Kangaroo Island ecologically sustainable water take limits project final report

Department for Environment and Water

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity-building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

Acknowledgments

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This report was undertaken through funding provided by the Kangaroo Island Landscapes Board.

This report and all the underlying assessment was completed by Douglas Green (DEW).

The author acknowledges Aboriginal people as the First Peoples and Nations of the lands and waters we live and work upon and we pay our respects to their Elders past, present and emerging. We acknowledge and respect the deep spiritual connection and the relationship that Aboriginal and Torres Strait Islander people have to Country.

Contents

Summary

This report is the culmination of a project started in 2015 to establish the level of risk to the aquatic ecosystems of Kangaroo Island based on different management options. It is designed to provide insights to assist the Landscape Board in identifying options for future updates to the Water Affecting Activities Control policies for the Island.

Aquatic ecosystem monitoring data including macroinvertebrate samples, riparian vegetation and flow information has been collected annually across Kangaroo Island since 2016 and, in combination with Environmental Protection Authority Aquatic Ecosystem Condition Reporting data (including macroinvertebrate data), has formed a significant dataset used to model the response of the macroinvertebrate community across the flowing watercourses of the island. For the purposes of management, the Island is broken into management zones, based on sub catchments. As this is the scale of management, this was also the scale that was used for the modelling and assessment.

A form of machine learning called Boosted Regression Tree modelling was used to model the diversity of taxa and the number of sensitive taxa (termed EPT taxa). These models were used to predict the macroinvertebrate community response, as an indicator of overall aquatic ecosystem condition, to different management scenarios across the surface water management zones of Kangaroo Island.

A total of 42 different scenarios were tested including different water take limits (5% to 30%) and different proportions of riparian vegetation within the zone (sparse to fully vegetated along the river corridor). Scenarios were developed such that if the current water take from a zone is higher than the scenario being tested, the current take level was used to ensure consistency with the planning frameworks on the island. The “current” scenario was developed to represent the water development on the island (including forestry) prior to the 2019-20 bushfires.

The model outputs showed that there was a strong response in diversity and EPT taxa diversity to the (1) level of water take, and (2) level of riparian vegetation. The taxa diversity and EPT taxa diversity both showed a decline as the level of water take increased. This finding is consistent with conceptual modelling and previous assessments across the state. Higher levels of riparian vegetation supported more diverse and better condition aquatic ecosystems, again supporting conceptual understanding, although this is the first empirical assessment of the influence of changes in riparian vegetation on macroinvertebrate communities in South Australia.

The risk of degradation of the current aquatic ecosystem condition was assessed using a risk assessment framework. The assessment clearly identified that the risk of degradation increases with increasing water take and decreasing riparian vegetation.

The assessment shows that there is a high/very high risk to the maintenance of current ecological condition under levels of take allowed under the current Water Affecting Activity Control Policy (25%), and the current level of riparian vegetation. The 25% water take limit showed a large variation in risk due to different levels of riparian vegetation, ranging from very high risk at sparse riparian vegetation to low risk in areas with full riparian vegetation cover. This same pattern was observed for most of the water take scenarios assessed. This suggests that management of risk to aquatic ecosystems could consider the level of riparian vegetation cover when developing water use limits.

The assessment clearly identifies that any additional activities that result in an increase to water take will likely lead to an overall decline on the condition of aquatic ecosystems. However, given the confidence bounds around the data and the variability observed across the island, as well as issues discussed in the report (e.g. the impact of low flow devices on new development), the levels of risk should be interpreted as relative measures and need to be considered in the framework of acceptable levels of risk, akin to water planning in the Mt Lofty Ranges.

The results presented here are developed based on data mostly collected before the 2019-20 bushfires but are applicable to the post fire landscape once the immediate impacts of the fire have recovered.

Key Findings are:

- There is increased risk to the condition of aquatic ecosystems with increasing water take
- There is decreasing risk to aquatic ecosystem condition with increased riparian vegetation.
- The level of water take and the proportion of riparian vegetation interact to produce the risk rating
- The result provided here can act as to guide to developing island wide water management policy, but should not be used for site specific investigations.

The models used to inform these findings are robust and the results are supported by strong conceptual understanding and similar assessments undertaken in other regions across the state. While the models are not capable of reflecting all of the nuances of existing or future development on the island (e.g. low flow requirements) they are considered suitable for contributing to the development and future assessment of water policy for Kangaroo Island.

1 Background and Context

The current Kangaroo Island Water Affecting Activity Control Policy limits the take of water from catchments, sub catchments and/or properties (Kangaroo Island Natural Resource Management Board 2017). The allowed take of water is based on the '25% Rule'. This rule means that the development of water resources, such as dams, diversions and interception by commercial forestry for socio-economic benefits, can occur up to 25% of the mean annual catchment yield (runoff). The total water taken is calculated to be the sum of average annual volume of water deemed taken by dams, walls or other structures and the runoff intercepted by commercial forestry. By default the volume of water deemed taken by dams, walls or other structures is 50% of storage capacity. This policy has been adopted in recognition of investigations into volumes of water taken from farm dams which have found that on average the annual take (including evaporation and seepage) from a dam over multiple years is around 50% of a dam's capacity, although this does vary with dam volume and design (larger dams generally have less overall losses relative to their volume) (McMurray 2003). Although where better information is available such as metering or modeled results average annual take over multiple years is used. The water deemed taken by commercial forestry is equivalent to 85% of the mean annual yield within the net planted area based on the state government policy.

The '25% Rule' does not necessarily reflect an ecologically sustainable water take limit; rather it sets out to protect the equitability/reliability of supply for other users in the catchment. The effectiveness of this rule as a means of maintaining the health of water dependent ecosystems was questioned by a Commonwealth Scientific and Industrial Research Organisation (CSIRO) review of the current methods used for managing water on Kangaroo Island (Aryal 2010), which concluded that the current provisions may not be adequate for maintaining the health of water dependent ecosystems (WDEs). The CSIRO report recommended that the board progress to more ecologically considered methods for calculating water take limits in the region.

Inherent in this recommendation of Aryal (2010) is the assumption that the development of water resources on Kangaroo Island has had a detrimental impact on the WDEs of the island. This assumption is based on an extensive evidence base from South Australia, as well as internationally. In summary, the rivers of Kangaroo Island are mostly seasonal rivers that have a natural cease to flow period over the dryer parts of the year. In seasonal rivers like these, the duration of the cease to flow period is considered to be the master variable in driving the ecological community (Datry et al. 2014). As this is a natural process, the ecosystems of these rivers are adapted it, shorter cease to flow periods are linked to more diverse systems while longer cease to flow periods are associated with less diverse and more tolerant communities (Poff and Zimmerman 2010). The abstraction of water from rivers changes the flow regime of the river, in particular, dam development causes a delay in the onset of flow while dams fill (Alcorn 2008). The delay increases the duration of the cease to flow period putting pressure on the aquatic ecosystems who may not be adapted for longer cease to flow durations, potentially leading to degradation of the aquatic ecosystem (Poff and Zimmerman 2010).

It is also important to note that the impacts from water resource development vary across the Island and with factors other than water resource development (Acreman and Dunbar 2004). Factors such as the clearance of land (Richardson, Holmes et al. 2007), changes to water quality (Quinn, Cooper et al. 1997, Buck, Niyogi et al. 2004, Sheldon and Fellows 2010) and increased volume and speed of runoff due to lack of vegetation (Poff and Zimmerman 2010) have a direct impact on the way the rivers flow throughout the year, and therefore, the condition of WDEs. There are also effects not directly related to flow regime (e.g. channel incision: Quinn, Cooper et al. 1997). The combined effects of these changes has led to the overall degradation of the condition of WDEs (Allan 2004).

The Kangaroo Island Natural Resource Management Board (predecessor of the Kangaroo Island Landscape Board) commenced the ecologically sustainable water take limits project for Kangaroo Island in 2015-16. The objective of this project was to collect ecological and hydrological data from the WDEs of the Island and to use these data to assess the hydrological requirements of WDEs and the level of risk posed to them under different water take limits. This could then allow the managers of the island's water resources to make environmentally considered decisions that would progress the Island towards its environmental objectives and maintain the island's "clean, green" image (Kangaroo Island Landscape Board 2021). The project originally planned to collect data for three years and then analyse the data in 2019-20. Due to the significant bushfires and due to the COVID-19 pandemic disruptions, this work was delayed until 2022, which allowed for additional data collection.

For data collected in 2020, data from the fire affected area of the island was not used as part of this assessment, as the dominating factor in the condition of those sites will be fire itself. The extrapolation of the results of this work are designed to be applicable to the post-fire landscape once recovered, including areas where landuse is potentially being converted from forestry to agriculture. However, it does need to be acknowledged that the impact of the fires itself will be evident in the condition of impacted WDEs for several years.

This report describes the methods used to undertake the assessment of the ecological data and the subsequent assessment of risk to WDEs based on a series of different policy scenarios. This report does not propose new water take limits for Kangaroo Island but provides inputs that could potentially inform water policies in the future. The Kangaroo Island Landscape Board will determine how the findings of this work are applied to inform the islands water take limits.

The risk assessment process used an ecological objective of *no further degradation of water dependent ecosystems as a result of water resource development* as the baseline for this assessment. The general objective of the *Landscape SA Act 2019* (Section 7(1, 2)) is to support and enhance ecologically sustainable development by establishing an integrated scheme to promote the use and management of the water resources. Ecologically sustainable development comprises the use, reuse, conservation, development and enhancement of natural resources and landscapes in a way, and at a rate, that will enable people and communities to provide for their economic, social, cultural and physical well-being while—
(a) sustaining the potential of landscapes, including natural resources, to meet the reasonably foreseeable needs of future generations; and
(b) safeguarding the life-supporting capacities of natural resources and landscapes; and
(c) avoiding, remedying or mitigating any adverse effects of activities on natural resources and landscapes.

2 Methods

2.1 Data collection and sourcing

Ecological data were collected for the project as per the overarching project plan for the environmentally sustainable water take limits project (DEWNR 2016, DEW 2018). Data collected related to geomorphology, vegetation, macroinvertebrate, water quality and water level across multiple sites across the island.

The key dataset used in this assessment was the macroinvertebrate data sourced from this project as well as data from the EPA's Aquatic Ecosystem Condition Reporting program (South Australian Environmental Protection Authority 2022). Both sampling programs use the same macroinvertebrate collection method which involves sampling 10 metres of the pool and 10 metres of riffle (where present) habitat using a sweep net (Goonan et al. 2018). Specimens are identified to an agreed level (species, genus or family), not all taxonomic groups are identified to species level. Due to this, in this report, diversity is referred to as "taxa diversity" rather than species diversity. Importantly, Ephemeroptera, Plecoptera and Trichoptera (EPT) are all identified to species level. Abundance is recorded in a categorical manner in the field but is not used in this work, all data is presence/absence.

Spatial data were sourced from the EGIS DEW spatial database, Kangaroo Island Landscape Board staff and modelled outputs.

2.2 Environmental modelling

The environmental modelling process was divided into two sections. The first was the development of models that were effective at modelling the observed results. The second was the extrapolation of those data across the island using parameters based on spatial data as model predictors.

2.2.1 Establishing condition

The modelling process used in this assessment required a measure of environmental condition to use as the target for modelling that is a direct measure of the overarching objective. The establishment of condition is a subjective measure and there is debate around how best to establish condition, and what that condition actually represents. In aquatic ecology, macroinvertebrates are considered to be one of the best indicators of aquatic ecosystem condition with a considerable body of literature supporting the use of various methods of condition rating (Chessman 2003). This is because there is a large number of different macroinvertebrate species found in aquatic habitats that have very diverse habitat requirements, tolerances and traits. Looking at both the number of different species and which species are present provides a good insight into current state of the site sampled.

Multiple models were trialed to identify the optimal method for understanding the ecological response to changes in catchment conditions. Two key methods were trialed; 1) direct measures of community diversity; and 2) condition scores underpinned by a series of community metrics tied to the EPA's aquatic ecosystem condition reporting condition scoring system (Goonan et al. 2018).

The two metrics used for the direct measure of community diversity was; 1) taxa richness; (i.e. number of taxa present) and 2) the well-established EPT score (i.e. number of the EPT (Ephemeroptera, Plecoptera and Trichoptera) species).

The condition scoring method incorporated three different metrics (Taxa richness, EPT taxa richness, and Trait richness) into a single summary score. Flow and salinity sensitive macroinvertebrate taxa were also considered but were not used for further assessment as they provided limited information at most sites. For sites sampled by the EPA, the scores for the three metrics were binned against the final EPA condition score for the site (very poor – excellent or 1 to 6) providing a 1 to 6 score for the metric. These three individual metric scores were then averaged to get an overall condition score for the site. This condition score was compared back to the original EPA condition score to validate the method. Once validated, the scoring system was applied to all sites.

2.2.2 Macroinvertebrate model development

Boosted Regression Tree (BRT) modelling was used to build two models, taxa diversity and EPT taxa. The condition score was not used for model development as the range of possible results was too narrow to be effectively modelled. The combination of taxa diversity and EPT taxa was considered to be sufficient to examine the modelling results in the context of overall WDE condition as they represent two of the key measures used for the assessment of ecosystem condition (Chessman 2003, Lenat & Penrose 1996).

The BRT modelling technique is a form of machine learning that uses a series of decision trees to get the best model fit (Elith, Leathwick et al. 2008). The "boosted" part of the process relates to the weighting of unexplained parts of the dataset, such that the model fits progressively explain all of the data. This process was selected as it is a robust method that establishes the contribution of the various input variables and is suitable for prediction to spatial data (Elith, Leathwick et al. 2008). This process allows for the exploration of not only the predicted variables but also what the model considered the driving processes. For sites where there were multiple results (i.e. repeated sampling) the average of all years was used as all other time series datasets (e.g. runoff) were averages.

Boosted regression tree modelling was undertaken in RStudio (R Studio version 2022.02.2, running R version 4.2.0 (Vigorous Calisthenics) (R Core Team 2013) using the GBM package (Greenwell, Boehmke et al. 2019). The modelling process used methods developed by Elith, Leathwick et al. (2008) to facilitate easier modelling and interpretation of results. Initial models were built using the full suite of predictor variables based on a conceptual understanding of the drivers of WDE condition on Kangaroo Island (DEW 2018) and literature review (Deane, Wallace et al. 2016) (listed in Appendix 1). A stepwise variable elimination process was used to remove variables not contributing to the final best model fit. Manual interrogation and input variable selection were undertaken to achieve the optimum model results based on minimising the unexplained residual.

The final variables identified for use in the final version of the models are shown in Table 1. For predictor variables that represent a time series (e.g. temperature), the average of the time frame available was used to align with other hydrological investigations currently underway on Kangaroo Island (see Appendix 1). Averages were used rather than raw time-series data to ensure the model would be useful for prediction. Using the annual predictor data to assess each sampling event for the year of sampling would likely have produced a more accurate model, however, there is no method of predicting this model forward into the future. This relates to the inability to accurately predict annual conditions into the future. Rather, this modelling approach assumes that the next 10-20 years will be, on average, the same as the last 10-20 years.

Models were built using data from both the zone incorporating the sampling site as well as the cumulative catchment area above the sampling site. This means that for some of the predictor variables there are two values used, within zone and cumulative of all upstream area). The descriptions of each of the input variables used in the modelling process are described in Table 1, more details including spatial and temporal scale of the data is included in Appendix 1. The prediction was done assuming a sampling site at the end of each of the zones. All of the spatial data were calculated accordingly.

Table 1: Spatial data used in the prediction of condition scores across Kangaroo Island

Data Type	Layers Used	Description	Unit	Source
Administration	Management Zones	Subcatchment zones used for water planning on Kangaroo Island	-	Landscapes KI
Water use	Dam volume	The total volume of all dams. Calculated both for each zone and for the area upstream catchment	Megalitres (ML)	Landscapes KI
	Dam density	The relative volume of all dams in the area of interest divided by the area of upstream catchment. Calculated both for each zone and for the area upstream catchment	Megalitres per square kilometre (ML per KM^2)	Landscapes KI
	Total demand	The total volume of water deemed taken. Calculated both for each zone and for the area upstream catchment	Megalitres (ML)	Landscapes KI
	Yield per zone	Total volume of runoff generated. Directly related to rainfall. Calculated both for each zone and for the area upstream catchment	Megalitres (ML)	Landscapes KI
	Impact metric	Index of the level of impact to the low flow components of the flow regime in response to water resource development	Derrived index	(Green, Savadamathu et al. in prep.)
	Riparian vegetation	Measure of the proportion of the photosyntetically active vegetation over the summer months (Dec-Feb) within 50m of watercourses. Calculated both for each zone and for the area upstream catchment	Proportion	Sentinel Satellite data
Ecological	Land cover	Area of land classified as native vegetation, forestry and herbaceous	Hectares (Ha)	Modelled based on Sentinel satellite data
	Macroinvertebrate community metrics	Taxa richness and EPT richness	Number of taxa	Calculated
Physical	Salinity – watertable induced	Classification of the salinity of the watercourse	Classification	DEW Mapping product
	Watercourses	Mapped watercourses produced from LiDAR mapping of the island	-	Landscapes KI

2.3 Risk assessment

The purpose of this work is to provide an assessment of the risk to WDEs based on different water take and riparian vegetation scenarios across all of Kangaroo Island.

The scope of the risk assessment was to assess the risk to the WDEs within watercourses that require seasonal or perennially flowing water (lotic environments). This risk assessment is not designed to assess the risk to all types of aquatic ecosystems on the island. Some watercourses are too small and flow is too episodic to support aquatic ecosystems suitable for assessment using the models generated. Assessment of ecosystems within lakes and wetlands, estuaries, and those dependent on groundwater was outside the scope of this approach.

The Kangaroo Island Landscape Board, as a water resource manager, has a regional objective within the Kangaroo Island Water Affecting Activity Control policy '*To support the development of water resources in a sustainable and equitable manner, optimising productive use while providing for the needs of water-dependent ecosystems and other water users.*'

To assess the risk, the input data to the predictive component of the BRT modelling process were modified to have different levels of water resource development for each zone. This additional water resource development was represented in the input data by increasing total dam capacity and dependent parameters that include total dam capacity, water deemed taken by dams, water deemed taken by dams (cumulative), total deemed taken, total deemed taken (cumulative), dam density and impact metric. Several scenarios were assessed including scenarios limits of 5%, 10%, 15%, 20%, 25% and 30%. If the current level of water deemed taken was higher than the scenario being tested, the current level was retained. In line with the current Kangaroo Island WAA Control Policy, the dam capacity was set at double the water deemed taken (i.e. a water take limit of 15 ML per year means the limit of total dam capacity is 30 ML).

Based on preliminary results, riparian vegetation (all photosynthetically active vegetation within the river corridor) was assessed to examine the impact on the condition scores. There were five scenarios considered for riparian vegetation, 20%, 30% 40%, 45% and 50% photosynthetically active vegetation over summer. It is important to note that the percentage of photosynthetically active vegetation within the river corridor is not reflective of the portion of land covered in vegetation. The percentages chosen roughly correspond to cover levels of sparse (<20%), limited (30%), lower mixed (40%), upper mixed (45%) and nearly fully vegetation (50%). For context, fully vegetated zones, such as those in Rocky River are around 60%. Example zones are shown in Appendix 2.

Including the current water take and the current riparian vegetation scenarios, there was a total of 42 scenarios tested. To predict risk across the management zones of the island, a prediction dataset was created that contained the same variables as the input for the final BRT model but with the updated scenario data. The data were checked to ensure that the prediction dataset was within the bounds of the original dataset (i.e. scenario data were not outside model bounds). Not all of the management zones were assessed as there are a variety of aquatic ecosystems present on the island and not all of them are impacted heavily by water resource development or are not suitable for this assessment. The ecosystem type for each of the zones was identified as either lotic, lentic, wetland/flat, episodic (karst/sand) or episodic (<8km of watercourse) and only lotic zones were included in the assessment. These zones are those that have seasonally flowing watercourses. Additionally, all zones that had no defined watercourses and zones that are less than 100 hectares were excluded from the assessment. For the risk assessment process, zones that were mostly contained in National Parks or conservation areas were not assessed as development is highly unlikely in these areas and their inclusion would bias the results.

The risk level associated with each of the scenarios was estimated as the total estimated change in the community across all of the assessed zones. This method provides a simple investigation of both likelihood and consequence, with the likelihood represented by the frequency of results that showed a negative outcome, and the consequence represented by the magnitude of the change. Through this method, the maximum amount of information was preserved through to the final assessment, rather than using summary metrics (e.g. averages). The resulting risk index was categorised based on a simple assessment of how negative the index was (i.e. the risk of not maintaining the current condition) (Table 2).

Table 2: Table used to assign risk ratings to the outputs of the risk assessment process. The index represent the cumulative impact to the EPT community across all zones assessed. Greater than zero suggests an improvement over current conditions while a negative value suggests an overall decline in condition.

Risk	Taxa richness risk index values	EPT richness risk index values
Low	> 0	> 0
Moderate	-50 to 0	-40 to 0
High	-100 to -50	-75 to -40
Very high	-200 to -100	-90 to -75
Extreme	< -200	< -90

3 Results

3.1 Macroinvertebrate community results

A total of 100 individual macroinvertebrate data points were used for the assessment, representing 75 individual sites. These were sourced from historic EPA records (Goonan, Corbin et al. 2018) and sampling as part of the current program. The data collected ranged across 48 management zones from 2008 to 2020. Of these, 54 were sites sampled once, 17 were sites sampled twice and four were sites sampled three times (Figure 1).

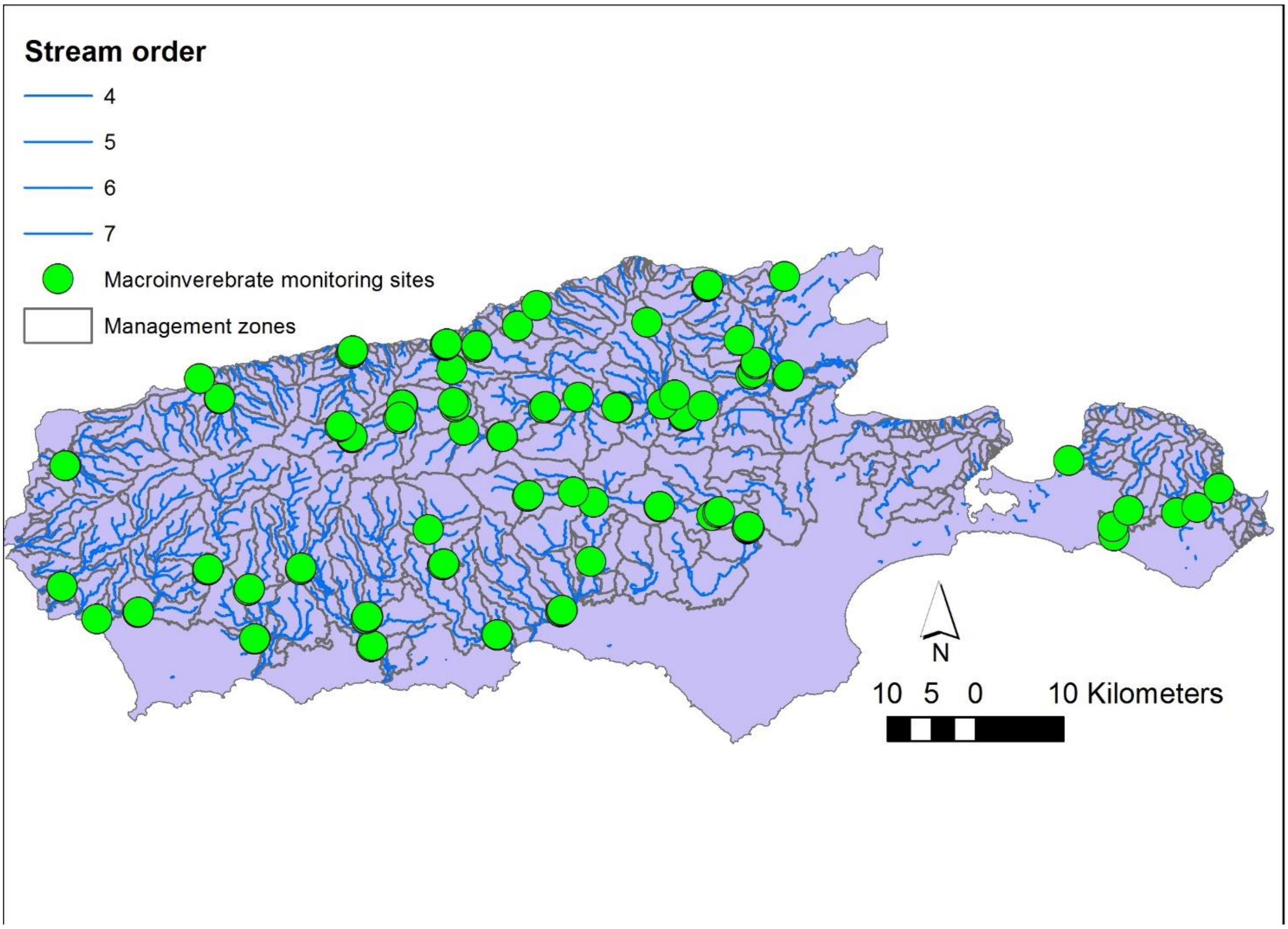

Figure 1: Map of Kangaroo Island showing the location of macroinvertebrate sampling sites sampled between 2008 and 2020 used in this assessment.

Table 3 shows summary statistics from the conditions assessment. The condition score showed a strong relationship with each of the input metrics, however, all showed variability suggesting that all three were contributing to the final score (Figure 2).

Table 3: Summary statistics from the macroinvertebrate condition assessment including the three input metrics and the final condition assessment.

	Taxa Richness	EPT Species Richness	Trait Richness	Condition Score
Mean	26.5	2.8	69.3	4.1
S.D.	9.8	2.6	2.3	0.9
Max	65	11	73	6
Min	11	0	61	1.6

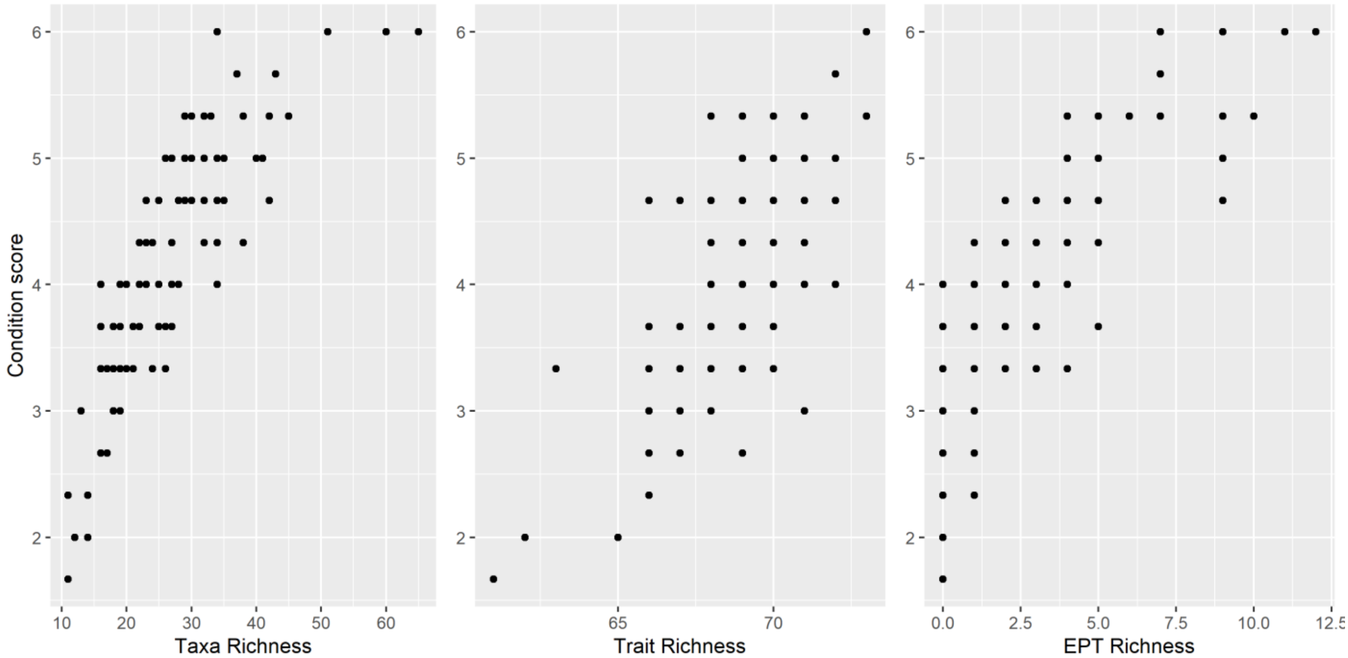

Figure 2: Comparison of the final condition rating against the three input metrics. (Condition scores: 1 very poor, 2 poor, 3 Fair, 4 good, 5 very good, 6 excellent).

Condition was on average highest in 2018 and lowest in 2013 (Figure 3, left). There was a general increase in condition between 2013 and 2020, likely driven by an increase in average annual rainfall and better flow conditions. The high diversity recorded in 2018 is likely linked to higher rainfall experienced in 2016 and 2017. The decline to 2019 and 2020 is likely linked to the low antecedent rainfall in 2018 and 2019. There was a difference in the diversity and corresponding condition scores between the data from Kangaroo Island and the data from the Mt Lofty Ranges (Figure 3, right) when assessed using the Kangaroo Island condition model. While the median scores are similar, the strong clustering of data at the maximum (5-6) suggests that the model is inappropriate for the Mt Lofty Ranges data. This was driven by higher diversity in the Mt Lofty Ranges across all three of the input metrics into the condition score, likely driven by frequent disturbance to the Kangaroo Island landscape (fire). This supported the need for a Kangaroo Island specific model.

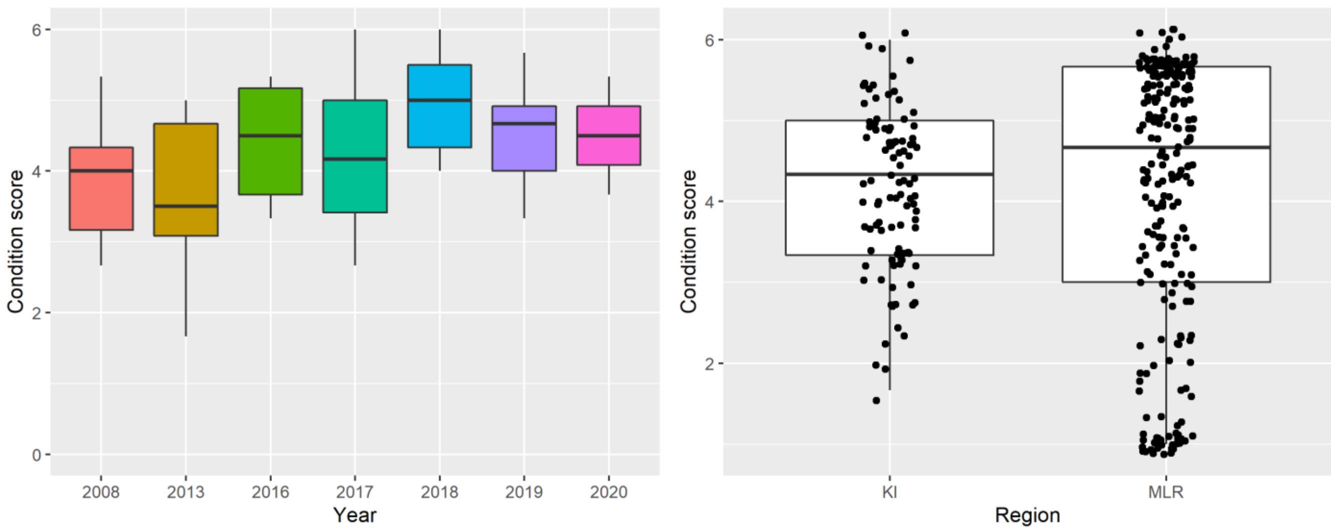

Figure 3: Macroinvertebrate condition scores for Kangaroo Island from 2008 to 2020 (left) and comparison of Kangaroo Island data to data from the Mt Lofty Ranges (right).

3.2 BRT modelling results

Modelling was undertaken on the number of EPT taxa and the taxa richness. Both the EPT richness and the taxa richness models showed good initial results with residual deviance values being relatively low and the correlation scores being greater than 65%. Further development using the GBM.step function acted to optimise variables. Through successive runs of the models and implementation of the GBM.step function, variables that either showed little/no influence or showed nonsensical results were removed. Final variable selection was undertaken by manual trial and error assessing the mean residual deviance, cross validation correlation and training data correlation to maximise the fit of the model without overfitting.

The final input dataset used for the assessment had nine input variables modelling 100 separate data points from across the island (shown in Table 4). The final taxa richness model was built using a laplace model distribution with tree complexity of 10 with 8 folds resampled every 50 trees. The bag fraction was 75% and the model had a learning rate of 0.05. The resulting model had a mean residual deviance of 0.43. The cross validation deviance was 0.859 with a standard error of 0.02. The training data correlation was 94.2% with a cross validation correlation of 86.0%.

The final EPT richness model was built using a laplace model distribution with tree complexity of 10 with 8 folds resampled every 50 trees. The bag fraction was 75% and the model had a learning rate of 0.008. The resulting model had mean residual deviance of 0.168. The cross validation deviance was 0.278 with a standard error of 0.045. The training data correlation was 96.7% with a cross validation correlation of 93.4%.

The comparison of the original data to the predicted data is shown in Figure 4. The contribution to the final models of the predictor variables is shown in Table 4. The linear regression through the model results suggests an over estimation in the lower diversity numbers and a under estimation in the higher diversity numbers. Despite this the overall fit was considered to be good enough to proceed with prediction.

Table 4: Relative contribution of the input variable to the final model for taxa richness and EPT.

Input	Relative contribution Taxa Richness (%)	Relative contribution EPT (%)
Total water deemed taken (forestry and dams, cumulative)	12.83	11.34
Water deemed taken by dams (cumulative)	12.41	16.66
Yield (cumulative)	12.25	11.80
Riparian vegetation	11.51	11.04
Salinity class	10.56	12.63
Impact metric	9.70	8.05
Yield	8.79	9.47
Native vegetation	8.09	5.73
Water deemed taken by dams	6.79	6.42
Total water deemed taken (forestry and dams)	3.31	6.84

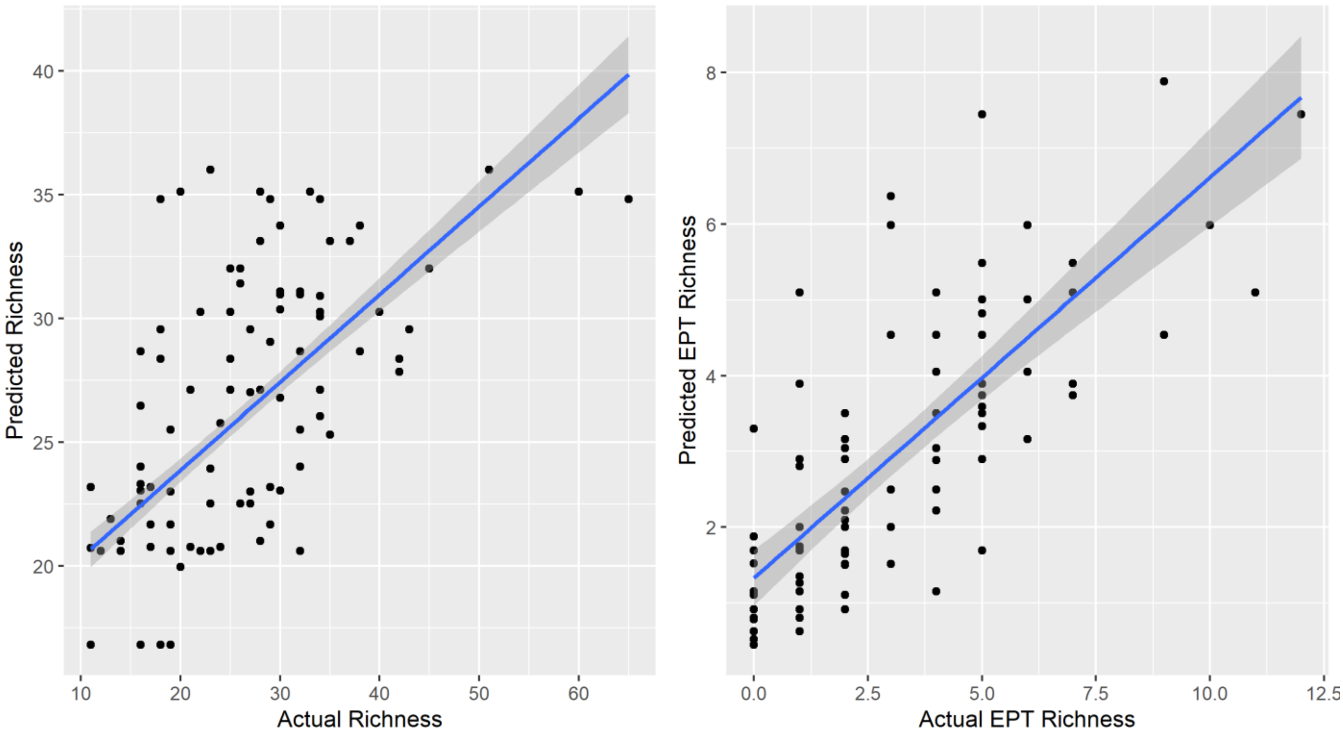

Figure 4: Comparison of actual scores across all years against the predicted values for taxa richness and EPT richness. The blue line represents the best fit to illustrate the relationship and the shaded area represents the 95% confidence interval.

The prediction of results across the island using the model was undertaken to assess the spatial variability of the results. The results showed a clear east to west pattern with the rivers in the west generally showing greater condition than those in the east (Figure 5). This reflects several known gradients on the island including the increase in riparian vegetation on the western end of the island, the increasing salinity around the central plains (especially the region around Timber Creek) and the higher rainfall on the western end of the island.

The results for the EPT and the taxa richness models showed similar patterns though there are some zones which show different results. These are likely due to the difference in response of sensitive taxa and general taxa diversity as well as differences within the models. These results were used for the basis of the risk assessment, whereby and loss of condition relative to these values was considered to be failing the ecological objective.

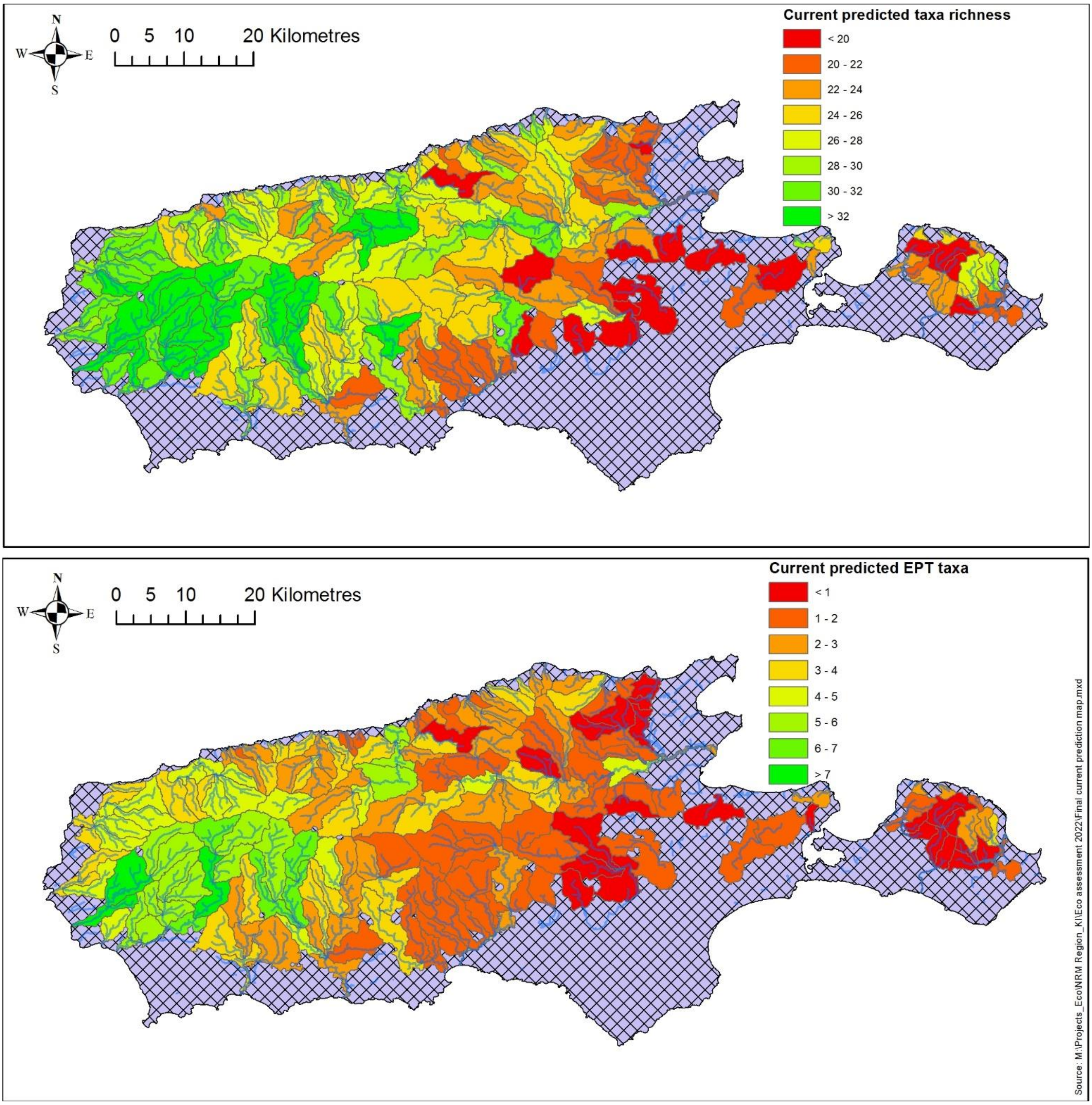

Figure 5: Prediction results for both the taxa richness model and the EPT model for each management zone on the island under current conditions. Management zones not used for assessment are hashed out.

3.3 Scenario prediction

The prediction for the difference scenarios was undertaken in a single run of the prediction function for each model by compiling all of the scenarios into a single dataset. The resulting predictions were assessed to see if they were logical in regards to how they related back to conceptual understanding and general understanding of WDE condition of the island. The nature of BRT models is that prediction can sometimes lead to nonsensical results where data from the prediction dataset falls in gaps from the training dataset, i.e. predicted results falling outside expected ranges. Any management zone where the predicted data for the 5% scenario showed worse condition than the 30% scenario were removed from the assessment as well as any site that showed a strong increasing trend with increasing water take (individual site slope result greater than 0.001). This resulted in a total of 128 zones being used for the taxa richness model scenario prediction and 138 zones being used for the EPT model scenario prediction. The majority of the zones that were dropped from the assessment were zones that had very low taxa richness or EPT numbers predicted, presumably as the model was not overly well calibrated to the lower condition end of the site spectrum.

The results showed that increasing the water take limit had a negative impact on the number of both total taxa richness and EPT taxa present (Figure 6). Looking at the averaged results across all assessed zones, every scenario showed a decline in condition with increasing water take (using the current level of riparian vegetation), however, there was considerable variability in the data so the average values do need to be interpreted with this in mind. The decline in both total taxa richness and EPT taxa showed a decreasing rate at higher water take limit scenarios suggesting that further increases past 30% may result in limited further decline (i.e. all the sensitive taxa are gone). Increasing levels of riparian vegetation were linked to increased total taxa richness and EPT taxa. In both the total taxa richness and the EPT model results, there is minimal change between the 20% and 30% riparian vegetation scenarios, however, there is a sharp increase in both between 30% and 50%

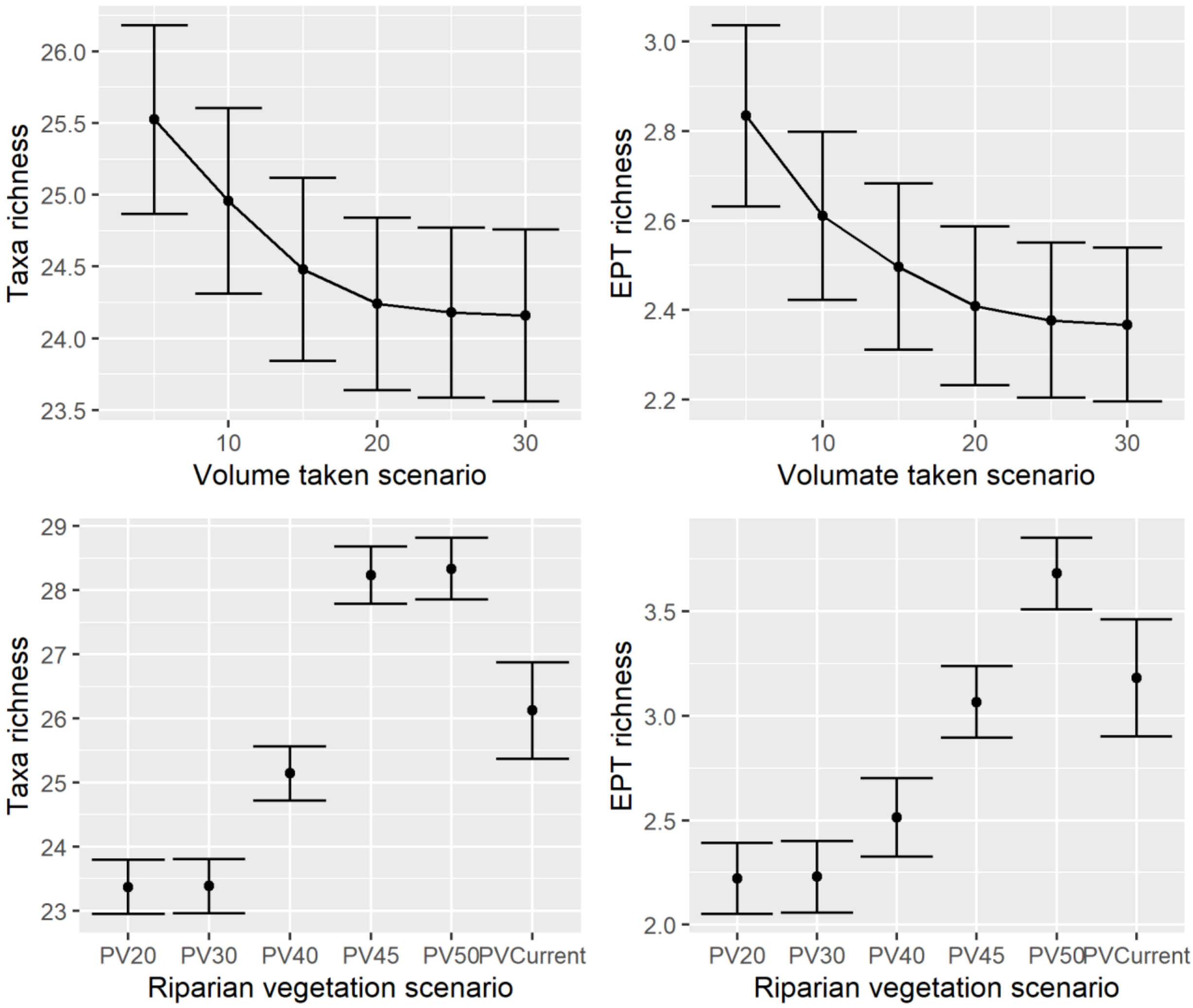

Figure 6: Scenario results showing the average results in taxa richness and EPT taxa under different water take limits (top row) and riparian vegetation (PV) scenarios (bottom row). Error bars illustrate the 95% confidence intervals of the mean for each of the scenarios across the zones assessed.

Combined, the two sets of scenarios show that the highest average taxa richness and EPT taxa scores were predicted for the 5% limit scenario with 50% riparian vegetation while the lowest results are for the 30% limit scenario and the 20% riparian vegetation scenario (Figure 7 and 8) This supports the conceptual understanding of how these systems work and the respective influence of these two drivers. The variability within the data was highest in the current riparian vegetation scenario as there is considerable variation in the current level of riparian vegetation represented in the current data (range from 9.4 to 68.8).

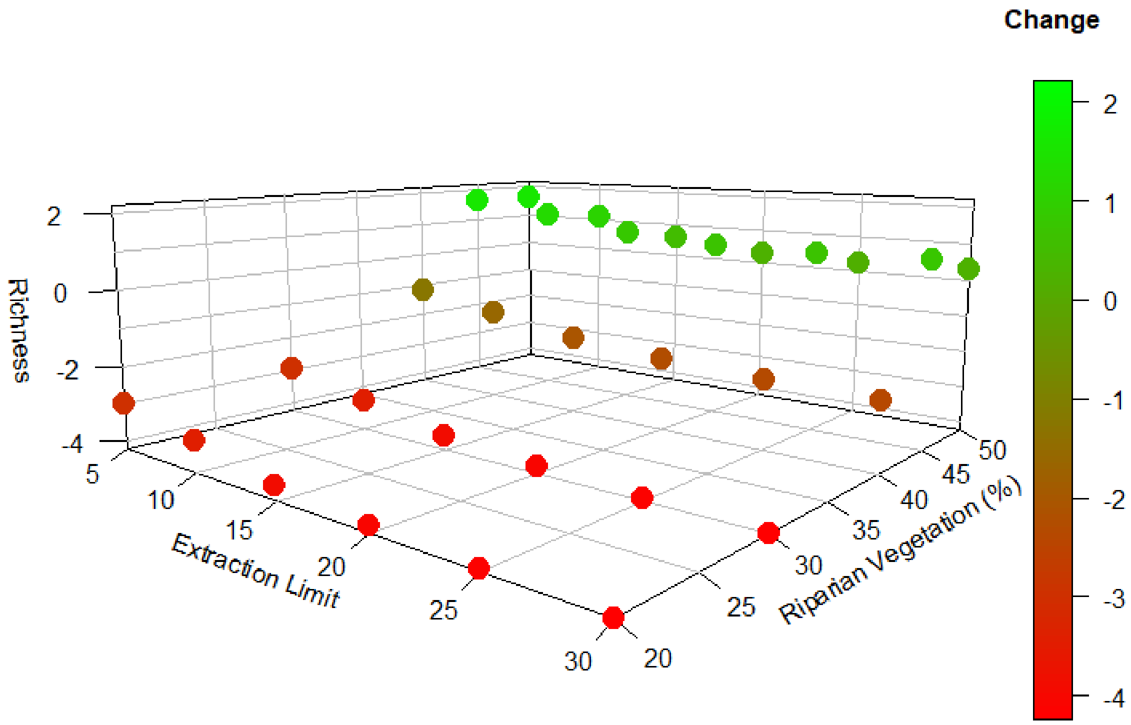

Figure 7: Average change in taxa richness from current condition across all of the scenarios assessed

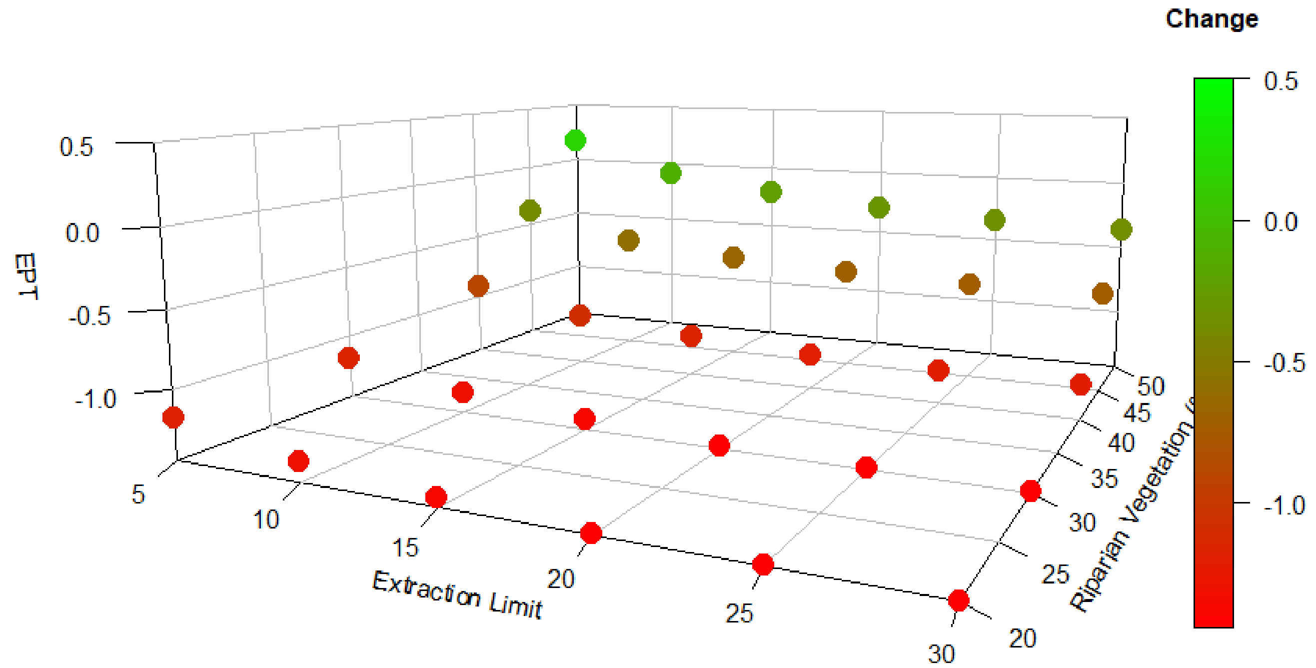

Figure 8: Average change in EPT taxa from current condition across all of the scenarios assessed

3.4 Risk assessment

The risk assessment index illustrating cumulative impact to the taxa richness and EPT community across all zones assessed generally followed the same pattern as the average values from the scenario analysis. Values greater than zero suggested an improvement over current conditions while a negative value suggested an overall decline in taxa richness and the number of EPT taxa. The values ranged from -387.4 to 277.5 for the taxa richness and -109.6 to 75.8 suggesting that there is a wide range of outcomes covered by the different scenarios.

The scenario with the highest risk index (largest overall improvement in condition) was the current water take limit scenario with 50% riparian vegetation for both the taxa richness and the EPT results. The lowest risk index (largest overall loss of condition) was the 30% water take limit scenario with 30% riparian vegetation for taxa richness and the 25% water take limit scenario with 20% riparian vegetation (Table 5).

There were several scenarios that showed improvement in taxa richness and/or EPT. There was 15 of the 42 scenarios showing improvement in taxa richness. These scenarios were all in the higher riparian vegetation scenarios (40%, 45% or 50%) and generally associated with the lower use limits, with the exception of the 50% scenario that showed improvements over all scenarios. Positive outcomes were limited to 9 of the 42 scenarios for the EPT models, reflecting the more sensitive nature of the EPT taxa. These positive EPT outcomes were limited to the low use, high riparian vegetation scenarios.

Table 5: Summary table of results from the risk assessment for both the taxa richness and EPT scenario modelling. The current limit is highlighted in blue.

Water take limit scenario	Riparian vegetation scenario	Zones that lose taxa richness (%)	Zone that lose EPT taxa (%)	Risk assessment index (Taxa richness)	Risk (Taxa Richness)	Risk assessment index (EPT)	Risk (EPT)	Overall risk level (out of 10)
5	PV20	84.3	73.2	-259.1	Extreme	-82.2	Very High	8.5
10	PV20	79.5	73.9	-299.0	Extreme	-95.3	Extreme	10
15	PV20	81.9	75.4	-343.7	Extreme	-102.1	Extreme	10
20	PV20	81.1	75.4	-366.9	Extreme	-107.6	Extreme	10
25	PV20	81.1	76.1	-378.3	Extreme	-109.6	Extreme	10
30	PV20	83.5	78.3	-387.2	Extreme	-109.6	Extreme	10
Current	PV20	85.0	76.8	-253.8	Extreme	-77.8	Very High	8.5
5	PV30	72.4	68.8	-257.9	Extreme	-81.5	Very High	8.5
10	PV30	74.8	71.0	-298.3	Extreme	-94.7	Extreme	10
15	PV30	79.5	73.9	-343.2	Extreme	-101.5	Extreme	10
20	PV30	78.7	73.9	-366.8	Extreme	-107.0	Extreme	10
25	PV30	80.3	75.4	-378.4	Extreme	-109.1	Extreme	10
30	PV30	82.7	77.5	-387.4	Extreme	-109.1	Extreme	10
Current	PV30	71.7	71.0	-252.5	Extreme	-77.1	Very High	8.5
5	PV40	36.2	50.0	-64.2	High	-54.3	High	5
10	PV40	44.1	55.8	-99.1	High	-69.4	High	5
15	PV40	48.0	63.0	-141.8	Very High	-76.6	Very High	7.5
20	PV40	52.0	65.9	-166.3	Very High	-82.2	Very High	7.5
25	PV40	55.1	65.9	-178.2	Very High	-84.4	Very High	7.5
30	PV40	55.9	65.2	-186.2	Very High	-84.5	Very High	7.5
Current	PV40	37.0	51.4	-60.2	High	-49.1	High	5
5	PV45	15.7	32.6	269.5	Low	7.6	Low	0
10	PV45	15.7	38.4	242.7	Low	-11.2	Moderate	1.5
15	PV45	18.9	44.2	200.6	Low	-19.0	Moderate	1.5
20	PV45	20.5	45.7	172.8	Low	-23.5	Moderate	1.5
25	PV45	22.0	47.8	170.4	Low	-26.5	Moderate	1.5
30	PV45	24.4	50.0	177.7	Low	-26.5	Moderate	1.5
Current	PV45	15.7	31.2	275.5	Low	14.0	Low	0
5	PV50	21.3	23.9	265.7	Low	67.3	Low	0
10	PV50	23.6	28.3	224.3	Low	42.5	Low	0
15	PV50	27.6	33.3	167.1	Low	30.6	Low	0
20	PV50	29.9	36.2	126.7	Low	22.5	Low	0
25	PV50	31.5	37.0	117.3	Low	17.1	Low	0
30	PV50	33.9	37.0	121.8	Low	15.0	Low	0
Current	PV50	19.7	21.7	277.5	Low	75.8	Low	0
5	PVCurrent	74.8	71.7	-15.2	Moderate	-7.1	Moderate	2.5
10	PVCurrent	63.0	65.2	-63.1	High	-26.3	Moderate	3.5
15	PVCurrent	72.4	71.0	-115.2	Very High	-35.4	Moderate	4.5
20	PVCurrent	78.0	72.5	-148.6	Very High	-43.2	High	6
25	PVCurrent	80.3	75.4	-158.8	Very High	-47.4	High	6
30	PVCurrent	85.8	77.5	-164.4	Very High	-48.8	High	6
Current	PVCurrent	-	-	0.0	Low	0.0	Low	0

The current water take limit (25%) and riparian vegetation levels on the island resulted in very high risk ratings for taxa richness and high for EPT, suggesting that allowing development up to the current water take limit would almost certainly result in a significant decline in aquatic ecosystem condition, which does not meet policy objectives. It was ranked at the 19th scenario for taxa richness and 23rd for EPT out of the 42 assessed. This mid-range score was expected here and due to the large spread of riparian vegetation cover values across the assessed zones.

4 Discussion

The assessment of different levels of water resource development on Kangaroo Island supported the conceptual understanding of ecosystem condition and previous work illustrating that increased use of water resources leads to a decline in ecosystem condition. Similarly, the results supported the prior expectation that increasing riparian vegetation would lead to an increase in ecosystem condition. The final risk assessment showed that all but one of the scenarios that resulted in maintenance of the current condition (or improvement of condition) across both taxa richness and EPT were scenarios that increased riparian vegetation to 50% and had lower levels of resource development. The current water take limit of 25% was shown to result in a wide variety of risk levels depending on the riparian vegetation in the zone, ranging from moderate (50% riparian vegetation) to extreme (10% riparian vegetation).

The two models used in this assessment (taxa richness and EPT) show the same general patterns across the island but the EPT model shows higher susceptibility of loss of ecosystem condition. This is likely due to the higher sensitivity of the EPT taxa to changes in the flow regime (Lenat and Penrose 1996). The reason that macroinvertebrates are considered good indicators for aquatic ecosystems is that they will be present in nearly all aquatic environments, with the makeup of the community describing and indicating responses to different stressors as well as providing a picture of overarching WDE condition. They often have longer lifecycles than other macroinvertebrate species requiring more permanent water. It is for these reasons that when considering the risk assessment results, higher weighting in terms of confidence in decision-making should be given to the EPT model results. It is worthy to note however that the increase in water take limits will in some cases result in the complete loss of EPT taxa used as either principle or cumulative indicators.

Both the taxa richness and EPT model results showed a flattening of the response curve between 25% and 30% water deemed taken. This is contrary to the prior conceptual understanding and was investigated during model development. The key driver of this is thought to be the correlation between higher development levels and areas of intense forestry, and forestry being linked to higher rainfall areas with more bio-diverse communities. There is also a potential over-estimation of the amount of water forestry is currently using. The estimates for forestry water use are based on the lifecycle of the crop and includes higher water use during early growth and less water use by mature trees. As the crops on Kangaroo Island were are all mature during the sampling window, it is likely they are using less water than assumed under the water policies. The link between forestry, rainfall and biodiversity is a complex pathway that was unable to be captured in the model. Therefore, the increase in taxa richness and EPT should not be viewed as an expected gain of increasing water take, rather an artifact of the input data and the modelling process.

Currently, the water take in management zones on Kangaroo Island ranges from 0% to 60.0% with a median value of 4.5% and a mean value of 7.9%. This reflects several key points about water resource development on Kangaroo Island, notably that some areas are not suitable for water resource development due to salinity issues while other areas are protected from development (e.g. National and Conservation parks and areas of remnant vegetation protected by the *Native Vegetation Act 1991*). It is important to consider that the results of this assessment are general and based on the whole of the island. Further spatial assessment of the results suggests that the limitation of water resource development in some areas may not be effective at managing the condition of the aquatic ecosystems due to the impact of other drivers. A key driver to consider on Kangaroo Island is salinity. As an example, Timber Creek is known to be highly saline and as such supports a low diversity of macroinvertebrates. The high salinity means that the water is of little value for agriculture and therefore, development of water resources is limited in the catchment. Setting limits in these areas might seem illogical given the current level of development, however, some protections may still be warranted.

The findings relating to the development of water resources are supported by previous work across South Australia, most notably the body of work used to underpin the Mt. Lofty Ranges Water Allocation Plans (VanLaarhoven 2012, VanLaarhoven and van der Wielen 2012). These reports use the achievement or failure of environmentally relevant flow metrics to assess the impact to water dependent ecosystems. While the approach is different to that used here, the results are similar, suggesting that anything more than 5% use of the resource (without low flows) leads to an unacceptable risk to the environmental outcomes sought in the Mt Lofty Ranges Water Allocation Plans. More recently, the work in the Barossa Valley has clearly demonstrated that the risk to water dependent ecosystems is lowest when resource development is lowest (Green, Maxwell et al. 2014).

The importance of riparian vegetation on the model results supports the significant emphasis that is placed on the value of riparian vegetation and the restoration of riparian vegetation in the contemporary literature (Wondzell, Diabat et al. 2018, Graziano, Deguire et al. 2022). As noted in the methods section, the percentage values should not be interpreted as cover values as that is not where they are derived from. The example zones shown in Appendix 1 illustrate that the 50% riparian vegetation in the data is more accurately referred to as near complete riparian vegetation cover to 50m either side of the watercourse for the whole zone. The key interaction here is that negative ecological outcomes driven by an increase in water take can potentially be offset by an increase in riparian vegetation. This potentially opens up a new management option for the region, whereby higher levels of water resource development (water take) can be maintained within the acceptable levels of risk by ensuring improvements in the proportion of riparian vegetation within the upstream catchment area. The measures used here are based on a buffer 50m either side of the watercourse, although current literature suggests that buffers of 25m are effective in protecting and enhancing intermittent water course condition (Stella, Rodriguez-Gonzalez et al. 2013, Graziano, Deguire et al. 2022). There is currently no work based in South Australia focused on the impacts of levels of riparian vegetation on macroinvertebrate community condition to which this work can be compared.

The impacts of riparian vegetation on aquatic ecosystem condition is conceptually well understood and multi-faceted but can be broken down into some distinct components including:

- Shading: the overstory shades the watercourse which has two key benefits of firstly reducing water temperature thereby minimizing evaporation and direct mortality of fauna and secondly reducing the potential for algae growth (Burrell et al. 2014).
- Carbon inputs: riparian vegetation provides a wide variety of carbon inputs into the watercourse which provide habitat structure and diverse food supplies for the food web (Graham et al. 2017).
- Water filtration and peak attenuation: riparian vegetation intercepts water flowing over the surrounding soil and slows it down allowing greater infiltration and filtration in the vegetation and surface cover (Dosskey et al. 2010).
- Increased interaction with the terrestrial environment: Riparian vegetation promotes the use of the area to terrestrial fauna increasing food availability for predators (both terrestrial and aquatic) as well as overall enhanced environmental condition (Naiman et al. 1993).

The impacts noted above, especially the impacts of shading, are key in protecting aquatic ecosystems from and slowing the impacts of climate change (Palmer et al. 2009).

The models developed and the results of the risk assessment are considered to be robust and suitable for use to inform policy. They can be improved by providing additional training data. In this instance, the training data were considered to be sufficient but on the lower end of what would be optimal. While macroinvertebrate data is available on the island back to 1994, a change in sampling method meant that only data post-2008 were available for use. Most of the data from 2020 and 2021 were excluded as these data were mostly impacted by the fires –the strongest driver of condition. If a review and update of this modelling process and outputs is needed, it is suggested that collection wait until 2023 to allow the rivers time to recover from the fires. Data collected across 2020-2022 would still be of interest in regards to fire recovery but ultimately not suited for this modelling process. Data collection is recommended follow the current process of a mix of new sites and old sites such that the data are suitable for both expanding on this modelling as well as getting longer term trend data to support the evaluation of current and future policy decisions.

The impact of the 2019-20 fires is not limited to short-term impacts to the ecology of the island, there is a potential of landuse change, notably from forestry to agriculture. The models developed here are perfectly suited for informing policy positions to guide this transition. While this type of landuse change is a significant change to the landscape, the models clearly show that regardless of other conditions, levels of water taken and riparian vegetation will impact on the condition of aquatic ecosystems.

The process used here opted for simple interpretations of hydrology (water collection and storage) and the current Kangaroo Island Water Affecting Activity Control Policy for the generation of the scenarios (Kangaroo Island Natural Resource Management Board 2017). The scenarios effectively model a single large dam within each zone that is varied to the scenario limits. This lumped dam type approach is very simple and does miss intricacies associated with dam location and dam interaction. This approach allowed for the assessment of general patterns of response and is considered sufficient for this exercise. It is acknowledged that more involved modelling for the hydrological components of this assessment would likely lead to better understanding. Based on these results, as well as additional hydrological and ecological understanding, there are additional scenarios that could be run such as scenarios that limit the dam capacity for higher volume developments.

Further to this, it should be noted that additional surface water modeling would be required to account for the low flow policies in the current plan. Low flows have been demonstrated to be an effective way of mitigating the impact of dam development (Alcorn 2011, Green, Maxwell et al. 2014, Deane, Wallace et al. 2016), with large scale implementation currently underway in the Eastern Mt. Lofty Ranges through the *Flows for the Future Program*. It could be possible that the impact metric could be modified to represent the low flows, however, this would only be able to represent a scenario where all dams over 10ML are treated with low flows, not a selection across the landscape (Green, Savadamathu et al. in prep.). The issue would still remain that existing dam development would not be passing low flows and the mixed implementation can only be effectively modelled using surface water modelling programs such as eWater Source (eWater 2022).

In previous studies, the impact of passing low flows has been dramatic on the level of risk to water dependent ecosystems (VanLaarhoven 2012, VanLaarhoven and van der Wielen 2012, Green, Maxwell et al. 2014). However, these were all modelled under the assumption that all dams over a set volume had low flow by-pass/release structures. The impact of a mixed scenario has been inadvertently modelled through the Flows for the Future program, where uptake of the program has been incomplete to date (DEW 2019). The result of this is flow outcomes can be impacted by a single non-participating dam, sometimes significantly so, potentially limiting the benefits for Kangaroo Island. This is not to discount it as a strategy, or to suggest that it should not be applied to new developments. Rather, that the outcomes in zones with mixed old and new development will be tempered by the existing development.

When considering the outcomes of previous studies and the work presented here, it is clear that the use of low flow devices on new development will increase the amount of water that can be captured while maintaining an acceptable level of risk to WDEs. Without detailed individual dam scale surface water modelling it is not possible to quantify this, however, through expert elicitation, some generalised rules could be developed to assist in the development of policies.

The time window of inclusion of time series dataset, such as rainfall used in this assessment was 2000-2021. This period was chosen as it covered all of the sampling undertaken, as well as multiple high and low rainfall periods and aligns with other hydrological investigations currently underway on the island. This rainfall window resulted in lower average rainfall values than previous assessments, resulting in lower yield values and therefore higher development levels (as a proportion of yield). This is a relevant issue as the long term impacts of climate change suggest that rainfall will decline across the island meaning that the relative impact of development will increase. It is suggested that this be a strong consideration when developing policy options for the island.

The method used in this report is different to those used previously. Previous methods have used expert opinion followed by simple linear regression modelling (e.g. VanLaarhoven and van der Wielen 2012), simple single-factor modelled hydro-ecological relationships (e.g. Green, Maxwell et al. 2014) or complex multi-factor generalized linear mixed models (e.g. Maxwell, Green et al. 2015). These previous methods were not used for this assessment as they either relied too heavily on expert opinion, were data deficient or were generally unsuitable for predictive purposes. The BRT approach used here demonstrated the clear ability to model the response in the EPT taxa and provide logical predicted results. The methods developed by Elith, Leathwick et al. (2008) provided a simple and effective modelling process. This work clearly demonstrates the effectiveness of this approach for a data-driven risk assessment process.

The underlying BRT modelling process also suggested that several other aspects of catchment condition were important in establishing overall risk to aquatic ecosystems. Key amongst those were salinity, native vegetation and rainfall. All of these impacts are conceptually well understood individually, however, the ability to model them in the same modelling approach is novel for South Australia. The advantage of this is controlling some of the noise inherent in macroinvertebrate data. The drivers of macroinvertebrate community condition are complicated and multi-faceted leading to data that is difficult to interpret against a single driver (e.g. flow). By including multiple variables in the model, the reasons behind some of the variability can be understood, quantified and controlled for (Elith, Leathwick et al. 2008).

The variables used in the final model draw heavily from both the modelling process itself and the conceptual understanding of the aquatic ecosystems on Kangaroo Island. Each of the variables are briefly discussed in Table 6.

Table 6: Discussion of the conceptual understanding behind the final input variables used and their impact on the final modelled results.

Input	Discussion
Impact metric	One of the more influential variables in the model is the impact metric which is supports the understanding that flow regime, particularly intermittency, is the ‘master variable’ that drives macroinvertebrate communities and therefore, in this context, ecosystem condition (Datry, Larned et al. 2014, Deane, Wallace et al. 2016).
Salinity class	The high contribution of salinity class to both models was not considered to be surprising as salinity is a key driver of aquatic systems (Hart, Lake et al. 2003) major issue on the island that impacts water resources as well as land use and land management practices.
Riparian vegetation	Riparian vegetation is linked through multiple pathways to aquatic ecosystem condition such as shading, erosion control, nutrient input and improved water quality (Collins, Doscher et al. 2013). The strong increase in condition shown in both models for higher levels of riparian vegetation supports the idea notion of fencing and revegetation to support aquatic ecosystems.
Water deemed taken by dams (both within the zone and cumulative)	The impact of dams on the flow regime downstream of the dam is heavily influenced by the volume of the dam, hence it being the key controlled factor in water resource management. Dams will delay the onset of flow until after the dam has filled, the larger the volume of dam development, the longer this delay is and the larger the impact to aquatic ecosystems (VanLaarhoven 2012, VanLaarhoven and van der Wielen 2012)
Yield (both within the zone and cumulative)	Yield was included in the model as a surrogate for rainfall as these two are directly correlated through the tan-H function used to calculate yield. It was chosen over rainfall as yield is also needed for the calculation of the scenario prediction dataset so was easier for the overall modelling process. It is important to consider the link between ecosystem health and yield (rainfall) in context, as it is very location specific, i.e. lower rainfall does not automatically mean lower condition and systems may be adapted to lower rainfall. In this context, systems with lower rainfall are likely to have less EPT taxa naturally due to the lack of flow generation so it is important to control for this in the model.
Native vegetation	The amount of native vegetation in the zone has been identified as an important variable for South Australian ecosystems for a considerable period of time (P. Goonan, South Australian Environmental Protection Authority, pers comm.). The link between native vegetation and aquatic ecosystem condition is complex and has multiple components above those of riparian vegetation including water quality impacts, runoff characteristic changes and limitation of anthropogenic changes such as sediment inputs, chemical inputs and stock impacts.
Total demand (forestry and dams) (both within the zone and cumulative)	Total demand was included in the model to capture the impact of forestry on the aquatic ecosystems. Moving forward, the impacts of forestry are likely to be reduced however, the impact of forestry was considered important enough to ensure it was represented in the process.

The macroinvertebrate community on Kangaroo Island is less diverse than that of the Mt. Lofty Ranges, which is likely due to a combination of effects relating to the isolation from the mainland source populations and the frequency of disturbance events (bushfires). The natural and anthropogenic fire history and clearance activities of the island both pre- and post-European settlement has likely contributed to general lack of diversity observed today. This diversity loss should not be interpreted as the WDEs of Kangaroo Island are not as valuable as those in the Mt. Lofty Ranges, rather that the WDEs of Kangaroo Island need to be considered in the context of recent history. The use of the taxa richness and EPT in this process rather than a condition assessment is not considered to be an issue for two key reasons. The first is the strong relationship between richness and EPT and the calculated condition score suggesting that the two are highly correlated. The second is the support in the literature for the use of EPT as an index for assessments such as this (Lenat and Penrose 1996, Chessman 2021).

Using the macroinvertebrate community, in this case represented by taxa richness and EPT, as a measure of WDE condition is a long standing premise in aquatic ecology (Chessman 2003). The other two key components of the WDEs on Kangaroo Island are the riparian vegetation community and the fish community. The Landscape Board staff have been collecting riparian vegetation data on the island concurrently with the macroinvertebrate data and have established a large dataset. These data can be used to assess the links between vegetation species and the riparian vegetation score detected from the LandSat data to provide insights and information relating to the condition of riparian vegetation and the condition of the macroinvertebrate community. The estuarine and freshwater fish community on the island was ruled out as a condition assessment mechanism for two key reasons. Firstly, macroinvertebrates are generally considered to be a better indicator of aquatic ecosystem condition (Chessman 2003) and secondly, there are only two commonly caught species across the inland zones, with only a single species being present in the upper reaches and there is no consistent monitoring program for fish on the island. This would lead to a presence/absence assessment for many zones, some of which would naturally have not supported fish. Therefore, the level of detail provided by the fish community would fail to provide the level of insight needed for the assessment of risk to WDEs.

5 Conclusion

This assessment suggests that a broader approach to water planning could be considered on Kangaroo Island. Incorporating additional parameters into the assessment of water take limits, such as riparian vegetation, allows for a more flexible planning system to be considered that would allow landholders to have more ownership in the management and development of their properties, with their decision having differing outcomes on the water take limits assigned to their properties. The results of this assessment reflect previous work suggesting that any further development of water resources on the island will have a negative impact on aquatic ecosystem condition. Therefore, the balance of risk to WDEs and social, economic and cultural outcomes needs to be considered before establishing an acceptable level of risk to WDEs and establishing environmentally sustainable water take limits.

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7 Appendices

Appendix 1 – Full table of predictor variables assessed as part of the modelling process.

Input variable	Timeframe	Area of interest	Short name	Unit
Average photosynthetic vegetation	March - May	Far	PV0305_MEAN_Far	Proportion
Average photosynthetic vegetation	June - August	Far	PV0608_MEAN_Far	Proportion
Average photosynthetic vegetation	September - November	Far	PV0911_MEAN_Far	Proportion
Average photosynthetic vegetation	December - February	Far	PV1202_MEAN_Far	Proportion
Average photosynthetic vegetation annual	2008-2017	Far	PV2008_2017_MEAN_Far	Proportion
Sum of photosynthetic vegetation annual	2008-2017	Far	PV2008_2017_SUM_Far	Hectares
Evaporation	1990-2013	Far	SA_Evap_MEAN_Far	mm
Soil acidity - proxy for soil salinity	2008-2017	Far	Soil_pH_MEAN_Far	pH
Average rainfall	2000-2021	Zone	Rain_MEAN	mm
Sum of rainfall	2000-2021	Zone	Rain_SUM	mm
Average temperature	2008-2017	Far	Temp_MEAN_Far	Degrees celcius
Water erosive potential	2008-2017	Far	Water_erros_2008_2017_MEAN_Far	Derived index
Average photosynthetic vegetation	March - May	Near	PV0305_MEAN_Near	Proportion
Average photosynthetic vegetation	June - August	Near	PV0608_MEAN_Near	Proportion
Average photosynthetic vegetation	September - November	Near	PV0911_MEAN_Near	Proportion
Average photosynthetic vegetation	December - February	Near	PV1202_MEAN_Near	Proportion
Average photosynthetic vegetation annual	2008-2017	Near	PV2008_2017_MEAN_Near	Proportion
Sum of photosynthetic vegetation annual	2008-2017	Near	PV2008_2017_SUM_Near	Hectares
Evaporation	1990-2013	Near	SA_Evap_MEAN_Near	mm
Soil acidity - proxy for soil salinity	2008-2017	Near	Soil_pH_MEAN_Near	pH
Average temperature	2008-2017	Near	Temp_MEAN_Near	Degrees celcius
Water erosive potential	2008-2017	Near	Water_erros_2008_2017_MEAN_Near	Derived index
Bare ground or urban environment	2021	Far	Bare_or_urban_Far	Hectares
Hardwood forestry	2021	Far	Forestry_hardwood_Far	Hectares
Softwood forestry	2021	Far	Forestry_softwood_Far	Hectares
Annual herbaceous cover	2021	Far	Herbaceous_annual_Far	Hectares
Perennial herbaceous cover	2021	Far	Herbaceous_perrenial_Far	Hectares
Irrigated herbaceous cover	2021	Far	Irrigated_herbaceous_Far	Hectares
Irrigated woody vegetation	2021	Far	Irrigated_woody_Far	Hectares

Native Mallee	2021	Far	Native_mallee_Far	Hectares
Native scrubland	2021	Far	Native_shrubland_Far	Hectares
Native woodland	2021	Far	Native_woodland_Far	Hectares
Wetland or open water	2021	Far	Wetland_or_water_Far	Hectares
Bare ground or urban environment	2021	Near	Bare_or_urban_Near	Hectares
Hardwood forestry	2021	Near	Forestry_hardwood_Near	Hectares
Softwood forestry	2021	Near	Forestry_softwood_Near	Hectares
Annual herbaceous cover	2021	Near	Herbaceous_annual_Near	Hectares
Perennial herbaceous cover	2021	Near	Herbaceous_perrenial_Near	Hectares
Irrigated herbaceous cover	2021	Near	Irrigated_herbaceous_Near	Hectares
Irrigated woody vegetation	2021	Near	Irrigated_woody_Near	Hectares
Native Mallee	2021	Near	Native_mallee_Near	Hectares
Native scrubland	2021	Near	Native_shrubland_Near	Hectares
Native woodland	2021	Near	Native_woodland_Near	Hectares
Wetland or open water	2021	Near	Wetland_or_water_Near	Hectares
Impact to flow regime	2008-2017	Zone	ImpMet_Predicted	Derived index
Zone area	Current	Zone	Hectares	Hectares
Current water use limit	Current	Zone	WUL_ML_cum	ML
Cumulative total dam volume	Current	All upstream area	DamVol_ML_cum	ML
Cumulative water deemed taken from dams	Current	All upstream area	DamUse_ML_cum	ML
Cumulative water deemed taken by forestry	Current	All upstream area	ForDem_ML_cum	ML
Cumulative total water deemed taken	Current	All upstream area	TotDmnd_ML_cum	ML
Cumulative yield for all upstream catchment area	Current	All upstream area	YieldML_cum	ML
Salinity classification	Current	Zone	Salinity_Class	Derived class
Cumulative percentage of current development	Current	Zone	Dev_lvl_cum	percentage
Total dam volume	Current	Zone	DamVol_ML	ML
Water deemed taken by forestry	Current	Zone	ForDem_ML	ML
Water deemed taken from dams	Current	Zone	DamUse_ML	ML
Total water deemed taken	Current	Zone	TotDmnd_ML	ML
Catchment yield	Current	Zone	YieldML	ML
Percentage of current development	Current	Zone	Dev_lvl	ML
Native vegetation (pre fires)	2021	Zone	Native_Veg	Hectares
All herbaceous cover (pre-fires)	2021	Zone	Herbaceous	Hectares
Forestry (pre-fires)	2021	Zone	Forestry	Hectares

Appendix 2 – example riparian vegetation cover maps.

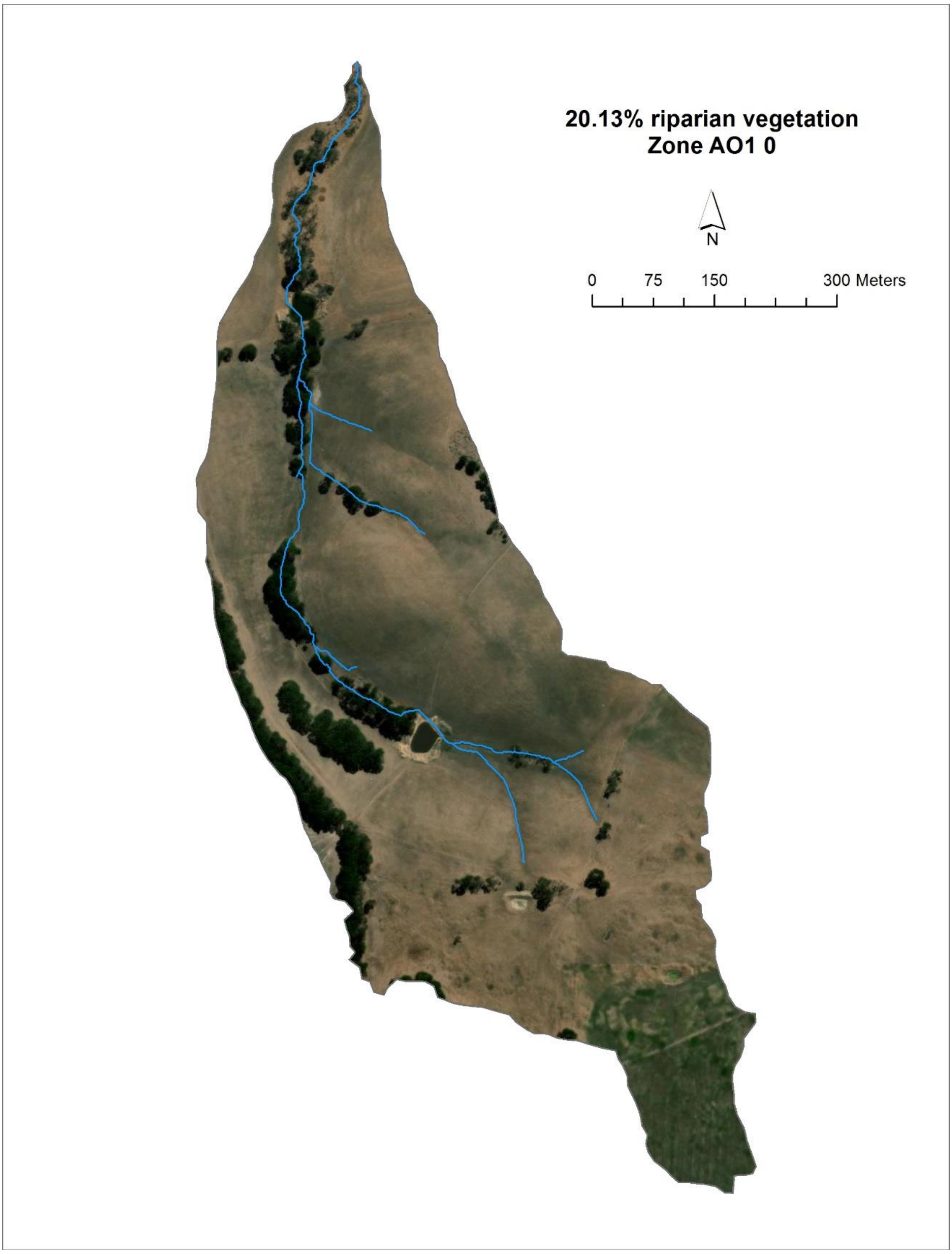

Figure 9: Example catchment with ~20% riparian vegetation representing a sparse vegetation cover in the modelling process. Zone AO1 0 with 20.13% riparian vegetation.

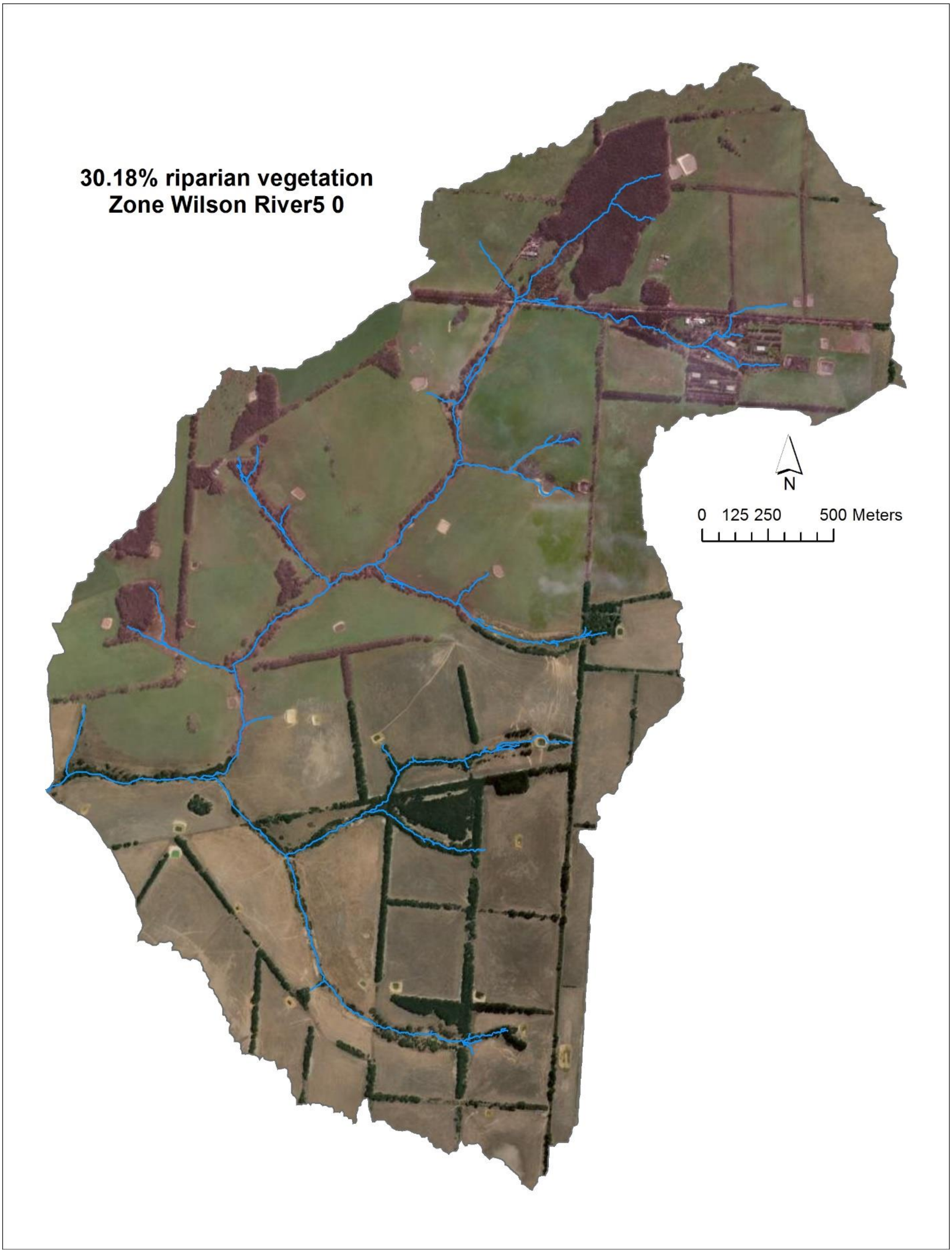

Figure 10: Example catchment with ~30% riparian vegetation representing a limited vegetation cover in the modelling process. Zone Wilson River5 0 with 30.18% riparian vegetation.

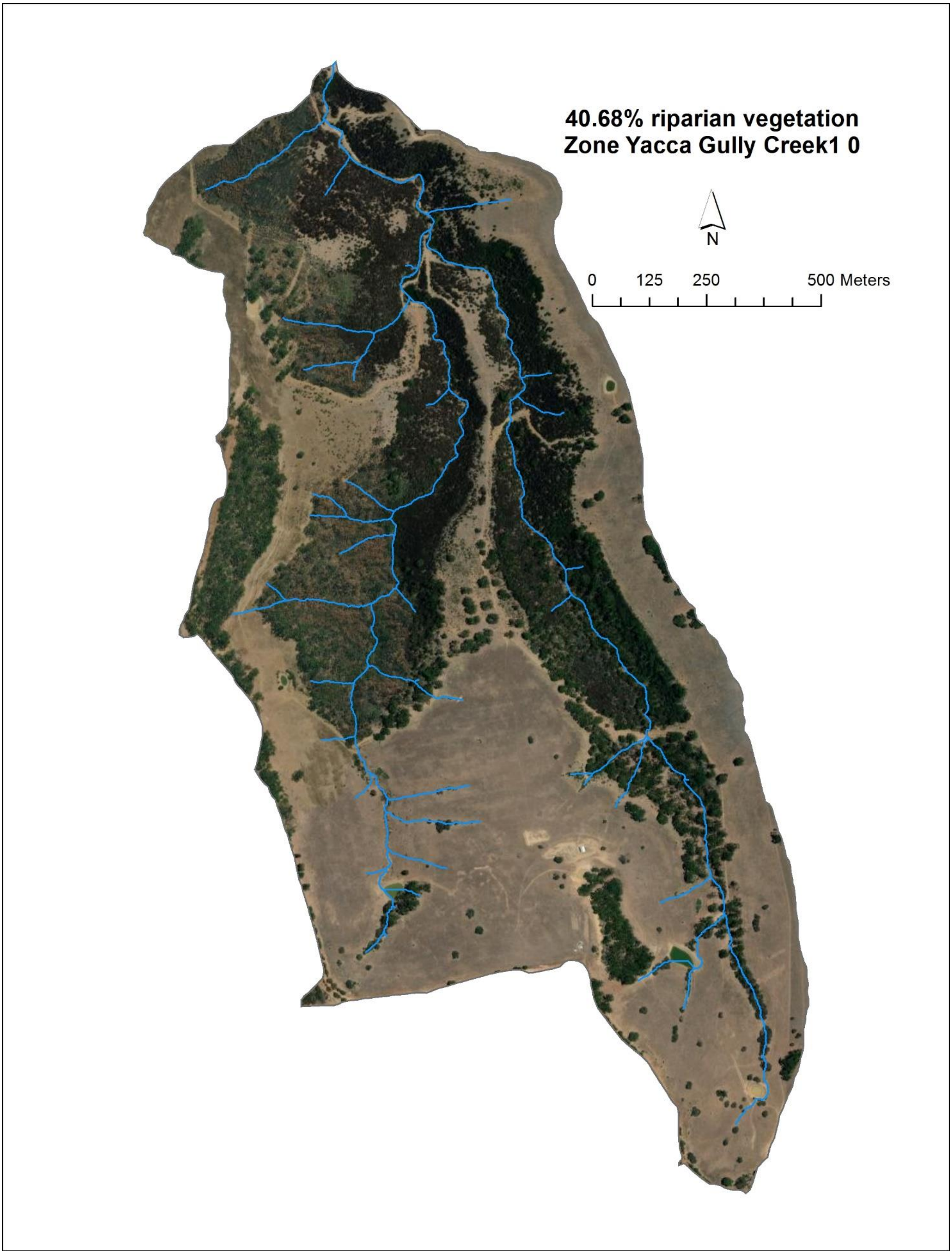

Figure 11: Example catchment with ~40% riparian vegetation representing a lower mixed vegetation cover in the modelling process. Zone Yacca Gully Creek1 0 with 40.68% riparian vegetation.

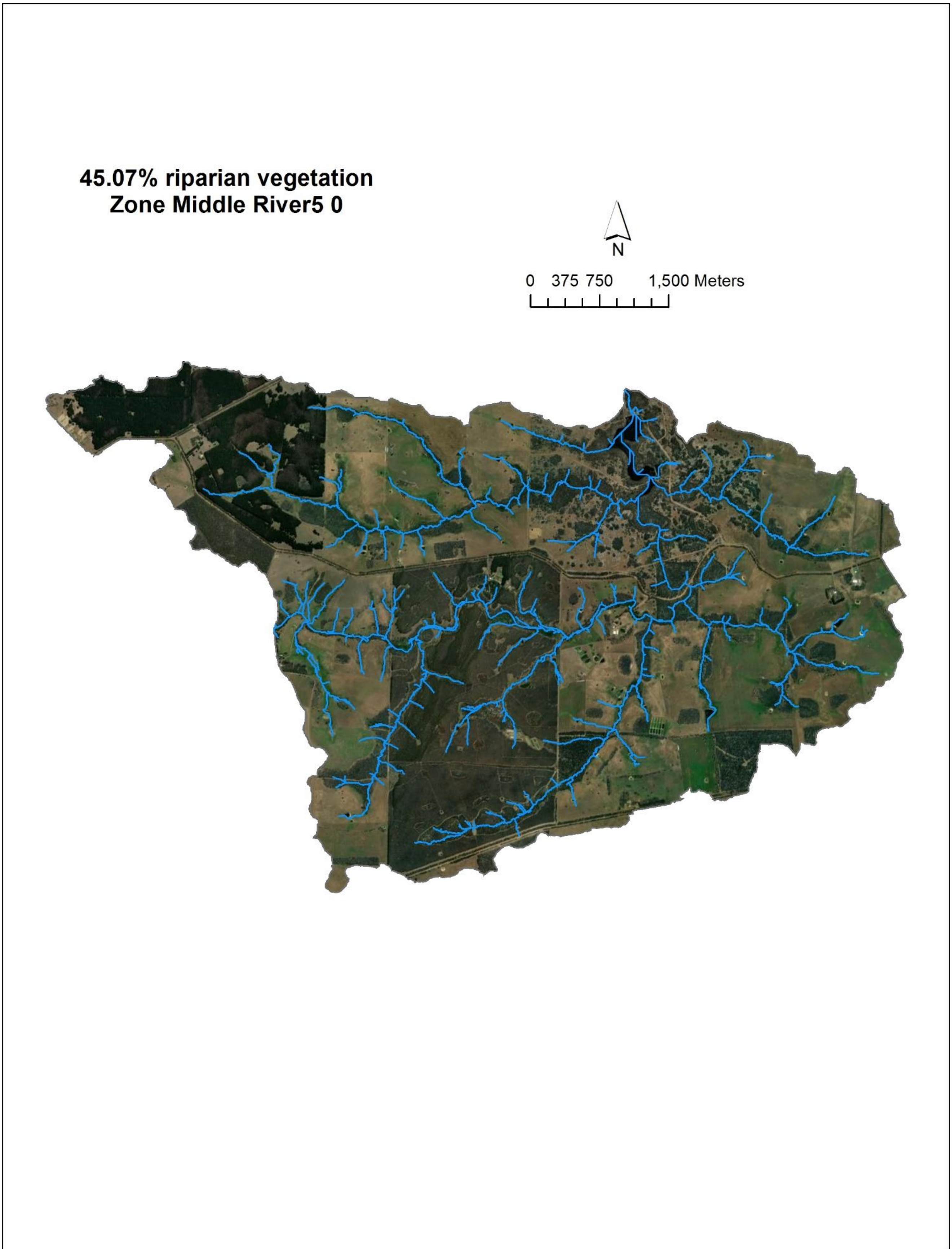

Figure 12: Example catchment with ~45% riparian vegetation representing an upper mixed vegetation cover in the modelling process. Zone Middle River5 0 with 45.07% riparian vegetation.

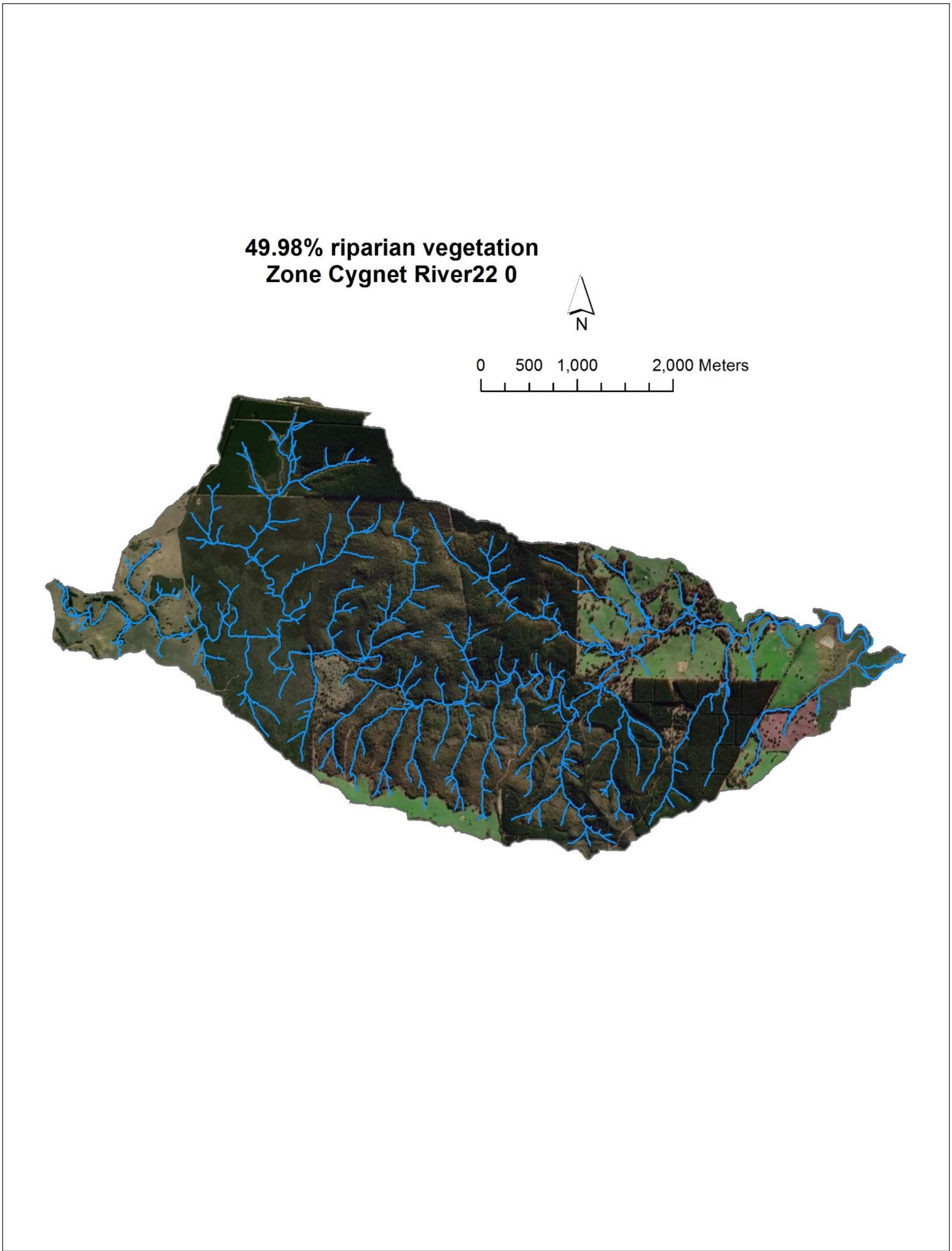

Figure 13: Example catchment with ~50% riparian vegetation representing near full vegetation cover in the modelling process. Zone Cygnet River22 0 with 49.98% riparian vegetation.