Sodic Soils Assessment

Wallan East (Part 1) Precinct Area

05 | Final

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Victorian Planning Authority

Sodic Soils Assessment

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Author: Peter Sandercock, Christian Bannan, Craig Clifton, Graeme Jardine, Adam Hall, Filomena Losi and Claudia Pelizaro
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Jacobs Australia Pty Ltd.

Floor 11, 452 Flinders Street
Melbourne, VIC 3000
PO Box 312, Flinders Lane
Melbourne, VIC 8009
Australia
T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

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Contents

Executive Summary

Jacobs was engaged by the Victorian Planning Authority (VPA) to provide an assessment of the distribution of sodic and dispersive soils, erosion risks and consider their implications for future planned development in the Wallan East (Part 1) Precinct Area.

The soils of the Wallan East (Part 1) Precinct Area that were assessed in this investigation are classified as Sodosols, with a clear or abrupt textural B horizon in which the major part of the upper B2 horizon is sodic and not strongly acid. The topsoils are typically sodic with an average Exchangeable Sodium Percentage (ESP) value of 9.8%, but not dispersive, this being attributed to higher electrical conductivity, along with very high organic carbon levels. Subsoils exhibit high to extreme sodicity with ESP values ranging from 9 to >15% (max 58%). Deeper samples recorded extreme ESP values, ranging from 19 to 37%. A horizon depths vary across the Precinct, with measurements in the field ranging from 28-65 cm.

A vulnerability assessment approach was used to assess the implications of sodic soils for the construction phase and for the future developed land use.

Vulnerability (V) = Exposure (E) + Sensitivity (S)

Exposure (E): refers to attributes of soils that characterise their sodicity and propensity to erosion. Exposure criteria included sodicity of topsoil and subsoil, A horizon depth and slope.

Sensitivity (S) refers to attributes of the land or activities that influence the extent to which the land and urban developments may be disrupted or detrimentally affected by sodic soils. Sensitivity criteria included position relative to waterway, potential disturbance associated with construction activity for different land use types and water balance change expected for future land use.

During construction, areas identified with a high vulnerability to sodic soil erosion are the waterways and areas with high to very high sodicity in topsoils and subsoils. Activities that expose these soils to rainfall and associated runoff will present significant construction challenges and need to be managed carefully.

Water balance changes resulting from future developed land use and associated impervious areas will generate high volumes of runoff, which will drain into the surrounding waterways, including Merri Creek. This section of the creek has been drained and straightened. Further increases in runoff could accelerate erosion of bed and bank materials.

Areas identified with a high vulnerability to sodic soils erosion risks and recommended treatments include:

- **Drainage depressions/seasonal wetlands** – Ideally these areas should be identified and reserved as linear green spaces to maintain their important hydrological function in retaining and temporarily storing water in the landscape and regulating the flow of water and nutrients throughout a catchment. Surface ground cover measures are critical for protecting the soils against dispersion and erosion.
- **Merri Creek** - The section of the creek within the Precinct Area has been drained and straightened. Further increases in runoff from urban development may result in increased erosion. Engineering works may be required to stabilise this waterway so that is resilient to stormwater runoff from future land development.

It is recommended that detailed plans are developed for managing sodic soil-related erosion risks in high vulnerability areas identified in this investigation.

Important note about your report

The purpose of this report and the associated services performed by Jacobs is to provide an assessment of the distribution of sodic soils and erosion risks that relate to the characteristics of these soils, their position in the landscape and the implications of this for future planned development within the Wallan East (Part 1) Precinct Area. Advice is also provided on the range of treatment options that are available to manage identified sodic soils and erosion risks. The work has been conducted in accordance with the scope of services set out in the contract between Jacobs (Australia) and Victorian Planning Authority.

In preparing this report, Jacobs has relied upon, and presumed accurate information provided by Victorian Planning Authority and/or other sources as referenced in the report. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, the observations and conclusions in this report may change.

The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession following applicable standards, guidelines, procedures and practices at the date of issue of this report. No other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be used in full, and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, Victorian Planning Authority subject to, and issued in accordance with, the provisions of the contract between Jacobs and Victorian Planning Authority.

1. Introduction

1.1 Background

Jacobs was engaged by the Victorian Planning Authority (VPA) to map sodic soils and erosion risk and provide advice on treatment options in light of future planned development in four Precinct Areas located to the north of Melbourne: Beveridge North West, Shenstone Park, Wallan South and Wallan East.

1.2 Scope

This report provides an assessment of the distribution of sodic soils and erosion risks that relate to the characteristics of these soils, their position in the landscape and the implications of this for future planned development within the Wallan East (Part 1) Precinct Structure Plan (PSP).

Wallan East PSP has been identified as a project on the VPA's Fast Track Program. The VPA are currently in a phase of completing background studies, landowner and agency input in plan preparation. The VPA will shortly commence preparation of a draft PSP and planning scheme amendment before proceeding to agency engagement. This phase will be followed by a phase of final public consultation.

Wallan East (Part 1) covers a total of 140 hectares and is bounded by Epping-Kilmore Road to the east, Wallan-Whittlesea Road to the South, the Melbourne to Sydney rail line to the west and Kelby Lane to the north. It is envisaged that land uses will be designed to support and complement the existing Wallan township. Figure 1.1 shows the Concept Place-Based Plan that has been prepared for the Wallan East (Part 1) PSP area. It represents the direction for the PSP area and key elements that it should contain following the next phase, agency endorsement and public consultation.

Vulnerability assessment was used to explore the implications of sodic soils for future planned urban development. This assessment was completed for two scenarios, first the construction phase and second for the future developed land use. Advice is provided on the range of treatment options that are available to manage identified sodic soils and erosion risks.

1.3 Report structure

This report has been structured as follows:

- Section 2 provides a brief summary of sodic and dispersive soils definitions and terms used in this report, Victorian context regarding the distribution of sodic soils and their implications for urban development.
- Section 3 describes our approach to mapping sodic soils and erosion risks.
- Section 4 presents the results of the assessment.
- Section 5 provides discussion and recommendations on options to manage identified erosion risks, including potential planning control measures.
- Section 6 documents gaps in knowledge/requirements for further soil investigations and further work to validate the predictions of the distribution of sodic soils and erosion risks.

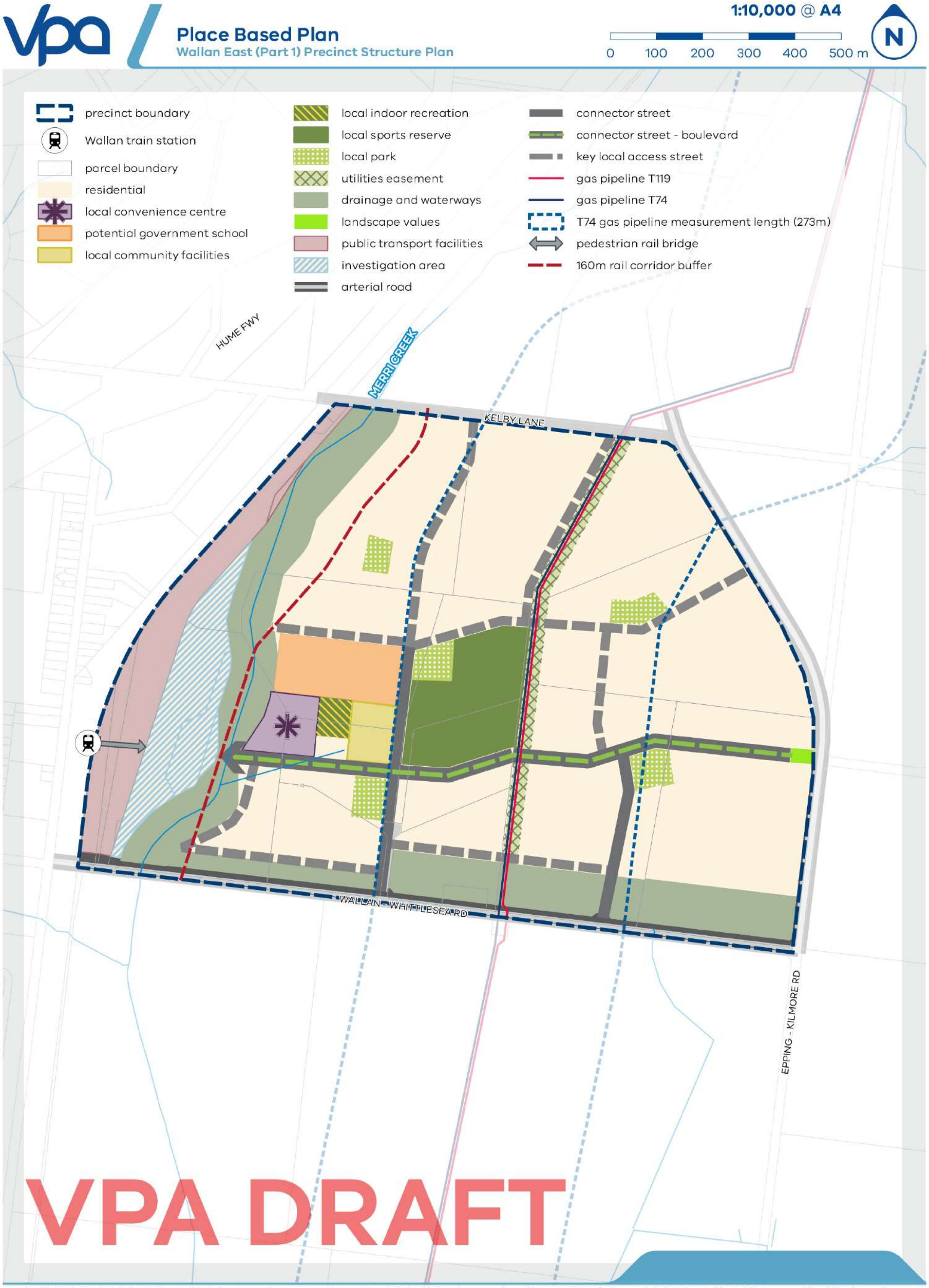

Figure 1.1: Wallan East PSP (Part 1) Place-Based Concept Plan.

2. Sodic and dispersive soils

2.1.1 Sodic and dispersive soil definitions and terms used in this report

Sodic soils are defined in Australia as those with an exchangeable sodium percentage (ESP) of 6% or greater (Northcote and Skene 1972). An ESP of 6% is considered to be the threshold where the cation sodium in soil has an adverse impact on soil structure when in contact with fresh water, causing clay dispersion (Northcote and Skene 1972). Soils may also reveal dispersive behaviour under the influence of elevated exchangeable potassium (K) and magnesium (Mg) (Marchuk and Rengasamy 2012, Dang et al. 2018). These considerations are necessary in the evaluation of sodic and dispersive soils where dispersion is evident when ESP levels are below 6%. Figure 2.1 provides examples of the Emerson Aggregate Test where varying levels of dispersion are recorded (Armstrong 2019).

Figure 2.1: Examples of soil aggregates subject to the Emerson Aggregate Test, showing nil dispersion on the left with increasing levels of dispersion to the right (Armstrong 2019).

Wetting of sodic and dispersive soils may lead to soil structural decline, crusting, waterlogging, low rates of hydraulic conductivity, excessive runoff, erosion and poor agricultural performance. Sheet, rill, gully and tunnel erosion may all be observed in areas with sodic and dispersive soils. Erosion is exacerbated when sodic soils are disturbed or groundcover is removed or absent. Figure 2.2 shows photographs of erosion that has developed in sodic and dispersive soils, elevated turbidity and sedimentation in waterways. Charman and Murphy (2007) provide further details of the impact of sodic and dispersive soils in an Australian context.

Figure 2.2: Example of erosion of sodic and dispersive soils which can result in elevated turbidity and sedimentation in waterways.

The Australian Soil Classification (Isbell and NCST 2021) outlines 14 soil orders, several of these contain soil materials that are sodic and dispersive. The soil order 'Sodosol' is a specific class that has strong texture contrast between the A horizon and sodic B horizon, with the latter characteristically being dispersive. This report seeks to identify 'Sodosols' and other soil orders across the Wallan East (Part 1) Precinct. Soil orders other than Sodosols can be identified with sodic and dispersive properties.

2.1.2 Sodic soil distribution across Victoria.

The distribution of sodic soils across Victoria is well known and documented by Ford et al. (1993) with further mapping by others, including Agriculture Victoria (2020), as shown in Figure 2.3. Sodic soils are common across large expanses of land used for agricultural and urban development. Sodicity and dispersion characteristics vary depending on parent material, geomorphic processes, particle size distribution, rainfall and leaching. In most cases, soils with sodic horizons are texture contrast soils with a clear or abrupt A horizon topsoil layer overlying a finer textured, clay-dominant B horizon subsoil with lower permeability and a high propensity to adsorb cations including sodium.

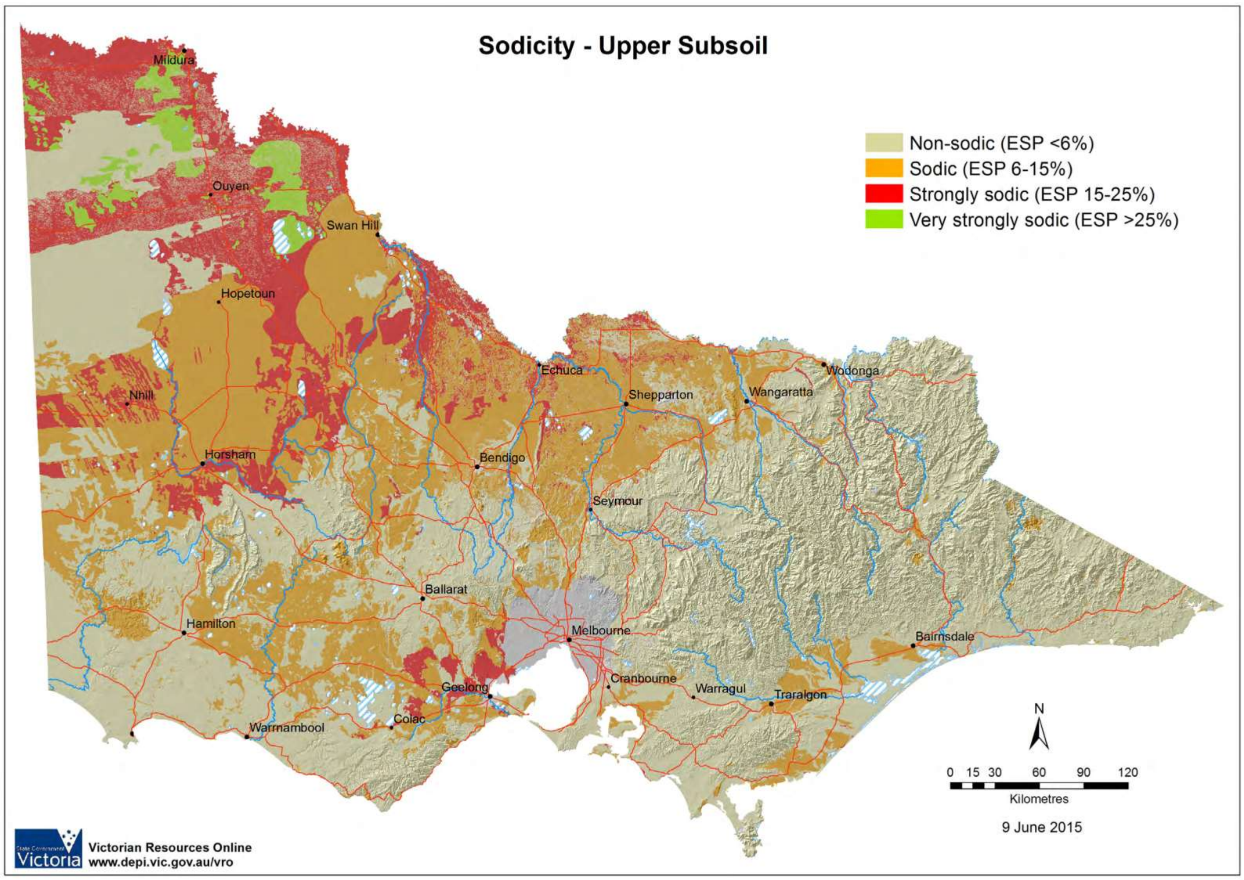

Figure 2.3: Mapping of Sodicity in Upper Subsoil, Victoria (Agriculture Victoria 2020).

2.1.3 Sodic soil implications for urban development

Urban development and site construction cause significant ground disturbance, eliminate vegetative ground cover and expose sodic soils to erosion. Erosion risks are directly influenced by sodic soil exposure and changes in landscape hydrology. Changes to hydrology, including the concentration of flow in culverts, runoff from impervious areas and ponding of rainfall contribute to increased erosion risk.

Urban development and site construction cause significant ground disturbance, impacting surface ground cover and exposing sodic soils to erosion.

Development on sodic and dispersive soils potentially have on and off-site impacts. On-site impacts include:

- Dispersion of topsoil and subsoil.
- Loss of topsoil and subsoil with overland and subsurface flow (sheet, rill, tunnel and gully erosion).
- Poor infiltration and increased volumes of stormwater runoff.
- Water ponding in hollows, break of slope areas or depressions, increasing groundwater recharge.
- Poor ability to establish vegetation due to adverse soil chemical conditions.
- Lack of trafficability.

Other on-site or off-site development impacts arising from sodic and dispersive soil conditions include:

- Increased turbidity in waterways in response to runoff from development areas and a deterioration in water quality and degradation of aquatic flora and fauna habitat with effects on populations.
- Increased erosion potential in downstream waterways in response to larger volumes of stormwater runoff from developed areas with eroding sodic and dispersive soils.

3. Method

3.1 Spatial Logic Assessment Framework

Jacobs' Spatial Logic Assessment Framework was used in the delivery of this project (Figure 3.1). Spatial Logic is an approach that brings together source information, with the data used to represent criteria that reflect exposure or sensitivity. An assessment was made of potential sodic/dispersible soils' extent and their level of vulnerability to proposed future land uses.

Spatial Logic has 5 key stages (Figure 3.1):

- Define – Define the sodic soil/landscape profile relationships, scenarios for assessment and supporting data sources, including an assessment of data suitability.
- Collate and integrate – Collate source data and document for transparency, collate any accessible literature that supports soil studies in the area of interest that will inform or be the basis of the assessment. Integrate by converting source data into documented criteria.
- Assess – With reference to landscape profile criteria, undertake an assessment of potential sodic soil extent, severity and/or risk. The assessment indicates where sodic/dispersible soils may occur and their level of risk, based on available evidence.
- Communicate – Provide a report on the study area, the project evidence base, assessment of findings and the information package.

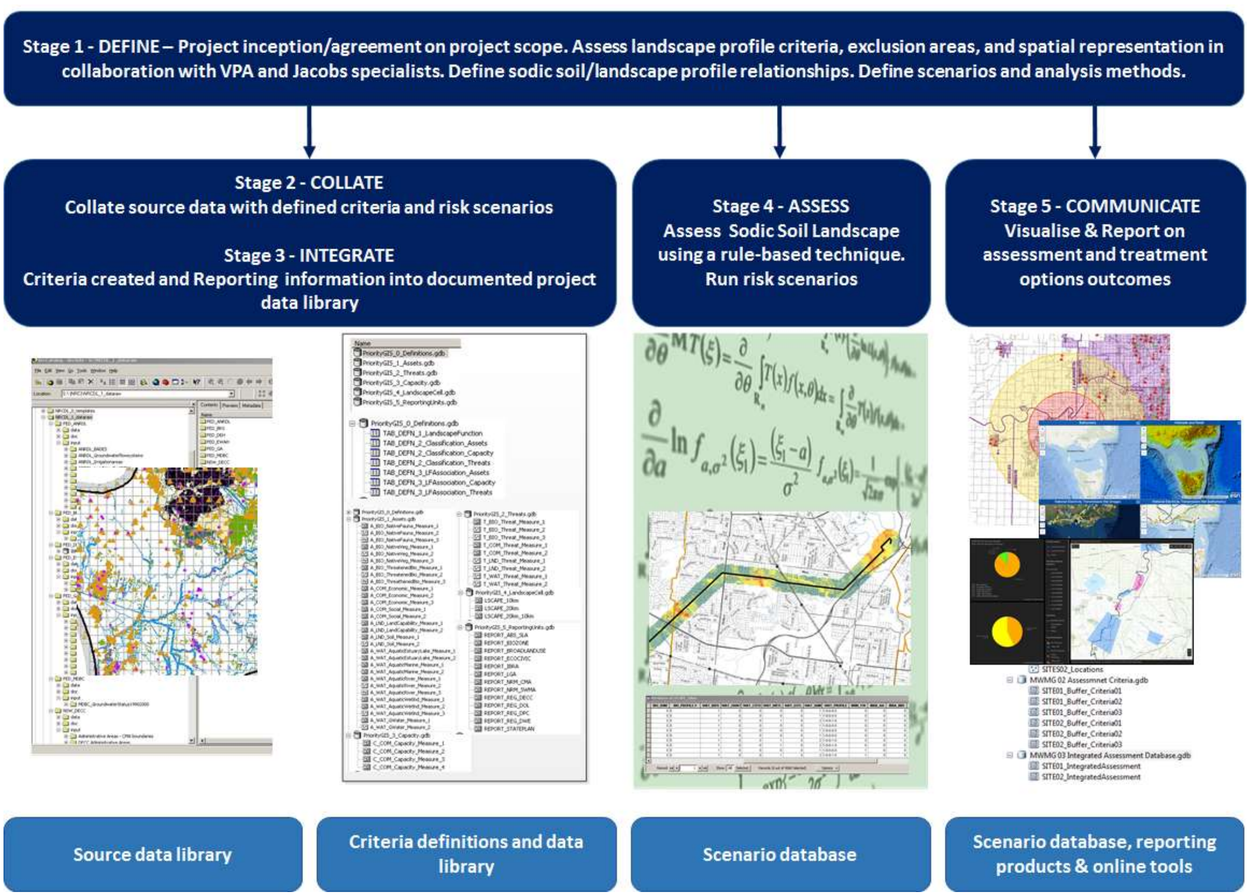

Figure 3.1: The Spatial Logic Assessment Framework.

3.2 Vulnerability Assessment

A specialist workshop was convened early in the project to define sodic soil/landscape profile relationships, risk scenarios and analysis methods for the Beveridge North West, Shenstone Park, Wallan South and Wallan East PSP sodic soils assessments. The principles of the Vulnerability Assessment approach and how they would be applied to this assessment were agreed upon in this workshop. Vulnerability is defined for the purposes of this assessment as:

Vulnerability (V) = Exposure (E) + Sensitivity (S)[1]

Where Exposure (E): Attributes of soils that characterise their sodicity and propensity to erosion
Sensitivity (S): Attributes of the land or activities that influence the extent to which the land and urban developments may be disrupted or detrimentally affected by sodic soils.

3.2.1 Exposure criteria

Attributes of soils that were used to characterise their sodicity and exposure to erosion are:

- Sodicity of topsoil (0-10 cm) - Exchangeable Sodium Percentage (ESP) values. This soil layer is also referred to as A horizon topsoil throughout the report.
- Sodicity of subsoil (30-40 cm) – ESP. In most cases this layer is B horizon subsoil clay, but can include A2 horizon topsoil where topsoils were deeper than 40cm.
- A horizon depth – subsoil exposure/erosion risk decreases with depth.
- Slope – erosion risk increases with slope (which, for this assessment, was derived using 2017 LiDAR)

These attributes form the exposure criteria, with criteria values ranked according to the scoring system outlined in Table 3.1. Table 3.2 provides a description of the Exchangeable Sodium Percentage (ESP) values used to define the Sodicity exposure criteria.

3.2.2 Sensitivity criteria

Attributes of the land or activities that influence sensitivity to sodic soils are:

- Position relative to waterway – Based on mapped drainage extent in Future Urban Structure (FUS) Dataset. Waterways are points of convergence for runoff and flows which makes these areas more sensitive to erosion.
- Construction activity – Potential disturbance of construction for future land use sub types mapped in FUS Dataset. Sensitivity to sodic soils increases with clearing of landscape and earthworks.
- Water balance change – Potential for change in water balance due to future land use (based on FUS classes)[2]. This considers potential for increases in overland flow from impervious surfaces and stormwater pipes in proposed developments. Sensitivity to sodic soils is heightened as a result of increases in runoff.

These attributes form the Sensitivity criteria, with criteria values ranked according to the scoring system outlined in Table 3.3. Table 3.4 and Table 3.5 provides a description of scorings used for Construction Activity and Water Balance Change criteria.

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[1] Vulnerability is typically expressed as Exposure (E) + Sensitivity (S) – Adaptive Capacity (AC). In this case we have not included Adaptive capacity (AC) in the assessment. The Vulnerability assessment is essentially an assessment of potential impacts. Adaptive capacity is included in the discussion when considering aspects of urban development that can be managed to mitigate risks.

[2] This is an assessment of where in the PSP landscape the water balance is likely to change the most due to development. Note that waterways within the PSP may experience additional impacts caused by changed hydrology outside of the PSP area, this potential has not been considered by this high-level assessment.

Table 3.1: Exposure criteria and scores. For further descriptions of ESP values/scores, refer to Table 3.2.

	Score				
Criteria	**1**	**2**	**3**	**4**	**5**
Sodicity of Topsoil (ESP)	<5%	5 to <7%	7 to <10%	10 to <15%	>15%
Sodicity of Subsoil (ESP)	<5%	5 to <7%	7 to <10%	10 to <15%	>15%
A horizon depth	>40cm	30-40cm	20-30cm	10-20cm	<10cm
Slope	0-1 %	1-5%	5 to 10%	10 to 20%	>20%

Table 3.2: Exchangeable Sodium Percentage (ESP) values used to define Sodicity exposure criteria.

Score	ESP Range	Description
1	<5%	Non-sodic, unlikely to reveal dispersion when in contact with fresh rainfall or runoff.
2	5 to <7%	Transition between non-sodic and sodic soil (sodic soil of 6%). Clay fraction within samples likely to evince dispersion when in contact with fresh rainfall or runoff.
3	7 to <10%	Moderate to high sodicity. Dispersion likely to occur when in exposed to fresh rainfall or runoff.
4	10 to <15%	High to very high sodicity. Dispersion likely. Significant erosion risk when exposed to fresh rainfall or runoff.
5	>15%	Very high to extreme sodicity. Significant erosion risk when exposed to fresh rainfall or runoff.

Table 3.3: Sensitivity criteria and scores. For further description of Construction Activity and Water Balance Change values/scores, refer to Table 3.4 and Table 3.5.

	Score				
Criteria	**1**	**2**	**3**	**4**	**5**
Waterway[1]	No	-	-	-	Yes
Construction activity	Minimal disturbance				High level of disturbance
Water balance change	Low (stay the same, infiltration)				High (generate runoff)

[1] Based on waterway extent as mapped as Drainage (LU_TYPE Attribute) in Future Urban Structure (FUS)

Table 3.4: Descriptions of scorings for Construction Activity ranked by level of disturbance expected for Land Use Sub Types (LU_SUBTYPE Attribute) mapped in the Future Urban Structure (FUS).

Score	Level of Disturbance	Land Use Sub Types (LU_SUBTYPE)
1	Minimal disturbance	Local Park
2		*(No land use subtypes fall in this category)*
3		Local Sports Reserve
4		Community Facilities, Existing Rail Reserve, Existing Road Reserve, Government School, Indoor Recreation, Local Convenience Centre, Residential
5	High level of disturbance	Retarding Basin/WQT Wetland, Waterways

Table 3.5: Description of scorings for Water Balance Change expected for Land Use Classes (LU_CLASS Attribute) mapped in the Future Urban Structure (FUS).

Score	Water Balance Change	Land Use Class (LU_CLASS)
1	Low (stay the same, infiltration)	Credited Open Space
2		*(No land use classes fall in this category)*
3		*(No land use classes fall in this category)*
4		Education/Community/Government, Developable Area – Residential
5	High (generate runoff)	Transport, Uncredited Open Space (Drainage LU_TYPE)

3.2.3 Risk scenarios

The distribution of erosion risk associated with sodic soils was modelled using the collated datasets. This assessment was undertaken using Jacobs' Vulnerability Assessment Engine (VAE) - a tool that assists in assembling and analysing spatial data sets.

The VAE was used to assess the risks associated with sodic soils for the following two scenarios:

- Construction phase, where the Vulnerability of land and urban development to sodic soil erosion risks during the construction phase is a function of the following Exposure and Sensitivity criteria:
  - Exposure (E) – Sodicity topsoil, Sodicity subsoil, A horizon Depth, Slope
  - Sensitivity (S) - Waterway, Construction Activity
- Future developed land use, where the Vulnerability of land and urban development to sodic soil erosion risks in the future land use is a function of the following Exposure and Sensitivity criteria:
  - Exposure (E) - Sodicity topsoil, Sodicity subsoil, A horizon Depth, Slope
  - Sensitivity (S) - Waterway, Water Balance Change

Exposure and Sensitivity criteria scores are summed to calculate Vulnerability. The decision was made to apply an equal weighting of scores to Exposure and Sensitivity criteria, they are all considered to be similarly important. The spatial distribution and range of Vulnerability scores informs an assessment of the potential impact of land and urban developments have on sodic soils erosion risks.

4. Results

4.1 Sodicity of soils and their exposure to erosion

The soils of the Wallan East (Part 1) Precinct sampled for this investigation are classified as Sodosols. The characteristics of these soils is consistent with definition of Sodosols (Isbell and NCST 2021), as 'soils with a clear or abrupt textural B horizon in which the major part of the upper B2 horizon is sodic and not strongly acid'.

The stability provided by organic matter including ground cover, plant growth and plant roots is vital for preventing erosion of Sodosols with sodic and dispersive soil horizons. Disturbance to land such as clearing of vegetation, topsoil removal or construction of drainage channels impacts these sources of organic matter and exposes subsoil layers with negligible organic matter to fresh rainfall, increasing susceptibility to erosion. A good cover of grasses was present at the time of sampling.

Some photographs of the field area showing flat topography, headwater stream/drainage depressions and Merri Creek are presented in Figure 4.1.

Figure 4.1: Selected photographs of Wallan East (Part 1) Precinct:: flat (upper left), headwater stream/drainage depression on north west side of PSP (upper right), Merri Creek (lower left) and drainage depression on south west side of PSP (lower right).

The sodicity of soils of the Wallan East (Part 1) Precinct is summarised with reference to exchangeable sodium percentage (ESP) values as follows:

- 0-10cm (A1 horizon topsoil): Average ESP of 9.8%. Of the 16 samples collected, 13 samples (81%) were deemed sodic and 3 samples (19%) were deemed non-sodic. Sodic topsoils are common even in light textured surface soils.
- 30-40cm (mixture of subsurface A2/A3 horizon loams and B-horizon clay subsoil): Average ESP of 19.5%. Of the 16 samples collected, all were found to be highly sodic from laboratory test results.
- 60-140cm soil samples were also collected: A total of 8 deeper samples were collected. All samples were highly sodic, with an average ESP of 26.59%. Subsoils in this PSP area are expected to be highly unstable if exposed to rainfall runoff or overland flow.

Detailed tables of soil test results are included in Appendix A.

An inverse distance weighted (IDW) interpolation was used to estimate values of soil sodicity (topsoil and subsoil) and A horizon depths at unsampled locations across the Precinct. IDW interpolation is a standard method that is used for spatial interpolation and development of soil maps

Maps showing the spatial distribution of these three exposure criteria are presented on the following pages (Topsoil Sodicity - Figure 4.2, Subsoil Sodicity - Figure 4.3; A horizon depth - Figure 4.4). The final exposure criteria used is slope, with classes shown in Figure 4.5. Figure 4.6 presents the sum of the four exposure criteria (Topsoil sodicity, Subsoil sodicity, A horizon depth and slope).

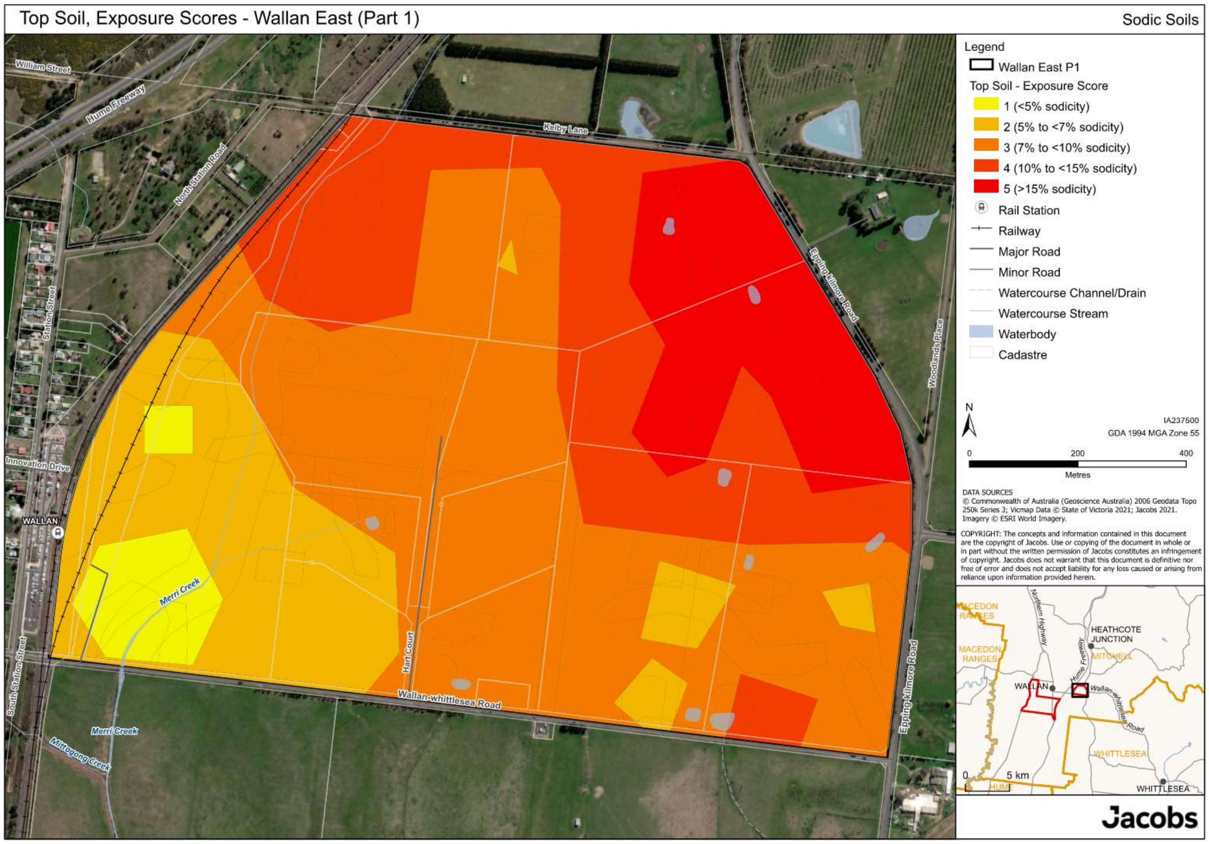


Figure 4.2: Sodicity of topsoil.

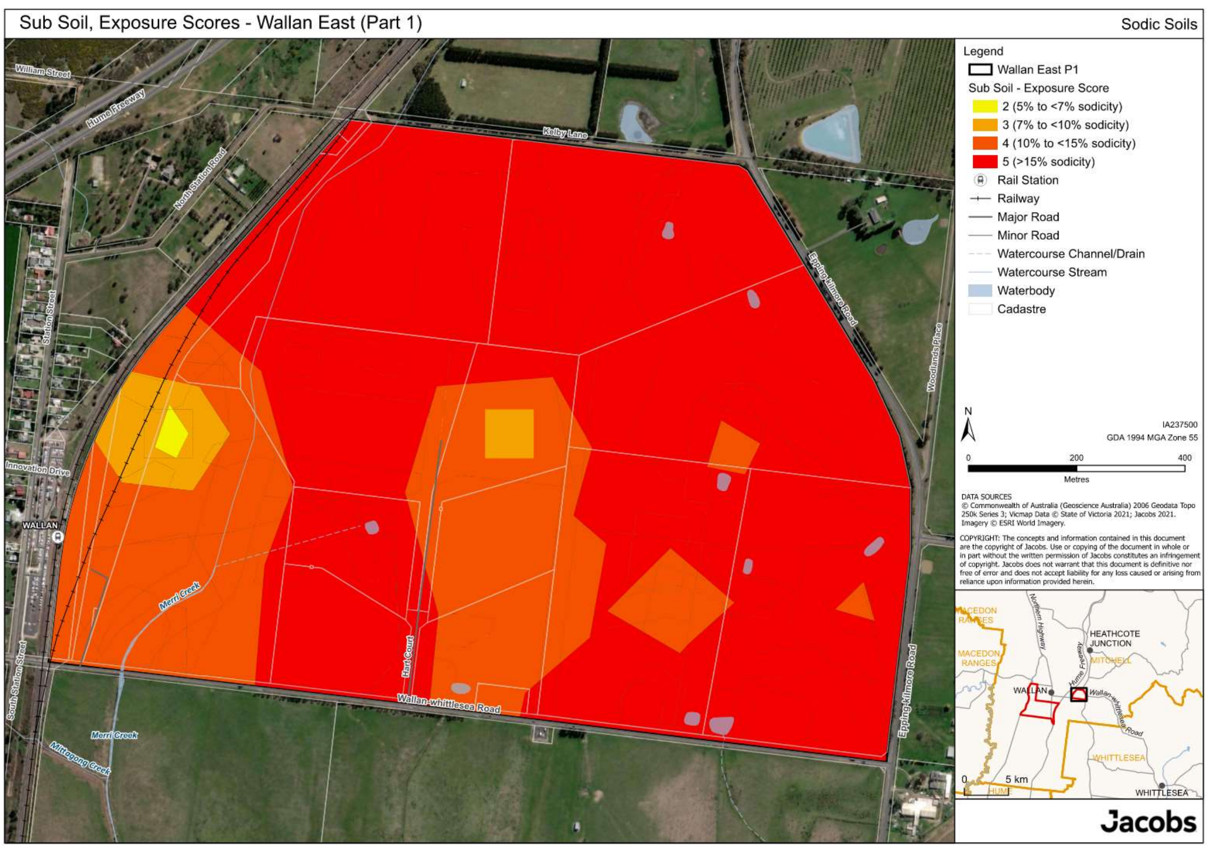


Figure 4.3: Sodicity of subsoil.

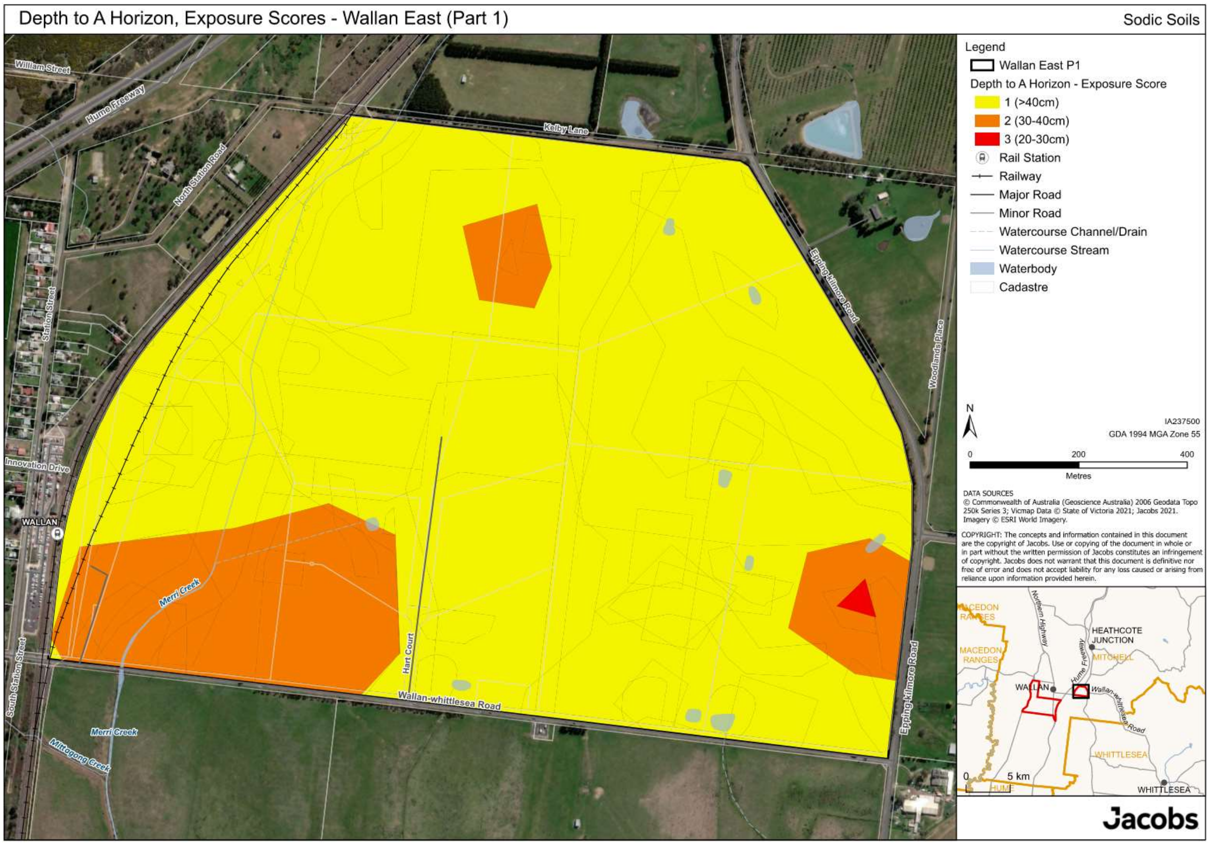


Figure 4.4: A horizon depth.

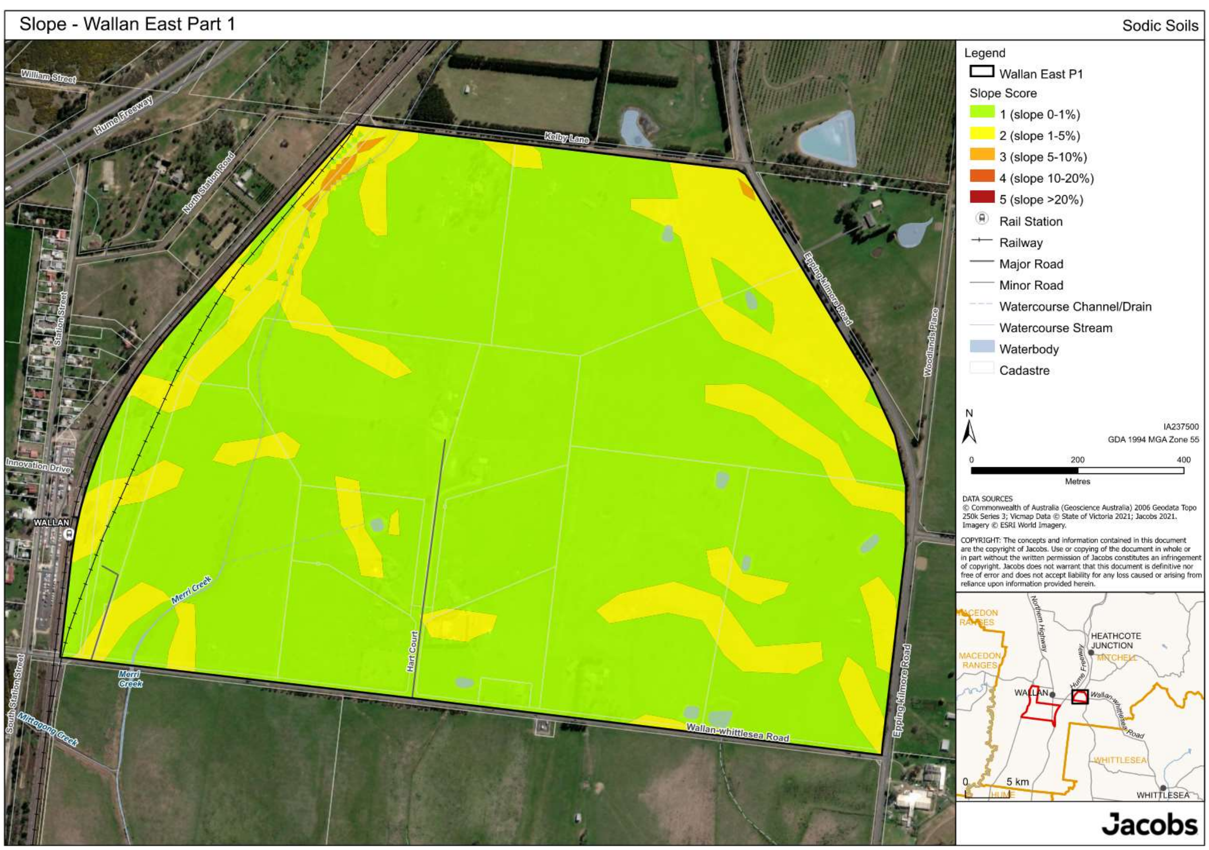


Figure 4.5: Slope.

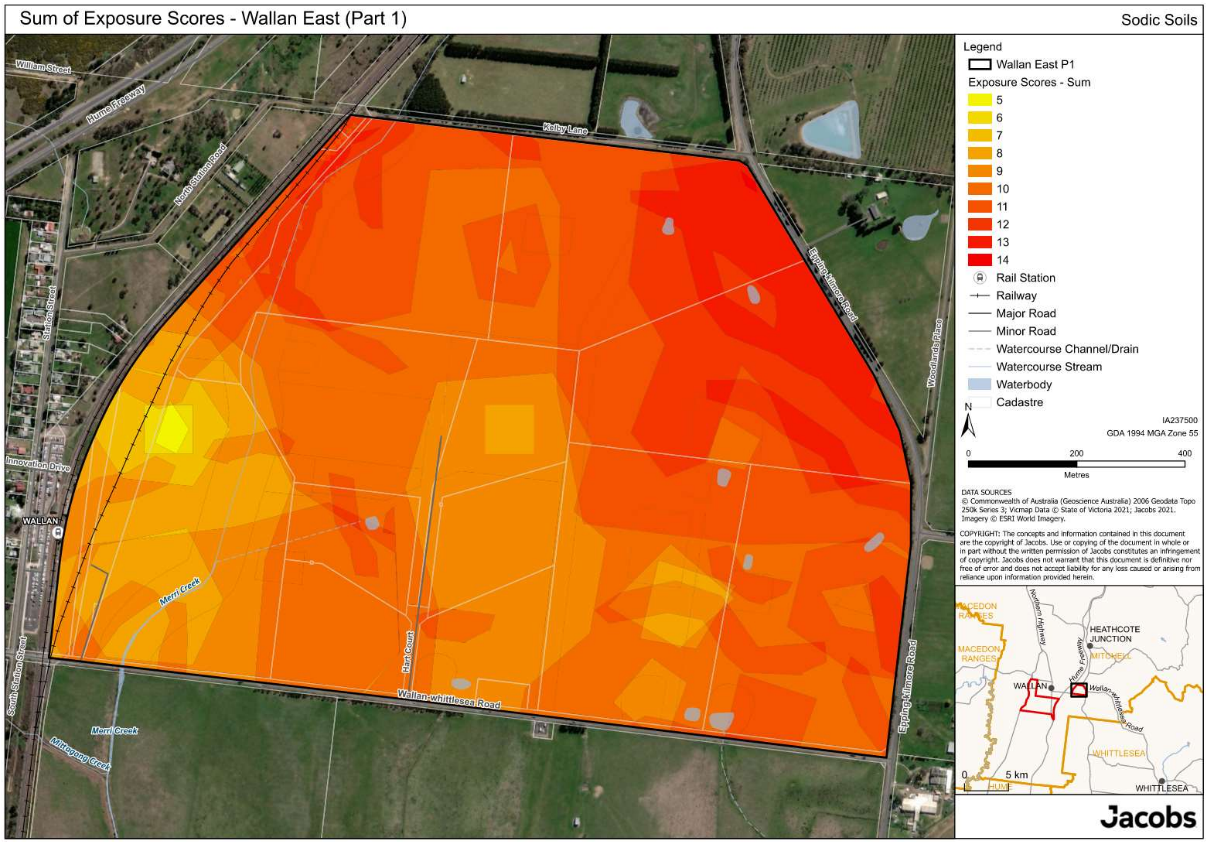


Figure 4.6: Sum of Exposure Criteria.

4.2 Sensitivity of land and urban development to sodic soils

The Future Urban Structure (FUS) dataset has been used as the basis for defining the sensitivity of land and urban development to sodic soils. Waterways are identified as areas that are particularly sensitive to disturbance of sodic soils. The waterway extent across the Precinct is mapped as Drainage in the FUS. These areas score 5, whereas all other areas outside of the waterway extent score 1 (Figure 4.7).

Figure 4.8 and Figure 4.9 present the spatial distribution of sensitivity scores as applied to the FUS dataset for construction activity and water balance change. Construction activities in different land use types are ranked on a scale for sensitivity from minimal disturbance (low sensitivity) to high levels of disturbance (high sensitivity). Areas that are set aside for local park have low levels of development and are scored as minimal disturbance (1), with the level of disturbance increasing with the intensity of development. The majority of the land use sub types are given a score of 4, with Waterways (Retarding Basin/WQT Wetland and Waterway Corridors) experiencing the highest level of disturbance (5). Similarly, in scoring water balance change, open space areas, with the exception of areas with a Drainage LU_TYPE are expected to experience low levels of water balance change (1). Increasing development of land use, will result in development of impervious areas that generate runoff and therefore result in high levels of water balance change (5).

Figure 4.10 and Figure 4.11 present the combined sensitivity scores for the construction and future development scenarios. These show a similar pattern in that Waterways are identified as areas of highest sensitivity. Transport corridors are also identified as areas with high sensitivity in the future urban structure, due to the high water balance change and generation of runoff associated with impervious surfaces in these corridors.

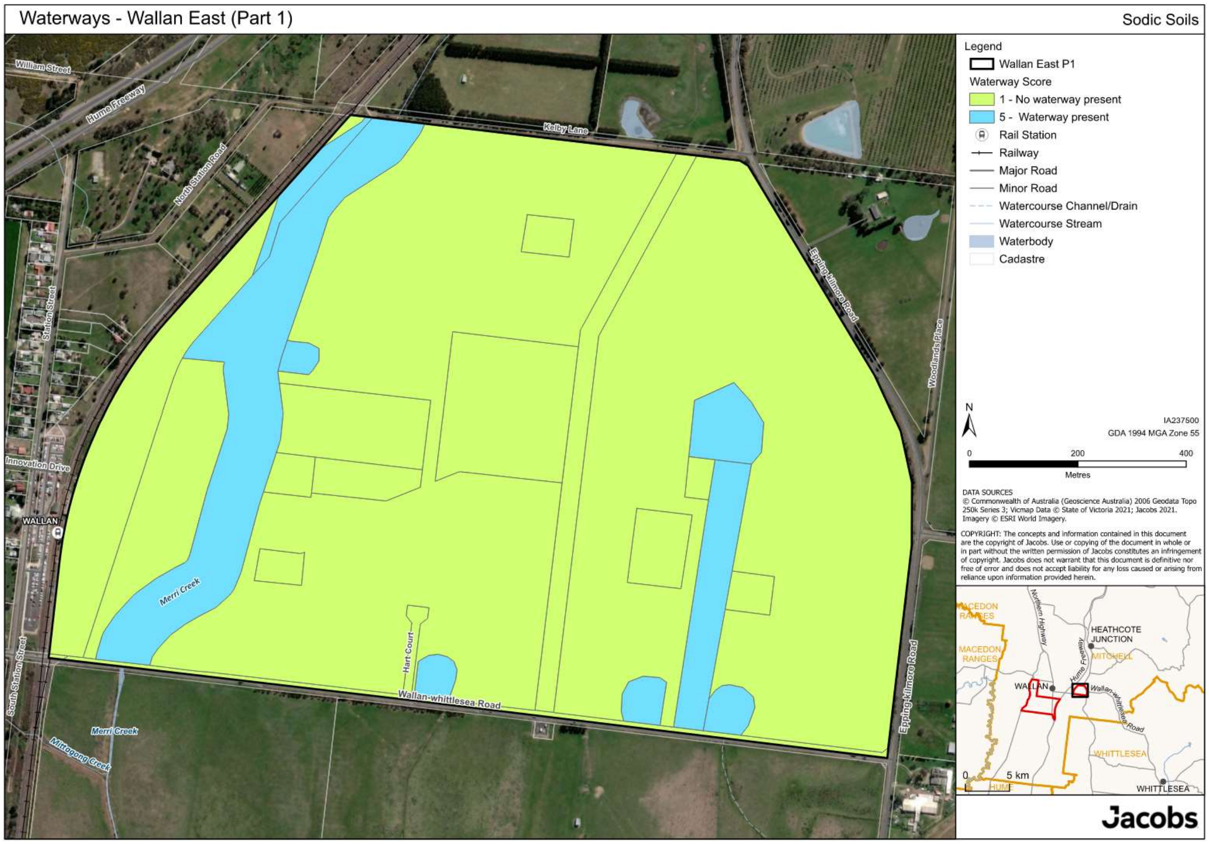


Figure 4.7: Waterway extent as mapped as Drainage in Future Urban Structure (FUS) Dataset.

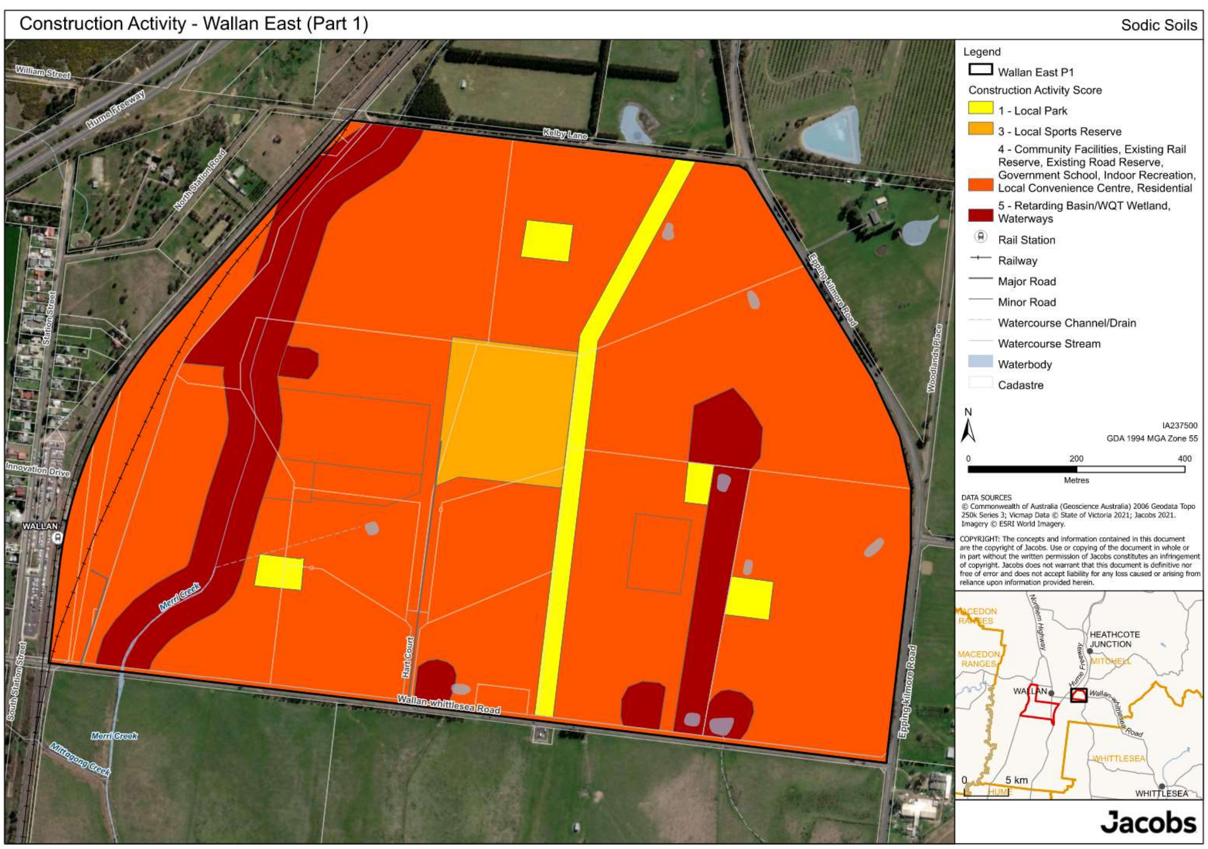


Figure 4.8: Construction activity.

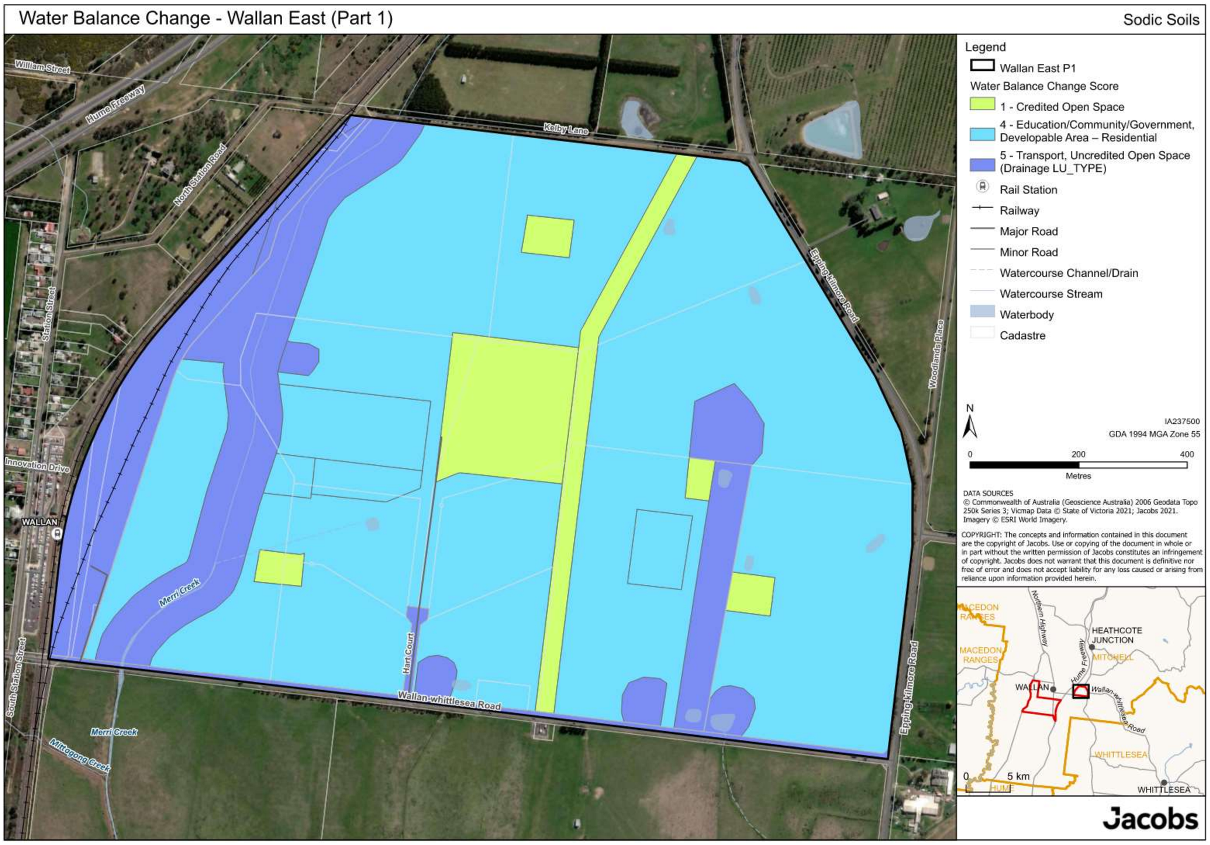


Figure 4.9: Water balance change.

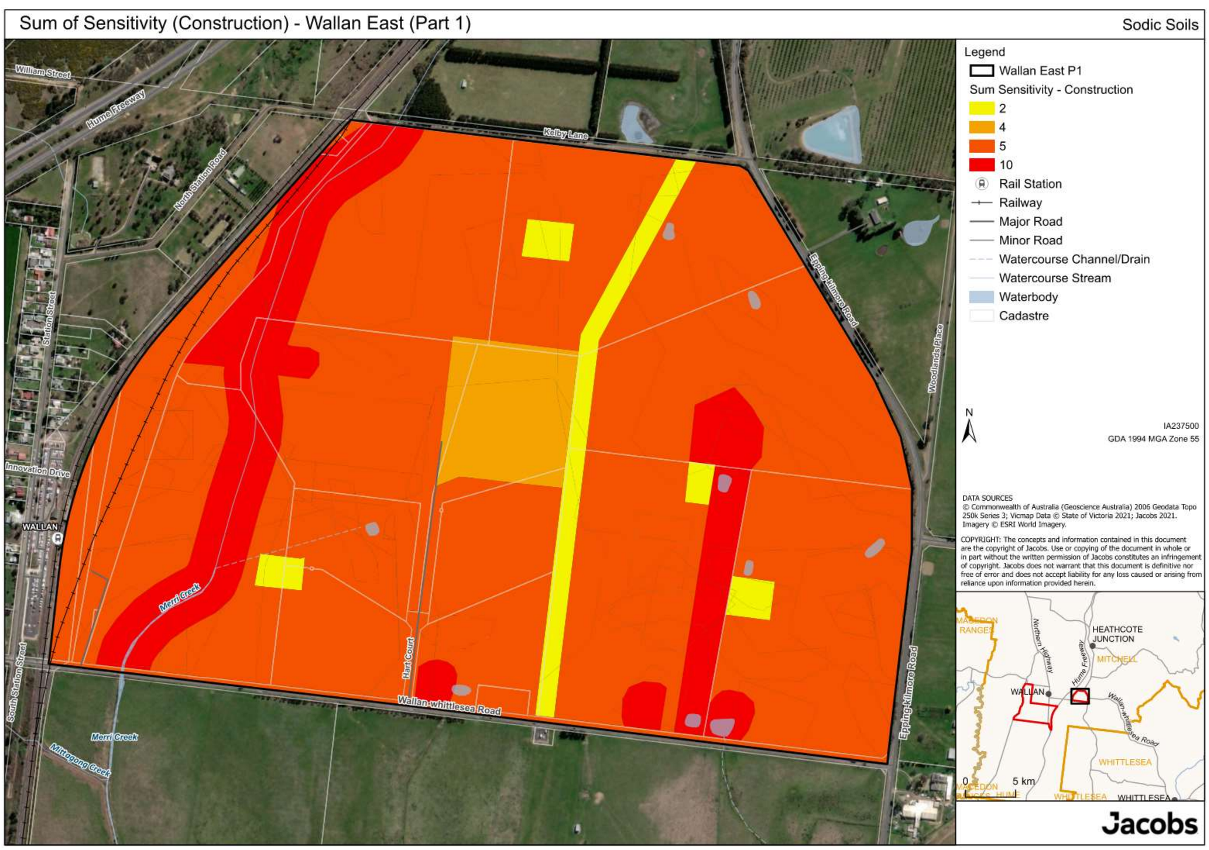


Figure 4.10: Sum of Sensitivity Criteria for Construction.

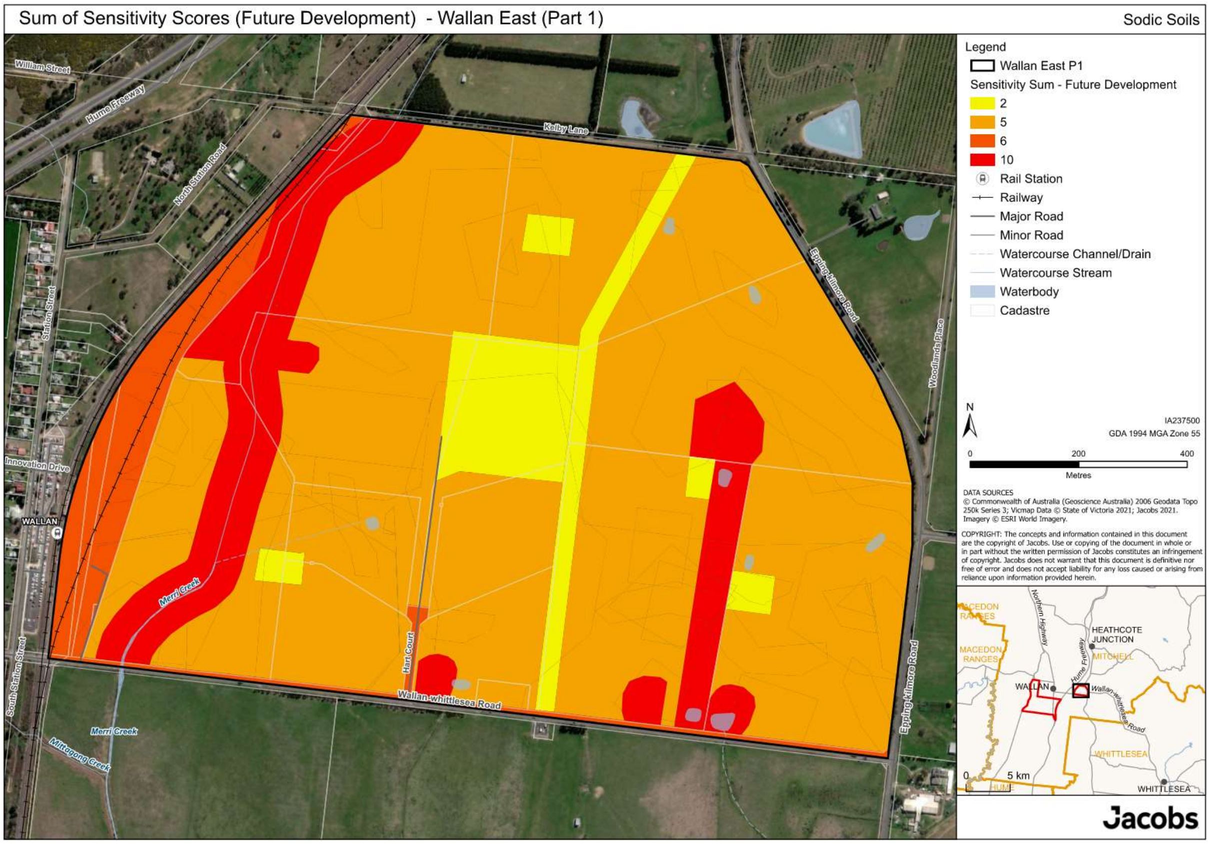


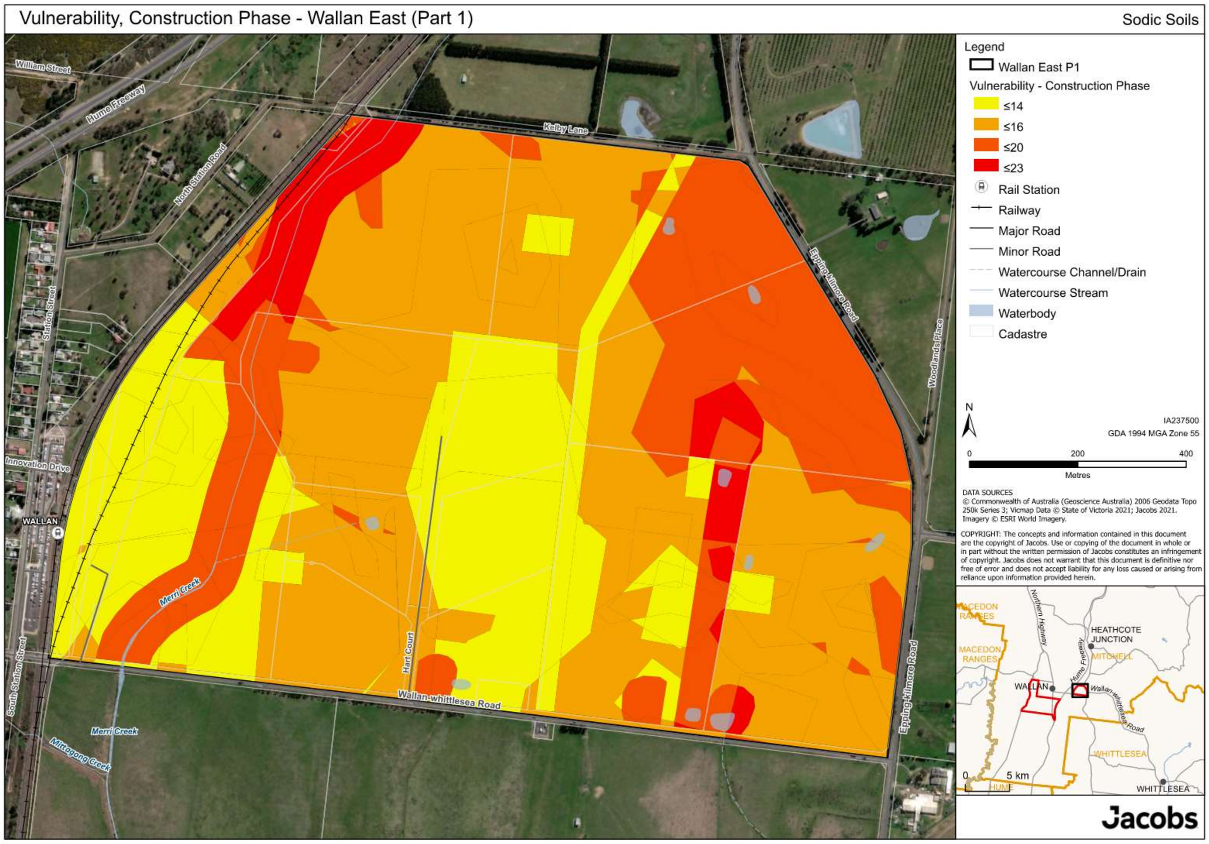
Figure 4.11: Sum of Sensitivity Criteria for Future Urban Structure.

4.3 Vulnerability assessment

The outcomes of the vulnerability assessment for the construction phase and future developed land use scenarios are presented in Figure 4.12 and Figure 4.13.

During construction, areas identified with a high vulnerability to sodic soil erosion are the waterways and areas with high to very high sodicity in topsoils and subsoils (Figure 4.12). Activities that expose these soils to rainfall and associated runoff will present significant construction challenges and need to be managed carefully.

For future developed land use, waterways and areas with high to very high sodicity values in topsoils and subsoils are identified with a high vulnerability to sodic soil erosion (Figure 4.13). Water balance changes resulting from future developed land use and associated impervious areas will generate high volumes of runoff, which will drain into the surrounding waterways, including Merri Creek. This section of the creek has been drained and straightened. Further increases in runoff could accelerate erosion of bed and bank materials.



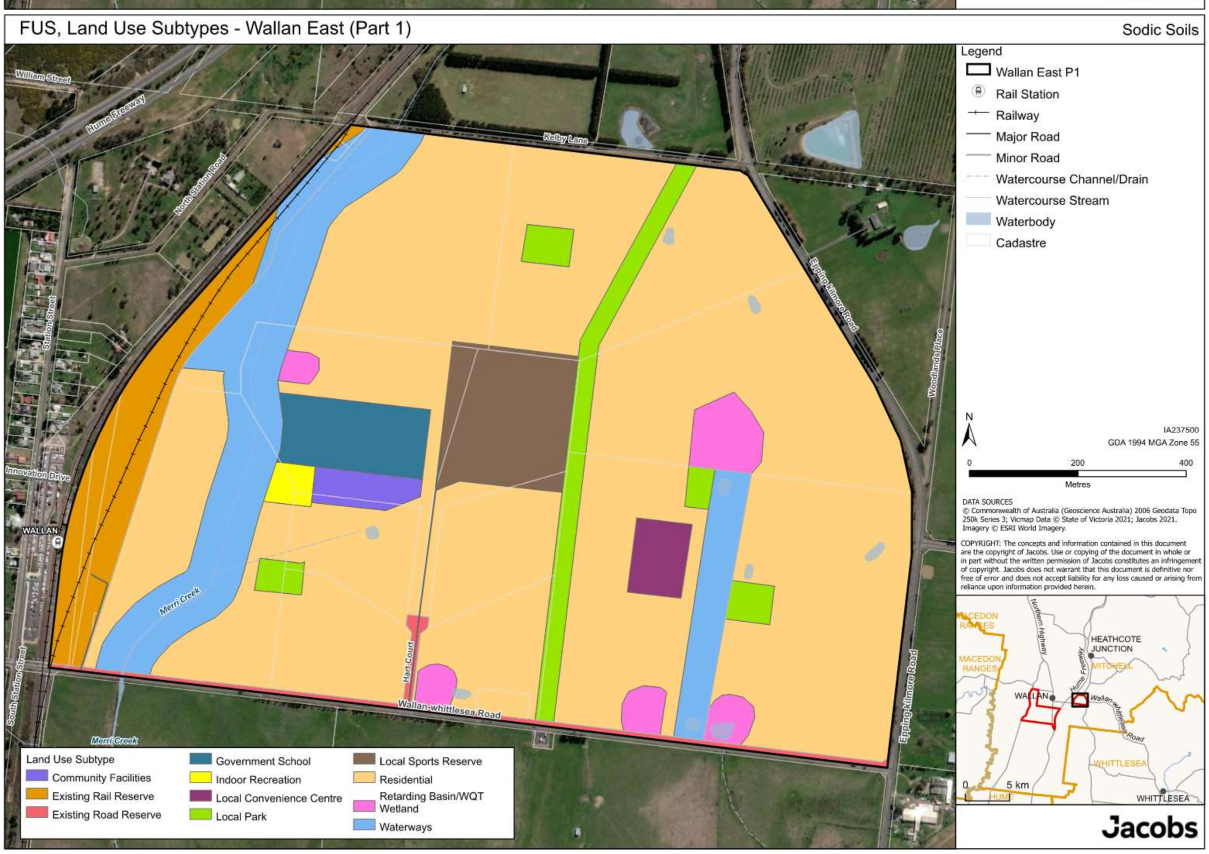
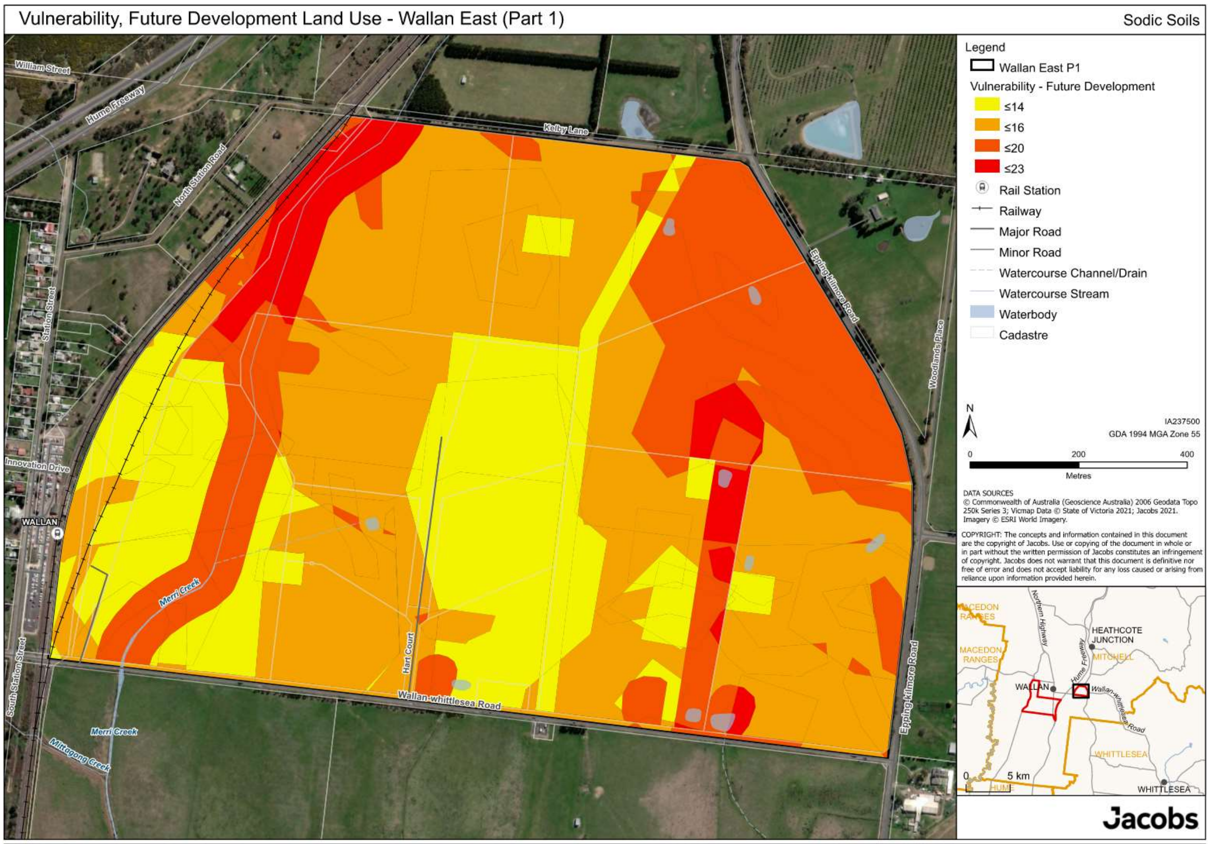


Figure 4.12: Vulnerability Construction Phase (upper). Yellow represents bottom 25% of data (low vulnerability) and red top 25% of data (high vulnerability). Map of Future Land Use Sub Types (below).



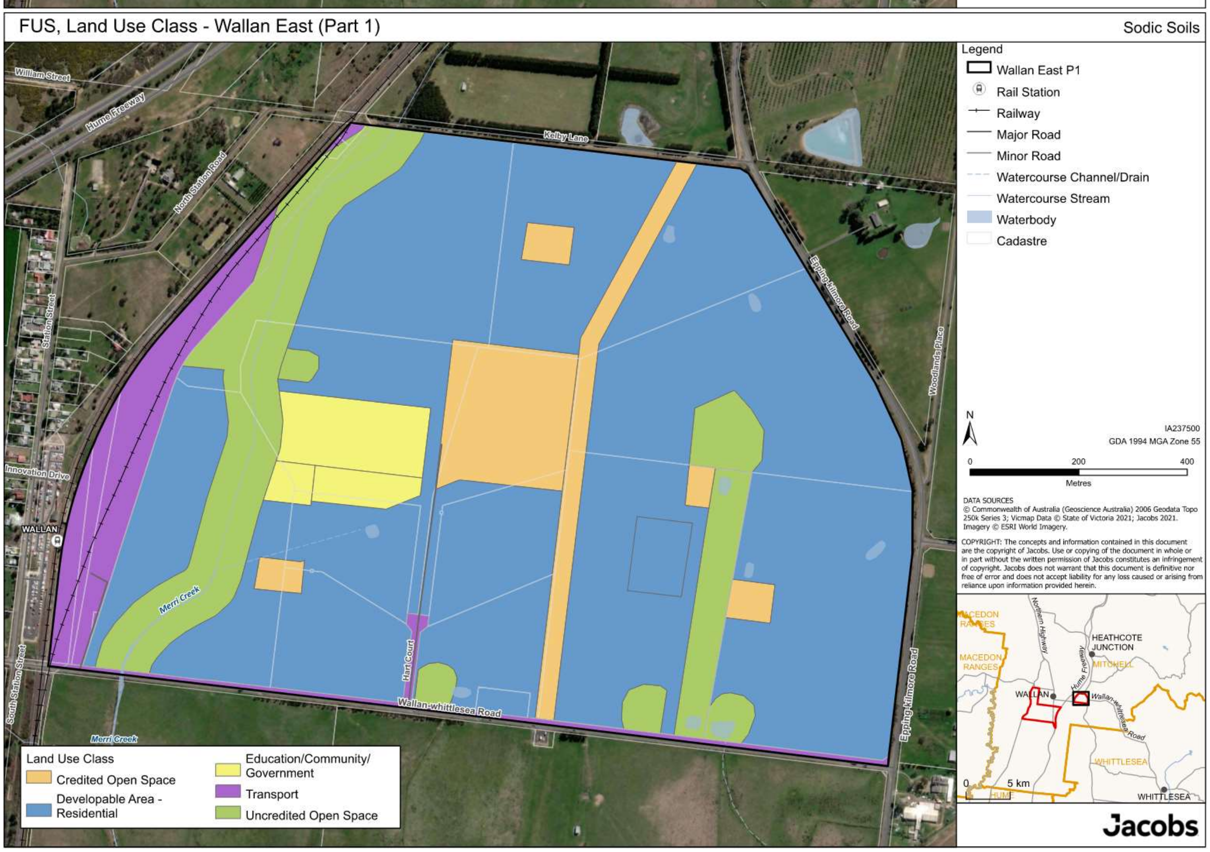


Figure 4.13: Vulnerability Future Developed Land Use (upper). Yellow represents bottom 25% of data (low vulnerability) and red top 25% of data (high vulnerability). Map of Future Land Use Classes (below).

5. Discussion and recommendations

5.1 Erosion risks

Erosion risks are directly influenced by sodic soil exposure and changes in landscape hydrology. Examples of activities that may potentially expose sodic and dispersive soils include disturbance to vegetation and groundcover, removal of topsoil, subsoil excavations (cut and fill), supply of services by trenches and construction of roads and culverts. Changes to hydrology, such as the concentration of flow in culverts, runoff from impervious areas and ponding of rainfall can lead to concentrated, elevated velocity water flow and may also increase erosion risk.

Clay-loam and clay-dominant soil textures were recorded across all of the surveyed areas. Soils with these characteristics evince slow or poor infiltration and permeability. Consequently, when rainfall intensity exceeds the soils' capacity to infiltrate water, or when profiles are at field capacity, rainfall is rejected and becomes subject to accessions by overland flow. Overland flows will entrain sand, silt and clay particles when they are loose and disturbed, when velocity or shear stress of flows exceed thresholds for particle entrainment or where dispersive conditions lead to a deterioration in soil structure, breaking down aggregates and soil particles leaving them liable to erosion. Clay dispersion from fresh rainfall contact with sodic clay may induce sheet or rill erosion on exposed surfaces. This is the primary threat to the quality of stormwater, where turbidity will be high if soils on disturbed areas remain untreated. Turbid water will pond in localised depressions, or enter drainage lines and result in increased turbidity in waterways that drain off-site.

Erosion may also occur in areas of localised groundwater discharge, following recharge of rainfall upslope, seepage on top of clay or rock layers and a soak or discharge point appearing where clay or rock is close to the surface and/or there is break in slope. Erosion risk is potentially compounded by the accumulation of salt in groundwater discharge areas as water is evaporated. This increased erosion risk is typically associated with the break of slope below steeper slopes and was observed across several sample areas.

Erosion issues are also expected to arise along drainage depressions and waterways and may be compounded by historical changes to the physical form of the waterway, such as the removal of vegetation from the landscape and the formation of artificial drains. Initiation of scour in drainage depressions arising from increased runoff, exposure of subsoils and the dispersive nature of these soils require specific management. Future urban development, with clearing and removal of topsoils, trenching and changes to drainage patterns increases the erosion risk. Sand and silt particles are heavy by comparison with suspended clay particles. All will migrate downslope with the flow of water, however sand and silt are likely to fall out of suspension in low-energy detention points, or where erosion control measures are installed. There are high prospects for the capture of sand and silt particles with erosion control measures proposed but not suspended clay particles.

The following areas are identified as areas of high erosion risk:

- **Drainage depressions/seasonal wetlands** – These areas can be broadly classified as headwater streams – small flow lines (swales/wetlands), creeks and streams that are closely linked to adjacent slopes. They may only flow or have ponds of water immediately after rainfall events, however they do play an important role in retaining and temporarily storing water in the landscape (Jacobs 2016). This ability slows down the rate of flow over the land and assists in regulating flows and reducing downstream flood peaks. The infiltration of surface water in headwater streams into the local groundwater system also plays an important role contributing to groundwater levels and maintaining base flows in downstream waterways. In fact, many headwater streams have their source of water as groundwater. If small headwater streams are destroyed because of urbanisation there is likely to be an increase in the number of high flows to downstream reaches. These high flow events can cause bed and bank erosion that significantly degrade community and environmental values (Bond and Cottingham 2008).

Headwater streams make up a significant proportion of the stream network and collect the majority of the runoff and dissolved nutrients from a catchment. Nutrient cycling and retention in headwater streams can significantly reduce nutrient exports to downstream reaches, estuaries and bays. This is because headwater streams provide the ideal mix of shallow depths, high surface-to-volume ratios, water-sediment exchange and biotic communities required for nutrient cycling (Peterson et al. 2001). If the nutrient processing capacity of headwater streams is diminished (for example through changed flows or the clearing of riparian vegetation), or lost altogether (e.g. through drainage and urbanisation), then more nutrients are delivered to downstream reaches (Jacobs 2016). With urban development, many headwater streams are converted into stormwater drains and these modified drainage courses become a key driver in the degradation of downstream reaches (SKM 2013).

- **Merri Creek** – The section of the creek within the Precinct Area has been drained and straightened. It has the characteristics of a constructed waterway. Further increases in runoff from urban development may result in increased erosion.

5.2 Planning measures

Erosion risks associated with sodic and dispersive soils can be managed by appropriate planning. This report concurs with the planning requirements and guidelines documented in the Beveridge North West and Shenstone Park Precinct Structure plans that relate to Integrated Water Management (Victorian Planning Authority 2019, Victorian Planning Authority 2019). These are reproduced in Table 5.1.

Table 5.1: Integrated Water Management Requirements and Guidelines (Victorian Planning Authority 2019, Victorian Planning Authority 2019).

Requirements
Stormwater conveyance and treatment must be designed in accordance with the relevant Development Services Scheme unless otherwise agreed by Melbourne Water and the responsible authority.
Final designs and boundaries of constructed wetlands, retarding basins, stormwater quality treatment infrastructure, and associated paths, boardwalks, bridges, and planting, must be to the satisfaction of both the responsible authority and Melbourne Water.
Development staging must provide for the delivery of ultimate waterway and drainage infrastructure, including stormwater quality treatment. Where this is not possible, development proposals must demonstrate how any interim solution adequately manages and treats stormwater generated from the development and how this will enable delivery of an ultimate drainage solution, to the satisfaction of Melbourne Water and the responsible authority.
Stormwater runoff from the development must meet the performance objectives of the CSIRO Best Practice Environmental Management Guidelines for Urban Stormwater prior to discharge to receiving waterways, unless otherwise approved by Melbourne Water and the responsible authority. Proposals that exceed the performance objectives will be considered to the satisfaction of the relevant authority.
Applications must demonstrate how: ▪ Waterways and integrated water management design enables land to be used for multiple recreation and environmental purposes. ▪ Overland flow paths and piping within road reserves will be connected and integrated across property/parcel boundaries. ▪ Melbourne Water and the responsible authority freeboard requirements for overland flow paths will be adequately contained within the road reserves.
Guidelines
Relevant Integrated Water Management (IWM) requirements of this PSP will be achieved to the satisfaction of the retail water authority, including the supply of recycled water where required by the relevant water authority.
The design and layout of roads, road reserves, and public open space should optimise water use efficiency and long-term viability of vegetation and public uses through the use of overland flow paths, Water Sensitive Urban Design initiatives such as street swales, rain gardens and/or locally treated storm water for irrigation to contribute to a sustainable and green urban environment.
Where practical, and where primary waterway or conservation functions are not adversely affected, land required for integrated water management initiatives should be integrated with the precinct open space and recreation system.

The Wallan East (Part1) Precinct Area is located in one of the Stormwater Priority Areas identified in the 2018 Healthy Waterways Strategy (Melbourne Water 2018, Melbourne Water 2018). One of the specific target objectives that have been set for this area is to constrain directly connected imperviousness (DCI)[3] levels to <2% and this will require undertaking significant harvesting and infiltration of stormwater. No Development Services Scheme (DSS) currently exists for Wallan East (Part 1). It is recommended that when the DSS is developed it includes provision for stormwater harvesting or for protection of existing drainage depressions/wetlands and waterways. It is recommended that further work is undertaken to align the DSS with Best Practice as summarised by the following references:

- *Urban Water: Best Practice Environmental Management Guidelines* (CSIRO 1999) states that stormwater management should be based on the principles of preservation, source and structural controls:
  - **Preservation**: preserve existing valuable elements of the stormwater system, such as natural channels, wetlands and stream-side vegetation;
  - **Source control**: limit changes to the quantity and quality of stormwater at or near the source; and
  - **Structural control**: use structural measures, such as treatment techniques or detention basins, to improve water quality and control streamflow discharges.

  These principles should be applied as part of an ordered framework to achieve environmental objectives as described in Figure 5.1.
- "Best practice planning for urban development requires that the catchment's hydrologic response is maintained as close as practicable to pre-development conditions. Appropriately conceived and designed water management infrastructure can achieve this outcome" (Melbourne Water 2009).
- Following on from this, it is now understood that maintaining ecologically and geomorphically important flow metrics close to their natural values requires preventing almost all the additional surface runoff generated by urbanisation from entering waterways (Duncan et al. 2016).

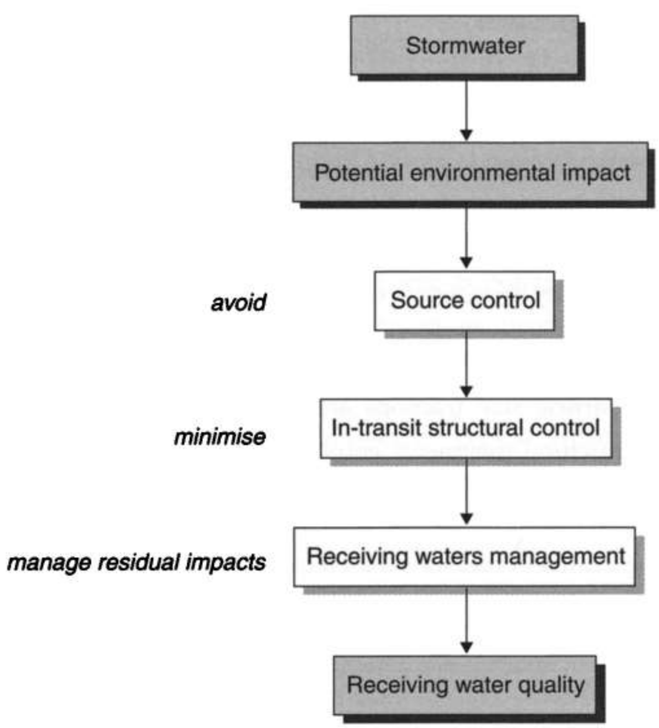


Figure 5.1: Stormwater management framework (CSIRO 1999).

[3] The proportion of impervious area within a catchment that is directly connected to a stream via the stormwater drainage system

It is recommended that Melbourne Water undertake further work on the DSS in light of the planned development in Wallan East (Part 1) PSP. This should consider the existing form of the waterways and how these may be protected or modified in future land developments. One design concept that Jacobs (2019) have previously recommended is that of distributed seasonal wetlands and swales that provides some stormwater treatment and flow conveyance. Further details of this design concept are provided here:

- Configuration - A series of seasonal wetlands positioned along and across the width of the waterway corridor, which are connected by a low-flow channel or series of low-flow channels (rocky/grassed swales).
- Hydraulic behaviour – Seasonal wetland and channel features extend across the width of the waterway corridor. Widening of features within the corridor and reduction of overall gradient will assist in lowering boundary shear stresses[4]. Low-flow channel(s) convey and spill water into wetland areas.
- How surface treatments may vary – Treatment of sodic soils with chemical and physical ameliorants will be required throughout, but it is expected that treatments will vary. For example, within the body and margins of a wetland, gypsum treatment, geotextile barrier, minimal topsoil and revegetation may be sufficient. More extensive rock treatment may be required in areas of high boundary shear stress (along low-flow channels and where water spills into wetland). Less rock treatment may be required within the body and margins of wetland where water ponds and boundary shear stresses are lower.

Figure 5.2 is a schematic to help illustrate the design concept and show how the wetland and swale/low-flow channel would be distributed and connect along the waterway corridor. Further detail in relation to the sizing and configuration of wetlands and low-flow channel(s) in the waterway corridor and how surface treatments (chemical amelioration, physical armouring/protecting) may vary would need to be worked through as part of the design process. It is expected that the hydraulic aspects of the design will require a number of iterations, varying the longitudinal grade and cross-sectional grades so as to distribute flow within the system of low-flow channels and seasonal wetlands, minimising bed shear stresses whilst also providing the required conveyance along the waterway corridor.

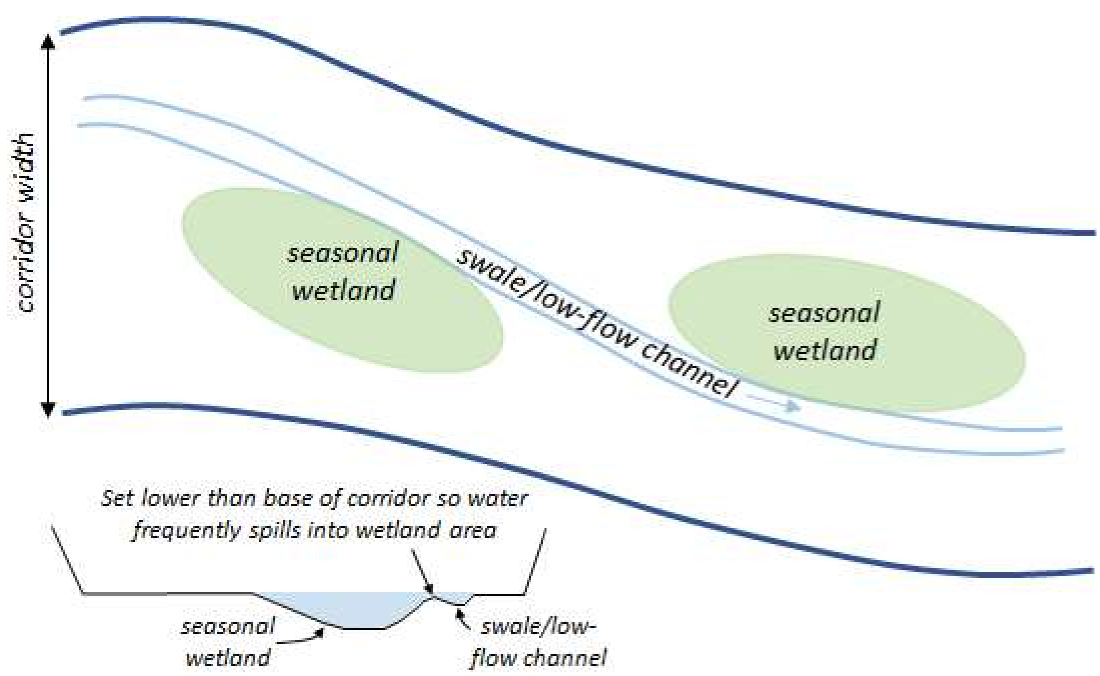


Figure 5.2: Schematic of distributed seasonal wetlands and swale/low flow channel (Jacobs 2019).

[4] Refers to the hydraulic forces acting on the channel bed, often used as a criteria to assess potential for erosion and sediment transport

Careful design and construction of swale and wetland features, with particular attention to the formation of a protective layer on top of sodic soils will be required to provide a stable waterway corridor. In the case of Merrifield Central Waterway, this concept is considered to provide better outcomes as it more closely aligns with the characteristics and functioning of the existing waterway as a headwater stream, which is a broad depression/seasonal wetland that periodically hold water following rainfall events. Similar design concepts may also be applicable to the waterway corridors in the Wallan East (Part 1) Precinct Area. Jacobs, Spiire and South East Soil and Water are also currently completing a project for Melbourne Water to redesign scheme water treatment assets in the Kalkallo Retarding Basin to cater for the sodic and dispersive soils within the catchment and the basin itself. The outcomes of this work will also be relevant for the future design of stormwater assets in the Wallan East (Part 1) PSP.

Wherever construction is proposed, it is critical that on-site management includes measures that provide for protection and treatment of sodic and dispersive soils to limit the potential for erosion and generation of turbid water. Turbid water from construction areas also needs to be treated on site, as once clays are in suspension and turbid water runs off into waterways, it is very difficult to remove this from the water. Vegetated swales and wetlands along waterways will assist with stormwater treatment and entrapment of silt and sand fractions, but are unlikely to be effective in removing dispersed clay from suspension. Treatment of water collected in sedimentation basins within the construction site may be required to remove suspended clays from water, prior to discharge of water into waterways. Water collected in sedimentation basins may be treated with a flocculant and involve the use of cyclones to improve water quality, prior to entering waterways.

5.3 Treatment options

5.3.1 Areas with high vulnerability to sodic soil erosion risks

For areas identified with a high vulnerability to sodic soil erosion risks, treatment options include:

- **Drainage depressions/seasonal wetlands** – Ideally these areas should be identified and reserved as linear green spaces to maintain their important hydrological function in retaining and temporarily storing water in the landscape and regulating the flow of water and nutrients throughout a catchment. Ecosystem services provided by these landscape features include reducing flood peaks, supporting infiltration to groundwater, maintaining base flows and reducing downstream export of nutrient and sediment to receiving waters (Jacobs 2016, Walsh et al. 2016). Surface ground cover measures, specifically managing organic matter including ground cover, plant growth and roots are critical for protecting the soils against dispersion and erosion.
- **Merri Creek** – Further increases in runoff from urban development could increase erosion. Engineering works may be required to stabilise this waterway so that is resilient to stormwater runoff from future land development (chemical and physical amelioration of sodic and dispersive soils, construction of grade-control structures, geosynthetic clay liners / rock treatment of low-flow channels and where water spills into wetlands).

5.3.2 Design and planning for construction of future drainage schemes

The drainage schemes for the waterways, in particular Merri Creek need to be designed with specific consideration to the erosion risks associated with sodic and dispersive soils. A high level of engineering will be required to create waterway corridors that are stable and can withstand the volume of water that will be generated from the developed areas. It is expected that all of the waterways will need to have a constructed form, with appropriate channel linings and/or armouring to provide protection for dispersive subsoils. Where possible, it is recommended that the waterway corridor includes distributed wetland and swales, to assist with attenuation and treatment of stormwater runoff.

It is recommended that further consideration is given to staging construction works, to manage erosion risks. In principle, it is better to work from top of catchment/higher areas in the landscape first and then progressively work downstream, but this may not be practical. Disturbances to high risk areas should be minimised, if not totally avoided, especially during the most erosive periods of the year (wetter months). The development sequence should allow the installation of temporary drainage and erosion control measures, and preferably a permanent stormwater drainage system as soon as practicable. As waterways are a high risk, if possible, commence with the construction of drainage services schemes so that waterway corridors are resilient to changes in hydrology with the future developed land use.

The stormwater drainage requirements of a site to be developed within the Precinct Area also needs to be appropriately incorporated into all stages of construction. This will require the development of temporary drainage control measures, separate to the sites' permanent drainage system. This will need to recognise the requirements and provide an appropriate drainage design for the diversion of up-slope "clean" water as opposed to the delivery of sediment-laden water generated within the construction site to sedimentation ponds. Appropriate hydrologic and hydraulic design is needed to size the drainage control measures for both the temporary and permanent drainage system (IECA 2008).

Runoff from construction sites should be managed by temporary drainage and sedimentation ponds, with the aim that it does not enter the waterway corridor until development is near completion. Harvesting of stormwater in appropriately designed sedimentation ponds within each development area, then dosing these with flocculants to drop out clay and improve water clarity before releasing downstream is recommended. Runoff dams can be designed and managed to capture runoff events, with immediate dosing and release in the days following collection. Consideration should also be given to the use of cyclones and appropriately designed sedimentation ponds and/or cascading v-notch weir type arrangement from inlets to outfalls so that clays and fine sediments are caught. These would require maintenance to remove captured sediments.

5.3.3 Management options during construction

A range of technical guidelines and manuals are available which provide advice on options for reducing the risk of soil erosion during construction arising from development works on dispersive soils (SCA 1979, DPIW 2008, Witheridge 2012, ICC 2016). Management options start with preservation and treatment of topsoil, with options variable depending on the level of disturbance (Table 5.2).

Table 5.2: Management options for reducing risk of erosion during construction for sodic and dispersive soils.

Management options	
Preservation and treatment of topsoil	▪ Preservation of A-horizon topsoil should be used to shroud sodic and dispersive subsoil in all areas across the precinct. ▪ Topsoils with clay-loam textures have a greater resilience to erosion by comparison with finer textured clay-dominant subsoils. Topsoils are also easier to stabilise from dispersion and erosion. ▪ Gypsum treatment of all topsoils to minimise dispersion of any clay within topsoil or subsoil. Gypsum treatment of topsoil is a simple, fast and cost-effective solution that can be applied without use of specialised equipment.
Undisturbed sites	▪ Maintenance of topsoil across undisturbed land, preferably with grasses to provide surface soil stability and root anchorage. ▪ Maintenance of tree cover where trees exist. ▪ Groundcover including a mix of perennial grasses and larger shrubs and overstory vegetation is critical for slowing down overland flow and providing root anchorage of soil.
Disturbed sites – large scale surface disturbance	▪ Minimise the amount of time land is exposed (e.g. by staging development). ▪ Apply gypsum to all topsoils for improved stability. ▪ Avoiding removal or disturbance to topsoil or vegetation until absolutely necessary. ▪ Covering dispersive subsoils with a shroud of stabilised topsoil (100-150mm), should works cease for any period of time or prolonged rainfall is forecast. ▪ Consider using appropriately specified geotextile barriers and other engineering measures to protect disturbed areas particularly where there is minimal topsoil, or where steep slopes occur. ▪ Re-vegetate exposed areas immediately after completion of earthworks, with specific emphasis on steep slopes.

Management options	
	▪ Avoid construction techniques that result in exposure of dispersive subsoils. ▪ Use alternatives to 'cut and fill' construction such as pier and pile foundations. ▪ Use of interception trenches stabilised with topsoil to catch runoff in a controlled fashion and divert flow to sedimentation ponds to capture sediments. ▪ Use of organic materials on finished surfaces to soften the impact of rainfall, filter runoff and aid the germination of seed or growth of turf. ▪ Use of agricultural fertilisers at sound agronomic rates to expedite the process of vegetation establishment.
Disturbed sites – Trenching, culverts and drains	▪ Where possible avoid the use of trenches for the construction of services i.e. water & power. ▪ Limit extents of trench open at any one time. Material stockpiles from trenching, particularly dispersive soils, to be covered temporarily as required. ▪ Ensure that trench backfill is properly compacted, treat with hydrated lime (subsurface treatment) and gypsum (topsoils) to limit dispersion and erosion. ▪ Consider alternative trenching techniques that do not expose dispersive subsoils. i.e. use of trenchless technology installations of utilities/services such as horizontal directional drilling. ▪ Ensure runoff from hardstand areas is not discharged into areas with dispersive soils. ▪ If necessary, create safe areas for discharge of runoff. ▪ If possible do not excavate culverts and drains in dispersive soils. ▪ Following engineered design, consider placement of non-sodic soil to create appropriate road surfaces and drains without the need for excavation. ▪ Ensure that culverts and drains excavated into dispersive subsoils are capped with non-dispersive topsoil, gypsum stabilised and vegetated.

The management of water flows over and through dispersive soils is a key tool in control of detrimental effects. Approaches may include:

- Diversion of water flows away from these materials. This is not always possible due to their extensive distribution within the PSP.
- Minimising potential convergence and/or ponding of surface flows, particularly on disturbed soils;
- Development of appropriate cover/protection of dispersive soils (i.e. creation of stable linings that a resistant to rainfall and runoff);
- Compacting to reduce pore spaces and minimise water movement through the material. This will reduce the potential for soil dispersion and piping developing, however it will promote overland flow. For road formation levels and any other areas stripped or in shallow excavations (culverts, utility ducts) consideration should be given to running plant over the surface a number of times or placing engineered fill. In the case of utility trenches, backfill material should be at least the same density as the material surrounding to minimise ponding, infiltration, leaching within the trench and around the ducting/piping;
- The use of concave batter slopes without benching or contour banks has been shown to reduce the potential for convergence of water flows and to minimise flow velocities leading to gullying. However, it should be borne in mind that building extensive bank systems on dispersive soils can be problematic, as it may lead to surface erosion and tunnelling/piping potential; and
- Reducing the potential for undercut and piping failures for proposed road formations could be achieved by excavating interception trenches below and parallel with both sides of the formations. If these trenches are to carry large flows, then the use of agricultural pipes with appropriate granular backfill would be appropriate, and where low flows are anticipated then the use of use appropriate granular porous backfill to the trench may be relevant. It may also be appropriate to line the trenches with impervious materials.

Soil chemical ameliorants are recommended for short-term stabilisation of dispersive soils on construction sites. Three primary soil chemical ameliorants and their uses for stabilising dispersive soils on construction sites are:

- Gypsum ($CaSO_4$), primarily for stabilising dispersive topsoil or subsoil not intended for construction or geotechnical use. Gypsum flocculates soil and increases soil permeability, rendering materials less favourable for compaction and geotechnical use. Gypsum significantly reduces dispersion of clay and turbidity of runoff.
- Hydrated Lime ($Ca(OH)_2$). When slaked in water, hydrated lime stabilises soil cations by supply of calcium (reducing or eliminating dispersion and sodicity) and increases soil strength. Hydrated lime is the favoured soil chemical ameliorant for stabilisation of soils in civil and geotechnical works such as around pipes, structures, roads, trenches and any works requiring compaction upon reinstatement.
- Agricultural Lime ($CaCO_3$). Standard agricultural lime will provide minor soil stability however the solubility is low and immediate response is poor. Where topsoils are acidic (pH water average 5.77) agricultural lime could be used to support improving plant growing conditions by adjustment of soil pH. However, the effect on soil stability is expected to be low or negligible in the short term by comparison with gypsum. Agricultural lime will be a critical ameliorant in the reuse of topsoil across recreational and environmental areas upon completion of works, where soils are acidic and an improvement in soil health and plant growth is sought with the application of agricultural lime.

Where strongly duplex soils exist, management and amelioration of lighter-textured topsoil is normally favoured because it provides a source of cover and protection of dispersive subsoil. Lighter textured topsoils are also easier to ameliorate by comparison with clay loams and clays. As organic matter plays a significant role in maintaining soil structure and providing some resilience to dispersion and erosion, careful management of any available topsoil is imperative. Staging of earthworks to minimise disturbance of soils and immediate gypsum treatment is recommended to reduce potential dispersion of clay with rainfall and runoff events.

Table 5.3 provides calculated rates of gypsum to minimise or eliminate dispersion based on the analysis of soils across the precinct. These rates are a guide only and should be further refined with the development of sodic soil management plans at an individual subdivision level.

Table 5.3: Calculated rates of gypsum to minimise or eliminate dispersion for soils in the Wallan East (Part 1) Precinct.

Gypsum treatment	Topsoil (0-10cm)	Subsoil (30-40cm)	Deeper subsoil (>40cm)
Full gypsum rate to displace exc. Na, Mg and K to optimum levels (t/Ha/100mm).	4.04 0.40% w/v.	7.52 0.75% w/v.	17.92 1.79%w/v.
Gypsum rate to displace exc. Na to below 5% (t/Ha/100mm).	0.56	1.79	5.87
Gypsum rate to displace exc. Mg to below 15%.	3.48	5.74	12.05
Gypsum rate to displace exc. K to below 5% (t/Ha/100mm).	0.29	0.00	0.00

Soil physical ameliorants are recommended for long-term structural stability of soils. Their effectiveness varies, depending on the nature of the ameliorant and how effective it is for protecting dispersive soils from direct contact with fresh water and erosion, or slowing down water flow. Examples of soil physical ameliorants and options include:

- Geotextile fabrics and mattings that provide sodic soil protection, shrouding and assist with plant establishment.
- Organic matter. Used as a protective shroud on topsoils, improving soil physical structure and biological condition. Hydro-mulching is a form of stabilisation using organic matter. Organic matter is not suitable

for stabilisation of soils for civil or geotechnical works unless it is a final layer of protection used for shrouding.

- Direct seeding of sites to fast-growing species by seed drills, spreader trucks or aerial seeding. This option will not necessarily reduce sodicity and dispersion.

6. Knowledge gaps and recommendations for further investigations

6.1 Knowledge gaps

The spatial assessment undertaken in this investigation broadly considers surface erosion potential, however subsurface seepage and tunnel erosion processes are difficult to assess with the data currently available. Processes of recharge and discharge are not well understood across the precinct area and are not represented in the spatial assessment. An assessment of the potential for subsurface seepage and tunnel erosion impacts should be considered as early as possible in the planning stages to assess their associated risks, avoidance/elimination or the scope and cost of appropriate preventative measures.

This assessment has focused on sodic and dispersive characteristic of soils as they relate to erosion risks. Some of the soils assessed may experience significant shrinking and swelling, resulting from drying and wetting. This often results in the development of features such as surface cracking and gilgai formation. These features are of significant importance for engineering purposes and controls against the adverse impacts of these soils character will be important if there is to be proposed development (pavement, shallow foundations, subsurface utilities etc). The controls to manage the effects of reactive soils may differ to those applicable to sodic, erosive soils. As for sodicity, it is recommended that the potential adverse effects of reactive soils on proposed developments should also be considered as early as possible in the planning stages to assess their associated risks, avoidance/elimination or the scope and cost of appropriate preventative measures.

6.2 Recommendations for further investigations

It is recommended that detailed Site Environment Management Plans (SEMPs) and Erosion and Sediment Control Plans (ESCPs) are developed for managing sodic soil related erosion risks. These plans would be developed during the planning of building projects within the Precinct Area. This should include consideration of staging of development from initial bulk earthworks down to the construction of individual lots. It is expected that further sampling of soils, testing and analysis of the sodicity of soils, dispersion and erosion potential will be required at a higher resolution to inform construction techniques and management of erosion risks.

It is recommended at a minimum that sodic soil management plans are a requirement at a subdivision / zone level with reference to a set of requirements or practices that need to be applied at an individual block level. The subdivision level needs to be a detailed investigation with a report that covers all aspects of the subdivision, works to occur and management techniques to manage sodic and dispersive soil and erosion. The individual block level could simply be a set of requirements set by local council that ensure good soil management practices are mandated and sodic soil exposure and disturbances are minimised, with disturbed areas treated or shrouded where possible.

7. References

Agriculture Victoria (2020). "Sodicity - Upper Subsoil." from http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_soil-sodicity.

Armstrong, R. (2019). "Do you have dispersive soil? Do this test to find out'." from https://communities.grdc.com.au/crop-nutrition/dispersive-soil-test-find/.

Bond, N. and P. Cottingham (2008). "Ecology and hydrology of temporary streams: implications for sustainable water management: eWater Technical Report.".

Charman, P. E. V. and B. W. Murphy (2007). Soils : their properties and management, South Melbourne, Vic. : Oxford University Press, c2007.

CSIRO (1999). Urban Stormwater: Best Practice Environmental Management Guidelines, Prepared for the Stormwater Committee with assistance from Environmental Protection Authority, Melbourne Water Corporation, Department of Natural Resources and Environment and Muncipal Associaion of Victoria.

Dang, A., et al. (2018). "Evaluating dispersive potential to identify the threshold electrolyte concentration in non-dispersive soils." Soil Research **56**(6): 549-559.

DPIW (2008). Dispersive Soils and Their Management: Technical Reference Manual, Department of Primary Industries and Water.

Duncan, H. P., et al. (2016). The feasibility of maintaining ecologically and geomorphically important elements of the natural flow regime in the context of a superabundance of flow: Stage 2 - McMahons Creek Study, Melbourne Waterway Research-Practice Partnership Technical Report.

Ford, G. W., et al. (1993). "Soil sodicity in Victoria." Australian Journal of Soil Research **31**(6): 869-909.

ICC (2016). Implementation Guide No. 28: Dispersive Soil Management. Ipswich Planning Scheme, Ipswich City Council.

IECA (2008). Best Practice Erosion and Sediment Control, International Erosion Control Association (Australasia), Picton NSW.

Isbell, R. F. and NCST (2021). The Australian Soil Classification, CSIRO Publishing, Melbourne.

Jacobs (2016). Headwater Streams Technical Note: The importance of protecting headwater streams, Report written by Jacobs for Melbourne Water.

Jacobs (2019). Independent Peer Review of Merrifield Central Waterway Geomorphology Report, Report prepeared by Jacobs for Melbourne Water.

Jeffrey, P. (1981). A study of the land in the catchments to the north of Melbourne, Soil Conservation Authority, Victoria.

Jones, E. B., G., et al. (1996). A land capability study of the shire of Mitchell, Centre for Land Protection Research.

Marchuk, A. and P. Rengasamy (2012). "Threshold electrolyte concentration and dispersive potential in relation to CROSS in dispersive soils." Soil Research **50**(6): 473-481.

Melbourne Water (2009). Constructed Waterways in Urban Developments Guidelines.

Melbourne Water (2018). Co-Designed Catchment Program for the Yarra Catchment.

Melbourne Water (2018). Healthy Waterways Strategy 2018.

Northcote, K. H. and J. K. M. Skene (1972). Australian soils with saline and sodic properties CSIRO Publishing, Melbourne.

Peterson, B. J., et al. (2001). "Control of Nitrogen Export from Watersheds by Headwater Streams." Science **292**: 86-90.

SCA (1979). Guidelines for minimising soil erosion and sedimentation from construction sites in Victoria, Soil Conservation Authority, Victoria.

SKM (2013). Monitoring framework for headwater streams, Report by SKM written for Melbourne Water.

Stace, H. C. T., et al. (1968). A handbook of Australian soils, Rellim Tech. Pubs: Glenside, SA.

Victorian Planning Authority (2019). Beveridge North West Precinct Structure Plan - August 2019.

Victorian Planning Authority (2019). Shenstone Park Precinct Structure Plan - September 2019.

Walsh, C. J., et al. (2016). "Principles for urban stormwater management to protect stream ecosystems." Freshwater Science **35**(1): 398-411.

Witheridge, G. (2012). Principles of Constructon Site Erosion and Sediment Control, Catchments and Creeks Pty Ltd, Brisbane, Queensland.

Appendix A. Soil Sampling and Analysis

A.1 Project scope

Jacobs and project partners South East Soil and Water (SESW) were engaged by Victorian Planning Authority to complete additional soil sampling and analysis so as to obtain additional data on the sodicity of soils in the Wallan South and Wallan East (Part 1) Precinct. The soil sampling and analysis methodology is similar to that which was undertaken for the Sodic Soils Assessment of the Beveridge North West and Shenstone Park Precincts (Jacobs 2020a, 2020b).

Fieldwork of the Wallan South and Wallan East (Part 1) precinct areas was carried out by Peter Sandercock of Jacobs and Christian Bannan of South East Soil and Water on the 10, 11, 23, 24, and 25 February. Samples were collected using a gridded sampling program, with approximately one sampling site per 10-hectares of land available for sampling. The extent of samples collected allow for a suitable representation of the range of geological conditions for use in interpolating data and providing an indication of variability of soil characteristics across the Precinct.

The total number of sites inspected in Wallan East (Part 1) was 16 with the total number of samples collected recorded at 40. Figure A.1 provides an overview of the sampling sites. A Garmin 76CX handheld GPS was used to locate sites in the field. The breakdown of samples comprised of:

- 0-10cm samples: 16
- 30-40cm samples: 16
- Deeper samples from 60-140cm: 8

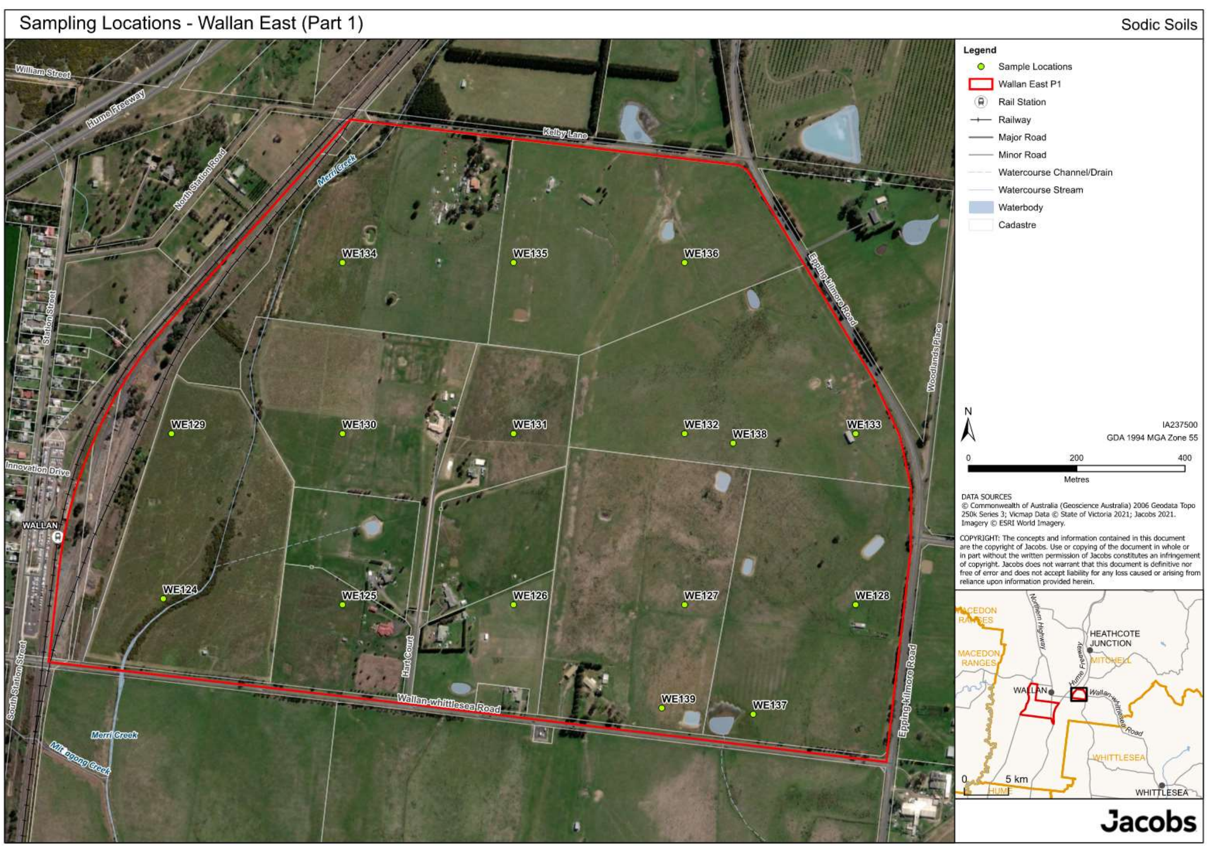


Figure A.1: Wallan East (Part 1) Sample Sites February 2021.

Soil cores were collected from proposed sample points at 0-10cm and 30-40cm, limited by the depth to rock. There were 8 selected sites where samples were collected from depths greater than 40cm to gain general information on deeper sodicity and textural characteristics. WE139 and WE137 were specific sites requested by Melbourne Water where deep cores and additional samples were collected. Examples of soil cores from selected sites are shown in Figure A.2, Figure A.3, Figure A.4 and Figure A.5.

Figure A.2: Soil core from site WE124.

Figure A.3: Soil core from site WE127.

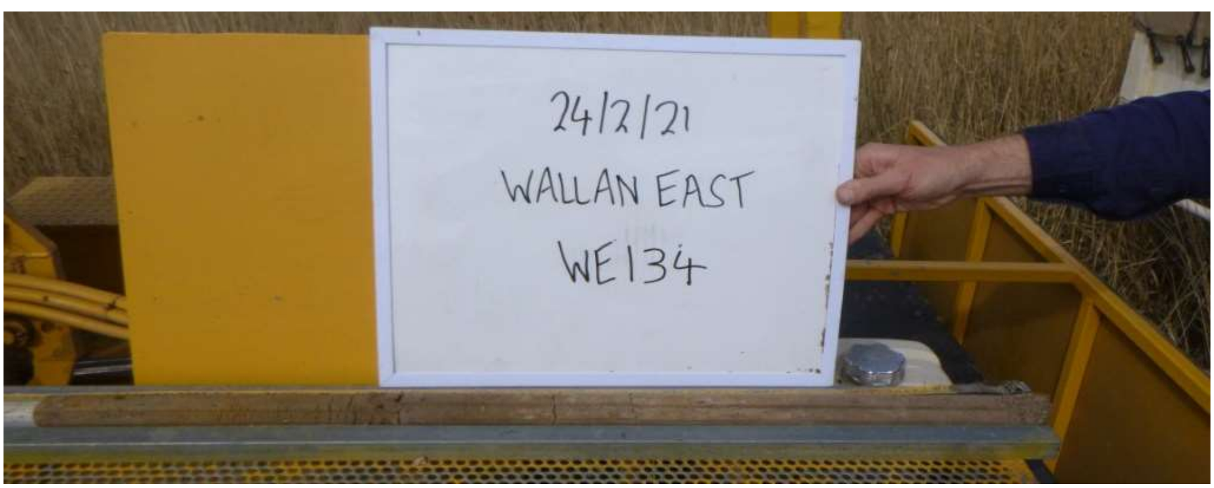


Figure A.4: Soil core from site WE134.

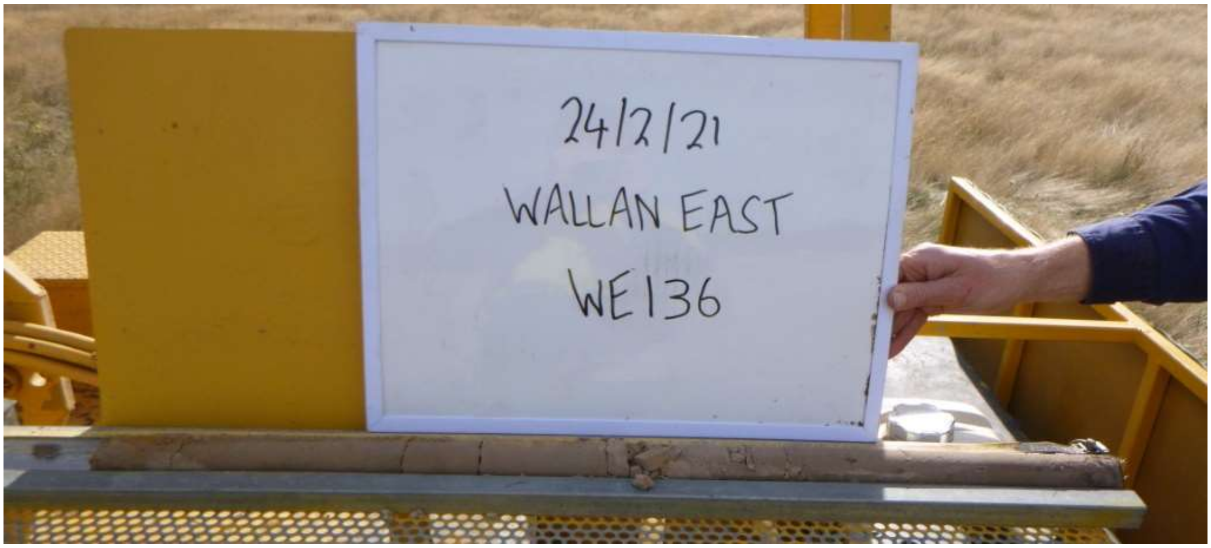


Figure A.5: Soil core from site WE136.

A.2 Soil sampling and laboratory analysis

At each location, a soil core was collected to sample specific soil depths and carry out a basic visual and textural classification of the profile. The following parameters were recorded:

- depth of A horizon topsoil.
- hand texture of the A and B horizons
- visual colour and Munsell colour of the A and B horizons
- other notes on soil physical characteristics defined by the assessor
- photograph of the core or sample collected.

Samples were collected from two depths, A horizon topsoil (0-10cm) and B horizon subsoil (30-40cm). Additional samples were also collected at greater depths at some locations (ranging from 60-140cm) sporadically across the sample areas. Soil samples were dispatched to Nutrient Advantage (NA) Laboratories, Werribee, Victoria on the 2nd of March with results received on the 19th of March. NA are an ASPAC and NATA accredited laboratory.

The following laboratory analysis were undertaken of the soil samples:

- Soil pH (water)
- Soil pH (CaCl2)
- Electrical Conductivity (1:5 soil water) (uS/cm and dS/m)
- Exchangeable Cations, including calcium, magnesium, potassium, sodium and aluminium (cmol/kg and base saturation percentage)
- Emerson Dispersion Class
- Loveday & Pyle Dispersion Score
- Calculated ESP and exchangeable cation levels.

Total Organic Carbon analysis was also undertaken for the 0-10cm samples. In addition to receival of laboratory results, calculations were carried out on all samples to calculate cation levels in mg/kg. Indicative gypsum calculations were carried out by SESW and results are provided in this report as a guide to gypsum requirements for minimising soil dispersion.

A.3 Summary

A.3.1 Geology and Soils

The geology units also match land capability mapping units by others which include 'Qap' Quaternary, alluvium (Jones et al. 1996) and the Whittlesea Land System, consisting of flood plains and river alluvium, with yellow-brown duplex soils most common (Jeffrey 1981).

Soils have developed on alluvial deposits present across flat to slightly undulating land. There are several drainage lines of various sizes across the precinct area confirming that seasonal water flow across the site is an annual occurrence. One site, WE134 occurs on the 'Sxk' geology unit however the physical and chemical properties are not dissimilar to remaining areas on alluvial deposits.

Soils are duplex with a sharp transition between loamy A horizons and clayey B horizons. A horizons vary from shallow (<20cm) to deep (>50cm), with textural transition to clay occurring from 28-60cm. A horizon textures are mostly fine sandy loams and contain a bleach in the 10-20cm zone above the transition to clay where seasonal waterlogging occurs. B horizon textures are dominated by medium to heavy clay textures, grey to yellow-brown in colour and likely to be of low permeability.

A.3.2 Soil Classification

Soils across the PSP area are broadly classified in accordance with Isbell and NCST (2021) as 'duplex soils on alluvial deposits'. Soils of this type are classified as Sodosols, where ESP levels throughout the B-horizon and particularly in the upper part of the B2 horizon are sodic with ESP levels of 6% or greater. In accordance with the old soil classification system, these soils are known as Solodic Soils (Stace et al. 1968). Occurrence is widespread across the 16 sample sites with all classified as Sodosols.

A.3.3 Soil Sodicity

A total of 16 sites and 40 samples were collected across the precinct area to characterise soil sodicity trends throughout soil profiles. In developing exposure criteria (refer to Section 3.2.1) we have chosen to base this on the Exchangeable Sodium Percentage (ESP), or 'sodicity' value where 6.0% is the trigger level (Ford et al. 1993, Isbell and NCST 2021). Exchangeable Sodium Percent (ESP) is the most common analytical technique used to identify sodic or potentially dispersive soils in Australia and there are general trends showing this correlation (DPIW 2008).

Of the sites and samples collected, sodicity results measured in terms of exchangeable sodium percentage (ESP) are summarised as follows:

- 1-10cm, total of 16 samples (A1 horizon topsoil): Average ESP of 9.8%. A total of 3 samples (19%) were deemed non-sodic while 13 samples (81%) were deemed sodic. Sodic topsoils are common even in light textured surface soils.
- 30-40cm, total of 16 samples (mixture of subsurface A2/A3 horizon loams and B-horizon clay subsoil): Average ESP of 19.5%. Of these, all were found to be highly sodic from laboratory test results.
- Deeper samples below 40cm and extending to 140cm, totaling 8 samples. All of these are highly sodic with an average ESP level of 26.5%. Subsoils in this PSP area are expected to be highly unstable if exposed to rainfall runoff or overland flow.

In addition to the results for ESP, the following observations are made from the data set:

- 0-10cm samples: Although the ESP levels average 9.8% and 13 of the 16 samples were sodic, results confirm that they are not dispersive. This is expected where there are some minor spikes in conductivity which is partially observed, along with very high organic carbon levels.

- 30-40cm samples: While all samples were sodic, several of these recorded Emerson Class 7 or 8 which are non-dispersive conditions. More commonly, the Loveday and Pyle Dispersion Scores were quite high, which show some reduction where an elevated EC condition occurs.
- Samples below 40cm: Of the 8 samples tested, all were highly sodic and dispersive, apart from one sample WE124. It is not apparent why this sample was not dispersive.

This site reveals a consistent and uniform trend in soil properties, both physical and chemical. Soils are strongly duplex with moderate to deep A-horizons over medium and heavy clay. All show sharp transitions between the A and B horizons with a prominent bleached A-horizon layer above clay. The average A horizon depth is 46cm, moderate to deep. The characteristics of profiles and their sodicity trends with depth into the subsoil are relatively consistent.

Organic carbon was tested in the A-horizon samples from 0-10cm to gain a greater understanding of factors influencing stability of the surface horizon. The results confirm that the average organic carbon levels are 4.2% across the precinct area, which correspond with an organic matter level averaging 7.2%. These levels are acceptable for sandy topsoils of this region under pasture production. Although high organic carbon assists with improvements in soil stability, soils remain dispersive within the A horizons. Significant amelioration of the A-horizon topsoil will be required to render topsoils stable and non-dispersive.

Across this PSP area, exposure and risk of sodic soil impacts are likely and will increase where any disturbance is recorded to the A1 horizon topsoil, exposing subsurface topsoil or clay subsoil with higher ESP values and lower organic carbon levels. All subsurface and subsoil materials are expected to be highly unstable. Special care is required in this PSP area to control soil dispersion on all disturbed sites by stabilizing both stripped topsoil and exposed subsoil using gypsum, or covering sodic subsoils with non-dispersive topsoil following amelioration.

We maintain that the measure of sodicity with reference to ESP values is effective for inferring dispersive soil risks to erosion across the precinct.

A.3.4 Gypsum Stabilisation

The results confirm that gypsum responses are likely to be observed. Table A.1 provides calculated rates of gypsum to minimise or eliminate dispersion. Calculations adopt the following criteria:

- Reduce ESP to below 5%
- Reduce exchangeable magnesium to below 15%
- Reduce exchangeable potassium to below 5%.

Table A.1: Calculated rates of gypsum to minimise or eliminate dispersion.

Gypsum treatment	Topsoil (0-10cm)	Subsoil (30-40cm)	Deeper subsoil (>40cm)
Full gypsum rate to displace exc. Na, Mg and K to optimum levels (t/Ha/100mm).	4.04 0.40% w/v.	7.52 0.75% w/v.	17.92 1.79%w/v.
Gypsum rate to displace exc. Na to below 5% (t/Ha/100mm).	0.56	1.79	5.87
Gypsum rate to displace exc. Mg to below 15%.	3.48	5.74	12.05
Gypsum rate to displace exc. K to below 5% (t/Ha/100mm).	0.29	0.00	0.00

A.4 Analytical results

Results from the laboratory were collated with additional information collected in the field. Results from the field and laboratory analysis of soils are also documented here in the following pages.

Table A.2: Wallan East (Part 1) Field Sheet.

				Topsoil 0-10cm Sample						Subsoil 30-40cm Sample					Deeper Sample below 40cm					
New Site Name	Photo Collect	Easting	Northing	Lab Barcode	0-10cm Sample Collected	Depth of A Horizon (cm)	0-10cm Sample Texture	0-10cm Sample Visual Colour	0-10cm Sample Munsell Colour	Lab Barcode	30-40cm Samp Collected.	30-40cm Sample Texture	30-40cm Sample Visual Colour	30-40cm Sample Munsell Colour	Lab Barcode	Deep Sample Collected	Deep Sample Depth	Deep Sample Texture	Deep Sample Visual Colour	Deep Sample Munsell Colour
WE124	Y	323680	5856865	22314760	Y	38	Fine Sandy Loam	B	7.5YR5/2	22314759	Y	Light to Medium Clay	DG	10YR4/1	22314758	Y	130-140	Medium-Heavy Clay	GB	10YR5/2
WE125	Y	324011	5856854	22314764	Y	30	Fine Sandy Loam	GB	10YR5/3	22314763	Y	Medium Clay	GB	10YR4/2	22314761	Y	130-140	Sandy Clay	YB	2.5Y6/6
WE126	Y	324327	5856854	22314771	Y	60	Fine Sandy Loam	GB	10YR5/2	22314772	Y	Fine Sandy Clay Loam	GB	10YR5/3		N	130-140	Heavy Clay	G	10YR6/1
WE127	Y	324643	5856854	22314859	Y	40	Fine Sandy Loam	GB	10YR5/2	22314860	Y	Fine Sandy Clay Loam	GB	10YR6/2	22314861	Y	120-130	Heavy Clay	G	10YR6/1
WE128	Y	324959	5856854	22314849	Y	28	Fine Sandy Loam	GB	10YR5/2	22314850	Y	Medium Clay	YGB	10YR5/3		N	80-90	Medium Clay	G	10YR6/2
WE129	Y	323695	5857170	22314743	Y	43	Fine Sandy Loam	G	10YR5/2	22314742	Y	Fine Sandy Loam	GB	10YR6/2	22314740	Y	130-140	Heavy Clay	G	10YR6/1
WE130	Y	324011	5857170	22314766	Y	42	Fine Sandy Loam	GB	10YR5/2	22314765	Y	Fine Sandy Loam	GB	10YR6/2		N	90-100	Heavy Clay	YGB	2.5Y5/3
WE131	Y	324327	5857170	22314770	Y	40	Fine Sandy Loam	GB	10YR4/3	22314769	Y	Fine Sandy Clay Loam	GB	10YR5/2	22314767	Y	130-140	Heavy Clay	G	10YR5/1
WE132	Y	324643	5857170	22314853	Y	42	Fine Sandy Loam	GB	10YR5/2	22314854	Y	Fine Sandy Clay Loam	GB	10YR6/2		N	90-100	Heavy Clay	G	2.5Y5/2
WE133	Y	324959	5857170	22314851	Y	65	Fine Sandy Loam	GB	10YR5/2	22314852	Y	Fine Sandy Loam	B	10YR5/3		N	65-90	Sandy Clay	G	2.5Y6/2
WE134	Y	324011	5857486	22314739	Y	50	Fine Sandy Loam	GB	10YR4/3	22314738	Y	Fine Sandy Loam	G	10YR6/2		N	90-100	Medium-Heavy Clay	YG	2.5Y6/4
WE135	Y	324327	5857486	22314745	Y	36	Fine Sandy Loam	GB	10YR5/2	22314741	Y	Fine Sandy Loam	GB	10YR6/2		N	80-90	Heavy Clay	YG	10YR6/1
WE136	Y	324643	5857486	22314757	Y	65	Fine Sand	GB	10YR5/3	22314756	Y	Fine Sand	LG	10YR6/3		N	90-100	Sandy Clay	YG	2.5Y5/6
WE137	Y	324770	5856652	22314846	Y	50	Fine Sandy Loam	GB	10YR4/3	22314847	Y	Fine Sandy Loam	G	10YR6/2	22314848	Y	130-140	Heavy Clay	G	2.5Y6/1
WE138	Y	324732	5857152	22314856	Y	60	Fine Sandy Loam	GB	10YR5/2	22314855	Y	Fine Sandy Loam	G	10YR6/2	22314863	Y	130-140	Heavy Clay	G	10YR6/1
WE139	Y	324601	5856663	22314862	Y	55	Fine Sandy Clay Loam	GB	10YR5/2	22314864	Y	Fine Sandy Loam	GB	10YR6/2	22314762	Y	130-140	Heavy Clay	G	2.5Y6/1

New Site Name	Photo Collect	Easting	Northing	Slope	Aspect	Notes
WE124	Y	323680	5856865	Flat, adjacent to waterway	South	Coarse fragments in A1 horizon may not be natural (fill layer). Could be brick and blue metal. Bleaching in the A2 horizon from 20-30cm. Full ground cover of Philaris with roots to 1.0m plus. Waterway infested with Gorse and blackberries.
WE125	Y	324011	5856854	Flat, depression	North south	Strong duplex profile, strong bleach in the A2 horizon from 20-30cm over clay. Full ground cover. Expect non-sodic topsoil over clay.
WE126	Y	324327	5856854	Flat	South west	Slight bleaching in the A2 horizon from 20-60cm. Duplex profile. Area looks poorly drained.
WE127	Y	324643	5856854	Flat drainage depression	South to south east	Bleaching in the A2 horizon from 30-40cm. Orange mottling throughour the B horizon from 40-130cm.
WE128	Y	324959	5856854	Flat to gentle slope	South west	Strong bleach in the A2 horizon from 15-32cm, yellow mottling throughout the B1 from 30-65cm.
WE129	Y	323695	5857170	Flat	South west	Bleaching in the A2 horizon. Orange mottling in the B horizon.
WE130	Y	324011	5857170	Flat to gently sloping	South west	Bleaching in the A2 horizon from 30-40cm. Strong orange mottling in the B horizon.
WE131	Y	324327	5857170	Flat, drainag depression	South west	Gilgai noted at surface. Philaris paddock with exceptional ground cover. Mass or organic matter from plant roots.
WE132	Y	324643	5857170	Flat	South west	Strong bleaching in the A2 horizon from 30-42cm above clay.
WE133	Y	324959	5857170	Lower to break of slope	South to south west	Bleaching in the A2 horizon from 50-65cm above clay.
WE134	Y	324011	5857486	Flat	South	Strong bleached A horizon from 40-50cm. Yellow mottling in the B horizon.
WE135	Y	324327	5857486	Flat	South	Strong bleach in the A2 and B1 horizons, orange mottling throughout the B2 horizon.
WE136	Y	324643	5857486	Slightly undulating plain	East	Deep fine sand over sandy clay.
WE137	Y	324770	5856652	Drainage depression	South west	A1 horizon approx 20cm. Organic matter diminishing with depth, slight bleaching with depth. A2 horizon 20-50cm, grey, bleached with orange mottling. Expect A2 horizon to be saturated during winter months. B horizon low permeability or impervious clay. 50-140cm Grey, heavy clay with orange and yellow mottling,manganese (expect to be highly dispersive and sodic). Profile is duplex with a sharp changein texture beween the A and B horizons at 50cm. Good pasture cover with spiny rush or other species.
WE138	Y	324732	5857152	Drainage line	South west	Strong bleach in the A2 horizon from 50-60cm above clay.
WE139	Y	324601	5856663	Flat, drainage depression	South east	Site in low area,close to dam, suspect waterlogging and drainage flows though winter months. Good grass/vegetative cover. Surface is stable. Topsoil is deep with bleached A2 horizon from 30-55cm over clay. Subsoil clays show strongly mottled orange colours. Strongly duple profile, critical to conserve all topsoils.

Table A.3: Wallan East (Part 1) 0-10cm Sample Analytical Results.

Sample ID	Site	Sample Name	Sample Start Depth	Sample End Depth	Zone	GPS Easting	GPS Northing	Texture	pH (1:5 Water)	pH (1:5 CaCl2)	Electrical Conductivity (1:5 water)	Exchangeable Sodium Percentage	Emerson Class	Disp. Index, Loveday/Pyle	Slaking 2Hrs
			cm	cm				**SESW Field Classification**			dS/m	%			
22314760	WE124	WE124. 0-10	0	10	55H	323696	5856854	Fine Sandy Loam	5.7	4.9	0.12	3.9	8	1	Water Stable
22314764	WE125	WE125. 0-10	0	10	55H	324012	5856854	Fine Sandy Loam	5.1	4.1	0.06	6.3	7	2	Water Stable
22314771	WE126	WE126. 0-10	0	10	55H	324328	5856854	Fine Sandy Loam	5.3	4.5	0.14	7.4	7	3	Water Stable
22314859	WE127	WE127. 0-10	0	10	55H	324644	5856854	Fine Sandy Loam	5.7	4.6	0.08	5.2	7	1	Water Stable
22314849	WE128	WE128. 0-10	0	10	55H	324960	5856854	Fine Sandy Loam	5.2	4.1	0.06	6.4	7	1	Water Stable
22314743	WE129	WE129. 0-10	0	10	55H	323696	5857170	Fine Sandy Loam	5.5	4.6	0.09	4.7	7	1	Water Stable
22314766	WE130	WE130. 0-10	0	10	55H	324012	5857170	Fine Sandy Loam	5.3	4.5	0.13	7.2	7	1	Water Stable
22314770	WE131	WE131. 0-10	0	10	55H	324328	5857170	Fine Sandy Loam	5.2	4.5	0.21	7.6	7	1	Water Stable
22314853	WE132	WE132. 0-10	0	10	55H	324644	5857170	Fine Sandy Loam	5.0	4.3	0.25	18.0	7	1	Water Stable
22314851	WE133	WE133. 0-10	0	10	55H	324960	5857170	Fine Sandy Loam	5.1	4.2	0.41	20.0	7	1	Water Stable
22314739	WE134	WE134. 0-10	0	10	55H	324012	5857486	Fine Sandy Loam	5.3	4.5	0.20	13.0	7	1	Water Stable
22314745	WE135	WE135. 0-10	0	10	55H	324328	5857486	Fine Sandy Loam	5.6	4.6	0.08	6.8	7	5	Water Stable
22314757	WE136	WE136. 0-10	0	10	55H	324644	5857486	Fine Sand	4.7	4.2	0.41	19.0	7	1	Water Stable
22314846	WE137	WE137. 0-10	0	10	55H	324770	5856652	Fine Sandy Loam	5.0	4.1	0.16	11.0	7	1	Water Stable
22314856	WE138	WE138. 0-10	0	10	55H	324732	5857152	Fine Sandy Loam	5.1	4.4	0.25	14.0	7	1	Water Stable
22314862	WE139	WE139. 0-10	0	10	55H	324601	5856663	Fine Sandy Clay Loam	5.3	4.4	0.10	6.2	7	1	Water Stable

Sample ID	Site	Sample Name	Calcium (Amm-acet.)	Magnesium (Amm-acet.)	Potassium (Amm-acet.)	Sodium (Amm-acet.)	Aluminium (KCl)	Calcium (Amm-acet.)	Magnesium (Amm-acet.)	Potassium (Amm-acet.)	Sodium (Amm-acet.)	Aluminium (KCl)	Cation Exch. Cap.
			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg
22314760	WE124	WE124. 0-10	620	617	180	83	9.4	3.1	5.1	0.46	0.36	0.1	9.2
22314764	WE125	WE125. 0-10	220	109	31	39	43	1.1	0.9	0.08	0.17	0.5	2.8
22314771	WE126	WE126. 0-10	420	399	106	108	14	2.1	3.3	0.27	0.47	0.2	6.4
22314859	WE127	WE127. 0-10	460	436	78	78	11	2.3	3.6	0.2	0.34	0.1	6.5
22314849	WE128	WE128. 0-10	380	145	82	60	43	1.9	1.2	0.21	0.26	0.5	4
22314743	WE129	WE129. 0-10	480	363	125	67	23	2.4	3	0.32	0.29	0.3	6.2
22314766	WE130	WE130. 0-10	380	339	74	90	12	1.9	2.8	0.19	0.39	0.1	5.4
22314770	WE131	WE131. 0-10	520	593	141	156	44	2.6	4.9	0.36	0.68	0.5	9
22314853	WE132	WE132. 0-10	420	387	90	299	34	2.1	3.2	0.23	1.3	0.4	7.2
22314851	WE133	WE133. 0-10	420	266	383	299	11	2.1	2.2	0.98	1.3	0.1	6.7
22314739	WE134	WE134. 0-10	360	411	74	196	23	1.8	3.4	0.19	0.85	0.3	6.5
22314745	WE135	WE135. 0-10	340	375	66	85	18	1.7	3.1	0.17	0.37	0.2	5.5
22314757	WE136	WE136. 0-10	140	48	27	76	20	0.7	0.4	0.07	0.33	0.2	1.7
22314846	WE137	WE137. 0-10	320	194	39	110	59	1.6	1.6	0.1	0.48	0.7	4.5
22314856	WE138	WE138. 0-10	400	436	141	253	75	2	3.6	0.36	1.1	0.8	8
22314862	WE139	WE139. 0-10	380	387	98	85	18	1.9	3.2	0.25	0.37	0.2	5.9

Sample ID	Site	Sample Name	Calcium (Amm-acet.)	Magnesium (Amm-acet.)	Potassium (Amm-acet.)	Aluminium Saturation	Calcium/Magnesium Ratio	**ESP% + EPP% Calculation**	Organic Carbon (W&B)	Organic Matter (W&B * 1.72)
			%	%	%	%		**SESW Calculation**	%	%
22314760	WE124	WE124. 0-10	34	56	5.1	1.1	0.6	9.0	3.6	6.3
22314764	WE125	WE125. 0-10	41	33	2.9	17	1.2	9.2	2.8	4.7
22314771	WE126	WE126. 0-10	33	52	4.3	2.4	0.6	11.7	5.1	8.7
22314859	WE127	WE127. 0-10	35	55	3	1.8	0.6	8.2	3.6	6.2
22314849	WE128	WE128. 0-10	46	30	5.1	12	1.6	11.5	3.4	5.9
22314743	WE129	WE129. 0-10	38	48	5.1	4.2	0.8	9.8	3.0	5.1
22314766	WE130	WE130. 0-10	35	52	3.6	2.5	0.7	10.8	4.9	8.4
22314770	WE131	WE131. 0-10	29	54	4.1	5.4	0.5	11.7	4.4	7.6
22314853	WE132	WE132. 0-10	29	44	3.1	5.3	0.7	21.1	4.8	8.2
22314851	WE133	WE133. 0-10	31	32	15	1.8	1	35.0	6.0	10.0
22314739	WE134	WE134. 0-10	28	52	2.9	3.9	0.5	15.9	4.8	8.3
22314745	WE135	WE135. 0-10	30	56	3.2	3.7	0.6	10.0	3.3	5.7
22314757	WE136	WE136. 0-10	39	25	3.9	13	1.6	22.9	3.7	6.4
22314846	WE137	WE137. 0-10	36	36	2.2	15	1	13.2	4.1	7.0
22314856	WE138	WE138. 0-10	26	46	4.6	10	0.6	18.6	4.9	8.4
22314862	WE139	WE139. 0-10	32	54	4.2	3.4	0.6	10.4	4.4	7.6

Table A.4: Wallan East (Part 1) 30-40cm Sample Analytical Results.

Sample ID	Site	Sample Name	Sample Start Depth	Sample End Depth	Zone	GPS Easting	GPS Northing	Texture	pH (1:5 Water)	pH (1:5 CaCl2)	Electrical Conductivity (1:5 water)	Exchangeable Sodium Percentage	Emerson Class	Disp. Index, Loveday/Pyle	Slaking 2Hrs
			cm	cm				SESW Field Classification			dS/m	%			
22314759	WE124	WE124. 30-40	30	40	55H	323696	5856854	Light to Medium Clay	6.1	4.9	0.12	11.0	7	8	Water Stable
22314763	WE125	WE125. 30-40	30	40	55H	324012	5856854	Medium Clay	8.4	7.2	0.19	20.0	1	16	Partial
22314772	WE126	WE126. 30-40	30	40	55H	324328	5856854	Fine Sandy Clay Loam	5.8	4.6	0.09	12.0	2	12	Partial
22314860	WE127	WE127. 30-40	30	40	55H	324644	5856854	Fine Sandy Clay Loam	7.5	6.2	0.10	12.0	2	13	Partial
22314850	WE128	WE128. 30-40	30	40	55H	324960	5856854	Medium Clay	6.7	5.7	0.18	14.0	8	9	Water Stable
22314742	WE129	WE129. 30-40	30	40	55H	323696	5857170	Fine Sandy Loam	6.4	5.1	0.06	6.6	8	12	Water Stable
22314765	WE130	WE130. 30-40	30	40	55H	324012	5857170	Fine Sandy Loam	6.4	5.1	0.10	16.0	2	13	Partial
22314769	WE131	WE131. 30-40	30	40	55H	324328	5857170	Fine Sandy Clay Loam	5.5	4.4	0.10	8.6	8	10	Water Stable
22314854	WE132	WE132. 30-40	30	40	55H	324644	5857170	Fine Sandy Clay Loam	5.7	4.5	0.11	15.0	2	14	Considerable
22314852	WE133	WE133. 30-40	30	40	55H	324960	5857170	Fine Sandy Loam	5.5	5.0	0.82	58.0	7	1	Water Stable
22314738	WE134	WE134. 30-40	30	40	55H	324012	5857486	Fine Sandy Loam	5.4	4.6	0.34	27.0	2	8	Partial
22314741	WE135	WE135. 30-40	30	40	55H	324328	5857486	Fine Sandy Loam	6.9	5.7	0.23	21.0	1	13	Partial
22314756	WE136	WE136. 30-40	30	40	55H	324644	5857486	Fine Sand	7.1	6.6	0.44	35.0	8	1	Water Stable
22314847	WE137	WE137. 30-40	30	40	55H	324770	5856652	Fine Sandy Loam	6.3	5.8	0.73	28.0	8	2	Water Stable
22314855	WE138	WE138. 30-40	30	40	55H	324732	5857152	Fine Sandy Loam	5.6	4.3	0.08	13.0	2	13	Partial
22314864	WE139	WE139. 30-40	30	40	55H	324601	5856663	Fine Sandy Loam	5.6	4.7	0.20	15.0	2	11	Partial

Sample ID	Site	Sample Name	Calcium (Amm-acet.)	Magnesium (Amm-acet.)	Potassium (Amm-acet.)	Sodium (Amm-acet.)	Aluminium (KCl)	Calcium (Amm-acet.)	Magnesium (Amm-acet.)	Potassium (Amm-acet.)	Sodium (Amm-acet.)	Aluminium (KCl)	Cation Exch. Cap.
			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg
22314759	WE124	WE124. 30-40	420	617	55	205	14	2.1	5.1	0.14	0.89	0.2	8.4
22314763	WE125	WE125. 30-40	360	1089	106	621	<9.0	1.8	9	0.27	2.7	<0.1	13.8
22314772	WE126	WE126. 30-40	240	448	59	170	25	1.2	3.7	0.15	0.74	0.3	6.1
22314860	WE127	WE127. 30-40	300	726	51	230	<9.0	1.5	6	0.13	1	<0.1	8.6
22314850	WE128	WE128. 30-40	400	569	43	276	<9.0	2	4.7	0.11	1.2	<0.1	8
22314742	WE129	WE129. 30-40	500	629	63	129	<9.0	2.5	5.2	0.16	0.56	<0.1	8.4
22314765	WE130	WE130. 30-40	220	520	55	230	<9.0	1.1	4.3	0.14	1	<0.1	6.6
22314769	WE131	WE131. 30-40	320	617	63	168	82	1.6	5.1	0.16	0.73	0.9	8.5
22314854	WE132	WE132. 30-40	160	387	43	202	73	0.8	3.2	0.11	0.88	0.8	5.8
22314852	WE133	WE133. 30-40	100	145	55	644	23	0.5	1.2	0.14	2.8	0.3	4.9
22314738	WE134	WE134. 30-40	120	399	51	391	45	0.6	3.3	0.13	1.7	0.5	6.3
22314741	WE135	WE135. 30-40	260	641	43	414	<9.0	1.3	5.3	0.11	1.8	<0.1	8.5
22314756	WE136	WE136. 30-40	240	194	8	345	<9.0	1.2	1.6	0.02	1.5	<0.1	4.3
22314847	WE137	WE137. 30-40	380	666	47	690	<9.0	1.9	5.5	0.12	3	<0.1	10.5
22314855	WE138	WE138. 30-40	80	290	47	133	110	0.4	2.4	0.12	0.58	1.2	4.6
22314864	WE139	WE139. 30-40	260	484	55	230	31	1.3	4	0.14	1	0.4	6.9

Sample ID	Site	Sample Name	Calcium (Amm-acet.)	Magnesium (Amm-acet.)	Potassium (Amm-acet.)	Aluminium Saturation	Calcium/Magnesium Ratio	ESP% + EPP% Calculation
			%	%	%	%		SESW Calculation
22314759	WE124	WE124. 30-40	25	61	1.7	1.8	0.4	12.7
22314763	WE125	WE125. 30-40	13	65	1.9	<1.0	0.2	21.9
22314772	WE126	WE126. 30-40	20	61	2.4	4.5	0.3	14.4
22314860	WE127	WE127. 30-40	17	70	1.5	<1.0	0.3	13.5
22314850	WE128	WE128. 30-40	25	59	1.4	<1.0	0.4	15.4
22314742	WE129	WE129. 30-40	30	62	1.9	<1.0	0.5	8.5
22314765	WE130	WE130. 30-40	17	65	2.2	<1.0	0.3	18.2
22314769	WE131	WE131. 30-40	19	60	1.9	11	0.3	10.5
22314854	WE132	WE132. 30-40	14	55	2	14	0.2	17.0
22314852	WE133	WE133. 30-40	9.6	24	2.9	5.2	0.4	60.9
22314738	WE134	WE134. 30-40	10	53	2.1	7.9	0.2	29.1
22314741	WE135	WE135. 30-40	15	63	1.2	<1.0	0.3	22.2
22314756	WE136	WE136. 30-40	27	37	0.44	<1.0	0.8	35.4
22314847	WE137	WE137. 30-40	18	52	1.2	<1.0	0.4	29.2
22314855	WE138	WE138. 30-40	8.7	51	2.6	25	0.2	15.6
22314864	WE139	WE139. 30-40	19	59	2	5.1	0.3	17.0

Table A.5: Soil colors/ranges and interpretation

Exchangeable Sodium Percentage (ESP) Interpretation

Colour	ESP Range	Interpretation
	<6%.	Non-sodic.
	6.1-10%.	Moderately Sodic
	10.1-15.0%	Strongly Sodic
	>15.1%	Very Strongly Sodic

Emerson Dispersion Class Interpretation.

Colour	Emerson Class	Interpretation
	4, 5, 6, 7, 8	Non-dispersive.
	3	Partial Dispersion after remoulding
	2	Partial Dispersion
	1	Complete Dispersion

Loveday & Pyle (L&P) Score Interpretation.

Colour	L&P Score	Interpretation
	0, 1, 2, 3, 4	Low to moderate. Nil to slight gypsum resonse expected where dispersive.
	5, 6, 7, 8	Moderate to high. Gypsum response expected to control dispersion.
	9, 10, 11, 12	High. Gypsum response expected to control dispersion. High rates required.
	13, 14, 15, 16	Very high. Very high rates required to control dispersion.

Slaking Class Interpretation.

Colour	Slaking Class	Interpretation
	Water Stable	Aggregate stable when wetted, nil or minimal breakdown in structure.
	Partial	Low aggregate stability. Partial breakdown in structure when wetted.
	Considerable	Unstable. High or significant loss of structure when wetted.

Organic Carbon Interpretation

Colour	Organic Carbon %	Interpretation
	<1.0	Low to deficient. Low or poor aggregate stability expected.
	1.0-1.9	Slightly low. Aggregates expected to be unstable, or partially stable.
	2.0-2.9	Acceptable. Variable water stability expected.
	3.0-3.9	Optimal. Water stable aggregates expected.
	4.0+	Optimal to high. Aggregate stability likely.