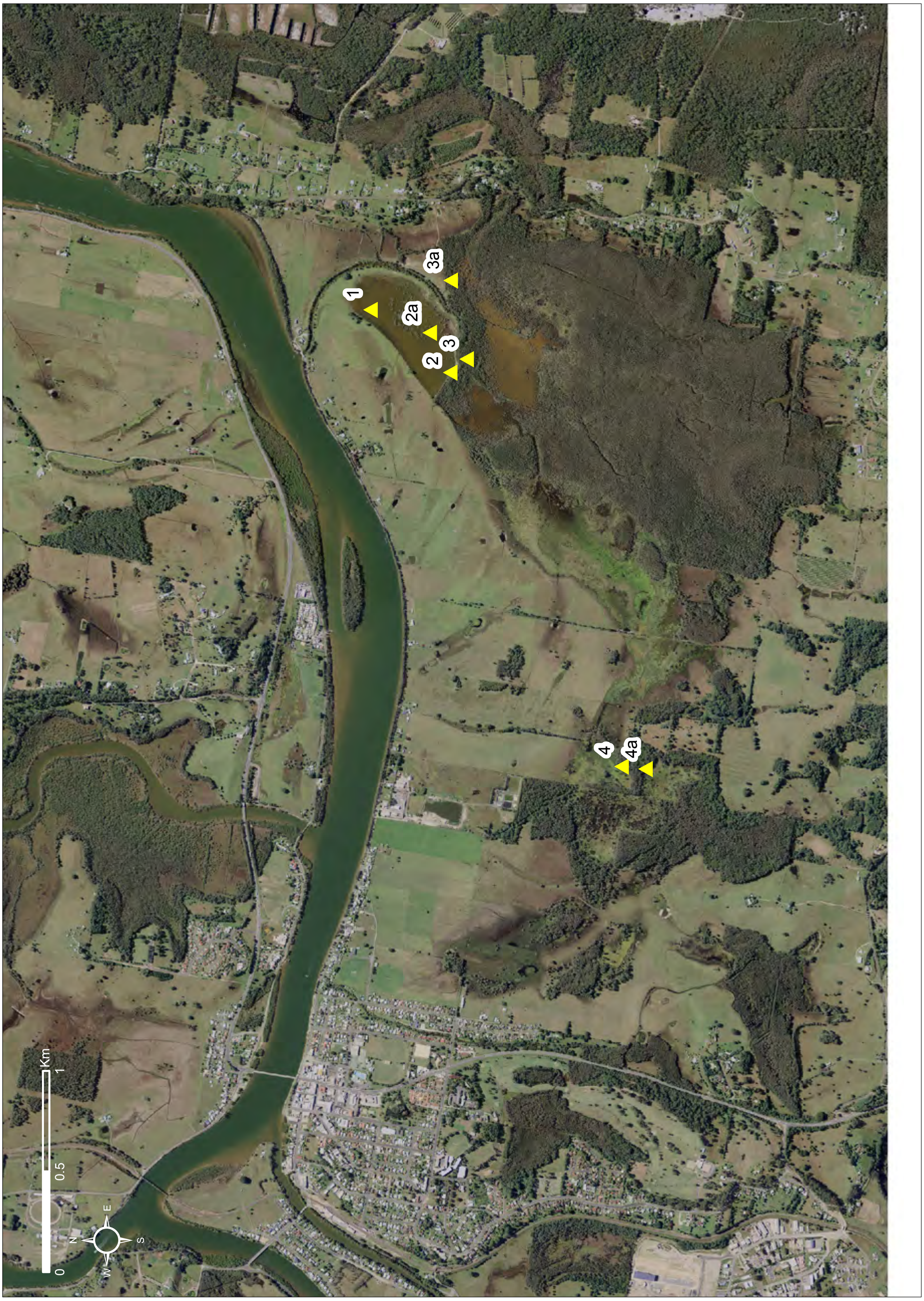
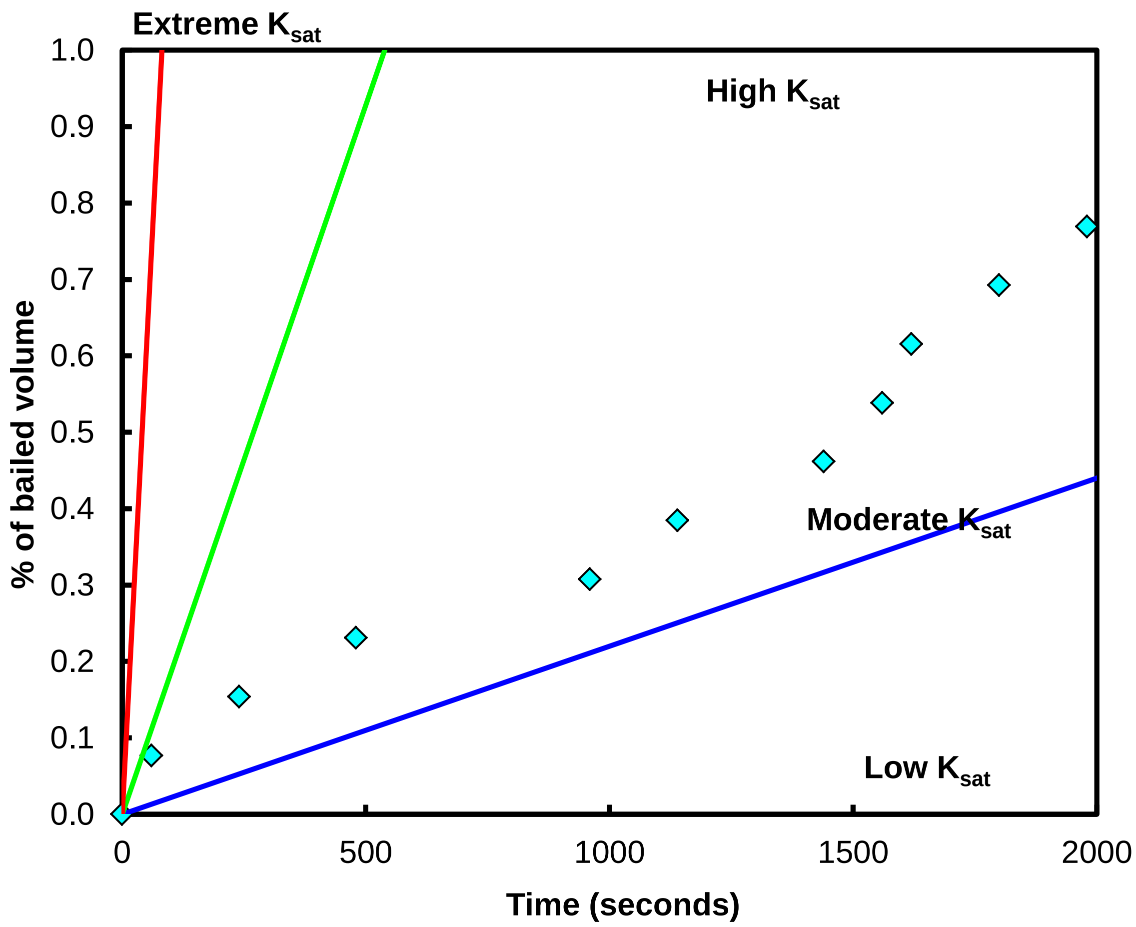


Figure 3.3

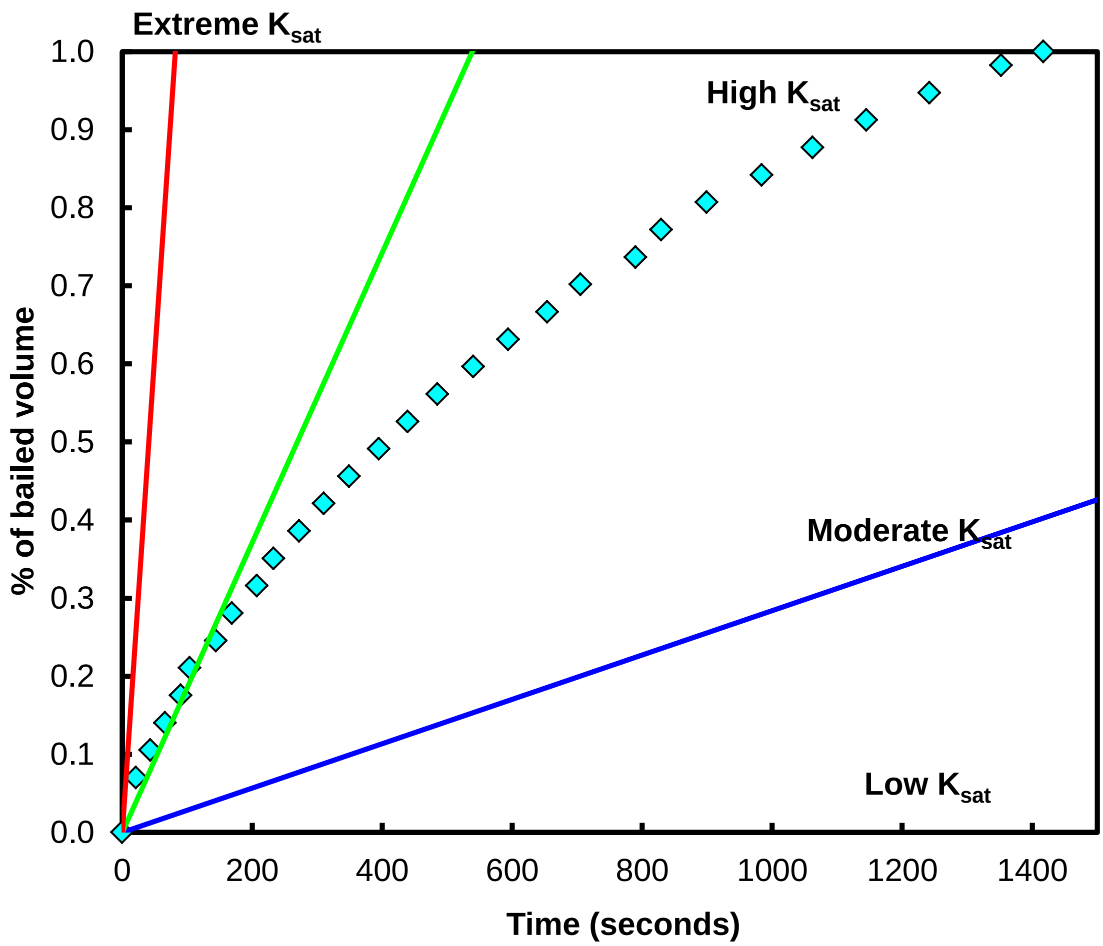


Locations of Bulk Hydraulic Conductivity Test Pits



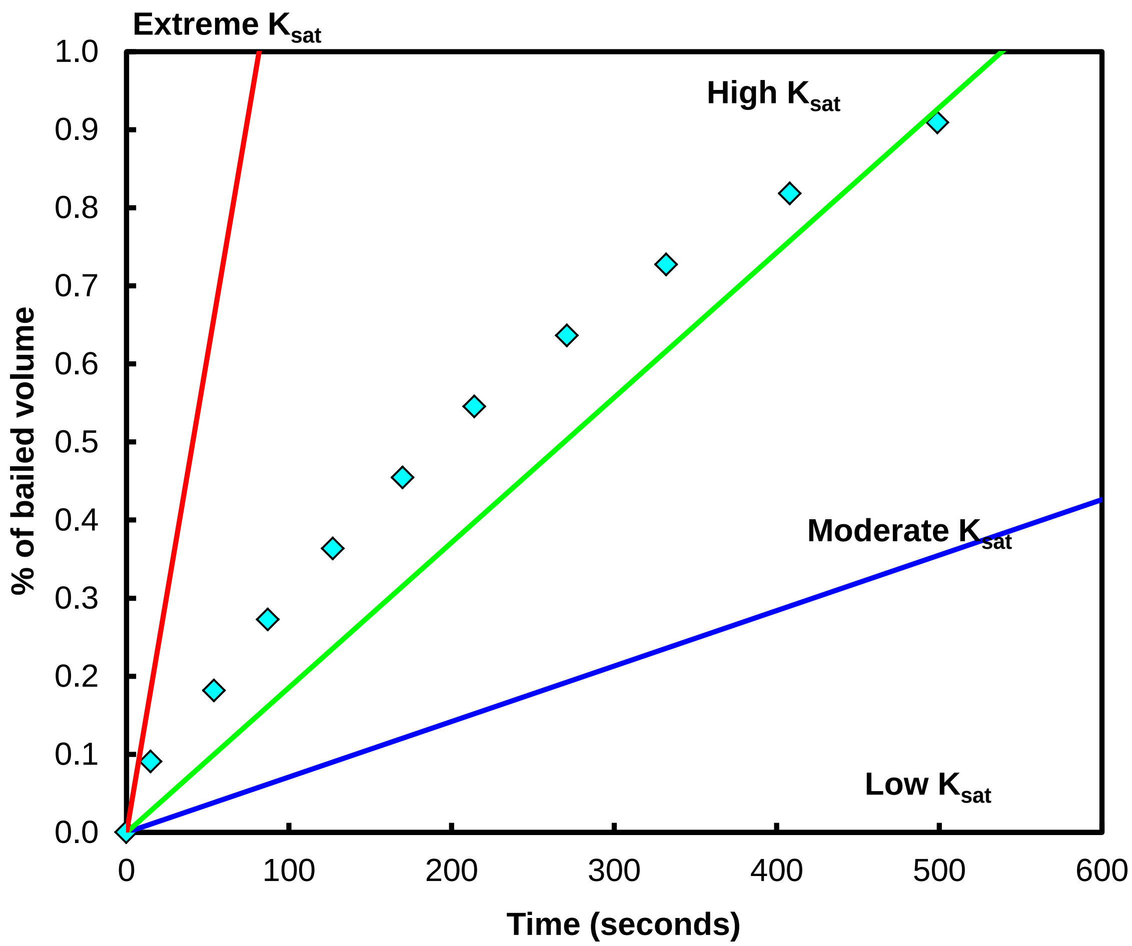
Rate indicated in chart	Approximate K_{sat} (m/day)
Extreme	~100
High	15 to 100
Moderate	1.5 to 15
Low	< 1.5

Bulk Hydraulic Conductivity Test Pit: 2



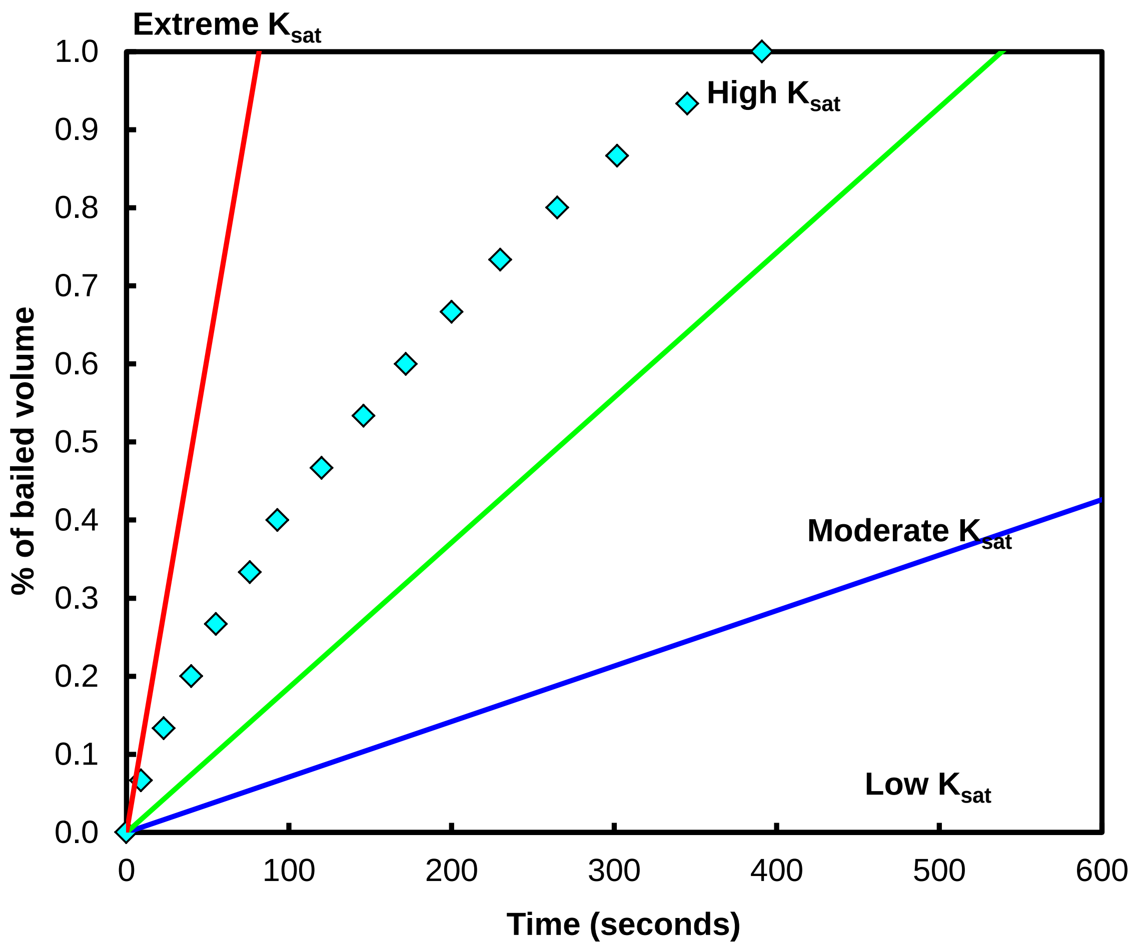
Rate indicated in chart	Approximate K_{sat} (m/day)
Extreme	~100
High	15 to 100
Moderate	1.5 to 15
Low	< 1.5

Bulk Hydraulic Conductivity Test Pit: 2a



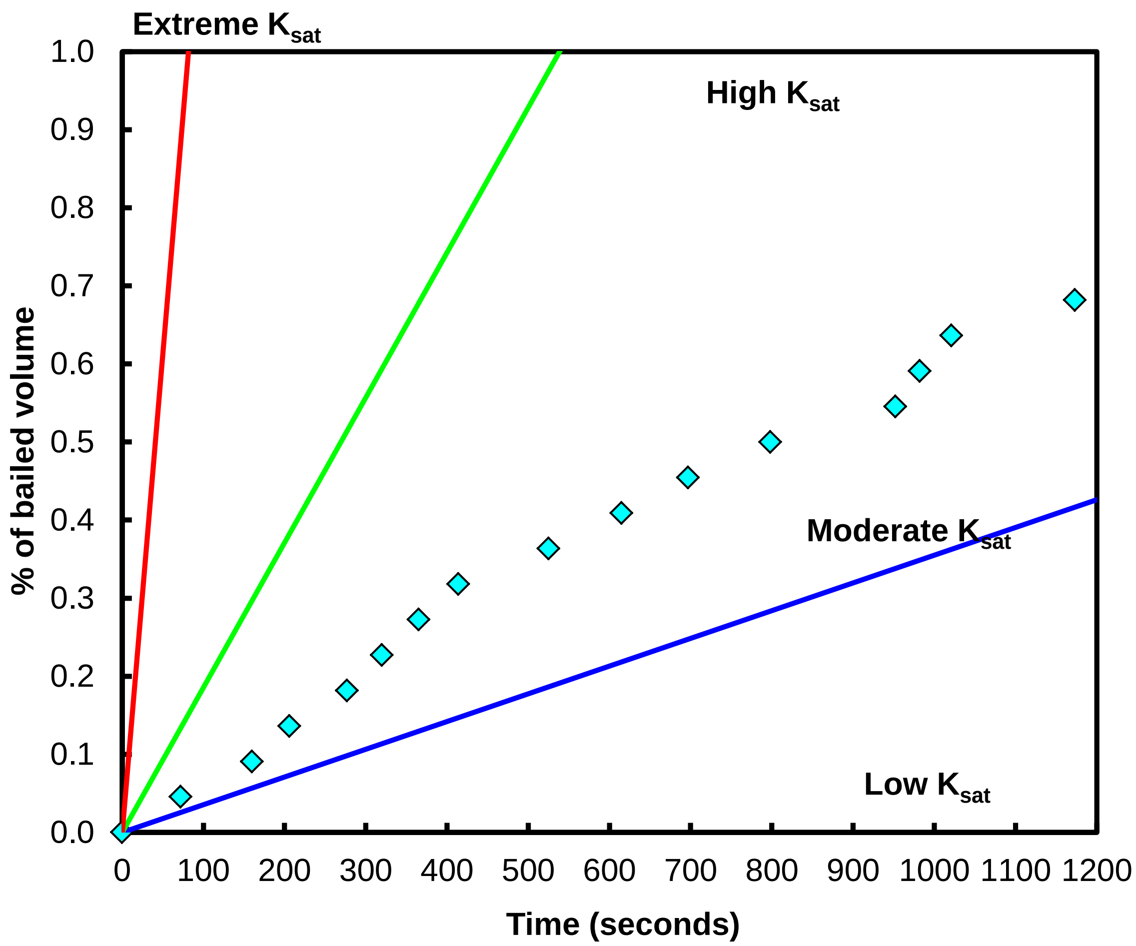
Rate indicated in chart	Approximate K_{sat} (m/day)
Extreme	~100
High	15 to 100
Moderate	1.5 to 15
Low	< 1.5

Bulk Hydraulic Conductivity Test Pit: 3



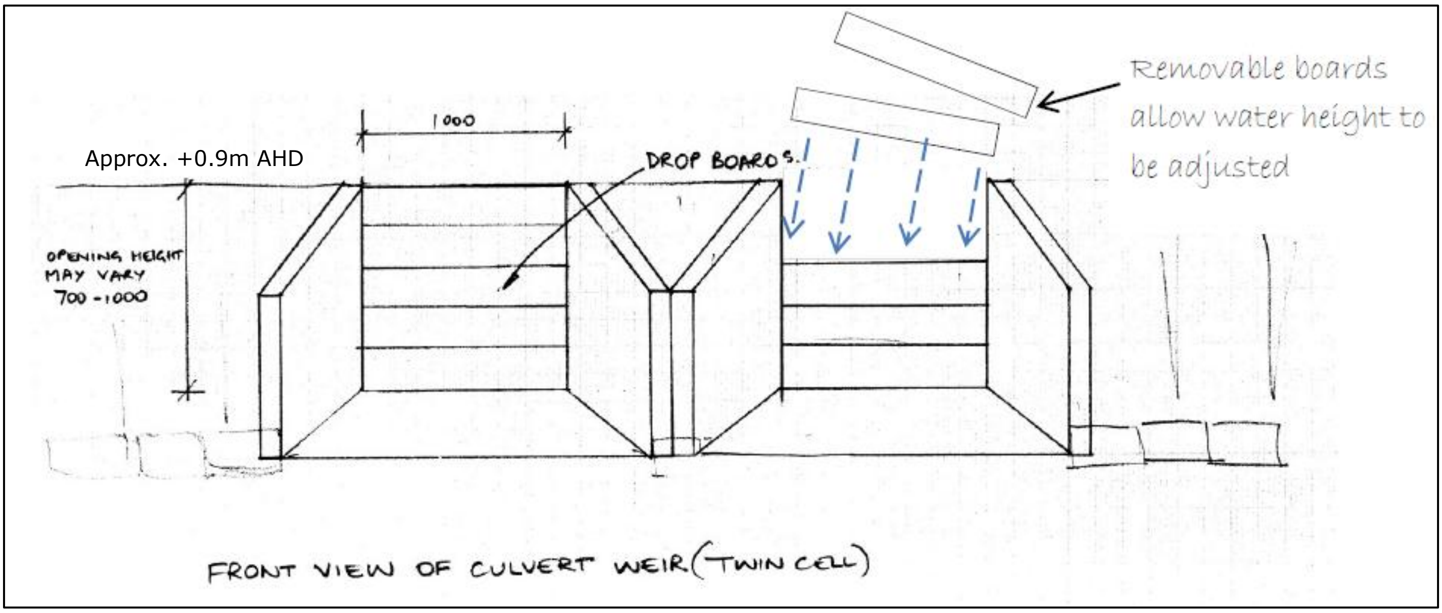
Rate indicated in chart	Approximate K_{sat} (m/day)
Extreme	~100
High	15 to 100
Moderate	1.5 to 15
Low	< 1.5

Bulk Hydraulic Conductivity Test Pit: 3a

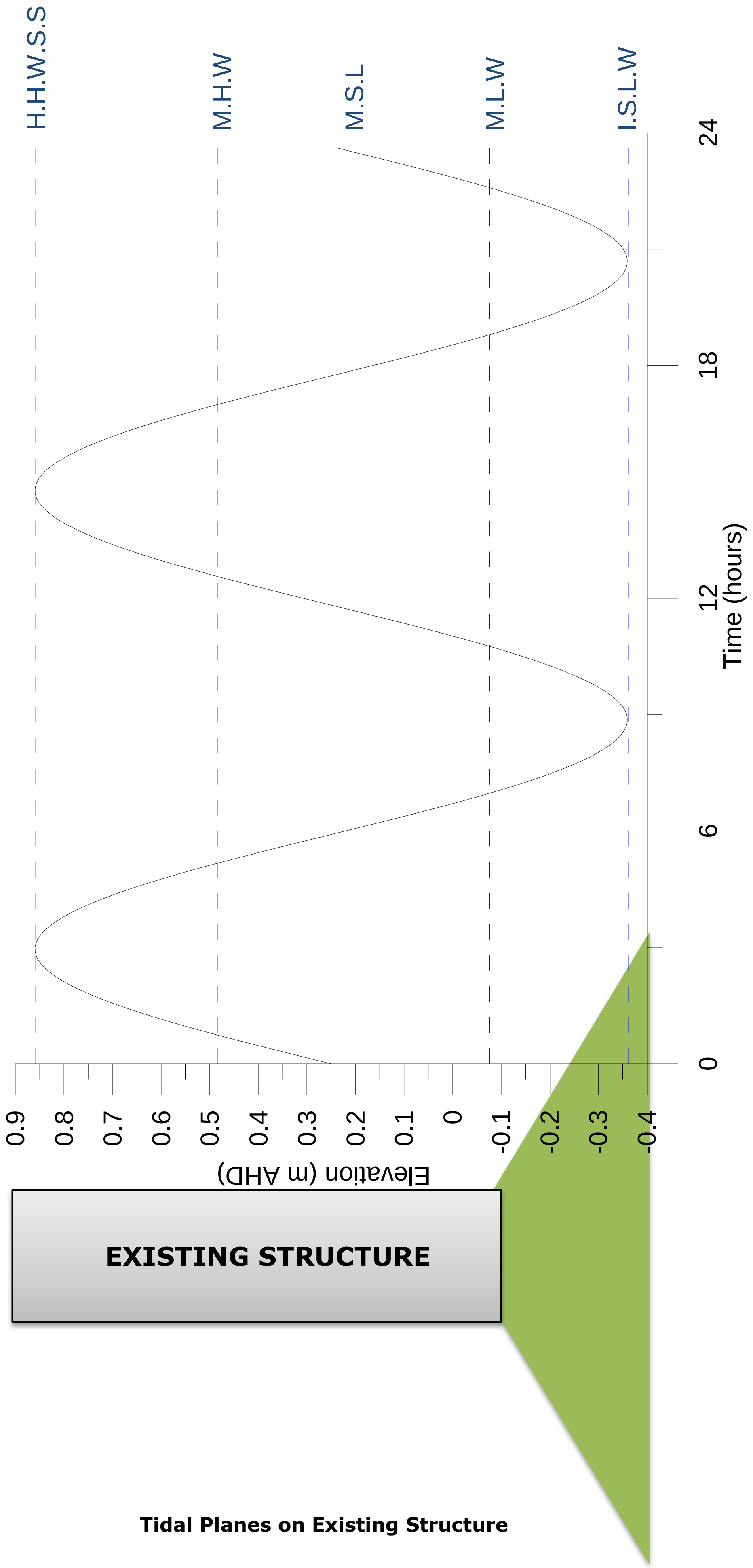


Rate indicated in chart	**Approximate K_{sat} (m/day)**
Extreme	~100
High	15 to 100
Moderate	1.5 to 15
Low	< 1.5

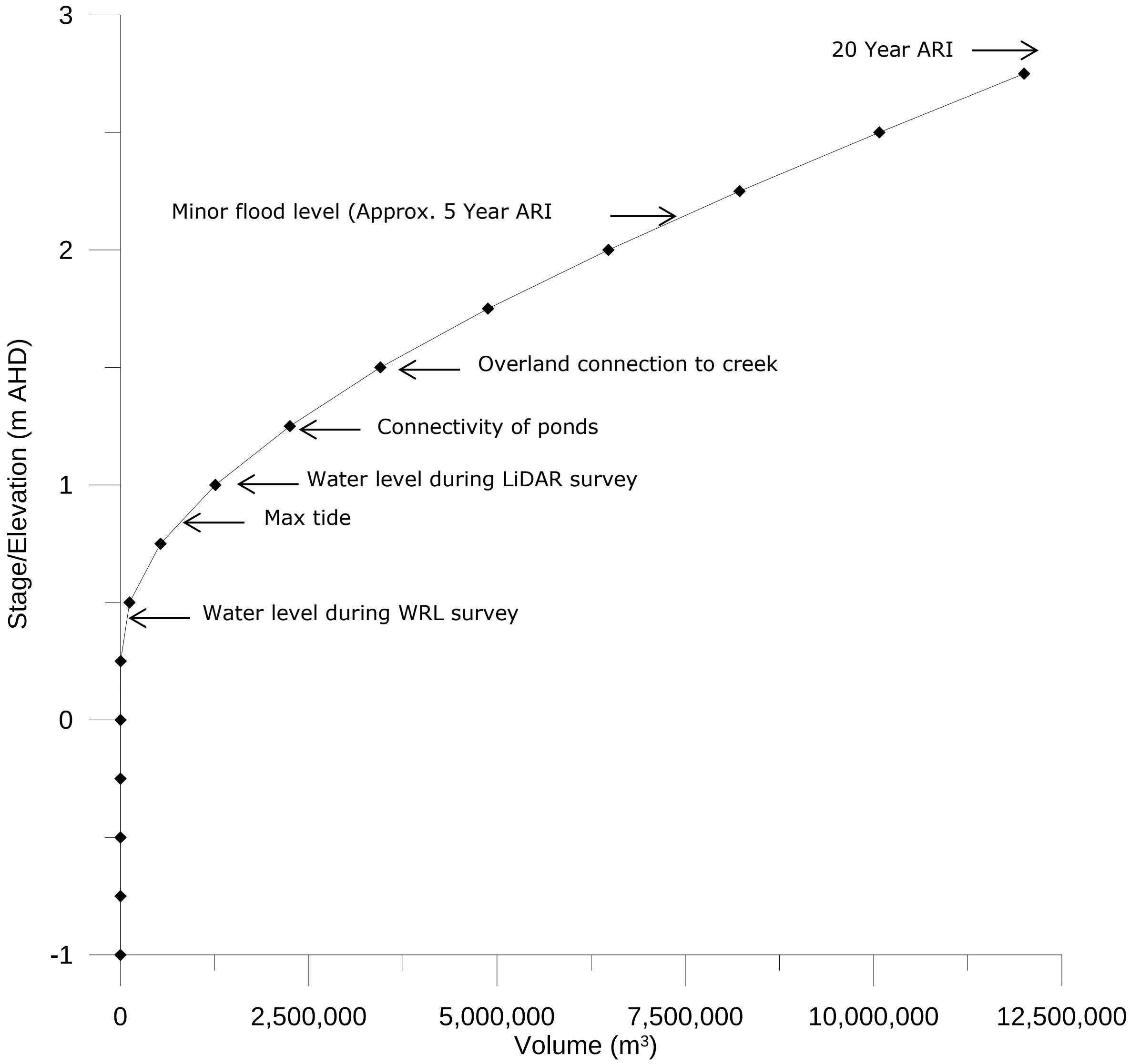
Bulk Hydraulic Conductivity Test Pit: 4a



Existing Structure (WetlandCare Australia, 2012)



Tidal Planes on Existing Structure



Gumma Gumma Swamp Stage/Volume Relationship

Macksville Tidal Planes (MHL, 2012)

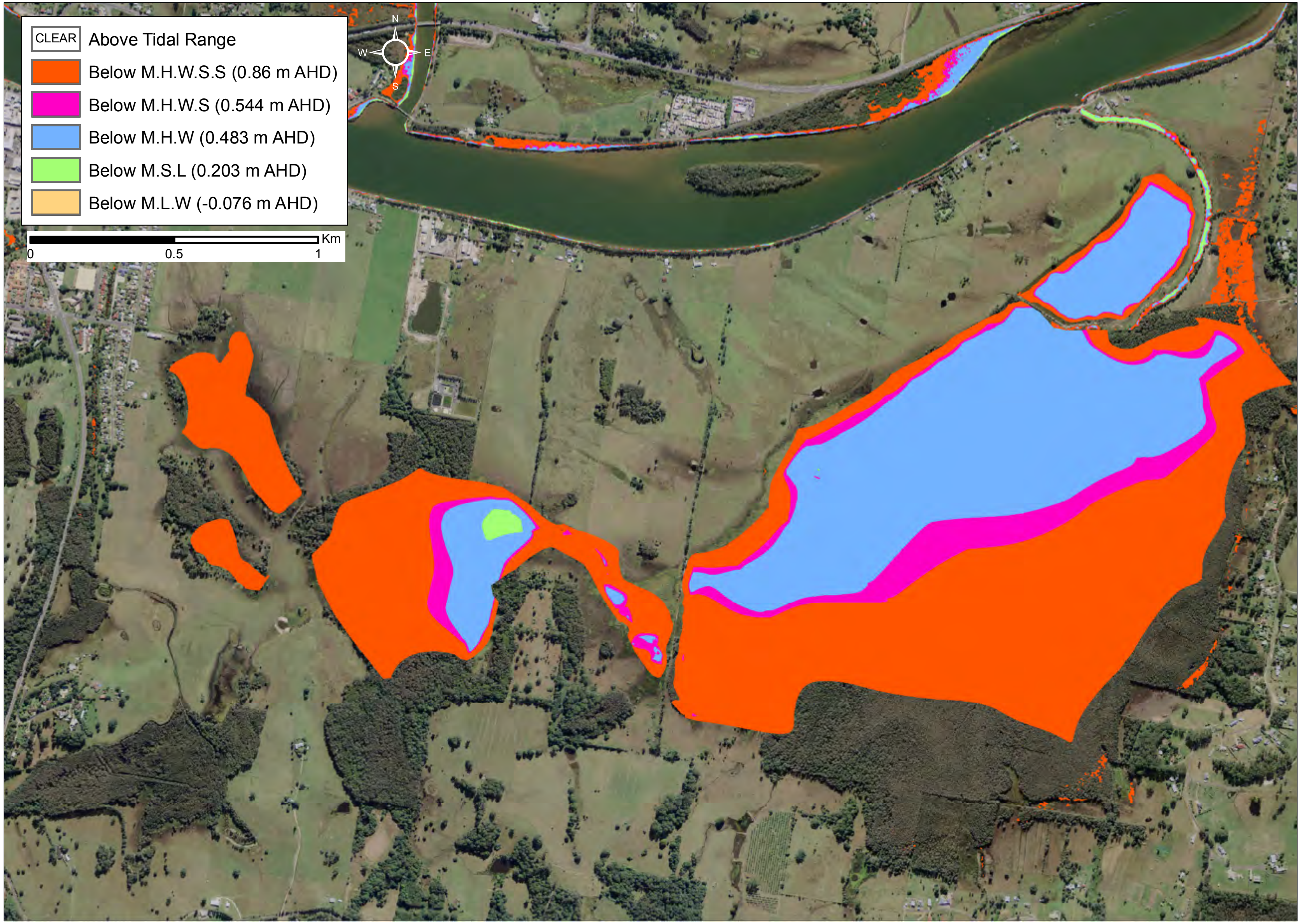


Figure 4.3

Site Salinity Characteristics Based on Observed Vegetation

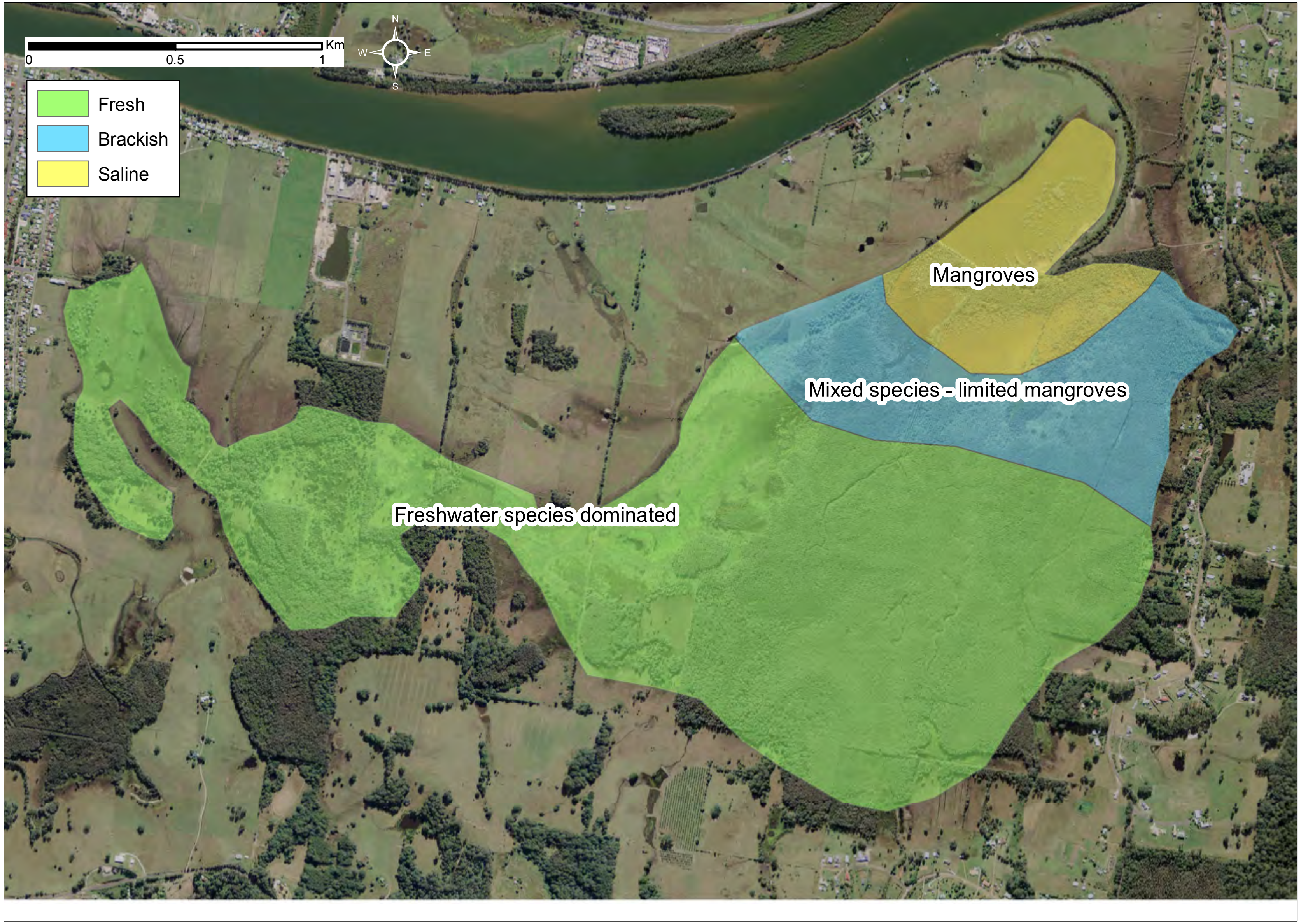
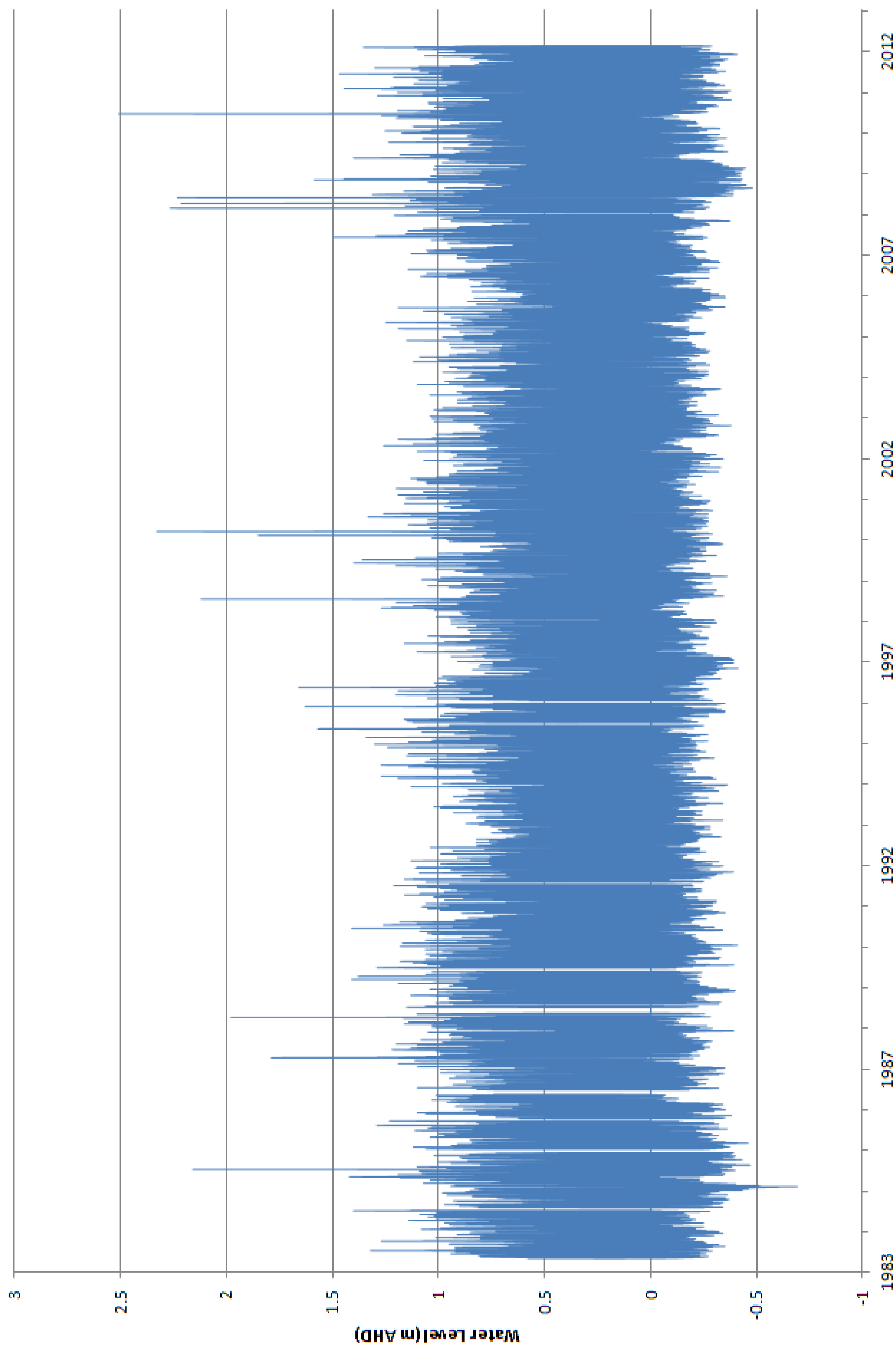


Figure 4.4



Historical Water Levels at Macksville (MHL, 2013)

5 Year (Approximate) and 20 Year ARI Flood Inundation Extent

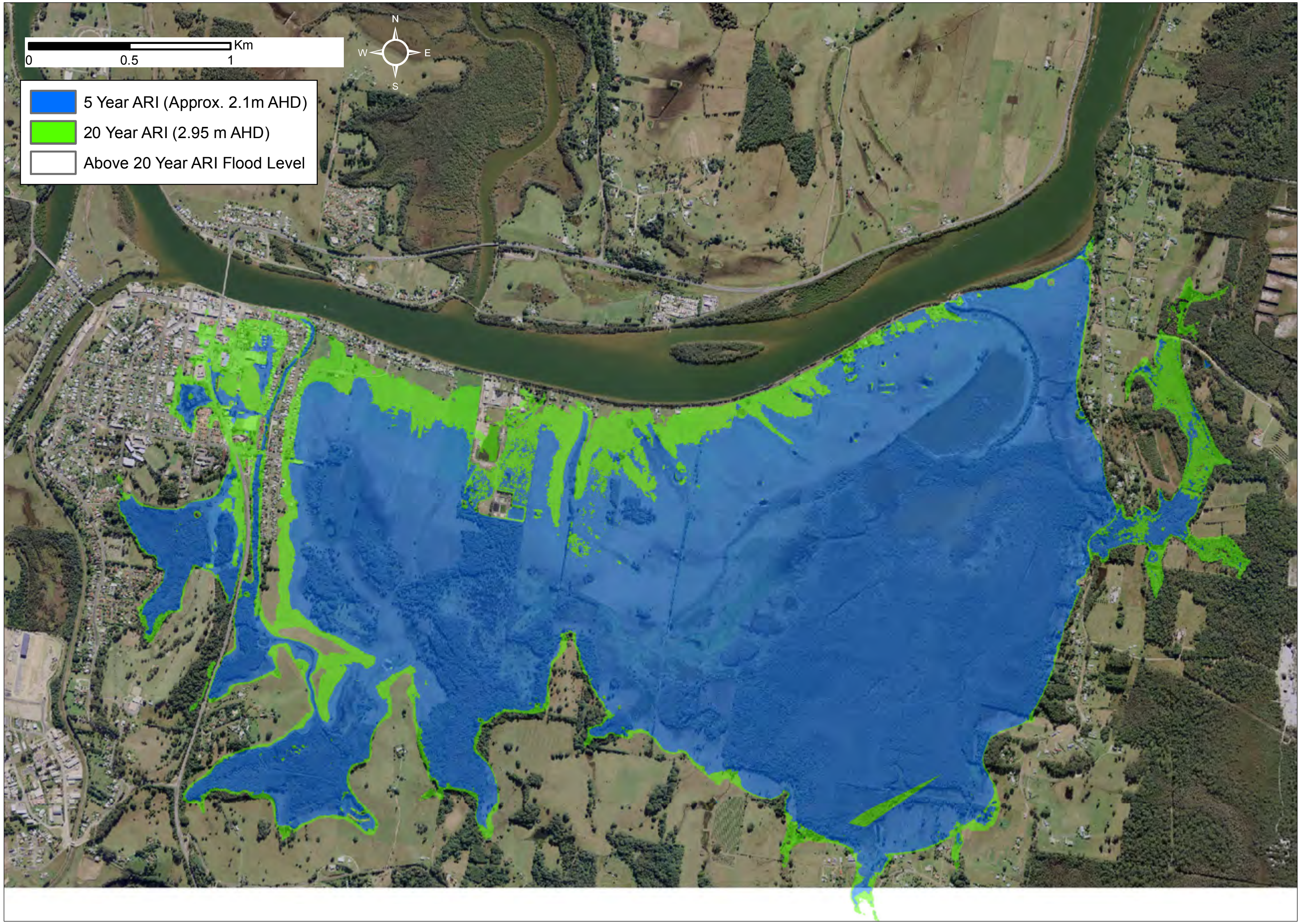
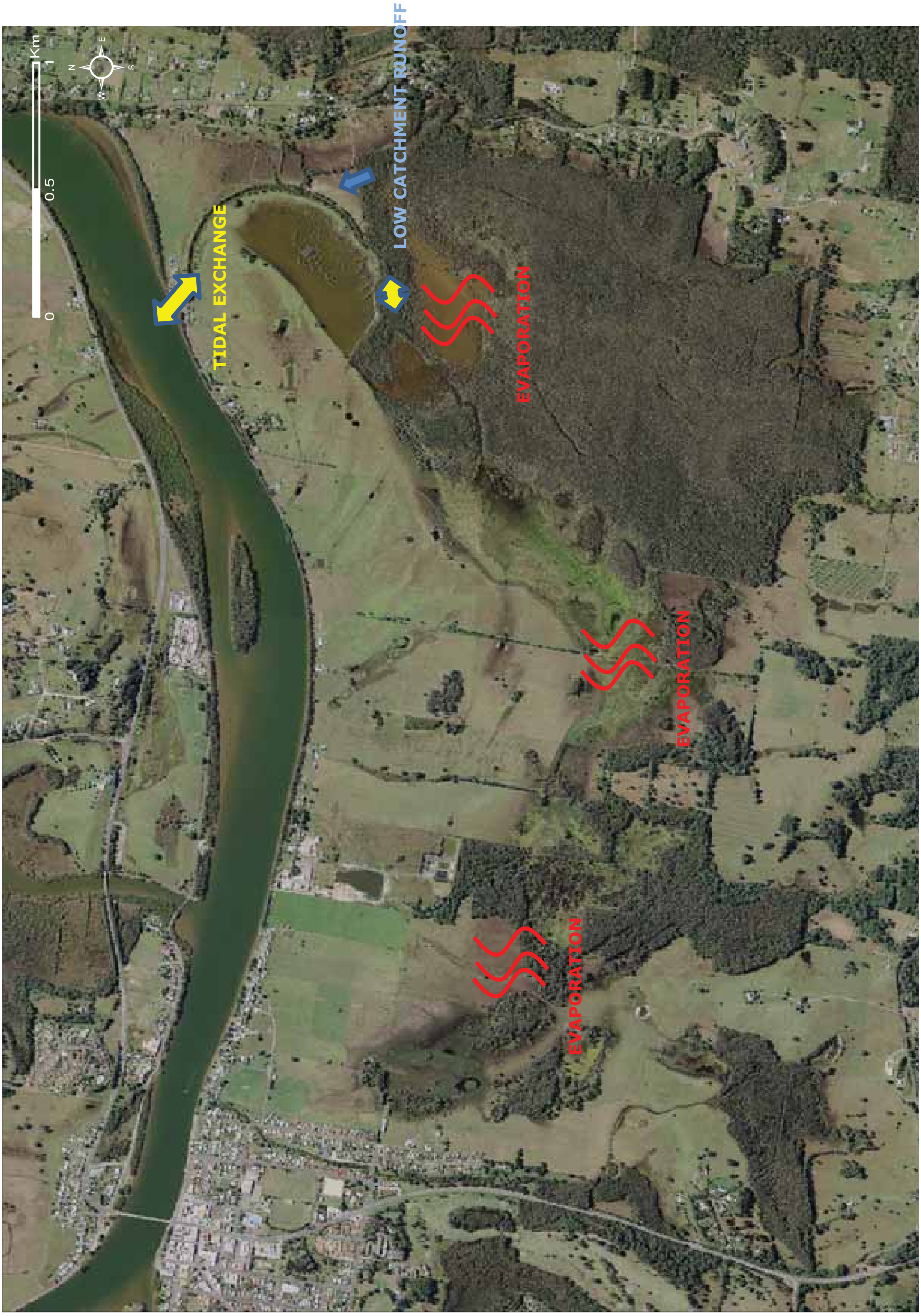
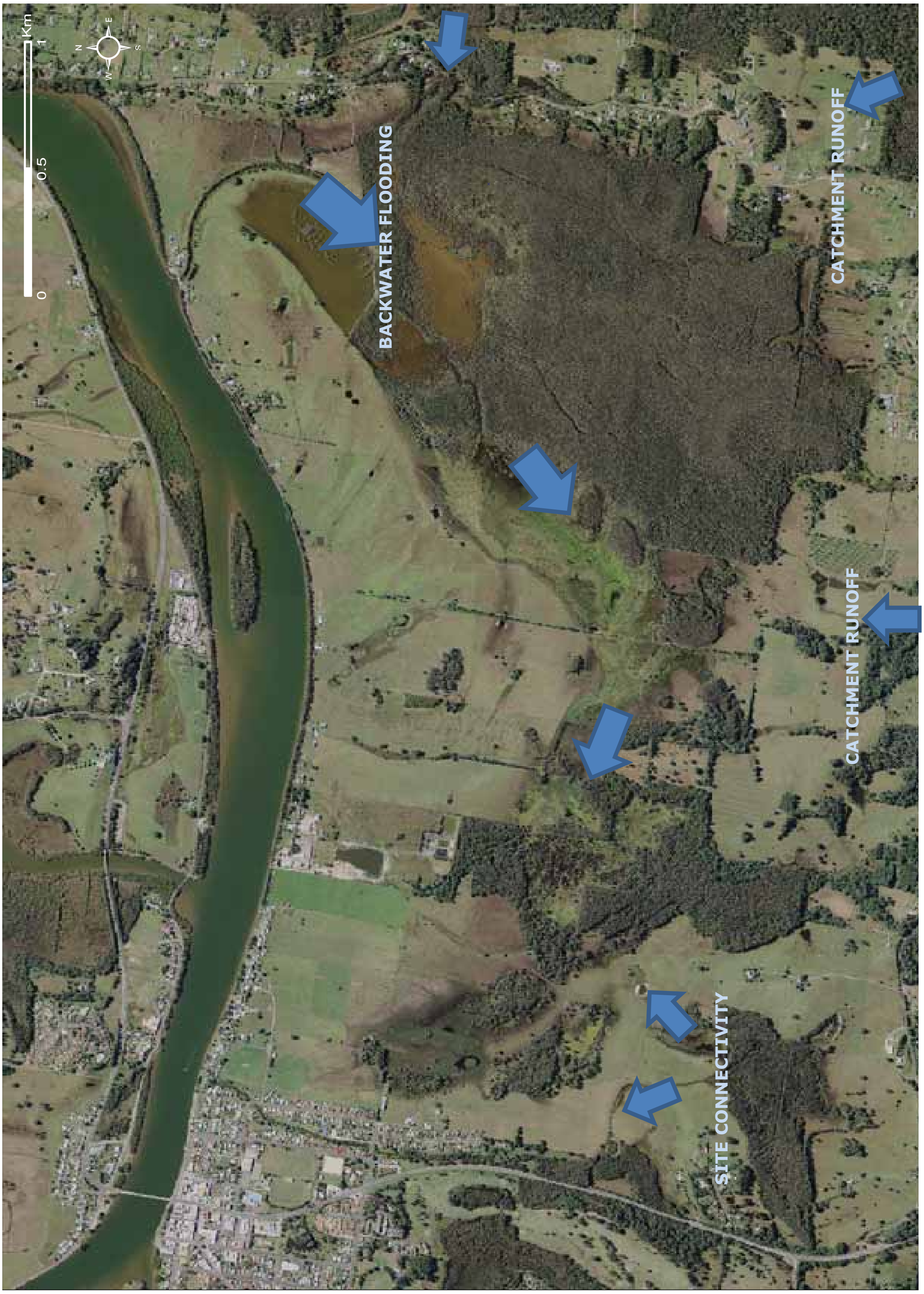


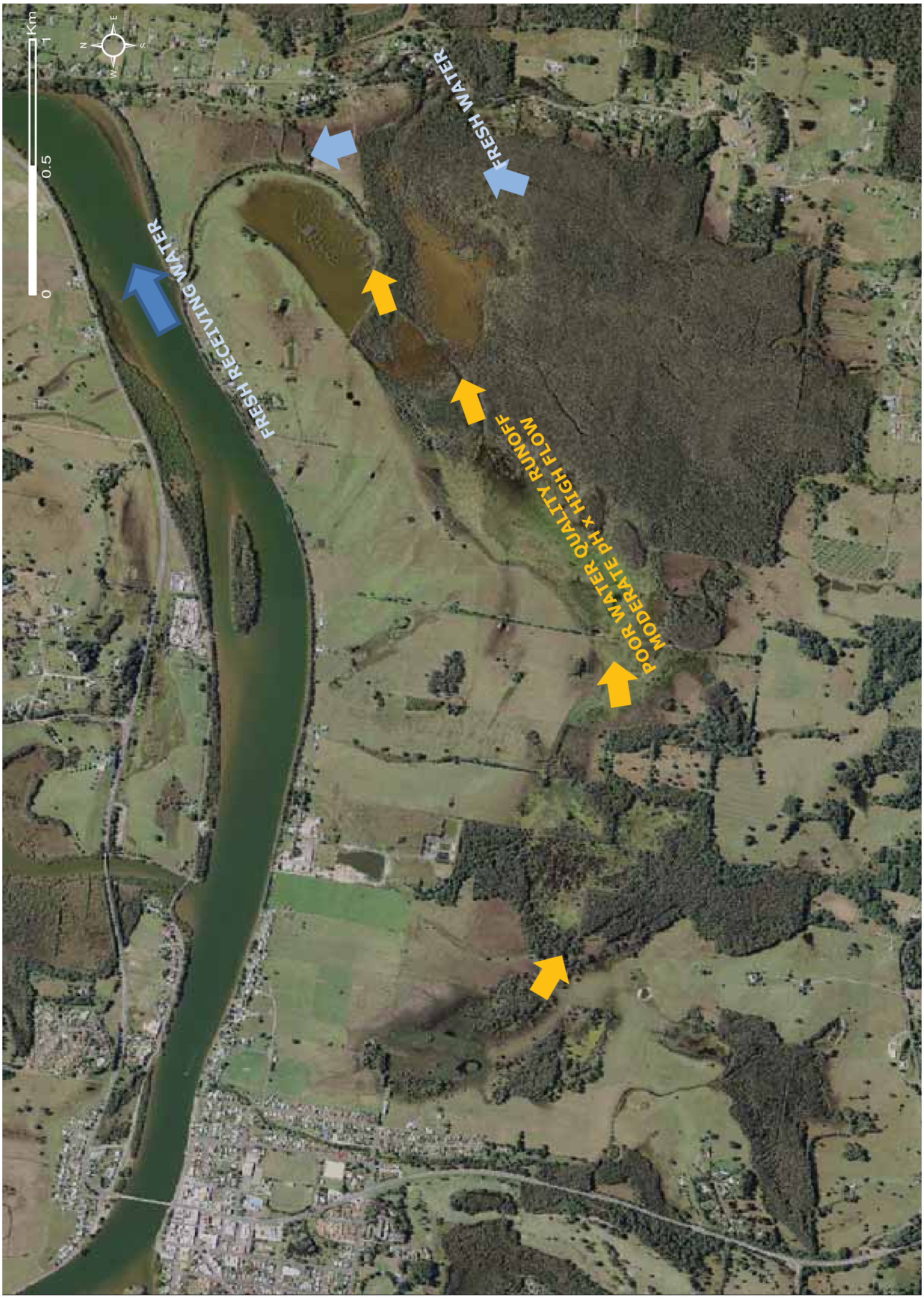
Figure 4.6



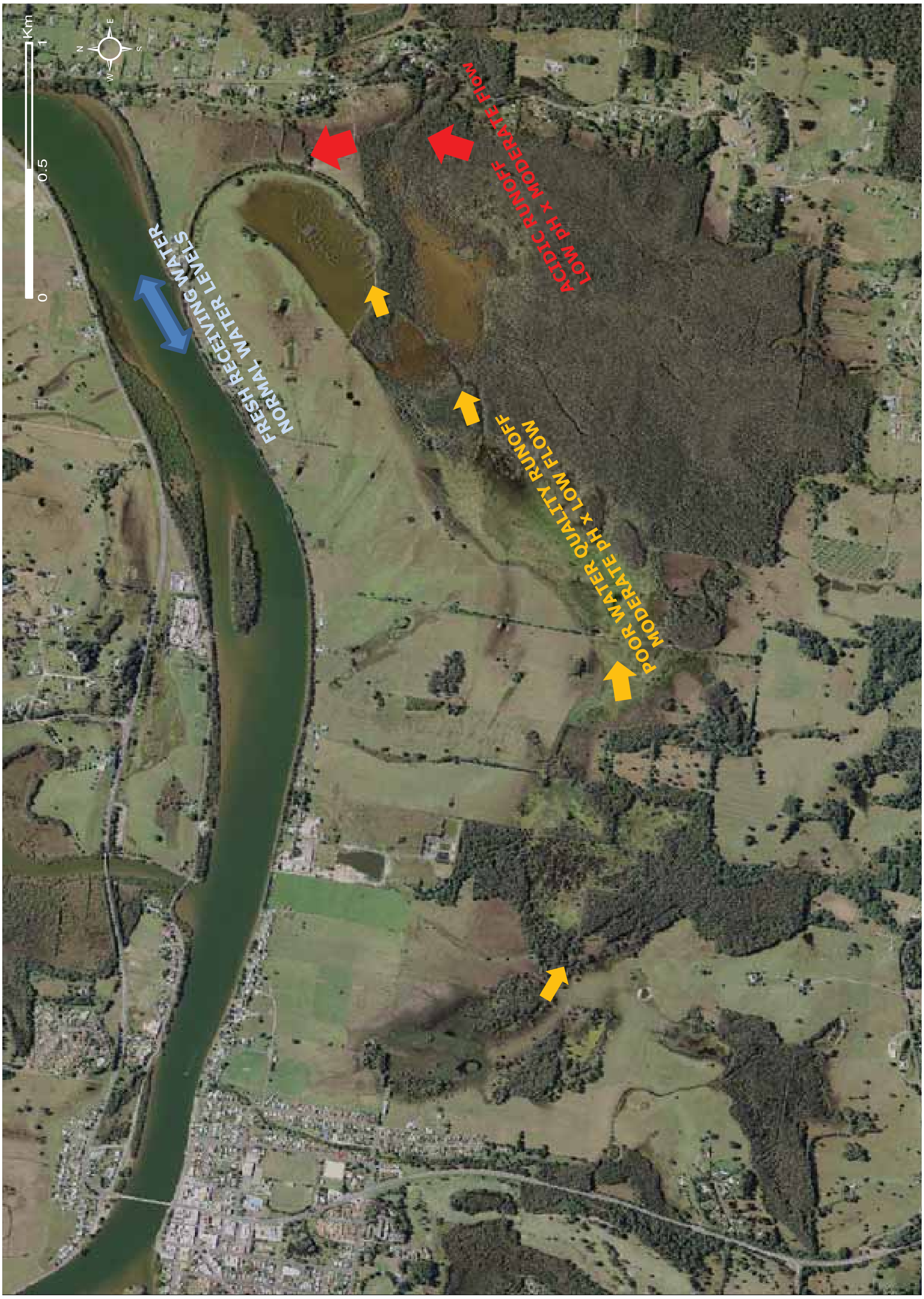
Conceptual Process: Dry Period



Conceptual Process: Flooding Period



Conceptual Process: Initial Drainage Period



Conceptual Process: Later Drainage Period Following Event (weeks)