A Geomorphic Assessment of ‘Keyhole Site’, Horsley Park, NSW

Flow and Loam Environmental

Report prepared for:
écologique

By:
P. G. Johnston
BSc, MSc
Fluvial Geomorphologist
Flow and Loam Environmental

ABN 22 584 335 355
4/59 Lindfield Avenue
Lindfield NSW 2070
Phone: 0417 206 007
petergeorgejohnston@bigpond.com

Document History

Issue	Date	Author/Reviewer
First Draft	17 May 2021	Peter Johnston
Review		Kathryn Duchatel

Cover Photograph.

Nearmap aerial photography of the Keyhole Study Site at scale 1:5,000

Table of Contents

Introduction 5
Objectives 5
Study Method 6
  Desktop Assessment Resources 6
    Aerial Photography 6
    Digital Elevation Model (DEM) 6
    Cadastral and Topographic Data 7
    Reliable Rivers and Regulated Rivers 7
    Parish map 7
Limitations 7
Discussion 7
  Natural Resources Access Regulator (NRAR) 7
2021 Study Sites 9
  Overview 9
  Area 1 10
    Desktop Assessment 10
    Site Assessment 10
  Area 2 11
    Desktop Assessment 11
    Site Assessment 12
  Area 3 14
    Desktop Assessment 14
    Site Assessment 15
Historic Aerial Photography Assessment 20
  Overview 20
  Area 1: Appendix 1 21
    10 February 1930 21
    27 June 1961 21
    6 May 1978 21
    22 January 2020 21
  Area 2: Appendix 2 21
    10 February 1930 21
    27 June 1961 21
    6 May 1978 21
    22 January 2020 21
  Area 3: Appendix 3 22

10 February 1930 22
27 June 1961 22
6 May 1978 22
22 January 2020 22
Conclusions 23
References 24
Appendix 1: Historical Aerial Photography Area 1 25
Appendix 2: Historical Aerial Photography Area 2 26
Appendix 3: Historical Aerial Photography Area 3 27
Appendix 4: Parish Melville circa 1841 28

List of Figures

Figure 1. Location of study areas 5
Figure 2. Study Area 1 10
Figure 3. Site 21. ‘A’ Looking down slope and ‘B’ Looking upslope 11
Figure 4. Site 22. 'A' Looking upslope and 'B' looking downslope 11
Figure 5. Study Area 2 12
Figure 6 Site 17 ‘A’ Looking downstream and ‘B’ looking upstream 13
Figure 7 Site 18 looking down slope to the location of the Hydroline meander bend. 13
Figure 8. Site 19. 'A' looking upstream over a pool and 'B' showing a step in the longitudinal profile that has formed at roots crossing the channel 14
Figure 9. Site 20. 'A' Looking upstream over an elongate pool and 'B' Riffles over root dam in base of channel 14
Figure 10. Study Area 3 15
Figure 11. 'A' shows knickpoint stabilised by rock fill. Defined channel ends here. 'B' is looking up slope from Site 2; no defined channel 16
Figure 12. 'A' looking upstream along the tributary towards site 4 and 'B' the tributary joining from left margin with recent deposition in the base of the channel 16
Figure 13 'A' looking upstream from site 6. 'B' looking downstream from site 6. In both instances the channel is straight and choked with weed infestation. 17
Figure 14 Site 8 looking upstream across the impoundment of the old agricultural dam that is now choked with weeds. 17
Figure 15. Location is site 9 at golf range boundary. 'A' is looking upstream to site 8 and 'B' is looking downstream to site 10. 18
Figure 16. Site 13. Artificially straightened channel extending upstream 'A' and downstream 'B' 18
Figure 17. 'A' Looking downstream from site 15 across the dam and 'B' is looking across the dam wall to a highly modified zone of degraded channel 19

Introduction

Flow and Loam Environmental has been contracted by écologique to provide an interpretation and assessment of the drainage patterns on the 'Keyhole Site' at Horsley Park, NSW (Figure 1).

There are three drainage pathways extending through the study area that have been identified as a 'river' by the Water Management Act 2000 (WM Act).

Schedule 2 of the Water Management Regulations 2018 (WM Reg.) specifies the Strahler system as the method to determine the stream order of watercourses shown on hydroline spatial data mapping published by the NSW Department of Planning, Industry, and Environment (DPIE) on their website.

Hydroline mapping indicates a first order watercourse extending through lots 63 and 54 on the north eastern (Area 1), a second order stream encroaching on to lot 59B on the western boundary and a first order stream extending laterally across the study area close to the southern boundary (Figure 1).

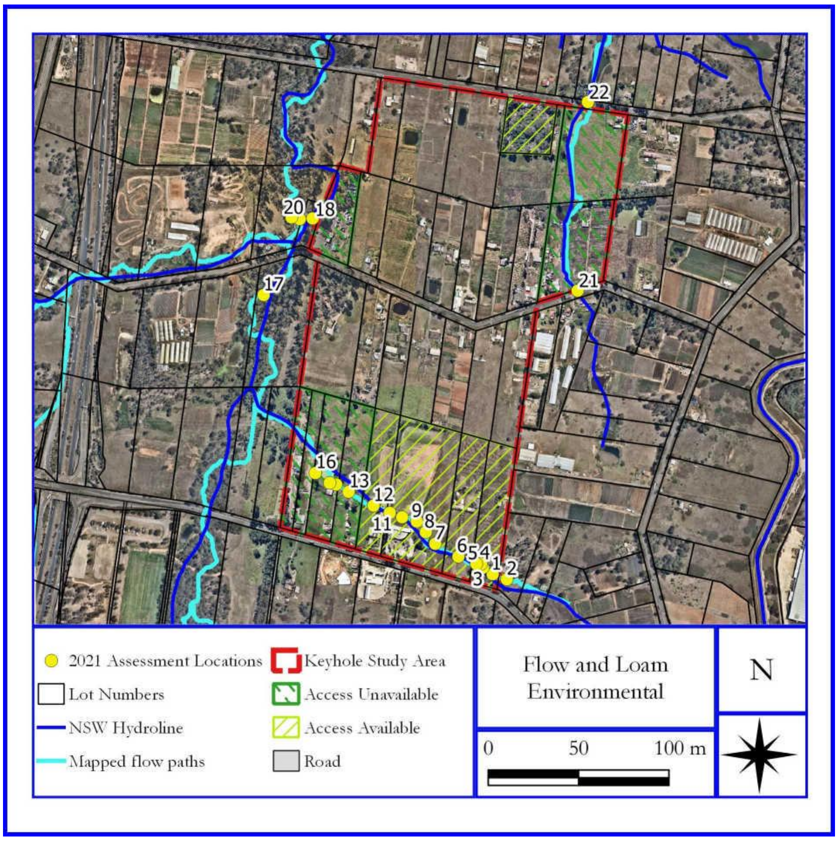


Figure 1. Location of study areas

Objectives

The objective of this investigation is to provide an assessment regarding whether the mapped Hydroline within the study area meets the definition of a 'river' as defined by The WM Act.

There are three areas within the 'Keyhole Site' that have drainage pathways as defined by the Hydroline data set. Access has been granted to only part of these areas and so it is necessary to evaluate the remainder by desktop assessment (Figure 1).

To complete this objective it was necessary to clarify the character and morphology of the drainage pattern within each area.

Study Method

The study method consists of three stages;

1. Desktop assessment;
   a. review of contemporary aerial photographs
   b. review of historical aerial photography
   c. review of historic parish map.
   d. review of GIS data.
2. Detailed site investigation
3. Reporting

Contemporary aerial photograph and GIS data interpretation was completed using QGIS cross-platform desktop geographic information system application.

Desktop Assessment Resources

This preliminary report and desktop assessment used the following data sources.

1. Aerial photography from Nearmap Australia Pty Ltd.
2. Historic aerial photography
3. The Paris map Preservation Project: NSW Spatial Information Exchange (SIX) viewer
4. ANZLIC Committee on Surveying and Mapping: ELVIS - Elevation and Depth - Foundation Spatial Data
5. New South Wales Government Spatial Information Exchange Cadastral and topographic data
6. New South Wales Government SEED website. Sharing and Enabling Environmental Data in NSW. Reliable Rivers and Regulated Rivers in NSW.

Aerial Photography

Aerial photography for the study area was acquired from Nearmap for the 22nd of January 2020 and the 15th of April 2021. These dates were selected because;

- Imagery for the 22nd of January 2020 was captured prior to a period of increased rainfall. Ground cover was at a minimum at this time and surface morphology was more apparent because of reduced ground cover.
- Imagery for the 15th of April 2021 represents the latest available capture of aerial photography.

Site specific Nearmap imagery for drainage pathways within the study area was sourced at the highest possible resolution of 0.075m per pixel. This resolution allowed the best possible interpretation of the surface morphology. Larger scale aerial photography that provides an overview of the study area and surrounds was acquired at 0.149 and 0.299 metres per pixel.

Digital Elevation Model (DEM)

New South Wales Government Spatial Services 1 metre DEM and LiDAR Point Cloud were sourced through the ELVIS web site. The 1 metre DEM had sufficient resolution for the interpretation of surface morphology and it was deemed not necessary to construct a higher resolution DEM from the point cloud.

The DEM was sourced as 32 individual tiles that covered the entire catchments of the flow paths extant within the study area. These tiles were imported into QGIS and merged into one tile. QGIS was then used to fill sinks and data gaps in the DEM so that a Strahler Stream Order could be generated that defined flow pathways within the study area. This process produced a raster image which was then converted into a shape file.

Cadastral and Topographic Data

Cadastral and topographic data for the study area was sourced from the New South Wales Government Spatial Information Exchange 'clip and ship' facility. There are multiple layers included in each product but only some were relevant to this review. These were layers for;

- NSW Hydroline (flow paths) and Hydroarea (lakes and dams)
- Contours: 2 metre contour interval
- Roads
- Property plan and lot numbers

Reliable Rivers and Regulated Rivers

The Reliable Rivers and Regulated Rivers in NSW layers were sourced from the SEED website. The layers that were available were 150 m buffers around Strahler orders (SO) 3, 4, 5 and Regulated Rivers areas. These layers were sourced in order to determine agreeance with the NSW Hydroline but SO 3 was identified as extending from a confluence 470 metres to the north of the study area. The Reliable Rivers and Regulated Rivers layers do not apply within the study area.

Parish map

The historic maps for parish Melville were sourced from the SIX viewer. The earliest map available is dated circa 1841 (Appendix 4: Parish Melville circa 1841) and shows South Creek, Ropes Creek, Kemps Creek, Reedy Creek and Eastern Creek as well as some unnamed tributaries.

South Creek is shown to extend through Parish Melville as a continuous channel while other streams are shown as chains of ponds (CoP) with a continuous channel.

Reedy Creek is shown to extend further to the south than Eastern Creek and is shown as continuous channel in its lower reaches and as a CoP in its upper reaches.

Similarly, Eastern Creek is shown as a continuous channel for a short distance upstream of its confluence with Reedy Creek but is shown as a CoP in its upper reaches. The map confirms the existence of CoP that was a common morphology of streams in western Sydney at time of settlement. Eastern Creek is shown as extending into the vicinity of the study area as a continuous channel to the approximate location of Chandos Road and then for a short distance as a CoP.

Limitations

GIS interpretation of flow pathways using a high resolution LiDAR DEM uses an algorithm that identifies a series of the lowest continuous points to define flow pathways. At their highest stream order these pathways may represent pathways of overland flow during periods of rainfall but they may not represent what can be referred to as a river or a stream. Further interpretation is essential to make this determination and verification is often impossible from even the highest resolution aerial photography. Often, only on site investigations can identify the presence, or absence, of the assemblage of geomorphic units from which channel, or bank, morphology can be defined.

Discussion

Natural Resources Access Regulator (NRAR)

Guidelines for controlled activities on waterfront land.

The WM Act and WM Reg. are administered by the Natural Resource Access Regulator (NRAR). The NRAR is required to assess the impact of any controlled activity to ensure that no more than minimal harm will be done to waterfront land as a consequence of carrying out the controlled activity.

Waterfront land is defined in the WM Act as that land within 40 m of the highest bank of a river.

If it can be demonstrated that drainage patterns and flow paths are not a river then this would alter the stream order that has been assigned by the NSW Hydroline and therefore modify the requirements and restrictions on development and the provision of riparian buffer zones each side of the channel, as defined by the banks.

What constitutes a river, stream, or creek, can be a contentious issue and legislation has attempted to standardise and systematically codify the legal definition of a river (Taylor et al. 2007*)*. However, such attempts at standardisation have not always been successful.

Many fluvial geomorphologists have sought to clarify the definition of exactly what constitutes a river and these investigations, and subsequent definitions, are based on fundamental morphological constructs that identify multiple geomorphic elements that combine to form a river. However, the issue is complex, and this method of river definition requires detailed assessment which can be time consuming, expensive and site specific.

Leopold et al. (1964) and Leopold (1994) examine the complex characters of various forms of channel and critically evaluate methods of defining what constitutes a river. Kellerhals et al. (1976) offer a process driven classification of river morphology. David Knighton (1998) explores these concepts further and offers clear insights into the interpretation of what constitutes a river in his pivotal book *Fluvial Forms and Processes: A New Perspective.* Knighton employs empirical and theoretical approaches to examine the complexity of fluvial form and process, detailing the structure and assemblage of geomorphic units that combine to define what is a river. Knighton (1998) also examined the Strahler (1952) method of classifying rivers by stream order. An alternate method of stream ordering is offered where channel linkages are ordered by magnitude and stream order is calculated by adding confluent stream order values (Knighton 1998).

The clear message here is that the issue is complex and a simplified method of determining exactly what constitutes a stream, or river, was needed. Fluvial geomorphologists will have an almost instinctual understanding of what constitutes a river but for catchment managers, land use professionals, and any other profession that is required to deal with rivers, the definition is often not so clear cut. Especially as some opinions on what constitutes a river often has a decidedly Eurocentric view and does not account for the complexity, and variability, of Australian rivers. To fulfil this need for simplification, a modified Strahler system of stream ordering has been used in conjunction with Geographic Information Systems (GIS) to produce the New South Wales Hydroline (2018).

The New South Wales Hydroline Data Set is an attempt to standardise and simplify the definition of what constitutes a river in New South Wales. However, such an attempt at standardisation risks an oversimplification that will present its own unique set of problems.

The fundamental problem with the Hydroline is that it is an artificial construct generated by GIS analysis. Information on the layer's metadata webpage (NSW Hydroline) states that the database is automatically and continuously updated as new information becomes available *"…from relevant stakeholders and custodians…"* but no information is provided what this means for the temporal recurrence of physical updates, or corrections, of the Hydroline. Comparison of the position of contemporary drainage pathways, generated from high resolution LiDAR DEMs, with drainage pathway locations indicated by the Hydroline, show a marked inconsistency in most locations. The capture method also embedded inherent positional irregularities into the dataset as the capture source was standard topographic maps and orthophoto image trace. Used in conjunction these sources serve to reduce errors extant in one source alone but still contain substantial positional inconsistencies. The Hydroline database, because of its character and areal extent, is rarely subject to the ground truthing processes that are essential in confirming the veracity of the data presented.

The inherent problem with the application of this construct is that its practical implementation is inflexible and requirements for conformity are resolute. However, axiomatic application of Hydroline dataset ignores the inherent errors and the complexity and variability of Australian water courses that have been defined by professional fluvial geomorphologists over many decades.

Desktop assessment of the flow paths within the study area shows that the drainage lines are poorly defined in the upper reaches as defined by the Hydroline. Interrogation of the aerial imagery showed a lack of defined banks, and other structural geomorphic units, which would normally be associated with a river system. Well defined banks and beds, or anything that could be defined as aquatic habitat, were absent in these upper reaches, except in artificially constructed water storages. The upper catchment above that which had been defined as a first order stream could only best be described as poorly defined drainage depression. To determine the location of the interface between poorly defined drainage depression and first order stream is often problematic. A generalised location may be determined by desktop assessment but a more qualified location can only be determined by physical inspection.

Strahler (1952, 1964) indicates that only channel networks with intermittent and perennial stream flows should be used in stream ordering. Because the uppermost drainage lines in the study area would be more precisely described as ephemeral, they do not fit into the Strahler method of stream order.

While the NRAR and WM Act require adherence to stream classification is based on a Strahler stream order classification, throughout the guidelines reference is made to the banks of the river and buffer zones are measured from top of bank, *viz*

Waterfront land includes the bed and bank of any river, lake or estuary and all land within 40 metres of the highest bank of the river, lake or estuary. (P4)

…channel which comprises the bed and banks of the watercourse (to the highest bank) (P5)

The riparian corridor consists of:

•the channel which comprises the bed and banks of the watercourse (to the highest bank) and

•the vegetated riparian zone (VRZ) adjoining the channel (P5)

The width of the VRZ should be measured from the top of the highest bank on both sides of the watercourse (P5)

Therefore, to conform to the guidelines stipulated by the NRAR and WM Act, it is essential to identify these geomorphic features within the study area. i.e. *the bed and bank of any river, lake or estuary…*

2021 Study Sites

Overview

The Hydroline Data Set (Planning, Industry and Environment 2018) utilised Strahler Stream Order assessment to identify stream within the study area (Figure 1). During preliminary desktop assessment using QGIS, three study areas were defined by locations that the Hydroline extended within the Keyhole Site. The Hydroline defined first order streams in Areas 1 and 3 and a second order stream in Area 2.

In natural fluvial systems as the channel gradient, and dominant particle size, decreases there is usually a corresponding increase in sinuosity. Stream sinuosity is the ratio of stream length to valley length. A straight flow path, or channel, will have a sinuosity of 1.0 to 1.05. Low to moderate sinuosity is 1.06 to 1.3. Moderate to high sinuosity is 1.3 to 2.0 and tortuous sinuosity is greater than 2.0.

The substrate in all three study areas consists of weathered claystone, siltstone and fine laminates of the Bringelly Shale, part of the Wianamatta Group (Clarke and Jones 1991). This fine grained substrate, and low gradients endemic within the study area, would normally exert controls on any existing channel such that they would have a moderate to high sinuosity. Desktop review of the flow pathways within each study area indicates that flow paths in areas 1 and 2 are highly modified. An assessment of sinuosity will give insights into the degree of anthropogenic flow path modification in each study area.

Site assessments of the study areas within the Keyhole Site were completed on the 12th of May 2021.

Area 1

Desktop Assessment

Area 1 extends through Lots 54 and 63 between Chandos Road and Redmayne Road (Figure 2). The contemporary position of flow pathways was determined by 1 m resolution LiDAR DEM and compared with the position of the NSW Hydroline. The relative position of the flow lines is comparable, but not exact. For example, the Hydroline passes through the centreline of the agricultural dams while the mapped pathways tend to follow more closely any existing spillway channel.

Desktop interpretation of contemporary aerial photography and DEM indicates that the reach between Chandos Road and Redmayne Road consists mainly of two agricultural dams, their associated spillways and connecting drainage pathways.

Within Area 1 the low gradient and fine grained substrate would normally define a reach of moderate to high sinuosity but the sinuosity here is very low at 1.03 for the Hydroline and 1.13 for the contemporary mapped flow paths.

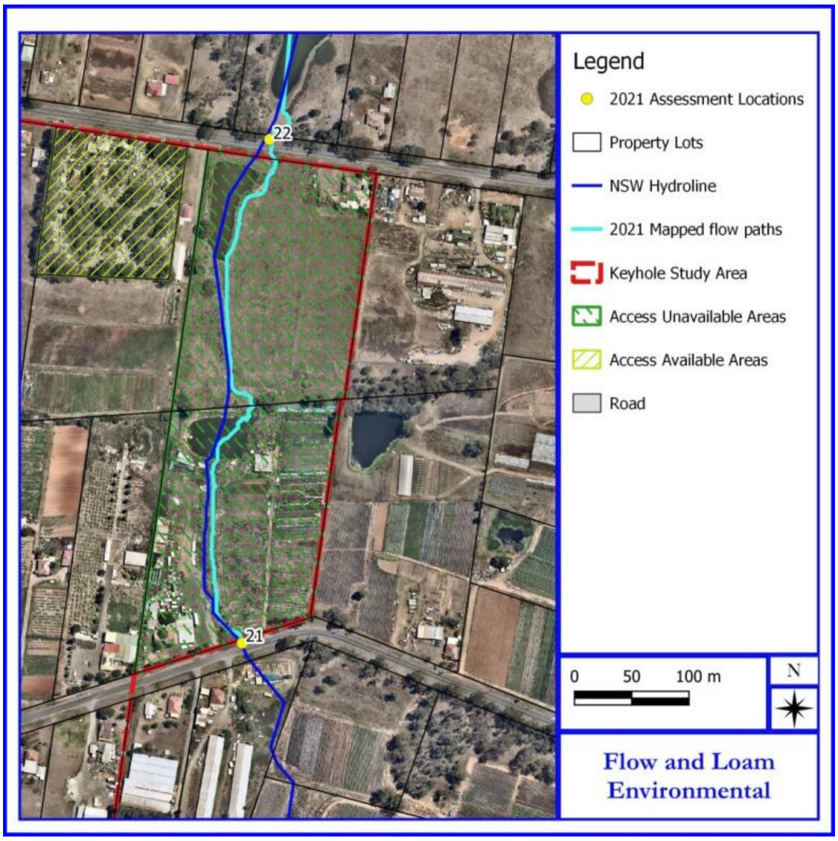


Figure 2. Study Area 1

An existing flow path can be identified from the aerial photographs but it is masked by dense growth of vegetation and its character cannot be determined by aerial photograph interpretation alone. With a very low sinuosity these channels are probably artificial and are essentially agricultural drains.

Site Assessment

There was no access for site assessment in lots 54 and 63 and therefore site inspection was limited to what could be viewed from the adjacent roadways. Inspection sites for area 1 are sites 21 and 22 (Figure 2).

At site 21 there is a very low sinuosity drainage line extending downslope from the road. Upslope, the channel passes around what appears to be an infilled agricultural dam. At road side the channel has a very narrow base with low angle stable banks. The channel cross section is trapezoidal which indicates anthropogenic modification (Figure 3).

Down slope there is a macro channel with width increasing to greater than 12 m. The inset base flow channel is masked by vegetation.

Figure 3. Site 21. 'A' Looking down slope and 'B' Looking upslope

At site 22, downslope from the road, there is a minor flow path is less than 2 m wide and is completely obscured by weed infestation. The character of the channel cannot be determined. The flow path leads to weed choked dam down slope (Figure 4).

There is a similar morphology on upslope side of road where the drainage channel from an agricultural dam spillway is choked with rushes.

The upslope channel appears to be narrow, very low sinuosity, and anthropogenically modified.

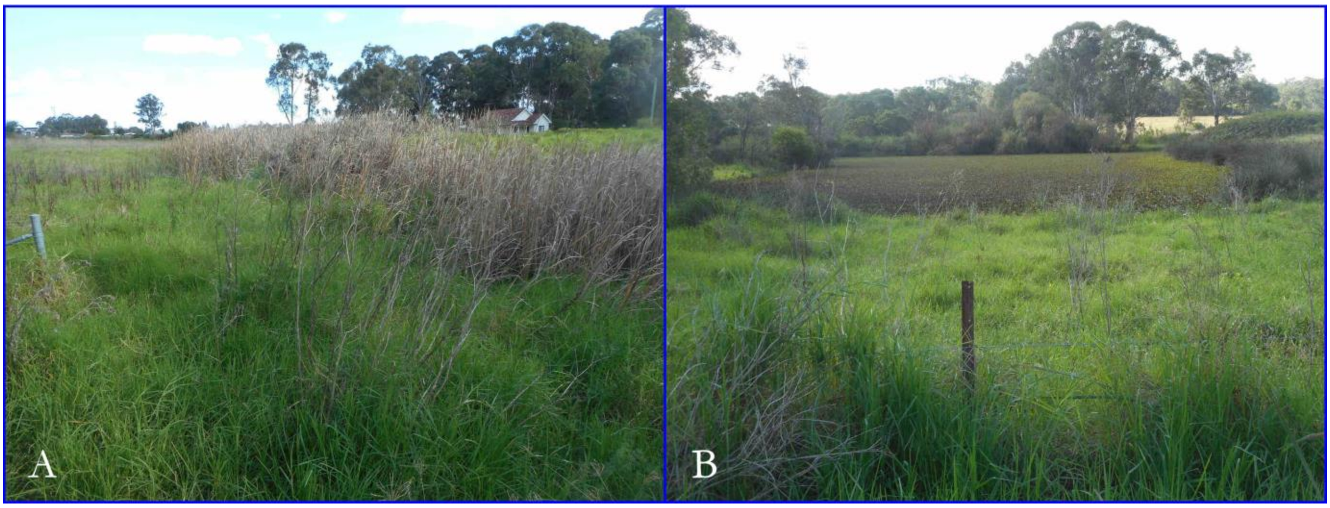


Figure 4. Site 22. 'A' Looking upslope and 'B' looking downslope

Area 2

Desktop Assessment

Study Area 2 is where a meander loop of Eastern Creek, as defined by the NSW Hydroline, extends into the neighbouring Lot 59B (Figure 5).

During desktop assessment there was no evidence found of a channel as at this location extending into Lot 59B. Mapping of the contemporary channel line indicates Eastern Creek as a well defined channel to the west.

Eastern Creek at this location is at least a second order stream but to define the stream order an assessment of upstream channels would be necessary as the Strahler Stream Order for the Hydroline is not included in the attribute table for the Hydroline layer. An assessment of upstream Stream Orders is not required for this assessment.

An assessment of channel sinuosity for Eastern Creek between Chandos Road and Redmayne Road was completed. The sinuosity of the Hydroline is 1.46 and the sinuosity of the 2021 mapped line is 1.37. The sinuosity for the Hydroline is artificially increased by the meander bend that has been mapped as extending into Lot 59B. This degree of sinuosity indicates a low level of anthropogenic channel modification. Ignoring channel incision processes as a function of changes in catchment hydraulics.

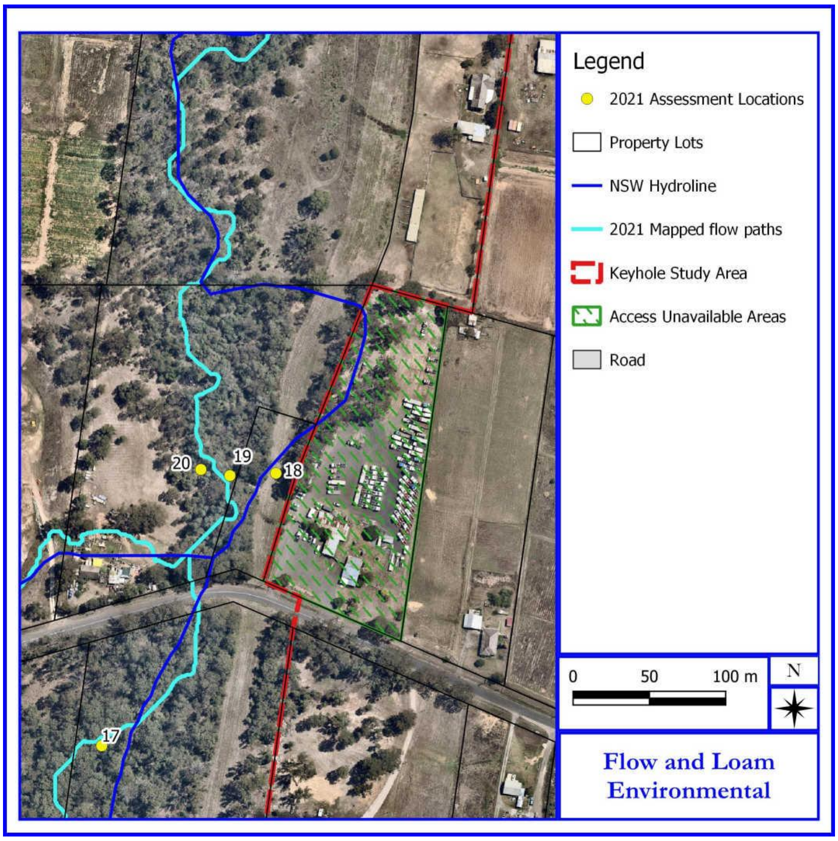


Figure 5. Study Area 2

Site Assessment

To confirm the presence, or absence, of a meander bend of Eastern Creek extending into Lot 59B a transect of three sites were assessed across the channel zone and these are sites 18, 19 and 20 (Figure 5). As a check on the morphology and character of the Eastern Creek, as mapped for this study, an additional site, site 17, was assessed upstream.

Site 17

At site 17 Eastern Creek exists as an elongate pool – glide – riffle sequence (Figure 6). Elongated pools and glides are separated by steps in the longitudinal profile varying between 0.40 and 0.80 m. There are three profile steps within 40m of site 17 location. The water surface over the riffles is not broken.

The low flow channel is moderately sinuous with multi step banks that are sub-vertical and erosional, in places. This morphology indicates that there has been multiple stages of incision pass through this reach.

There is a short length of, what may be, remnant floodplain inset within the low flow channel that has a scour feature around tree fall indicating an erosional environment.

Water depth is greater than 1.05 m in places and less than 0.10 m over riffles. The width of channel at water surface is variable from 0.40 m to a maximum of 3 m. The bank height is also variable to a maximum of 3.5 m. Channel width, bank top to bank top is 8 – 10 m.

Figure 6 Site 17 'A' Looking downstream and 'B' looking upstream

Site 18

The location of Site 18 is on the gas pipeline easement where the NSW Hydroline indicates a channel for Eastern Creek that crosses into Lot 59B.

Often, where channels are realigned for some reason, the old pre-existing channel is filled in. However, over time, there is often faint surface morphology reflecting the position of the old channel as the fill settles.

An assessment of historical aerial photography may reveal a pre-existing channel here but there is no indication or evidence of any pre-existing channel.

Figure 7 Site 18 looking down slope to the location of the Hydroline meander bend.

Site 19

The stream character and channel morphology is the same here as at Site 17 and Eastern Creek exists as an elongate pool – glide – riffle sequence (Figure 8). Riffles are over steps in longitudinal profile with localised relief of up to 0.80 m. The steps are commonly roots that have acted to trap woody debris and other litter to form small dams and induce deposition (Figure 8B). The elongate pools are greater than 1.05 m deep, in places, and generally less than 0.10 m deep over the riffles.

Multi phase, sub-vertical banks extend to 3.5 m; the channel width at water level varies between 4 and 5 m and the channel width from bank top to bank top is variable between 7 and 9 m. The banks are erosional.

At proximal bank top, right bank, there are scour zones and litter dams in and around vegetation indicating recent overbank flows and that the channel is still coupled with the floodplain..

Figure 8. Site 19. 'A' looking upstream over a pool and 'B' showing a step in the longitudinal profile that has formed at roots crossing the channel

Site 20

While the transect of sites 18 – 20 extend across the channel zone from east to west, the orientation of the channel of Eastern Creek means that Site 20 is located downstream from Site 19. The channel character and morphology at Site 20 are the same as at Site 17 and Site 19 (Figure 9).

There are scour zones proximal to right bank top indicating recent overbank flows.

There is opportunistic deposition of sediment in backwater of small tributary at left margin.

Figure 9. Site 20. 'A' Looking upstream over an elongate pool and 'B' Riffles over root dam in base of channel

Area 3

Desktop Assessment

Study Area 3 extends laterally across the southern boundary of the Keyhole Estate, from West to East, through Lots 78B, C and D, 79A and 79B, Lot 1 and Lots 81A and 81B (Figure 10).

The NSW Hydroline extends through the study area and upslope for another 360 m. The contemporary 2021 mapped channel also extends upslope of the study area for another 170 m.

Desktop review and analysis of the aerial photography reveal a channel with remarkable little variation of character and morphology. Channel sinuosity was measured from the confluence with Eastern Creek to the maximum upstream extent of the mapped channels. The sinuosity of the Hydroline is 1.04 over a channel length of 1125.3 m. The sinuosity of the 2021 mapped channel 1.11 over a channel length of 962.3 m. Both sinuosities are very low and are indicative of a highly modified channel.

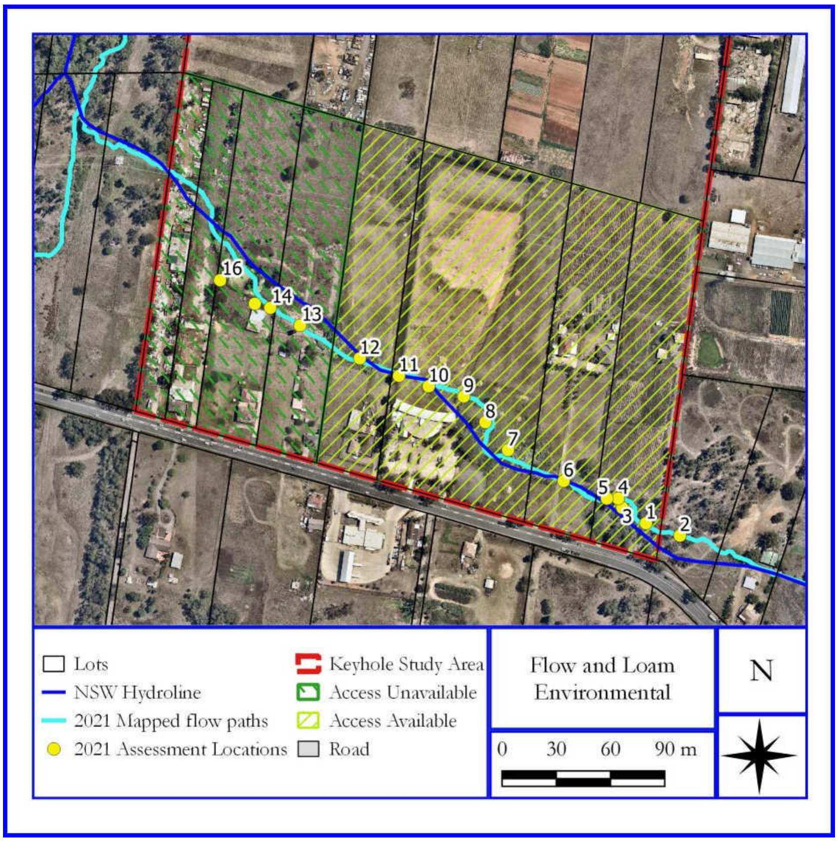


Figure 10. Study Area 3

Aerial photograph interpretation reveals what appears to be partially artificial channel and partly intact channel, especially in the upper reaches.

Analysis of recent aerial photography sequence shows artificial channel construction on Lots 78C and D after 27 12 2020 and prior to 26 01 2021. Artificial channel is also apparent upslope of the dam on lot 78B.

Channel morphology is more apparent on the golf driving range where surface vegetation is kept low. Here there appears to be a remnant chain of ponds morphology which would be expected in this area prior to settlement. However, given the development that is apparent in the area, and how this development would have impacted catchment hydraulics, the apparent channel capacity on the driving range is too low.

The defined channel, modified or not, ends at the boundary of Lot 81B, which is the upstream limit of the Keyhole study area.

Site Assessment

Sites 1 – 5. Upper reach of study site

There is a short length of channel between site 5 and the upper boundary of the study area that has remnant chain of ponds morphology with a continuous channel. The channel ends at the boundary between Lots 73B and 81B which is also the boundary of the study area. At this location the defined channel and has been stabilised by rock fill (Figure 11A). Site 2 is located outside of the study area upslope on an area where there is no defined channel (Figure 11B).

The low flow channel through this reach is well defined with low angled and well vegetated banks. At some locations the banks appear to be two stage which may indicate the passage of a knickpoint through this reach.

Figure 11. 'A' shows knickpoint stabilised by rock fill. Defined channel ends here. 'B' is looking up slope from Site 2; no defined channel

There is also some remnant pond morphology at site 3 where the channel widens out from 2 metres in width to more than 8 metres. The stagnant water that was evident at site 1 is not in evidence here. The channel and pond base has been dry for an extended period.

Sediment spear testing at sites 3 and 4 penetrates easily, with very little resistance to 1.05 m. There is a narrow, sub-horizontal, floodplain pocket at bank top left bank that has sediment over saprolite to 0.40 m as indicated by sediment spear testing.

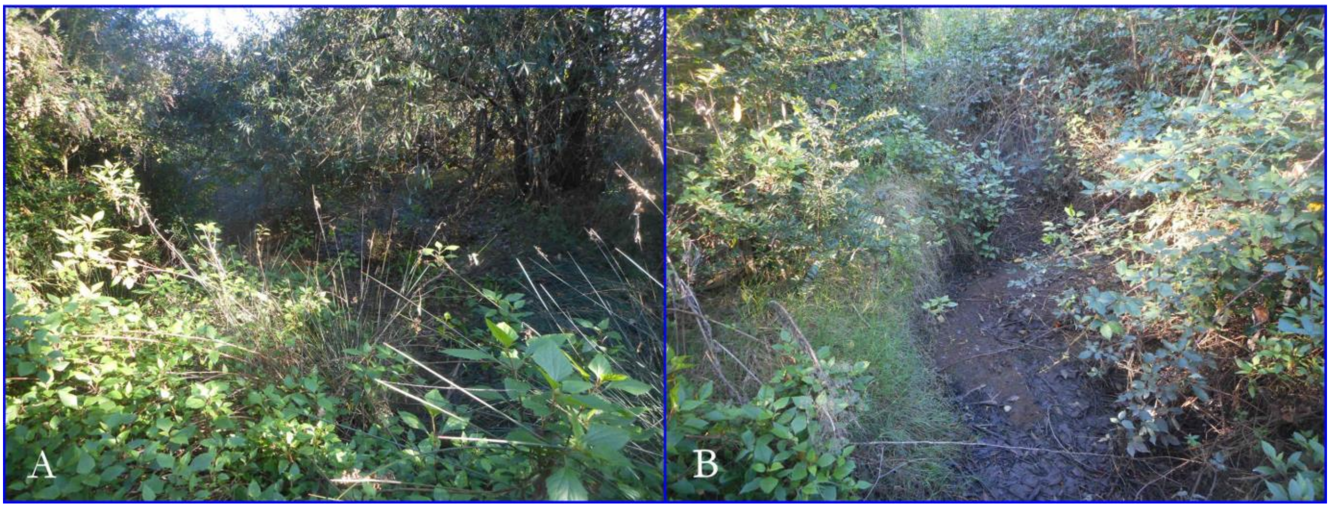


Figure 12. 'A' looking upstream along the tributary towards site 4 and 'B' the tributary joining from left margin with recent deposition in the base of the channel

At site 5 there is a confluence with a well-defined channel entering from left margin. This new channel extends from south of The Horsley Drive out of the study area. The channel is 3 – 4 m wide with high angle to sub-vertical banks to 1.4 m high. There is recent deposition of medium to coarse and granular sediment apparent in channel base.

The channel base of the tributary from site 1 is perched 0.60 m above base of new channel entering from left margin. This indicates that the majority of flow enters from this unmapped channel and it is erosional.

Sites 6 – 8

At site 6 there is a length of channel that flows through a pipe that is approximately 9 m in length. Only the upstream end of the pipe (Figure 13A) is apparent as the downstream end is obscured by abundant weed growth (Figure 13B).

There is a suspiciously straight channel extending upslope of crossing. A straight channel in this environment indicates anthropogenically modified channel or an artificial channel. Sub-vertical banks to 3 m high are vegetated and stable. The channel width, bank top to bank top, is between 5 and 6 m.

Access to the channel zone downstream of site 6 is extremely difficult and limited by abundant and dense weed growth, notably blackberry. Site 8 is located on an old dam wall and is looking upstream.

Figure 13 'A' looking upstream from site 6. 'B' looking downstream from site 6. In both instances the channel is straight and choked with weed infestation.

Figure 14 Site 8 looking upstream across the impoundment of the old agricultural dam that is now choked with weeds.

Sites 9 – 12

Piped section of channel.

The upstream intake of the pipe is located between site 8 and site 9 but this area is completely overgrown and the exact location was unable to be determined. Most flows are diverted underneath the driving range through a subterranean pipe. There is a surface inlet grid at site 10 and at site 11. The end of the piped section is between sites 11 and 12 but is obscured by vegetation.

There is a surface low flow channel that has a low to moderate sinuosity with remnant ponds morphology. The low flow channel has a low capacity and discontinuous banks to 0.30 m. Flows that are unable to be contained within the pipe flow across the surface of the golf range. Interrogation of the historic aerial photography for 1978 (Appendix 3) show an agricultural dam at this location.

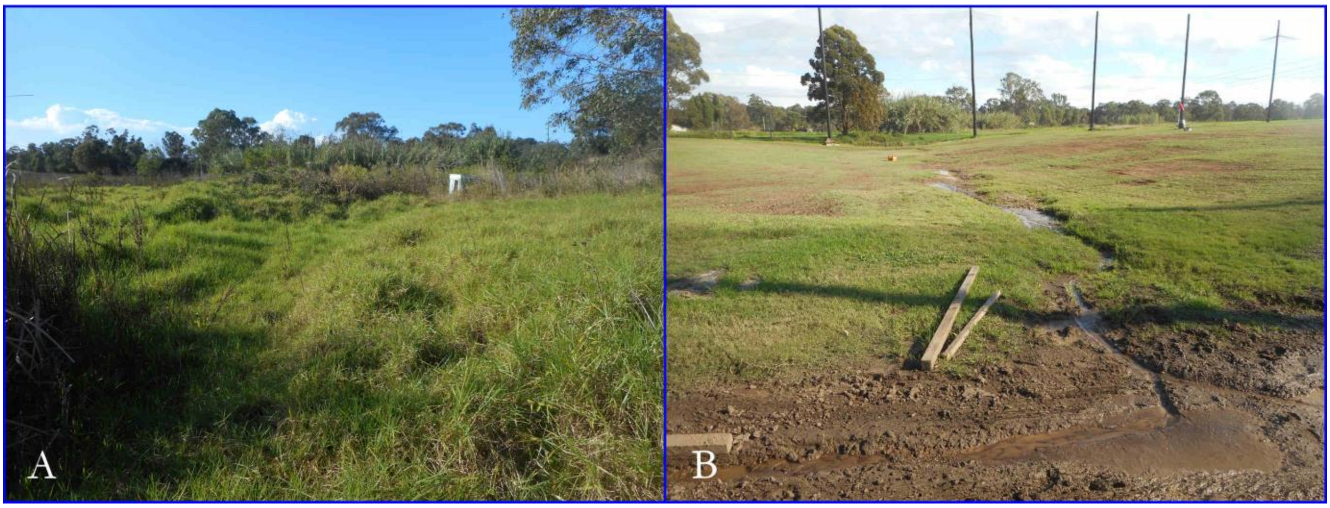


Figure 15. Location is site 9 at golf range boundary. 'A' is looking upstream to site 8 and 'B' is looking downstream to site 10.

Sites 12 – 14

There is a very low sinuosity channel that shows evidence of anthropogenic realignment. Most of this reach was unable to be viewed and was largely inaccessible due to the abundant growth of blackberry, and other weed, obscuring the channel.

Figure 16. Site 13. Artificially straightened channel extending upstream 'A' and downstream 'B'

At site 12 the channel zone becomes visible through gaps in weed infestation.

A deeply incised channel has a three stage right bank that indicates multiple stages of incision and possibly the passage of knickpoints upstream through this reach. The left bank is obscured by dense weed infestation. The stages of incision on right bank are from base to bank top, (approx.) 1.5 m, 1.4 m and 0.75 m

The base of the right bank is sub-vertical, erosional and is being undercut by channel migration of the low flow channel. At the time of inspection the low flow was low volume and was not impacting the base of the bank. During periods of elevated flow channel migration induces erosion. The upper stages of the right bank are vegetated and stable.

Immediately upstream the channel migration is undercutting the left bank where the low flow channel migrates from channel margin to channel margin.

The macro channel width, bank top to bank top, is variable between 16 and 18 m. A sub horizontal surface proximal to right bank top was tested with multiple spear points. Increasing resistance met with refusal at 0.35 m, on average. This is indicative of a thin layer of sediment over saprolite.

At site 13 there is a 15 m length of channel that passes through two pipes (Figure 16). The channel both upstream and downstream of site 13 is straight and has a trapezoidal profile that is indicative of anthropogenic realignment.

The channel emerges from weed infestation upstream, passes through a straight channel and into two concrete pipes. There is very minor base flow in evidence and appears to be stagnant. The channel emerges from the pipes into another straight section that has a trapezoidal profile. This profile indicates an anthropogenically modified stream.

The left bank downstream of the pipes is artificial and appears to be a fill of building waste; concrete and bricks.

The channel width, bank top to bank top, averages 6.0 m. Downslope, before flowing into a dam at site 14, the channel passes into a narrow slot that is 3 m wide and inset into two stage banks.

Channel bank height is approximately 4 m.

Sites 14 – 16

Agricultural dam (Figure 17). The channel ends where it flows into the dam at site 15. Site 16 is at the dam wall at property boundary.

Figure 17. 'A' Looking downstream from site 15 across the dam and 'B' is looking across the dam wall to a highly modified zone of degraded channel

Historic Aerial Photography Assessment

Overview

Historical imagery was sourced for the study areas from the New South Wales Government Historical Imagery Portal. Their availability and an assessment of quality are presented in Table 1.

Not all historical imagery was sourced. Sometimes this was because of insufficient change from the previous image or because the quality of resolution was insufficient to gain insight into changes of channel morphology.

Available Years	Acquired	Quality of Image	Notes
1930	Yes	Low	Earliest image available. Georeferencing completed using the upper canal as there are no other control points available in the image. Positional accuracy would be better with a broader spread control points.
1955	Yes	Good	Poor Georeferencing. Poor positional fix
1961	Yes	Very Good	Georeferenced
1965	Yes	Good	Georeferenced
1970	Yes	Good	Georeferenced
1975	No		Insufficient variation from 1970 image
1978	Yes	Very Good	Georeferenced
1983	No		Insufficient variation from 1978 image
1984	No		Insufficient variation from 1978 image
1986	Yes	Good	Georeferenced
1989	No		Insufficient variation from 1986 image
1991	No		
1998	Yes	Very Good	Georeferenced
2002	No		
2004	Yes	Low	Georeferenced. Low resolution
2005	Yes	Good	Georeferenced
2009	Yes	Very High	Nearmap
2020	Yes	Very High	Nearmap
2021	Yes	Very High	Nearmap

Table 1 Aerial photography used in this report

Area 1: Appendix 1

10 February 1930

There is no discernible channel at this time. Vegetation is relatively sparse and does not mask hidden channels. Flow pathways that are not channelised still follow the valley axis and will retain water longer than the surrounding slopes. They are usually characterised by more dense vegetation because of this but there is no evidence of preferential vegetation growth along the valley axis.

27 June 1961

There has been almost ubiquitous development of market gardens by this time. An agricultural dam has been constructed upstream of site 21 and a continuous, very low sinuosity, channel extends down slope to site 22. The dam downslope of site 22 has been constructed by this and there is an incised channel exiting the dam through the spillway. This dam is not within the study area.

6 May 1978

The channel alignment has not changed since the last photo but it is more pronounced. There are now four dams evident within the area 1 study site and market gardens occupy more of the catchment area.

There is no change in channel character or morphology since the 1961 image.

22 January 2020

There has been almost no change in channel character or morphology since the 1978 image. The image was captured at the end of a period of intense drought. There does not appear to be preferential growth of vegetation along the channel line but all dam levels are high. The dam that was immediately up slpoe of site 21 appears to have been infilled.

Summary

There are two well defined lengths of channel within this study area that are separated by agricultural dams. The channels are not evident on the 1930 photograph and their appearance coincides with the advent of market gardening in the area. The channels are in very poor condition, with very low sinuosity, no channel variability and are completely colonised by luxuriant growth of weeds.

Area 2: Appendix 2

10 February 1930

The quality of the 1930 photograph is insufficient to gain a clear insight into the existence of a continuous channel at this location. There appears to be some elongate patches of darker vegetation which may indicate water retention along flow paths but it is not conclusive. However, there is no evidence of a meander loop extending into lot 59B from Eastern Creek.

27 June 1961

The 1961 photograph is much clearer and has a good resolution. Market gardens occupy lot 59B and denser vegetation occupies the Eastern Creek corridor. While much of the meander channel length, as defined by the Hydroline, is masked by vegetation there is still sufficient gaps in the canopy to determine that there is no channel in the vicinity of site 18.

6 May 1978

The 1978 photo is clear and the resolution is good. There is a corridor that is cleared of vegetation along the western boundary of the study area and there is no channel in evidence.

22 January 2020

The 2020 aerial photograph has a high resolution and the quality is excellent. The cleared corridor along the path of the gas pipeline shows no evidence of a channel ever existing in the vicinity of the meander loop as shown by the Hydroline.

Summary

There is no evidence shown on any of the aerial photographs of the existence of a meander loop in this area. Nor does the DEM show any remnant channel morphology of where the channel may have been. It is unlikely that there was ever a channel at the location of the meander loop as shown by the NSW Hydroline.

Area 3: Appendix 3

10 February 1930

The 1930 imagery for Area 3 is much clearer than at other areas of the image. Eastern Creek can be easily seen to be a discontinuous channel to the west of the study area. The area of the Keyhole Estate has been largely cleared along the southern boundary and sparse vegetation does not mask the surface. There is no evidence of any channel existing in this area

27 June 1961

The 1961 imagery is of good quality and resolution. Market gardens extend across most of the study area and a low sinuosity continuous channel is also in evidence. The zone between sites 14 and 16 is masked by vegetation and there is no evidence of the dam that later occupies this location. The channel down slope of site 16 is poorly defined but the channel of Eastern Creek can clearly be seen in Lot 97B.

There is a low sinuosity, continuous channel in evidence extending upslope from the vicinity of site 14 to site 1 with dams having been constructed at site 12 and site 8.

6 May 1978

At the date of capture there is very little vegetation masking the channel zone. By this time the channel morphology that largely exists today is in place.

Highly modified and straightened sections of channel are in evidence downstream of site 16 where a dam has now been constructed. Dams are also in existence at sites 12, 10 and site 8. There is a continuous channel upstream of site 7 and it appears to be erosional at site 7 and site 2. Sheet erosion is evident at site 2.

At site 10 is where the golf driving range is today and there is now a pipeline carrying the flow under sites 9 and 10. The sheet erosion evident at site 2 has now been re-contoured and the channel evident in the 1978 photo is no longer in existence.

22 January 2020

The market gardening prevalent in the previous imagery is largely absent in the 2020 image. The dams at sites 16 and 8 are now choked with abundant vegetation, as is much of the channel length, and the dam at site 10 has been filled in and a pipeline now conveys the flows subterraneously.

Further channel straightening and piping has occurred at sites 13 and 6. The channel has a very low sinuosity and is generally in a very poor condition.

Summary

The channel as shown in the 1961 and 1978 imagery appears to have a very low sinuosity and very little morphological diversity. The channel appears to be in a very poor condition and becomes colonised by impenetrable weed growth prior to the 2020 imagery. The contemporary channel condition has not improved and is still very poor with a lack of morphological diversity.

Conclusions

- The channels within the study areas 1 and 3 are generally well defined and continuous
- The channels in study areas 1 and 3 are artificial and anthropogenically modified
- The bank morphology is study areas 1 and 3 have low variability indicating anthropogenic modification
- The sinuosity of the channels in study areas 1 and 3 is very low and is indicative of anthropogenic modification
- At study area 2 there is no evidence of any existing, or pre-existing, channel or meander bend of Eastern Creek extending into Lot 59B. The channel, as defined by the NSW Hydroline, is non-existent.
- Study area 1 has a channel that is essentially ephemeral and would more properly be described as an agricultural drain rather than a first order stream as indicated by the NSW Hydroline
- Because of the brevity and transitory nature of the flows in the upper reaches of study areas 1 and 3 the drainage lines within the study areas 1 and 3 would more precisely be defined as ephemeral and are therefore not first order streams as defined by Strahler
- The channel through study area 3 is described as a first order stream but there is a confluence of two tributaries at site 5. The right bank tributary is ephemeral and is therefore not a first order stream. The tributary entering from left margin contributes the majority of the flow and constitutes a first order stream that extends downstream to the confluence with Eastern Creek
- The channel upstream of site 2 defined by the NSW Hydroline as a first order stream is non-existent. There is no defining assemblage of geomorphic units, channels or banks, and this reach is incorrectly labelled as a first order stream.
- What appears to be intact valley fill at head of catchment in study area 3 is at the interface of colluvial margin and flow path. This area is not natural and sheet erosion evident in the historical aerials has been re-profiled.

References

ANZLIC: Intergovernmental Committee on Surveying and Mapping.

Clark, N.R. and Jones, D.C., 1991. Penrith 1:100 000 Geological Sheet 9030, 1st edition. Geological Survey of New South Wales, Sydney.

ELVIS - Elevation and Depth - Foundation Spatial Data. https://www.icsm.gov.au/

Kellerhals R., Church M. and Bray D. 1976. Classification and Analysis of River Processes. Journal of the Hydraulics Division. American Society of Engineers. 102 HY7, pp 813-829.

Knighton D.A. 1998. Fluvial Form and Processes. A New Perspective. Arnold, London.

Leopold L. B. 1994. A View of the River. Harvard University Press

Leopold L. B., Wolman M.G. and Miller J.P. 1964. Fluvial Processes in Geomorphology. Dover Publications, New York, 1995

Natural Resources Access Regulator. Guidelines for controlled activities on waterfront land. https://www.industry.nsw.gov.au/_data/assets/pdf_file/0004/156865/NRAR-Guidelines-for-controlled-activities-on-waterfront-land-Riparian-corridors.pdf

Nearmap Australia Pty Ltd. https://www.nearmap.com/au/en

New South Wales Government SEED: The Central Resource for Sharing and Enabling Environmental Data in NSW. https://datasets.seed.nsw.gov.au/dataset

New South Wales Government Historical Imagery Portal. https://portal.spatial.nsw.gov.au/portal /apps /webappviewer/index.html?id=f7c215b873864d44bccddda8075238cb

New South Wales Government Spatial Collaboration Portal https://portal.spatial.nsw.gov.au/portal/apps/sites/#/home

NSW Foundation Spatial Data Framework: Water Theme. Dataset/product title: NSW Hydro Line. https://data.nsw.gov.au/data/dataset/f04b2ae2-7cd4-41f9-93fa-ce68a15555e6/resource/9176747e-611a-4a7c-8169-c88dfbf3b8b1/download/ataset producttitle_nsw-hydro-line.pdf

New South Wales Government Spatial Information Exchange https://maps.six.nsw.gov.au/clipnship.html

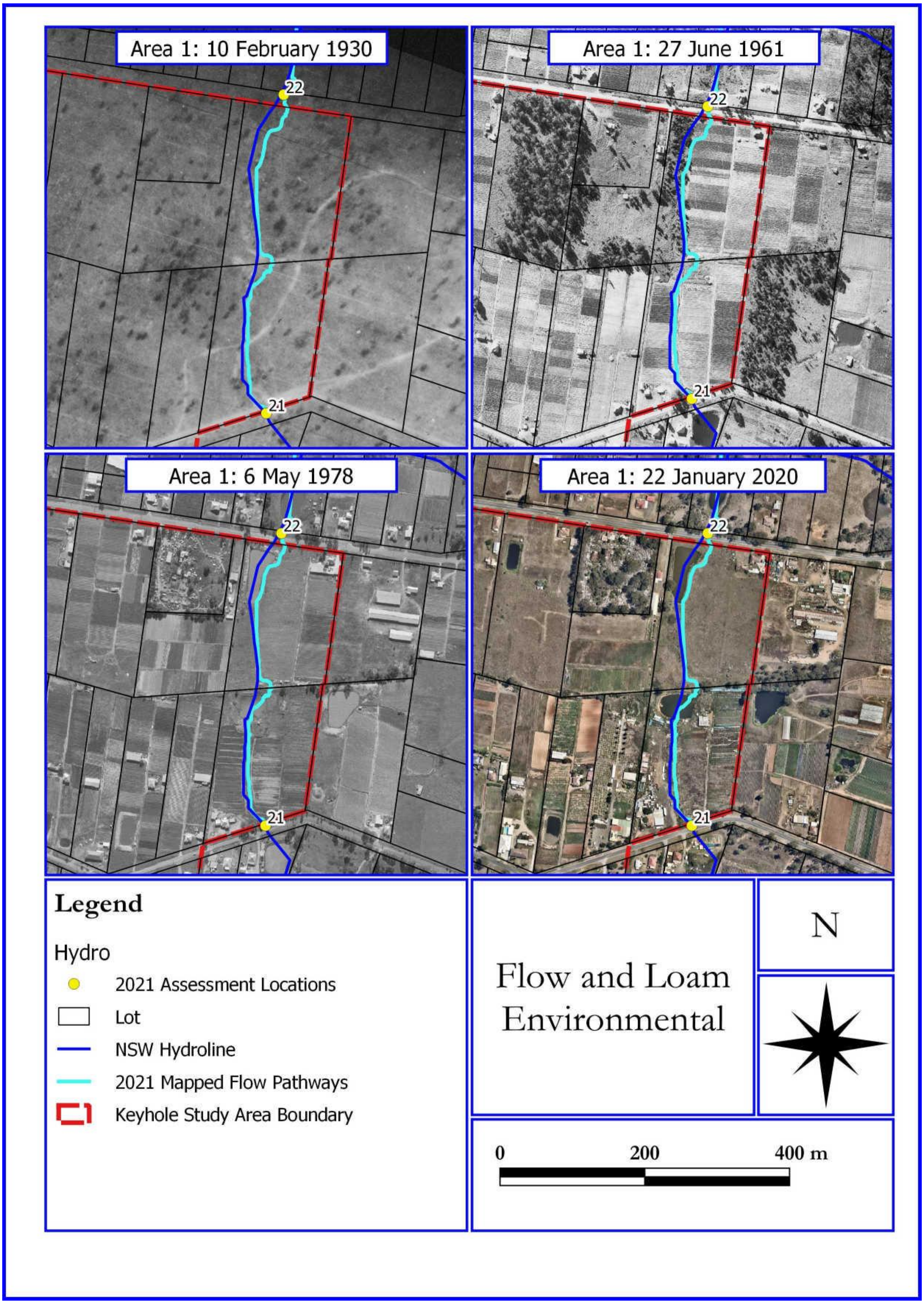
Planning, Industry and Environment 2018. Water Management (General) Regulation 2018 Hydro Line spatial data. https://www.industry.nsw.gov.au/water/licensing-trade/hydroline-spatial-data

Strahler, A. N. 1952. Hypsometric (Area-altitude) Analysis of Erosional Topography. *Bulletin of the Geological Society of America* 63, 1117 – 1142.

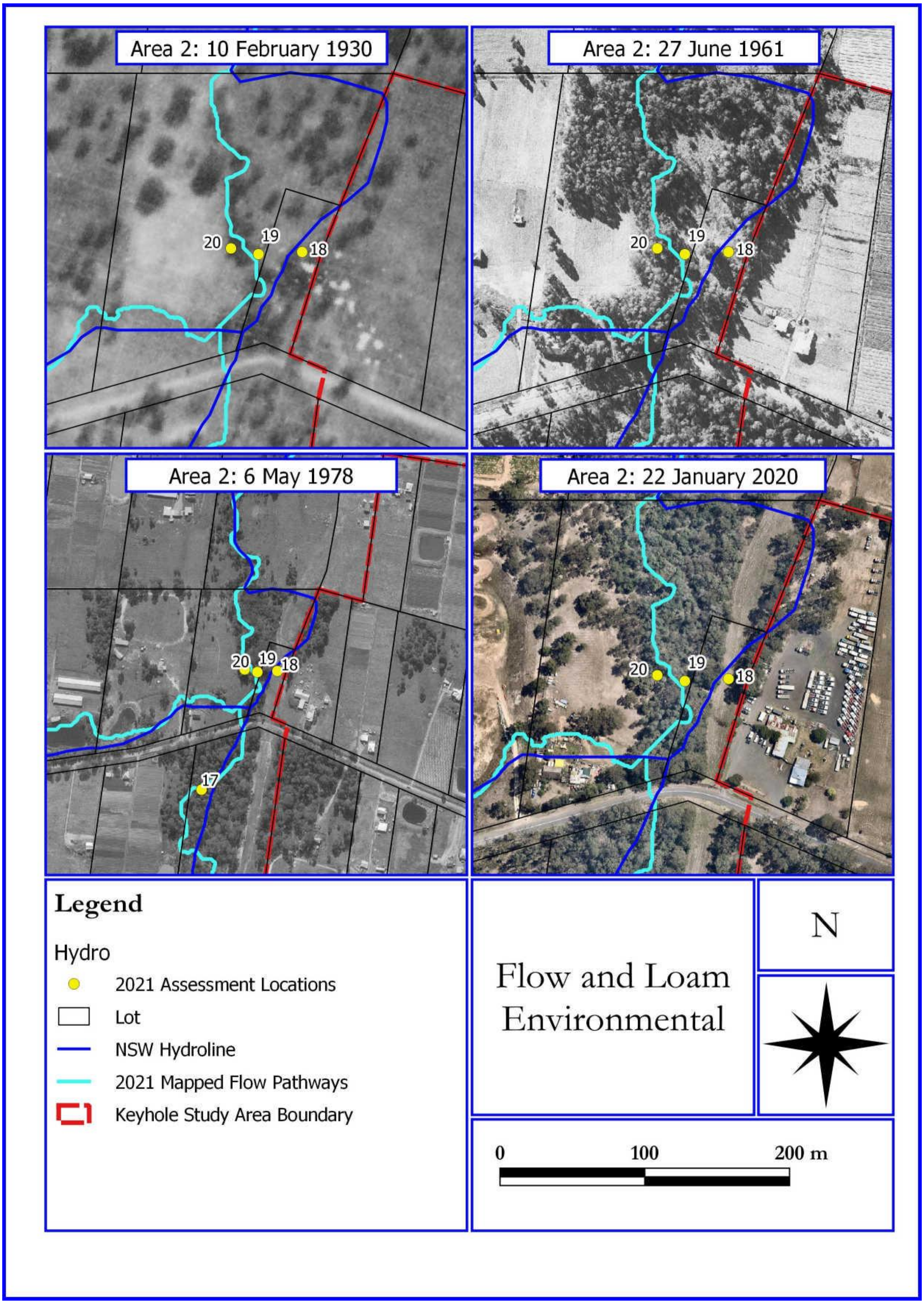
Strahler, A. N. 1964. Quantitative Geomorphology of Drainage basins and Channel Networks. In Ven Te Chow (ed) *Handbook of Applied Hydrology: A Compendium of Water Resources Technology.*

Taylor M. and Stokes R. Up The Creek: What is wrong with the definition of a river in New South Wales? Environment and Planning Law Journal, 2005

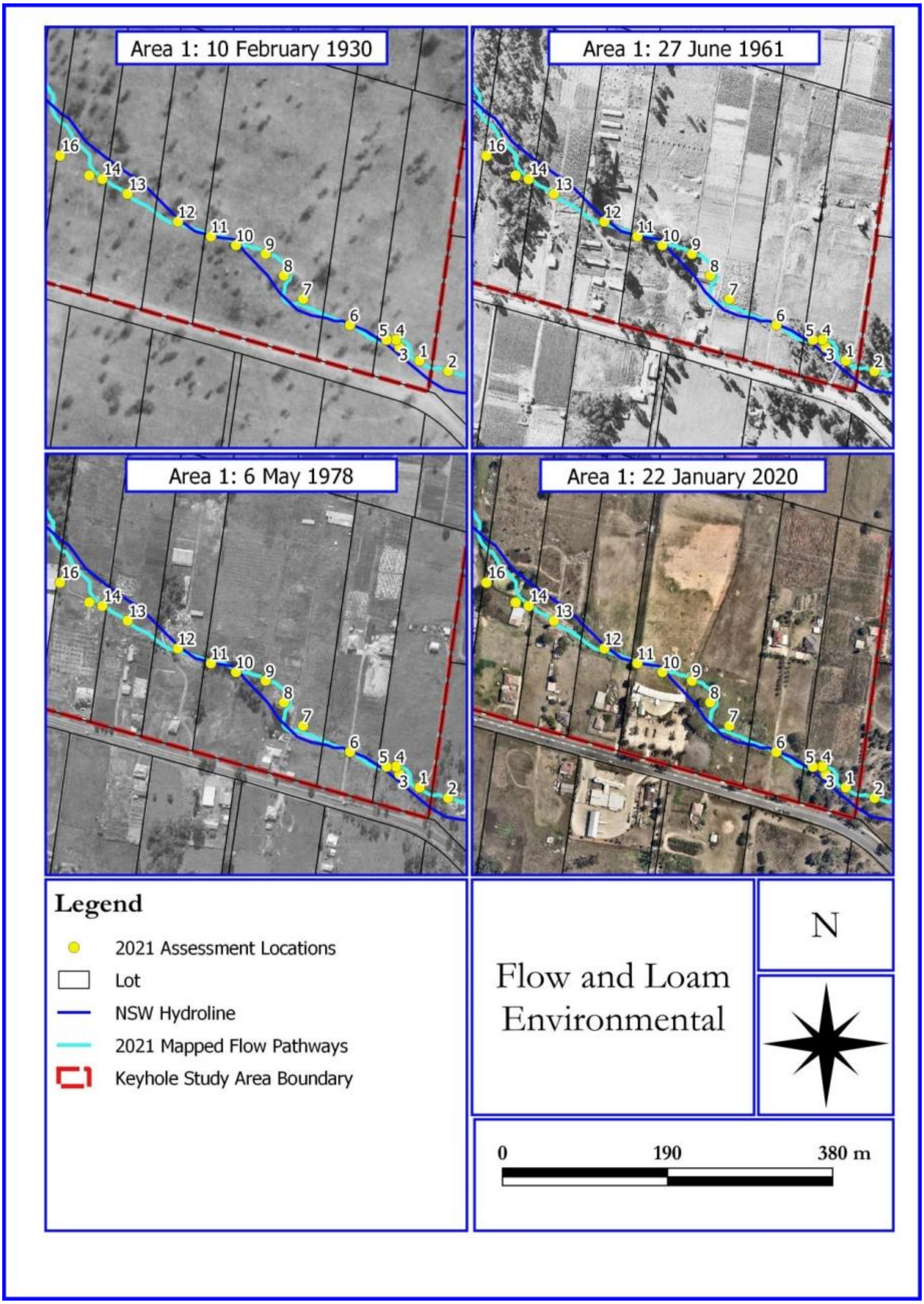
Appendix 1: Historical Aerial Photography Area 1



Appendix 2: Historical Aerial Photography Area 2



Appendix 3: Historical Aerial Photography Area 3



Appendix 4: Parish Melville circa 1841