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Integrating Resource Management

Nutrient and Irrigation Management Plan: Lot 209 Paterson Road, Ravenswood

Kelliher Bros
469 Fourteen Mile Brook Road
PO Box 6, Wandering WA 6308
Western Australia
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Nutrient and Irrigation Management Plan
Lots 209 Paterson Road, Ravenswood

Prepared by
Julia Heide
Environmental Engineer

Project Supervisor
Peter Keating
Managing Director

Bioscience Pty Ltd
488 Nicholson Road
Forrestdale 6112
9397 2446
www.biosciencewa.com

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Executive Summary

This Nutrient and Irrigation Management Plan was prepared by Bioscience Pty Ltd, as per the advice and recommendations of the Water Quality Protection Note from the Department of Water and Environmental Regulations (WQPN 33), on behalf of Kelliher Bros. Kelliher Bros plan to expand their grass-fed beef production business through irrigated pasture, aiming to prolong production from 6-8 weeks per year to year-round. The objective for this project is to increase pasture productivity under environmentally responsible management measures.

This report is supporting the stage 1 development application, on Lot 209 on Paterson Road in Ravenswood. A single 40 ha centre pivot irrigator for irrigating pasture on Lot 209 will be installed. The location of the site within the Peel-Harvey catchment area requires a strict nutrient and irrigation management regime to minimise nutrient input to the Peel-Harvey system.
The aim of this project is to demonstrate the optimisation of best practice in environmental and sustainable management for fertilised and irrigated pasture production. The following implementations address the minimisation of nutrient export rates.

Firstly, the maximum phosphorous (6.5 kg/ha/yr) and nitrogen (45 kg/ha/yr) input rates recommended by the Department of Water and Environmental Regulations will not be exceeded unless mass balance calculations demonstrate that at least 90% of these values have been exported from the site, or are in the form of stable biomass.
Nutrient leaching will be prevented through the following implementations onsite:

- Application of water and dissolved fertiliser (calcium, magnesium, potassium, sulphur and trace elements) used according to plant needs, stage of development of the crop, weather forecast, temperature, evaporation and soil moisture (no excess water or nutrients);
- Application of all phosphorous and most nitrogen solely by foliar spray;
- Soil amendments to increase the Phosphorous Retention Index (PRI) to at least 10, with the aim of retaining phosphate in the topsoil for plant uptake;
- Sowing combinations of annual and perennial, deep-rooted pastures of grasses and legumes;
- Soil moisture maintained between 10 – 18 % (w/w), prevention of soil saturation with water and thus runoff prevention;
- Sentek probes continuously measuring soil salinity, soil moisture and soil temperature in 10 cm increments up to 60 cm below ground level;
- Pivot irrigator can be controlled remotely based on soil data retrieved from probes (real-time irrigation management) and rainfall forecasts;
- To limit nutrient application, fertigation will not be included in every irrigation cycle;
- Soil permeability testing showed high infiltration rates (53 – 125 mm/hr) which theoretically means most heavy rainfall events (1% AEP, 1 hour) can infiltrate;
- Runoff from heavy rainfall events to be captured in spoon drain surrounding the pivot irrigation area and infiltrated into unfertilised bioretention basin, with all drainage structures lined with high PRI materials;

- Soil amendments such as spongolite and clays to increase nutrient retention as well as water holding capacity which prevents leaching.

For further assurance the following monitoring commitments and contingency plans will be adopted:

- Installation and monthly monitoring of shallow lysimeters to demonstrate no leaching of water and nutrients into groundwater underlying the site;
- Installation and monthly monitoring of upstream and downstream bores, and drains when water is present;
- Determination of trigger value based on data (1 year) from upstream groundwater monitoring (annual mean); Nutrient spikes in groundwater are expected to occur seasonally due to legacy fertiliser application in the vicinity or historical land use;
- If nutrient levels at the downstream bores exceed trigger levels by two standard deviations, the source of the nutrient spike will be investigated through intensified monitoring;
- If nutrient data from probes and lysimeters indicate any possible leaching, nutrient application rates will be reduced
- If the water quality does not show improvement over the following monitoring event, fertigation will stop and the water application rate is to be reduced.

As described above, the project aims to achieve environmentally safe practises to produce irrigated pasture to export to other Kelliher cattle farms. A range of implementations and monitoring commitments provide ongoing assurance of best practise management.

1 Summary of the Land Use Proposal

Proponent's name: Shane Kelliher of Kelliher Bros

Contact details: 08 9884 1550

Site location: Lot 209 Paterson Road, Ravenswood (the site)

Project description: Bioscience has been commissioned by Kelliher Bros to assist in establishing an irrigated pasture operation to expand their existing grass-fed beef production business. Kelliher Bros entered this emerging high value industry some years ago and recognised substantial market opportunities. However, without irrigation, emerging markets can only be addressed for about 6-8 weeks each year. The business objective is to produce grass fed beef for local markets on a year-round basis.

Timetable: Groundwork towards production on site will start as soon as development approval is obtained. The trial period for the stage 1 development is two years.

2 Project Setting

The site is located approximately 8 km east of Mandurah and is zoned "rural" under the Peel Region Scheme.

The property owned by Kelliher Bros consists of lots 190, 204, 205, 206, 209, 230, 536, 538 and 542, and covers an area of approximately 709 ha. It is bounded by the Kwinana Freeway to the west, Paterson Road to the east and Old Mandurah Road to the south (Figure 1). The property is flat, low lying land which is ideally suited to centre-pivot irrigation.
The intention is to initiate a staged development, starting with a single 40 ha centre pivot irrigator. This report supports the stage 1 development application to the Shire of Murray, which involves Lot 209 on Paterson Road, and covers an area of approximately 88 ha. Stage 1 of the development as described in this NIMP, involves installing a 40 ha centre pivot irrigator for irrigated pasture on Lot 209. The lot and site boundaries for lot 209 are shown in Figure 2.

The Stage 1 Development aims to optimise best practice and prevent environmental impacts associated with nutrient export within the Peel-Harvey Catchment, while at the same time increasing the efficiency of plant growth in pasture production.
Different soil amendments to increase water holding capacity and prevent nutrient leaching will be applied, and different pasture species will be sown. The objective is to optimise synergies between pasture production and soil amendments. The development will employ intensive monitoring of groundwater, surface water, soil moisture, soil temperature, soil salinity, and water quantity and quality in lysimeters.
Stage 1 of the development can be seen as a trial in which different measures are being tested while at the same time pursuing best practice to prevent nutrient export. The detailed design as well as monitoring and evaluation methods are described further in this report.
Further development across the site will be dependent on successful outcomes of Stage 1, and will be subject to further development approval. When Stage 1 is able to demonstrate that the risk of nutrient pollution of nearby environmentally sensitive receptors is low, and

that nutrient outputs can be managed to fall withing existing Environmental Protection Authority (EPA) policy and Department of Water and Environmental Regulation (DWER) guidelines, this system might expand to over 400 ha which are suitable for pivot irrigation. The further development of the site also depends on availability of groundwater, and the venture proving to be low risk and commercially attractive to Kelliher Bros. Eventually, about 400 ha of the property owned by Kelliher Bros could be irrigated via pivot irrigation, adopting industry best practices as tested and developed in Stage 1.

3 Land Use, Staff and Livestock

3.1 Land Use

The site has been cleared for its current land use, cattle grazing. For the last 40 years cattle on the site have been grazing on deep-rooted perennial pasture such as kikuyu and couch, annual grasses such as ryegrass, and legumes such as Serradella and Balansa. In recent years the site has not received any lime or fertilisers.

3.2 Staff and Livestock

There will be no staff living on the site. Currently livestock is rotationally grazed on the site. During the stage 1 development livestock will not generally graze the pivot site and the majority of grown pasture will be harvested for removal off site to other Kelliher Bros farms. It is likely that depending on the state of pasture development, cattle may be used for short periods to graze the pivot area. The sustainable stocking rate will not be exceeded.

4 Local Rainfall, Evaporation and Interception

The climate of the area is characterized by Mediterranean climate of cool wet winters and hot dry summers. There are no weather monitoring stations within the immediate vicinity, therefore the rainfall data has been taken from the Pinjarra Weather Station (15 km south of the site). Average monthly rainfall between 2001 and 2018 is shown in Table 1. The average yearly rainfall in Pinjarra is 694.6 mm/year. The Medina Research Centre (32 km north of the site) is the closest weather station monitoring evaporation. Evaporation at the site is likely to be similar to Medina which has an annual evaporation of 1725 mm between 1983 and 2017. Average monthly evaporation in Medina is also presented in Table 1.

Evaporation exceeds the annual average rainfall by a factor of 2.5. Monthly rainfall typically only exceeds evaporation during four months from May to August.

Table 1: Rainfall at Pinjarra and Evaporation at Medina Research Centre (Bureau of Meteorology)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average Rainfall (mm)	14.4	10.1	12.1	36.2	106.7	115.6	123.3	106.6	80.1	34.8	25.9	14.1	694.6
Average Evapo-ration (mm)	260	224	195	114	71	54	53	71	96	146	195	245	1725

5 Soils and Landform Description

5.1 Land Contours

Overall, the site is relatively flat at an average of 6 mAHD. The elevation at the eastern site boundary (along Paterson Road) is 8 mAHD and drops to around 4 mAHD at the western site boundary (Kwinana Freeway), with a slope of 1:480 (Figure 2).

5.2 Soil Type

The property is located within the Perth (sedimentary) Basin and is overlain by Superficial formations, comprised of Bassendean Sand, the Guildford Formation and Rockingham Sand. The Superficial formation overlies the Leederville Formation and the Cockleshell Gully (DoW 2012). Geophysical subsurface investigations carried out by GBGMAPS support these findings and give additional information about the layers within the Guildford Formation. Below the layer of Bassendean Sand it is suggested that there lies a layer of silty, slightly sandy clay of the Guildford Formation with high electrical conductivity. This overlays a fine to coarse grained quartz gravelly sand, and in some places, ferruginised limonitic (Coffee Rock) and an iron-organic hardpan layer that is somewhat impermeable to water (GBGMAPS – Appendix A). Ground proofing suggests the geophysical mapping has overestimated the extent of near surface clays.

Based on the hydrogeological survey findings of the recently installed production bore (PB1), the superficial formation within the vicinity of the site consists of Bassendean Sand of a depth of up to 6 m below ground level (mBGL), followed by a layer of grey clay of the Guildford Formation. Sandy clay of the Guildford Formation is found in depths up to 36 mBGL. Between 36 mBGL and 60 mBGL lies a layer of Rockingham Sand. The Wanneroo Member of the Leederville Formation starts at 62 mBGL. The stratigraphy of the observation bores shows the deviations in the homogeneity of the geology on the site. The observation bore (OBS1), located 20 m west of PB1, shows a thin layer of coffee rock between 3 and 4 mBGL within the Bassendean Sand. Again, a layer of grey sandy clay determines the start of the Guildford formation at 6 mBGL. The Rockingham Sand begins at 24 mBGL, represented by dark grey sand including chunks of clay. Below 39 mBGL the sand becomes lighter in colour and less clayey. Just before the Wanneroo Member of the Leederville Formation appears at 62 mBGL, pieces of shell are found within the sand. The second observation bore is located 50 m east of PB1 and shows similar stratigraphy as PB1. The major difference is the thickness of the Guilford Formation, reaching from 4 – 39 mBGL in OBS2. The locations of PB1, OBS1 and OBS2 are shown in Figure 3.

According to the natural resource mapping system of the Department of Primary Industries and Regional Development, lot 209 is mapped as Bassendean B4 Phase. The B4 Phase is described as a broad poorly drained sandplain consisting of deep grey siliceous sands or bleached sands, underlain at depths generally greater than 1.5 m by clay or less frequently a strong iron-organic hardpan. (NRInfo 2017)

The soil at five locations within lot 209 was tested for its properties and nutrients (Appendix B). The soil samples to 150 mm showed low pH values in the range of 3.62 – 4.79 ($CaCl_2$); hence the soil is quite acidic and requires amendment to neutralise the pH for optimal pasture production. The soil samples varied in their nutrient concentrations, e.g. nitrogen in the form of nitrate varied between 0.90 – 17.50 mg/kg in the five samples. Phosphorous concentrations (Olsen) in the form of phosphate were in the range of 4.06 – 10.3 mg/kg. Pivot irrigation and fertigation supports a uniform application of nutrients.

5.3 Phosphorous Retention Index

The Phosphorous Retention Index (PRI) describes the ability of the soil to retain phosphorous. Soil within the Peel Harvey catchment area is known for its low Phosphate binding, showing PRIs of 2-5 or even lower (EPA 2008). Bassendean Sand, as found on the site, is a typical surface formation of the Peel-Harvey catchment with very low PRI.
The PRI of the soil was tested at 5 locations within Lot 209. All samples had PRIs lower than 1.
Nutrient retention is essential for environmentally sound production using fertigation. To improve the PRI of the soils on site, various soil amendments will be tested as described in Chapter 5.6.

5.4 Acid Sulfate Soil

The Acid Sulfate Soil (ASS) Risk Map provided by the Department of Water and Environmental Regulation (DWER) defines the area as Class 2 - moderate to low risk of ASS for depths within 3m below natural ground (Figure 4).

5.5 Proposed Earthwork Details

No major earthworks are proposed on the site. To amend the soil to increased PRI, the upper soil (approximately 30 cm) needs rotary hoeing. This will simultaneously flatten minor depressions and hillocks on the site and increase efficiency of pivot irrigation.
In order to minimise any prospects of uncontrolled runoff in the event of heavy rainfall, soil will be raised by 0.5 m at the centre of the pivot relative to the outer western edge, thereby directing runoff to a perimeter gutter of soil amended to a PRI of over 25 (Figure 9).

5.6 Imported Soil Amendments

All soils will have agricultural lime applied to raise pH to at least 6.5. Various soil amendments will be implemented on site, to increase water holding capacity and the PRI of the soil, and hence reduce the leaching of nutrients. The soil amendments to be trialled are:

- Local clay
- Bentonite clay
- Iron Man Gypsum/Neutralized used acid effluent (NUA)
- Spongolite

Local clays will have PRI tested. Bentonite will be sourced from Watheroo and has a claimed PRI of 200 – 230. Spongolite, a natural mineral, has a PRI of 25 – 30. Through treatment, the phosphorous retention of spongolite can be significantly increased to PRIs of more than 1000. Iron Man Gypsum also has significant phosphate and organic nitrate binding capacities (DoW 2016). Bioscience has tested different batches of Iron Man Gypsum with PRI's between 600 - 900. The existing sand on site will be blended with various application

rates and combinations of amendments listed above. All of these application rates and combinations will be tested in the laboratory for PRI and Water Holding Capacity before final application rates are determined.
Amendments will be applied separately in strips to determine best working options for future development. The target PRI of the top 30 cm of soil will range from 10 - 20. Ratios of soil to soil amendment will vary based on laboratory trials on PRI of soil and each type of amendment.
Such soil amendments not only prevent nutrient leaching, they also increase water holding capacity of the soil and are expected to have positive effects on plant growth with increased Net Primary Productivity. Additionally, the pH of the soil will be neutralised with lime to promote better nutrient uptake, microbial biodiversity and soil organic matter production.

6 Water Resources Description and Use

6.1 Sensitive Water Resources

6.1.1 Wetlands

The site and its surroundings are mapped as one large Multiple Use Category Wetland:

- UFI 15802 – Multiple Use Wetland, site and surroundings

No other wetland is located on lot 209, the following wetlands are in the immediate vicinity of the lot (**Figure 5**):

- UFI 4832 – Conservation Wetland, located 1400 m north of northern boundary
- UFI 14608 – Conservation Wetland, located 1100 m north-west northern boundary
- UFI 4535 – Conservation Wetland, located 1500 m north-west of northern boundary
- UFI 4286 – Conservation Wetland, located 1500 m north-west of northern boundary
- UFI 4837, 4735, 4734, 4836, 4887, 5131, 4587, 4588 – Multiple Use Wetlands within the property, south of lot 209

6.1.2 Groundwater Users

The locations of groundwater users within the vicinity of the site are listed in Table 2. Existing groundwater users in the area were assessed through the Department of Water's Water Register database. 13 groundwater users are abstracting water from the Superficial Aquifer within a 3 km radius of the northern site boundary.
Groundwater licence (GWL) 1740472 is the closest groundwater user, located on the adjacent site west of the Kwinana Freeway less than 400 m west of the site.

Table 2: Groundwater Users Abstracting Water within the Superficial Aquifer

Licence No.	Number of Bores	Allocation (kL/yr)	Sub-Area	Approx. Distance from northern boundary
GWL 170472	1	10,000	Nambeelup	1270 m W
GWL 169926	1	14,650	Nambeelup	2300 m NW

GWL 60590	1	6,000	Nambeelup	3390 m W
GWL 182430	1	11,000	Nambeelup	2690 m NW
GWL 182488	1	11,750	Nambeelup	2900 m NW
GWL 178997	1	6,650	Nambeelup	2910 m NW
GWL 180242	1	13,750	Nambeelup	3000 m NW
GWL 174943	1	5,150	Nambeelup	3100 m NW
GWL 173258	1	195,000	Nambeelup	2470 m N
GWL 163374	1	20,000	Nambeelup	3340 m NW
GWL 180238	1	6,000	Nambeelup	2910 m N
GWL 110420	1	7,500	Nambeelup	3000 m NE
GWL 110690	2	9,000	Nambeelup	3150 m NE

6.1.3 Surface Water

According to DWER's Inland Waters Map, there are no drains crossing lot 209. The drainage management as described in Chapter 8 prevents runoff from leaving the pivot irrigation area so that no nutrients reach the drain south of lot 209.

6.2 Seasonal or Occasional Flooding

The site is not within the floodplain (Figure 6). Inundation of other parts of the property is common during winter. Inspection of Nearmaps imagery shows inundated areas occur in north/south strips. Field inspections show that these areas tend to be dominated by sedges. Minor earthworks as detailed in Chapter 5.5 will be used to raise the level of such winter inundated areas.

Probes will be placed on the site to continuously monitor soil moisture and soil salinity. Since irrigation will be scheduled based on the data retrieved from the probes, irrigation will be managed to avoid saturation of soil within the root zone. Non-phosphate fertiliser will be exclusively applied via pivot irrigation. Hence, if no irrigation is required due to water availability no fertiliser is applied and nutrient leaching via drainage can be prevented. Irrigation and fertigation is of much lower intensity during the winter months due to high rainfall as presented in Table 1. However, irrigation cannot be completely precluded in winter months due to seasonality of rainfall, wind and sunshine.

6.3 Groundwater Description

6.3.1 Aquifer Description

A large groundwater resource occurs in the regional unconfined aquifer known as the superficial aquifer. The superficial aquifer in the vicinity of the site consists of sediments of Bassendean Sand, Guildford Formation and Rockingham Sand. Generally, the Rockingham aquifer is connected with the superficial aquifer, the Leederville aquifer and the ocean interface. Locally, clay lenses can separate the Superficial Aquifer from the Rockingham Aquifer (DoW 2010).

Based on the bore log of the production bore of the hydrogeological assessment, the saturated thickness of the superficial aquifer at the time of the installation was 60 m.

6.3.2 Groundwater Flow, Discharge and recharge

DWER provides a Perth Groundwater Map, which shows groundwater contours and flow directions. On the site and in the immediate vicinity the groundwater flows in a westerly slightly south-westerly direction (Figure 7). Figure 7 shows the minimum groundwater contours in mAHD for the site.

North of the site, groundwater discharge is likely to occur towards Nambeelup Brook to the north and Nambeelup Pool towards the west of the site. Evapotranspiration and groundwater abstraction also play an important role in groundwater discharge.
The groundwater in the Superficial Aquifer is recharged by direct infiltration of rainfall. Low lying areas on the Swan Coastal Plain experience waterlogging in winter months, with wetlands and groundwater dependant ecosystem reliant on the seasonal rise in groundwater levels. Due to the connection of the Superficial and the Rockingham Aquifer, the recharge occurs simultaneously. However, the Rockingham Aquifer is also connected to the ocean interface.

6.3.3 Groundwater Level

In 2006 RPS conducted a groundwater monitoring program for an Environmental Assessment Report for this site. According to these findings, lowest water levels occurred in April 2006 at depths between 0.653 and 2.372 mBGL (mean 1.3 mBGL), highest groundwater levels in September were between 0.151 and 1.831 mBGL (mean 0.6 mBGL). The DWER bores adjacent to the site show variances in depth to groundwater to the RPS bores, which is likely to be due to differences in the elevation of the site and nearby where DWER bores are located. Additionally, the longer monitoring period of the DWER bores increases the range of groundwater levels. Based on recent groundwater level data (2008-2017) from HS92A, HS93A and HS93B, it is assumed that groundwater levels within the site can experience annual fluctuations of about 1.8 m between minima and maxima. Depth to groundwater varies between 0.78 m at HS92A and 4.01 m at HS93A, measured from top of casing level (TOC) to static groundwater level.

Top of casing levels in mAHD are not provided in the groundwater monitoring report by RPS, therefore a direct comparison of groundwater levels on the site to the DWER bores is not available.

On 25 January 2018 the water levels at PB1, OBS1 and OBS2 were 1.83 m below top of casing (mBTOC), 1.53 mBTOC, 1.58 mBTOC, respectively. Locations of DWER bores and PB1, OBS1 and OBS2 are shown in Figure 7.

Geotechncial investigation by GBGMAPS suggests clay is close to the surface in those areas experiencing winter inundation. As such, these are believed to areas of perched water, rather than reflecting groundwater levels.

6.3.4 Groundwater Quality

Based on the groundwater salinity contour map of the superficial aquifer presented by Davidson (1995), TDS of groundwater underlying the site ranges between 1000 - 1500 mg/L.

Analysis of the groundwater quality of the production bore PB1 (pre and post pumping test) was conducted by Bioscience. Results are provided in Appendix C. This groundwater quality is suitable for irrigation of annual and perennial pasture.

Results pre and post the pumping test are similar. The total amount of phosphorus dropped almost by half between pre and post the discharge test, from 0.11 mg/L to 0.061 mg/L. The sulphate concentration increased from 19.8 mg/l to 50.8 mg/l which is more than two-fold after 24 hours of pumping. Nitrate concentrations increased slightly from 0.06 mg/l to 0.084 mg/l, while the ammonia-N concentration dropped from 0.40 to 0.31 mg/L. The pH was slightly acidic and increased from 6.02 to 6.15. The electrical conductivity was constant over the period of pumping, however, was relatively high at 2.282 mS/cm, which indicated concentrations of total dissolved salts of around 1330 mg/L.

The groundwater monitoring program conducted by RPS in 2006 included two water analysis; in January and July 2006. Four monitoring bores were located at the corners of Lot 209 (from east [upstream] to west [downstream]: RGW 3, 8, 9, and 10).
RGW 3 and RGW 8 showed pH levels of 5.368 - 6.30, whereas the bore at the eastern boundary (RGW9) showed pH values lower than 4.74. Generally, nutrient levels were higher in January 2006 than in July 2006 at most bores. No other trend such as a downstream gradient is clearly identifiable. RGW8 which is located in the north-east corner of the lot showed the highest total phosphorous (3.1 mg/L) and lowest total nitrogen (0.8 mg/L) concentrations. Nutrient levels vary significantly between monitoring periods at one location as well as at different sampling locations during one monitoring event. It is noteworthy that no phosphate or nitrate fertiliser has been applied to the property in the last 10 years.

6.4 Source of Irrigated Water

This report is supporting the application of Kelliher Bros for a groundwater abstraction licence of 450,000 kL/annum within the stage 1 Development. A production bore was installed on 17 January 2018 within the superficial aquifer for the hydrogeological assessment. Locations of the production and monitoring bores are provided in Figure 3. The hydrogeological assessment (H2 Report) has been prepared and is currently under review.

6.5 PDWSA

The site is not within or near any Public Drinking Water Supply Areas.

7 Site Management

7.1 Irrigation System

Irrigation will use a center pivot irrigator with a radius of 355m. For stage 1 development one single pivot irrigator will cover an area of approximately 40 ha. Irrigation will be scheduled according to soil moisture, weather forecasts and plant needs. The pivot is able to deliver a maximum of 11 mm of irrigation water per day.
The soil amendments mentioned in Chapter 5.6 will increase both the water holding capacity and the nutrient retention capacity of the soil. Various blends of deep-rooted annual and perennial pasture varieties will be sown. These measures, plus the gradual development of

root biomass, soil organic matter and soil microflora, will continuously reduce the potential of leaching of irrigation water into groundwater.
The moisture content of the soil is central for the plant's performance. A moisture content of 10 – 18 % w/w is desirable, because it is well above the wilting point to prevent pasture from drying out and below the drained upper limit to prevent water seeping into the groundwater. Saturation of soil has adverse effects on pasture and will be prevented through irrigation management.

To monitor and maintain optimum soil moisture, 60 cm Sentek TriSCAN probes will continuously measure soil moisture, temperature and salinity up to 60 cm below ground level (BGL) in 10 cm increments. In the Sentek probe system, information is collated and sent through the central Data Transmission Unit via GPRS or NextG transfer to the internet. This way, the information is continuously updated and can be readily downloaded from anywhere with internet access. Through this decision making and management tool, the irrigation system can be adjusted to the current soil conditions. The computer-controlled irrigation management shows the real-time status of the pivot and can start and stop irrigation anytime.

The pivot irrigation system will be solar powered, backed up by a diesel generator. This means the operation of the pivot irrigator is mostly limited to hours of sunlight. The site will not be irrigated during forecast rain events or when the soil is approaching saturation. Irrigation is primarily scheduled from spring to autumn, because the winter months usually provide sufficient rainfall; however, winter is not excluded from irrigating. Irrigation can be adjusted to weather forecasts and current soil conditions to maximise water use efficiency.
It is anticipated that irrigation will be unnecessary if groundwater reaches within 250 mm of the surface, however, this will be calibrated using quantum fluorescence efficiency analysis of plants to measure water stress.

7.2 Crops

To maximize year-round efficiency, a combination of different crops will be trialed. Deep-rooted varieties are preferred to increase nutrient uptake and maintain soil moisture. A range of grasses and legumes will be grown as pasture on the site as described below.

- **Balansa Clover**: self-regenerating annual legume, adapted to most soils, tolerates water logging in winter, provides valuable grazing for livestock (DPIRD 2018)
- **Serradella**: annual legume, grows in autumn, winter and spring, deep rooted and can extract moisture and nutrients from depths up to 2 mBGL (DPI NSW 2018)
- **Lucerne**: perennial legume, main growth in spring, summer and autumn, drought resistant, (DPI NSW 2018)
- **Kikuyu**: perennial grass, drought tolerant, good for stabilizing soil (DPI NSW 2018)
- **Couch**: perennial grass, grows in wide range of soils, good salt tolerance (Agriculture Victoria 2018)
- **Biserrula**: persistent legume, deep rooted system, high level on grazing tolerance, deep-rooted (more than 2 mBGL) (DPIRD 2018)
- **Annual Ryegrass:** Oversown in perennial grass at the beginning of winter, ensures higher net primary productivity of pasture in colder winter months.

Most of the species listed above show great tolerance to different soil types as well as varying soil moisture. Due to the seasonal productivity variations of most pasture crops, a combination of pasture species is preferred to provide year-round feed for cattle . The choice of plants is not limited to the types listed above and will be based on the advice provided by successful irrigated pasture growers in and outside of Western Australia.
It is anticipated most pasture will be cut and baled into plastic silage wraps. Field experience may point to the requirement for direct controlled strip grazing by cattle remaining on the unirrigated parts of the property.

7.3 Design of the Irrigation Area

The soil amendments will be implemented in stripes through a fully factorial randomised design considering the following:

- Each soil amendment will be applied in multiple strips;
- These strips hold different application rates of the soil amendment;
- Combinations of multiple soil amendments in some of the strips;
- Strips of different pasture combinations will be sown orthogonal to strips of soil amendments to identify optimal combination of pasture and soil amendment.

7.4 Nutrient Application

Because the land is located within the Peel-Harvey catchment, we recognise there are a number of guidances and policies which must be adhered to before the necessary approvals for such a development can be obtained. However, with the adoption of management techniques including soil amendments, and the continuous monitoring of soil moisture and nutrient levels to adjust irrigation and fertigation rates, such a project will not exceed the target maximum values for nutrients exported to groundwater or surface drainage specified in current guidelines.

The *Peel-Harvey Environmental Protection Policy (Peel-Harvey EPP)* establishes phosphorous and nitrogen loading targets for the Peel-Harvey Estuary System, which new developments must adhere to. To comply with the nutrient loading targets, new operations within the catchment are required to achieve an export rate for total phosphorous (TP) lower than 0.28 kg/ha/year, as specified within the Department of Water’s modeling report (DoW 2011).

The Department's modeling report has also established maximum nutrient input (or application) rates for the Peel Harvey catchment in unamended soils, designed to achieve nutrient export loads within the thresholds mentioned above. Nutrient input rates are calculated, based on past practice to be less than 6.5 kg/ha/year for TP and less than 45 kg/ha/year for TN. In unamended soils these input rates will result in a maximum export rate of 0.28 kg/ha/year for TP according to the model. For amended soil, the model showed a decrease in total annual phosphorous loading of 68 % in the Nambeelup area. With combined implementation of amended soil and improved fertiliser efficiency, the model indicated an annual phosphorous loading reduction of 79 %. (DoW 2011)

It is anticipated that under fertigation, Net Primary Productivity (the production of pasture) will be very high, being potentially in to order of 100 tonnes wet weight or 13 tonnes dry weight per ha per year. The policy target input into non-amended soils is 6.5 kg elemental phosphorous and 45 kg elemental nitrogen per ha. Calculations show that this will produce a maximum dry weight of 2.2 tonnes of pasture. We therefore propose to undertake monitoring of phosphorous and nitrogen content of biomass removed from the site, either as mown or baled pasture. This will be determined by leaf tissue analyses of pasture, and dry mass per square meter. The data so generated will be used to calculate an overall mass balance of above ground TP and TN outputs relative to input.

Further, it is anticipated that deep rooted perennial grasses will lead to the progressive accumulation of carbon in the soil as plant roots, humus and microbial biomass. This total biomass is expected to contain a significant proportion of the applied phosphorous, and therefore will also be sampled and analysed. Below ground biomass will also be measured, to enable an understanding of the complete (above ground and below ground) nutrient mass balance. The maximum phosphorous (6.5 kg/ha/yr) and nitrogen (45 kg/ha/yr) input rates recommended by the Department of Water and Environmental Regulations will not be exceeded unless mass balance calculations demonstrate that at least 90% of these values have been exported from the site, or are in the form of stable biomass.

When this mass balance demonstrates that 90% of the applied P is accounted for by in situ or removed biomass then that same amount of P, being another 5.85 kg/ha of elemental P (90 %) can be applied. By this approach, maximum productivity can be achieved, while meeting the target of minimal or zero nutrient export. Adding phosphorous beyond 6.5 kg/ha/year and nitrogen beyond 45 kg/ha/year will not be allowed if lysimeter and monitoring bore data indicates that P and N is increasing in groundwater.

As described in Chapter 5.6, different soil amendments will be applied to raise the PRI of the soil and to minimize nutrient export levels.

To further minimize phosphorous and nitrogen export, no phosphorous and minimal nitrogen will be applied through fertigation. The science underlying foliar applications of fertiliser has advanced considerably in the last decade. Foliar spray will be applied when the pasture is established and the Leaf Area Index is high. Using appropriate adjuvants in the foliar spray mix, it is anticipated that 70-80% of the applied phosphorous will be directly taken up by foliage (Peirce et al. 2014). Therefore, application of phosphorous to soil will be significantly lower. Nitrogen will be applied in the form of urea in the foliar spray.

Additionally, a range of measures to prevent nutrient leaching such as deep-rooted pastures, irrigation scheduling according to current soil conditions, soil amendments to increase phosphate binding and runoff collection will be implemented, as well as a groundwater and surface water monitoring system. These measures are described further in this report (Chapter 8 and following).

Nutrient formulations will be based on hydroponic principles and include appropriate balances of all 5 major and 6 trace elements. Phosphorous will not be applied through fertigation, however, most plant nutrients will be applied via irrigation. Nutrients will not be applied with every irrigation cycle and application rates will vary. Fertigation rates will be based on leaf tissue analysis, soil analysis, mass balance, growing season, type of pasture and the stage of development of the plants.

8 Drainage and Nutrient Leaching Control

Surface soil on site consists mostly of medium grained sand (Geological Survey of Western Australia). This is supported by the results of soil investigation during bore installation and a permeability test of the soil conducted on the 28th of February 2018.
Two testing locations were determined according to the two different types of topsoil encountered during site visits. The soil at the first testing location was dry, partly cracked and was mossy rather than grassy. The second test location contained deep-rooted couch grass. Both soil surface types dominate the site (Figure 8).
Three different permeability tests were conducted at each location. A constant head permeameter and an infiltration ring with a diameter of 24.1 cm were used for the first test to determine infiltration of water in undisturbed topsoil. For the second test, the topsoil was disturbed with a shovel to represent infiltration when soil amendments are added. During the third test only a permeameter was used to determine infiltration of water 350 mm below the soil surface.
The soil at the second test location, which is characterised by deep-rooted couch, showed higher permeability than the soil at first test location during all three tests (33 – 102 mm/hr compared to 53 – 135 mm/hr) (Table 3). During the stage 1 development the soil will change from disturbed soil to pasture growing, so that infiltration rates of 53 – 125 mm/hr are most likely. This translates to the capacity of soil to handle rainfall and irrigation water in excess of 53 – 125 mm per hour. Accordingly, in heavy rainfall events (5 % AEP, 1 hour), rain water will infiltrate in soils and not lead to runoff. In the heaviest events (1 % AEP, 1 hour), water may transiently pool before infiltration (BoM 2018).
Soil amendment is anticipated to modify permeability and infiltration. Each amendment will have separate infiltration tests done in situ prior to sowing.

Table 3: Permeability Test

Test Ref	Northing	Easting	Test Depth (mBGL)	Permeability (mm/hr)	Comments
Location 1 Test 1	6399435	390236	0.00	33.3	permeameter and ring at surface
Location 1 Test 2	6399435	390236	0.00	85.0	permeameter and ring on disturbed soil
Location 1 Test 3	6399435	390236	0.34	102.4	only permeameter, below surface
Location 2 Test 1	6399340	389719	0.00	52.7	permeameter and ring at surface
Location 2 Test 2	6399340	389719	0.00	125.0	permeameter and ring on disturbed soil
Location 2 Test 3	6399340	389719	0.36	135.1	only permeameter, below surface

8.1 Drainage Management

As explained in Chapter 7.1, irrigation will be according to existing soil moisture and plant requirements to prevent soil saturation and runoff. The permeability tests (Table 3) showed the soil has a high draining ability and stormwater from most rain events can infiltrate in the soil. However, it is understood that the site is located in an environmentally sensitive area and drainage leaving the site should be avoided to prevent nutrient leaching.

It is anticipated that in late winter, when groundwater levels approach maximum, drainage water from heavy rainfall events at the pivot irrigation area could produce runoff. Such runoff will be directed via spoon drainage at the outer perimeter of the pivot to the vegetated, non-irrigated sector south-west of the pivot (Figure 9). The capturing structure will be approximately 4.5 ha and will be slightly depressed. Highest groundwater levels at RGW3 and 8 which are closest to the capturing structure showed lowest clearance to groundwater of approximately 0.24 mBGL. The spoon drain and the vegetated capturing structure will be lined with high PRI materials including NUA and calcined spongolite. These areas will not be fertilised beyond the need to establish phreatophyte vegetation.

8.2 Contaminant Leaching Control

8.2.1 Fertiliser Use Efficiency

On site, best management practices will be used to improve fertiliser use efficiency:

- Fertiliser applications will be based on the developmental stage of the plants;
- Fertiliser applications will be recorded to assist future fertiliser management decisions;
- Application of fertiliser via pivot irrigation and boom spray for uniformity of nutrient input across the site;
- Fertigation used when necessary, not in every irrigation cycle;
- No application of phosphorous through fertigation, but through foliar spray (for higher plant uptake);
- Application rates will be determined by leaf tissue analysis and mass balance.

8.2.2 Water Use Efficiency

On site, water use efficiency will be acheived through the following:

- The decision of when and how much to irrigate will be based on weather forecasts, soil moisture levels and plant requirements;
- Current soil conditions measured by probes will be accessible anytime via internet;
- Remote computer-controlled irrigation system that can be started and stopped anytime;
- High precision and uniformity at low application rates (11 mm per day maximum) will avoid soil saturation, to prevent seepage to groundwater.

9 Protection of Natural Water Resources

The objective of the project is to maximize pasture growth under environmentally responsible practices. The following chapter describes the steps to be undertaken to avoid nutrient leaching.

With a westerly groundwater flow, the site is upstream of the Black Lake, a sensitive wetland environment. With the best management practices used for irrigation and fertiliser application, prospects for any outside impacts are minimised. The first step is to apply water and nutrients only according to the plants needs, and hence avoid excess watering. Soil monitoring probes measure current soil conditions and the irrigation timing can be adjusted accordingly. Both systems (monitoring probes and the pivot irrigator) are remote controlled, to enable quick response to changing conditions.
To ensure no nutrient leaching, further measures will be implemented to treat local imbalances on a smaller scale. All excess water and drainage water that might occur from

rainfall at the pivot irrigation area will be collected in high PRI lined spoon drains and directed towards a vegetated, soil amended nutrient retention basin. The implemented soil amendments (Chapter 5.6) will have increased PRIs to bind phosphate.
Through harvesting pasture or minor cattle grazing, the nutrients that are built into biomass of pasture will be exported from the site in the form of plant or animal biomass.

To confirm exports of nutrients from the proposed activity are minimal and conform to guideline values, monitoring probes, groundwater bores and lysimeters will be installed. Shallow lysimeters and monitoring probes provide locally important data, because they are not influenced by nutrient inputs from off-site.
Groundwater monitoring bores will be installed upstream and downstream of the site to measure nutrient levels entering and leaving the site (Figure 10). Samples from groundwater monitoring bores are influenced by naturally occurring nutrient fluctuations or fluctuations due to fertiliser application in the vicinity of the site as well as historical nutrient application. Groundwater will be monitored on a monthly basis. Over many years Bioscience has undertaken groundwater analysis of a number of bores in the vicinity of the site, which shows that soluble anions phosphate, nitrate and sulphate, and the cation iron, show marked variations (by orders of magnitude) over relatively short time intervals, and independently of each other. At least a year of monthly monitoring data from both upstream and downstream bores is required to understand natural variance and stochastics before meaningful trigger values can be determined.
During the first year an acceptable trigger is when a nutrient concentration exceeds two standard deviations above the accumulated mean. If the trigger is exceeded, the contingency plan described in Chapter 10 becomes effective.

Nested bores will be installed to provide information about nutrient levels as a function of depth within the groundwater. This will provide an enhanced ability to understand the origins of nutrients.
Monitoring will start upon development approval and will follow the below commitments (Table 4).

Table 4: Monitoring Commitment

Commitment	Location	Frequency
Flow meter reading	PB1	Monthly
Groundwater level measurements	upstream and downstream bores	Monthly
Sample and water analysis	upstream and downstream bores	Monthly
Lysimeters	n/a yet	Monthly
Annual report	n/a	Annually

n/a – not available

Flow meter readings, groundwater level measurements and sampling will be recorded monthly, at least 20 days apart. Water sampling will be conducted as per AS/NZS

5667.11:1998. Water quality analyses will be carried out by Bioscience and a NATA accredited lab and will test the following:

- pH
- EC
- TDS
- Nitrate N
- Ammonium N
- Total N
- Reactive P
- Total P
- Chloride
- Sulphate
- Cations (calcium, magnesium, potassium, sodium)
- Metals (iron, manganese, zinc, copper)

The rate of aquifer drawdown due to irrigation will be inferred from the water level monitoring and rainfall data, and will be assessed once a year.

10 Contingency Plan

The objective of contingency planning is to provide assurance that the *Water quality improvement plan for the rivers and estuary of the Peel-Harvey system - phosphorous management (*EPA 2008) will not be compromised because of the site development.

The attainment of this objective cannot be judged without reference to existing groundwater nutrient values due to past and existing agricultural usage of the site and surrounding land. Water quality data will be collected from monitoring bores upstream of the site for reference purposes.

Comparing upstream and downstream monitoring bores will provide data about the site's influence on nutrients in groundwater. Therefore, nitrogen and phosphorous concentrations from the upstream and downstream monitoring bores will be compared. Nutrient levels should be the same or lower than upstream levels within a yet unknown lagtime, to show the site is not leaching nutrients. Nutrient spikes seem to occur randomly without the influence of fertigation input.
Once a year of upstream monitoring data is collected, a significant increase (two standard deviation units) of nutrient levels from the annual mean will be set as a trigger value. For the first year the mean of collected data will be calculated at each monitoring. If a measured N or P value exceeds the mean by two standard deviation units, monitoring will be repeated within two weeks. If the particular nutrient remains high, the source of nutrient spikes will then be investigated through intensifying of monitoring and comparing data from fertigation rates to data retrieved from probes, lysimeters and soil analysis that provide direct information about nutrient input and possible leaching.
Table 5 lists the trigger levels and the associated contingency actions. If any water in the shallow lysimeter occurs which is not explained by a rain event, then the irrigation volume will be reduced, the probes recalibrated and the lysimeter re-checked within one week. If

lysimeter water shows phosphorous or nitrogen concentrations in excess of 0.1 mg/L the fertigation and irrigation volume will be reduced. If monitoring probes show soil saturation at 50 cm below the surface, the irrigation volume will be reduced. If the total nitrogen or total phosphorous concentrations of the downstream bore are two standard deviation units above the annual mean, the phosphorous and nitrogen input rate will be reduced. If nutrients concentrations exceed the annual mean by more than two standard deviation units at the consecutive monitoring, fertigation and irrigation will stop until the cause of nutrient spike is determined and rectified. If two successive monitoring events and lysimeters and /or probes indicate nutrient leaching, the fertiliser rate will be reduced. If the water quality does not show improvement over the following monitoring event, fertigation will stop and the water application rate will be reduced (Table 5).

Table 5: Contingency Actions

Monitoring	Trigger levels	Contingency actions
Lysimeter	Any water in lysimeter which is not explained by rain event	Reduce irrigation volume and recalibrate Sentek probes, recheck lysimeter within 1 week
Lysimeter	Consecutive monitoring: Any phosphorous or nitrogen in excess of 0.1 mg/l	Reduce fertigation and irrigation volume
Monitoring Probes	Soil saturated at 50 cm below surface	Reduce irrigation
Upstream Bores	Data collection only	Data collection only
Downstream Bores	Nitrate or phosphate two standard deviations from annual mean	Reduce phosphorous and nitrogen input
Downstream Bores	Consecutive monitoring: Nitrate or phosphate two standard deviations from annual mean	Stop fertigation and irrigation until cause is determined and rectified

11 Vegetation Management

11.1 Clearing

The site is principally cleared of vegetation. Scattered paperbarks might need removal to enable pivot irrigation.

11.2 Erosion Control

Deep-rooted pastures improve soil structure and control erosion on the site.

11.3 Water and Nutrient Application Matching Plant Needs

As previously explained in Chapter 7.1, the irrigation intervals and duration will be determined by weather forecasts. The demand for water is greatest during summer months.

12 Pesticide and Storage Use

No pesticides will be stored onsite. Although no pesticides are likely to be used routinely, it is anticipated that insecticides may be required during the establishment phase of lucerne.

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