

DRAFT: Lower Balonne Floodplain grazing model report



November 2016

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Published by the Murray–Darling Basin Authority

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MDBA publication no.: 38/16

ISBN (online): 978-1-925221-64-0

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Cover image: Cattle grazing between Weilmoringle and Collierina (photo by Jennifer Bradley).

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This model described is a simulation model, wherein numbers of animals and earnings reflect simulated responses to water availability and not actual observations. It is intended to guide understandings about scenario impacts of water recovery across the northern Murray–Darling Basin as part of the Northern Basin Review being carried out by the Murray–Darling Basin Authority. It should not be relied on to make business decisions nor be used for any other purpose. In its current state it should not be read as representing any single property or the Lower-Balonne Floodplain.

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Contents

Figures.....	v
Tables.....	v
Summary.....	1
Introduction	2
Study area	2
Floodplain grazing systems	3
Floodplain grazing and the local economy	4
Water recovery scenarios	5
Model approach.....	5
Flow changes.....	7
Sequence and size of flows	9
Effects of small and medium sized flows	9
Distribution of flows	11
Climatic conditions.....	13
Water recovery in the Condamine-Balonne	15
Building the model.....	15
Model design.....	16
Supplementary feeding.....	18
Model tool.....	20
Model results.....	21
Model results	24
Model variable sensitivity.....	29
Results under recent climatic conditions: a 27 year simulation	29
Model result characteristics	32
Discussion.....	33
Water recovery and results	33
Community	33
Conclusion.....	33
Appendix A: Notes	35
Appendix B: Model Design	37
Model structure.....	37
Model features.....	38
Assumptions.....	41

Rule construction.....	41
Rules.....	42
Earnings model.....	45
Data.....	45
Sources.....	45
Data processing	48
Pricing variables	49
Sensitivity	50
Stocking variable sensitivity	50
Earnings variable sensitivity	51
Appendix C: Caveats	53
Data limitations	53
Use limitations	53
Farm structure.....	53
Geographical distribution.....	55
Farm financials.....	55

Figures

Figure 1: Map of the Lower Balonne Floodplain	3
Figure 2: Floodplain grazing structure	3
Figure 3: Problem structure	6
Figure 4: Changes to flows at Culgoa at Brenda gauge	8
Figure 5: Effects of recovered water on stock	10
Figure 6: Distribution of flow reduction from Without Development to Baseline	12
Figure 7: Distribution of flow reduction from Without Development to 390GL	13
Figure 8: Annual gauge flows at the Culgoa at Brenda gauge	14
Figure 9: Water recovery in the Condamine-Balonne under each scenario	15
Figure 10: Basic model structure	17
Figure 11: Stock numbers with and without supplementary feed	19
Figure 12: Earnings with and without supplementary feed	20
Figure 13: Modelled DSE/ha Without Development and Baseline	22
Figure 14: Modelled earnings/ha Without Development and Baseline	23
Figure 15: Fixed model settings DSE/ha results against water recovery in the Condamine-Balonne	25
Figure 16: Fixed model settings earning/ha results against water recovery in the Condamine-Balonne	27
Figure 17: 27 year results for changes in stock carrying capacity	30
Figure 18: Model schematic	37
Figure 19: Stock response pattern	39

Tables

Table 1: Model stock number point results relative to Baseline	26
Table 2: Model earnings point results relative to Baseline for the 100 year average	28
Table 3: 27 year model stock number results relative to Baseline (without supplementary feed)	31
Table 4: 27 year model earnings results relative to Baseline (without supplementary feed)	31
Table 5: Scenario descriptions	35
Table 6: Mapping data	46
Table 7: Model data	46
Table 8: Contextual information	47
Table 9: Variable sensitivities for stocking numbers	50
Table 10: Sensitivities for supplementary feed pricing variables	51
Table 11: Sensitivities for without supplementary feed pricing variables	52

Summary

The Northern Basin Review, carried out by the Murray–Darling Basin Authority (MDBA), seeks to evaluate the social, economic and environmental impacts of a range of water recovery scenarios in the northern portion of the Murray–Darling Basin. As part of the Northern Basin Review, the Murray–Darling Basin Authority has developed a simulation model to understand the impacts of returning water on grazing productivity on the Lower Balonne Floodplain.

The purpose of the study is to understand how environmental water produces associated benefits to agriculture and to further understand the changes and impacts on floodplain graziers.

The key results of the study are that:

- some graziers have been impacted by upstream development affecting business viability
- reductions in production have flow on effects on local communities, particularly Brewarrina
- across the floodplain water recovery of the scale considered in the review can return up to *one third* of lost stock productivity (31.9%) and earnings (34.9%)
- impacts vary over a range of property types and business models
- generally more water recovery upstream results in greater productivity and earnings gains, however targeting water recovery and restoring particular flows can have greater impacts than non-targeted recovery.

Graziers in the Lower Balonne Floodplain rely on overbank flows from the Culgoa, Birrie, Bokhara, and Narran Rivers and local streams. As agricultural development has increased upstream, flows to the floodplain have decreased. As well as decreases to the size and scope of large overbank flows, smaller flows which allow for in-channel environmental benefits and stock and domestic water have also markedly decreased. This has resulted in a significant impact on both the environment as well as on existing grazing businesses in the Lower Balonne. Some properties may have lost up to one quarter of their carrying capacity and earnings due to lower flows. This will have impacted on the lasting health of the floodplain as well as the surrounding communities of Goodooga, Brewarrina and Weilmoringle. In returning water to the environment, some lost productivity of floodplain grazing systems can also be returned.

This report examines the impact of various levels of water recovery on floodplain grazing by use of a simulation model. The model takes overbank flows, rainfall and property conditions to estimate grazing productivity on a seasonal basis. The model was built with a combination of computational and statistical estimation alongside grazer consultation. This model does not capture all the variation between properties, as almost every grazer has a unique set of circumstances, however it does capture a wide range of important differences. It shows the effect over a range of responses across properties.

The Authority will consider the results of this study along with other detailed studies of environmental, social and economic impacts when considering whether to recommend a change in the water recovery target in the northern basin. The results of the floodplain grazing study informs the triple bottom line assessment in the Condamine-Balonne catchment in particular.

Introduction

The MDBA made a commitment in the Basin Plan to conduct research and investigations into aspects of the Basin Plan in the northern Basin, including the basis for the long-term average Sustainable Diversion Limits (SDLs). The Floodplain Grazing (FPG) model described in this report examines the impacts of various water recovery scenarios on the productivity of floodplain grazing systems in the Lower Balonne. The modelling outputs and analysis informs the Northern Basin Review.

The FPG model that has been developed is a simulation based model designed to estimate the effects of changes in water availability under the different water recovery scenarios on stocking numbers and earnings per hectare in the Lower Balonne Floodplain. The data and information underlying the model has been drawn from historical measurements of rainfall, gauged and modelled stream flows and stock numbers as well as directly from graziers.

The sections that follow describe the study area, grazing systems in the region, the water recovery scenarios used in the modelling, design of the model and modelling outputs. The assumptions and limitations of the modelling are also addressed.

Study area

The Lower Balonne is situated in the most southerly portion of the Condamine-Balonne catchment covering approximately 1,700,000 hectares. It straddles the New South Wales and Queensland border — approximately 30% in Queensland and 70% in New South Wales, with the majority of floodplain grazing occurring in the New South Wales portion. There is also some opportunistic cropping carried out in the same area which is not included in this study or model. Its floodplain system is a predominantly unregulated distributary river network extending from St George in Queensland to the Barwon River in northern New South Wales, and includes the channels, connecting waterways, waterholes and floodplains of the Culgoa, Birrie, Bokhara and Narran rivers. The area under study is outlined in Figure 1.

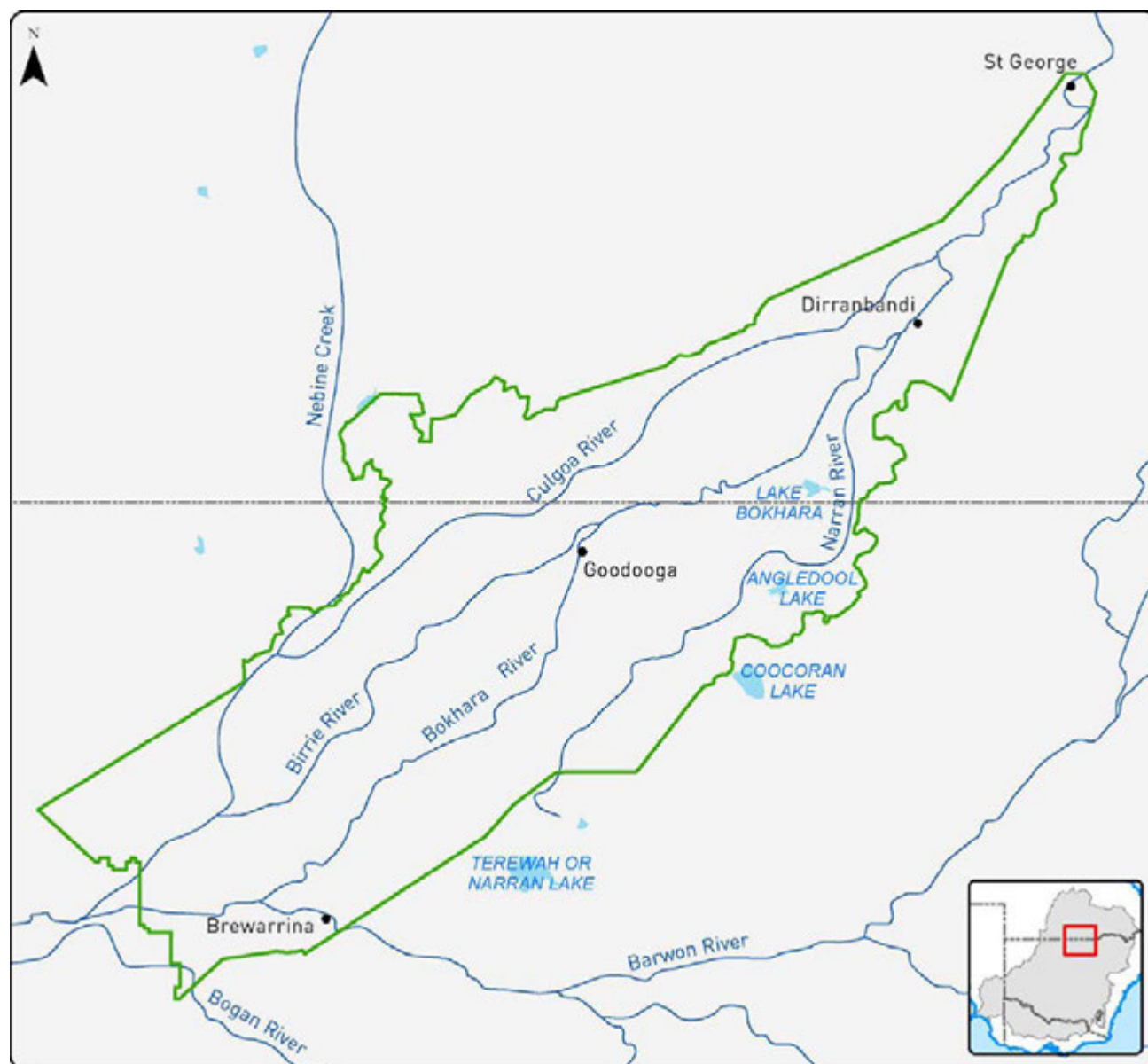


Figure 1: Map of the Lower Balonne Floodplain

Floodplain grazing systems

Agricultural production on the Lower Balonne Floodplain is highly dependent on stream flows and the effects of flooding from the four rivers that run down its length. A combination of rainfall and flood events of different sizes and durations work together to produce a range of pasture response and production benefits following each event. The pasture response and feed availability supports wool, lamb and beef production on the grazing properties. Figure 2 outlines the basic structure of relationships between water availability, grazing production systems and earnings on the floodplain.

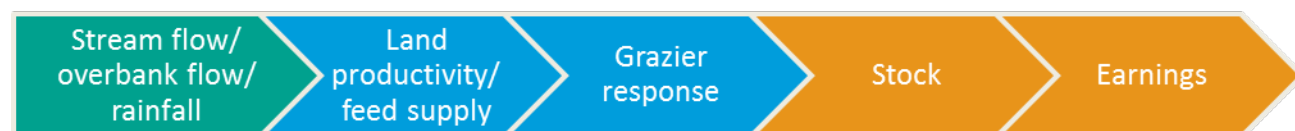


Figure 2: Floodplain grazing structure

The relationship between water and productivity of floodplain grazing systems means that stock numbers can fluctuate dramatically between wet and dry periods. Graziers have a number of options to manage fluctuating climatic conditions. During dry periods, if feed supply declines, graziers may provide supplementary feeding, agist stock out to other properties or destock if drier conditions persist. Agistment is an important management option used when feed supply is short on the home property which involves placing stock on another property for short durations. During wetter conditions or following flood events, graziers may breed up from existing stock or restock.

Grazing is most profitable when graziers are able to match stock numbers to the amount of available feed. Where stocking levels are higher than for the available feed, additional costs may be incurred for supplementary feeding, agistment, or stock losses. On the other hand, where stocking levels are lower than can be supported by the feed supply on hand, production opportunities may be missed.

Since the early 1990's, development of irrigated agriculture up-stream of the Lower Balonne floodplain has meant less water has been flowing downstream to reach floodplain grazing systems. This development, combined with droughts through the 2000's and more recently from 2012 have dramatically affected grazing businesses on the Lower Balonne Floodplain.

Over this period, the frequency and duration of flood events has been altered with fewer occurrences of high value flooding resulting in a decrease in the maximum stocking levels. Additionally, lower-flow events have also decreased in volume and frequency. These lower-flows, or 'lignum floods', historically came through the floodplain more regularly allowing stock numbers to be maintained through average or even below average years. Maintaining breeding stock in these dry to average years has been an important factor in enabling graziers to respond quickly to high-flow events as they could breed up from existing stock. The decline in the number and frequency of low-flow events may have increased the need to sell-off stock due to the lack of pasture feed supply affecting longer-term production levels.

The decrease in both high-flow, mid-sized and low-flow flood events has had an impact on grazing production systems. Given that these affect production differently and sequences of flows have been disrupted, the combined effect on production is not linear or one-for-one with the decrease in water. This is a key reason for using a simulation based approach.

Floodplain grazing and the local economy

The Lower Balonne regional economy is one of the most reliant on agriculture in Queensland with 36 per cent of employment directly in agriculture (MDBA, 2010b). The Lower Balonne River Floodplain has been grazed by cattle and sheep since the 1840s (MDBA, 2010a). One grazier gave the anecdote that his family would have been able to ride out to assist the Burke and Wills expedition of 1860-61 had they known they were passing. The growth of irrigated agriculture in the region over the past 30 years represents a significant shift in the use of water resources. The major irrigated crop upstream is cotton, with the area cropped increasing significantly since the 1980s.

Floodplain grazing has been a major industry in the region, supporting the economies of Brewarrina, Goodooga, Weilmoringle, Walgett, Lightning Ridge and even Bourke. Graziers rely on the local towns for contract shearing teams, seasonal and temporary workers, agricultural

supplies, consumables and household goods. Larger purchases will generally be made at larger surrounding towns. Hence, profits from floodplain grazing are an important cash flow for local businesses in these communities, particularly Brewarrina. Furthermore the properties on the floodplain have generally relied on the local communities of Brewarrina, Goodooga and Weilmoringle for their temporary and seasonal work force.

Up-stream development of irrigation systems and resulting reduced flows to the floodplain has affected floodplain grazing businesses and therefore the surrounding communities. This, alongside periods of drought, technological changes, commodity price changes, transportation infrastructure changes, regulatory changes and other environmental changes has changed the industry and in turn the local economy.

Water recovery scenarios

The FPG model estimates the potential benefits for productivity of floodplain grazing systems in the Lower Balonne based on a range of potential water recovery scenarios. The Basin Plan currently sets 3,468GL as the limit of water that can be extracted across the northern basin on average per year. This is 390GL or around 10% less than the amount that was taken before the Basin Plan. Given 390GL represents the current water recovery target for the northern basin, scenarios have been developed around this. A lower end scenario has been developed based on 278GL which is the level of water recovered as of December 2015. A number of other scenarios have also been developed between 278GL and 415GL.

The Baseline – which is the scenario ‘with development’ – and the Without Development scenarios provide further basis for comparison as they represent the highest and lowest flows. The Baseline scenario represents conditions reflecting water sharing arrangements and levels of infrastructure in place at June 2009 prior to any affect from the Basin Plan. The Without Development scenario represents a pre-development scenario. The full set of scenarios used in the FPG modelling are described in Table 5 (p.35).

Of note, the scenarios considered involve different combinations of water recovery across valleys as well as changes in water usage by environmental water holders. For this reason, greater volumes of water recovery across the scenarios may not always have increasing impacts on floodplain graziers as the study area is directly affected by the level of assumed water recovery in the Condamine-Balonne catchment.

Model approach

To inform the Northern Basin Review, the FPG model will provide estimates of production and earnings under various modelled flow scenarios. The modelling of the relationships between water availability and production and financial outcomes recognises there are several key factors influencing the productivity of grazing systems. Figure 3 sets out some of these key factors which include: water availability (such as rainfall and overbank flows); the natural productivity of the land; the level of pasture feed available, and grazer response to changes in climatic conditions.

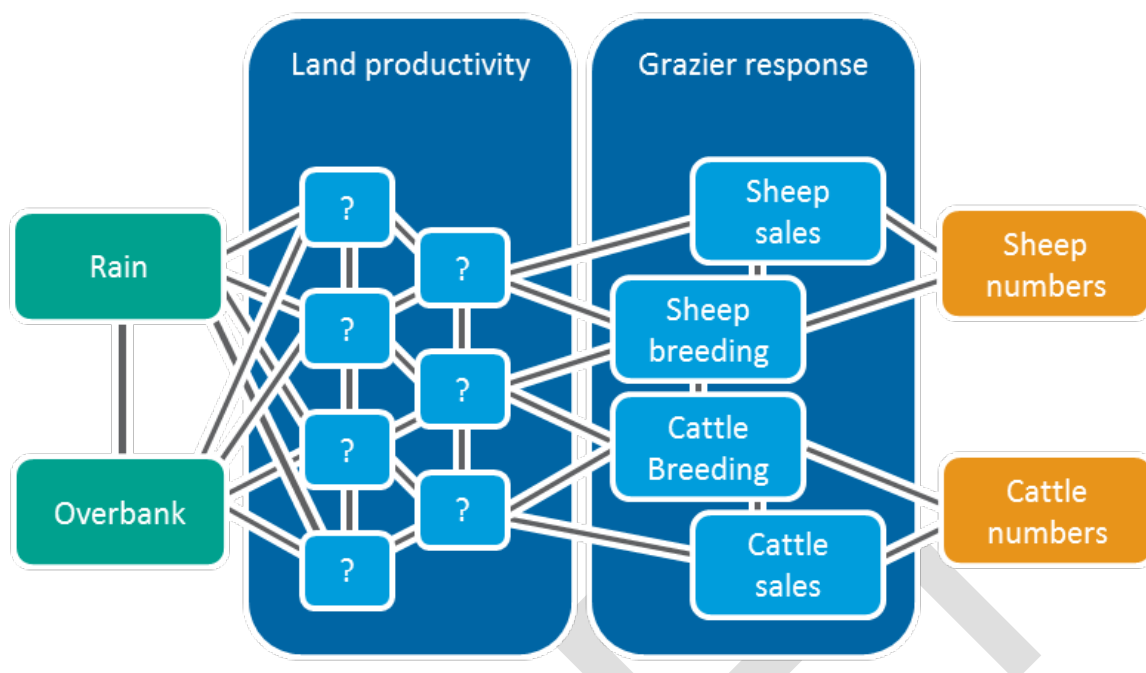


Figure 3: Problem structure

However, a primary challenge for the modelling work is the paucity of data and information available regarding floodplain grazing. The available data on flood inundation and pasture response were not sufficient for modelling purposes. Some input information is readily available such as measured rainfall and flow gauge data, as well as modelled flow data. However, data for stocking levels is more limited. It is highly variable between properties and exists only for a limited number of years in the post-development period. A further limitation is that it is only available on an annual scale and does not capture within-year fluctuations and responses.

This limited information on stock numbers posed a challenge for the modelling work because it is the only information available to estimate graziers' management responses to changes in production conditions. Importantly, this means that not all the complex relationships can be mapped, particularly on the land productivity side. Consequently, given this limitation on data availability, these parts of the model were estimated as a whole rather than as a series of parts. In other words, this means that in the FPG model some of the key elements of the floodplain grazing systems have been modelled together.

To account for the variety of water and stock conditions, a 'rules-based' simulation approach was used. Because of data limitations, the area flooded, the wetness in the soil profile, the type and value of feed growth, the stock response, the breeding response, and grazer decision making were compressed into a single biophysical/decision-making simulation model.

As grazer decisions can have dramatic effects on stock numbers and earnings, a number of farm-type variables have been included. Graziers choose different approaches based on personal preference, fiscal capability, risk preference, experience, soil-type, and position on the floodplain. In the model, these differences relate to herd mix (cattle/sheep/agistment), the use of supplementary feed, and how much stock to maintain in dry periods (if at all). The amount of black soil - soil which is highly productive as it is regularly inundated by flooding - and red soil -

poor sandy soils that are rarely flooded - also affect the way properties benefit from overbank flows. These decision and property differences are reflected in a number of choice variables in the model.

This approach was taken to reflect the important observations that:

- the relationship between water and stock is non-linear
- water in different seasons, from rainfall or overbank flows, or from different size flow events do not create the same response
- stock numbers are constrained by 'natural' effects such as the time it takes to breed up or that breeding up is not treated the same way as rapid selling-off in dry times.

Overall, the model predicts the aggregate stock density as if the floodplain were a single property with access to all river flows. The model has the capacity to account for differences in management strategies such as the use of supplementary feeding, basic soil types, and different ratios of cattle, sheep, and agistment.

Flow changes

Over the last three decades the pattern of water reaching the floodplain has been significantly altered. As the development of irrigation increased upstream the volume, frequency and duration of flows have decreased. Some parts of the floodplain have lost around half of all flows. This has impacted both the large overbank events and also the more frequent, but smaller, in-channel flows. Figure 4 shows the differences in flow between the Baseline and Without Development scenarios. It also shows a number of flows which no longer cause overbank flooding at that site, as indicated by those events which do not pass the overbank threshold under Baseline conditions.

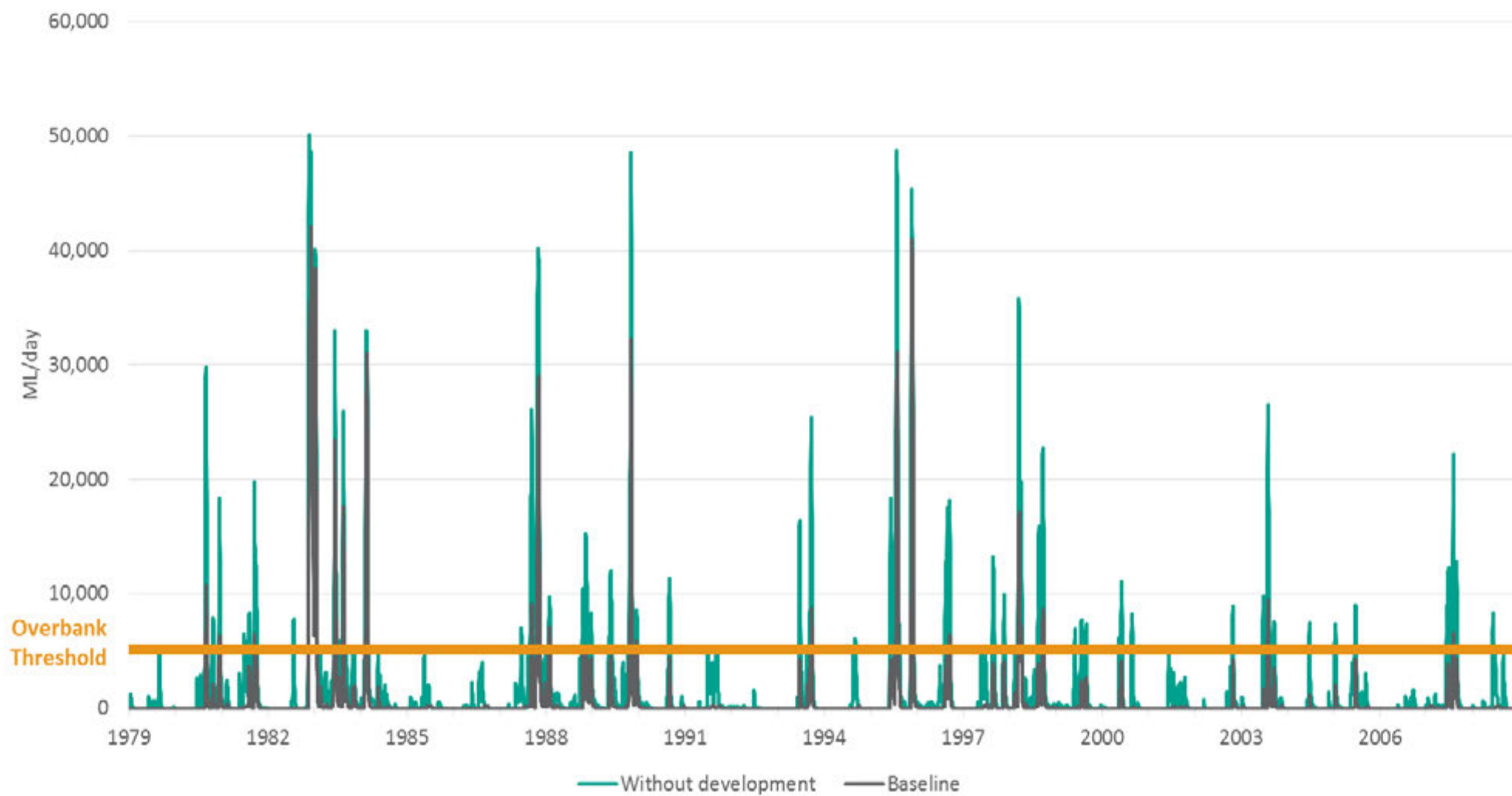


Figure 4: Changes to flows at Culgoa at Brenda gauge

Sequence and size of flows

The relationship between the volume of water in a flow and its associated flooding is not a simple one-for-one relationship. A range of conditions can affect where flooding occurs and what effect this has on production. Existing conditions such as preceding flows, the level of soil cracking, previous rains, and the amount of plant growth will all contribute to the outcomes of an additional flow. In addition the extremely flat nature of the floodplain, the branching topology of the waterways and interconnected nature of the rivers mean that flooding can follow complex patterns. For instance, a flood may sit in place for several days before rapidly expanding over a large area over several hours. This means that the duration of flows, how much travels down each river, and antecedent conditions can all be as important as the volume of water.

The FPG model does not try to model this complex inundation, however it does take into account that different types of flows can have different effects. In particular, it accounts for the very large flows which are acknowledged to produce substantial results for graziers. Additional water, by increasing the duration of events by several days, can have far larger impacts than just the increase in volume would have alone. The differences between scenarios are not only changes in volume, but also changes in the sequence and importance of flows.

Effects of small and medium sized flows

Decreased flows have not only reduced the size of the medium and large overbank flows, but have also increased the time between these flows, the smaller scale 'lignum flows' that produce small scale flooding, and the in-channel flows that some graziers used for stock and domestic water. While the large overbank flows as a single event have the potential to lead to the most significant change in stock numbers, the smaller flows are necessary to maintain and grow stock numbers between overbank flows. Hence, the increased duration between these smaller events also significantly decreases the benefits of overbank flows.

The importance of sequence and small to mid-sized flows on stock numbers are stylized in Figure 5. Given that stock numbers can take a significant period to rise through natural increase, the beneficial effects of a large overbank flow may take several years to play out. To provide maximum benefit, a large overbank flow in one year would be followed by several years of average or above average rainfall or flooding to allow herds enough time and favourable conditions to breed up. Panel A of Figure 5 shows what happens when a year of significant overbank flow is followed by a dry year. Panel B, shows how water recovery that enhances an already large overbank event followed by a dry year, which improves outcomes in the year that it occurs but with only a slight increase in the following year.

Panel C shows what will happen if water recovery serves to reinstate a smaller flow event in the year after an existing overbank flow. Preventing a dry spell by reinstating a small flow allows further breeding up of stock throughout years following a larger event. One grazier described the 'ideal' sequence being a large overbank flow followed by two years of average rain and lignum flooding, and that would be preferred to year after year of large floods.

The importance of when flow events occur, as much as how much, is equally important over seasons within the year. Flows in winter produce a different quality of feed to flows in summer. This is additionally affected by preceding conditions and whether the water comes from rainfall or overbank flow. The importance of sequence, as well as seasonality, is a core element of the FPGM design.

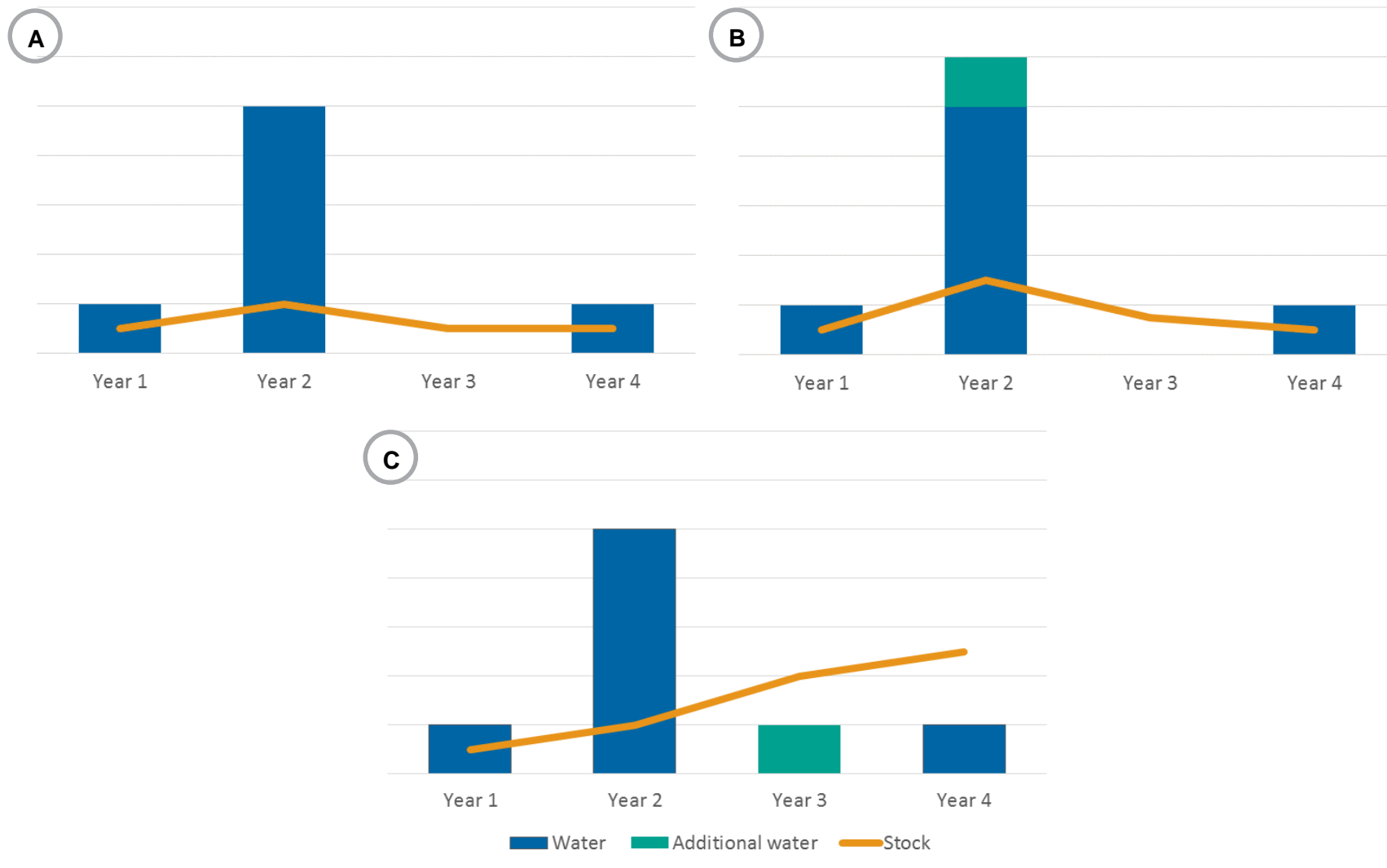


Figure 5: Effects of recovered water on stock

Work undertaken by the MDBA in comparing the duration between environmentally significant events on the Lower Balonne Floodplain shows that there has been a large increase in the maximum time between these events. The maximum duration between in-channel flow events that provide water connectivity (3,500ML/d for fourteen days at the Culgoa at Brenda gauge) has increased from 4.4 years to 10.8 years between the Without Development and Baseline scenarios. Similarly with small overbank flow events, the maximum duration between significant lignum floods (9,200ML/d at Culgoa at Brenda gauge) over the 113 years to 2009, has increased from 5.3 years in the Without Development scenario to 28.5 years in the Baseline scenario. See *Assessment of the environmental outcomes of water recovery scenarios in the Northern Basin* (MDBA, 2016a) for complete results for the Lower Balonne region.

These increases in the durations between events have also had an impact on stock and domestic water. The increasing length of time between flows, combined with a series of prolonged droughts in the 2000's and post 2012 have meant some properties are no longer able to rely on stock and domestic water being available. This is particularly important on those parts of the floodplain without access to groundwater sources. For those properties that do have access to groundwater, many have taken advantage of the NSW Government's Cap-and-Pipe program or have installed bores on their own account to ensure adequate access to water. However, this water is not enough to provide for cropping or pasture growth.

Distribution of flows

As well as the changes in volume and sequence of flows, the spatial distribution of flows across the floodplain has also changed. Figure 6 shows the modelled differences between the Without Development and Baseline scenarios for a selection of gauge sites on the floodplain. This shows a range of impacts from a decrease of 17% up to 64% of flows. Where water is being used, how water is managed, and the particular way that water moves across the floodplain during flooding, all work to determine which parts of the floodplain receive more or less water. As a general rule, the further down each river, the greater the relative change in flow. However, there are also changes between rivers. The Culgoa and Narran rivers have the largest relative changes in flows. Additionally, licence and water management changes have altered the relative balance between the rivers.

This change in flows has important implications for how the impacts are distributed. Those properties near rivers with the biggest reduction in flows will also have the biggest reduction in production. There are also impacts in terms of access. Properties that rely on the river for stock and domestic water, particularly on those most affected rivers and furthest downstream, have increasingly experienced problems in relying on and accessing this water source.

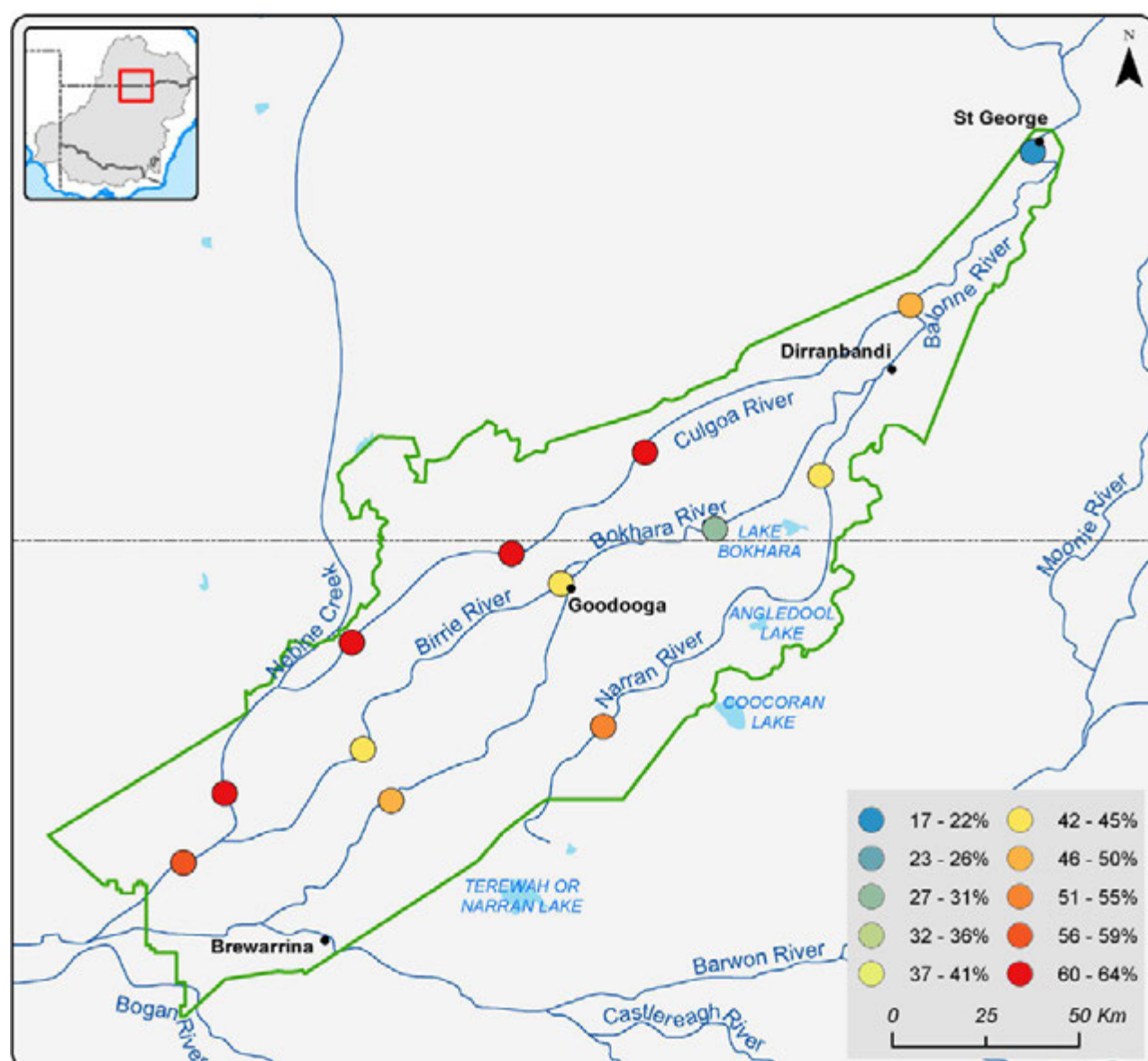


Figure 6: Distribution of flow reduction from Without Development to Baseline

Figure 7 illustrates the difference in the distribution of flows between the Without Development and the 390GL scenario. Similar to Figure 6, the gauges on the Culgoa River and those gauges downstream show the largest differences between these scenarios, ranging from a 46% to 55% decrease in flows. However, between the Baseline and the 390GL scenario, the Narran and Culgoa Rivers have relatively more water returned than under other scenarios due to assumptions about where water recovery is made. The pattern of water recovery also will affect the amount of water reaching the end of the floodplain.

Because the FPG model treats the floodplain as a single unit, it captures the aggregate effect of water recovery. It is nevertheless likely that the areas that receive more returned flows will also benefit more in terms of stock numbers and earnings.

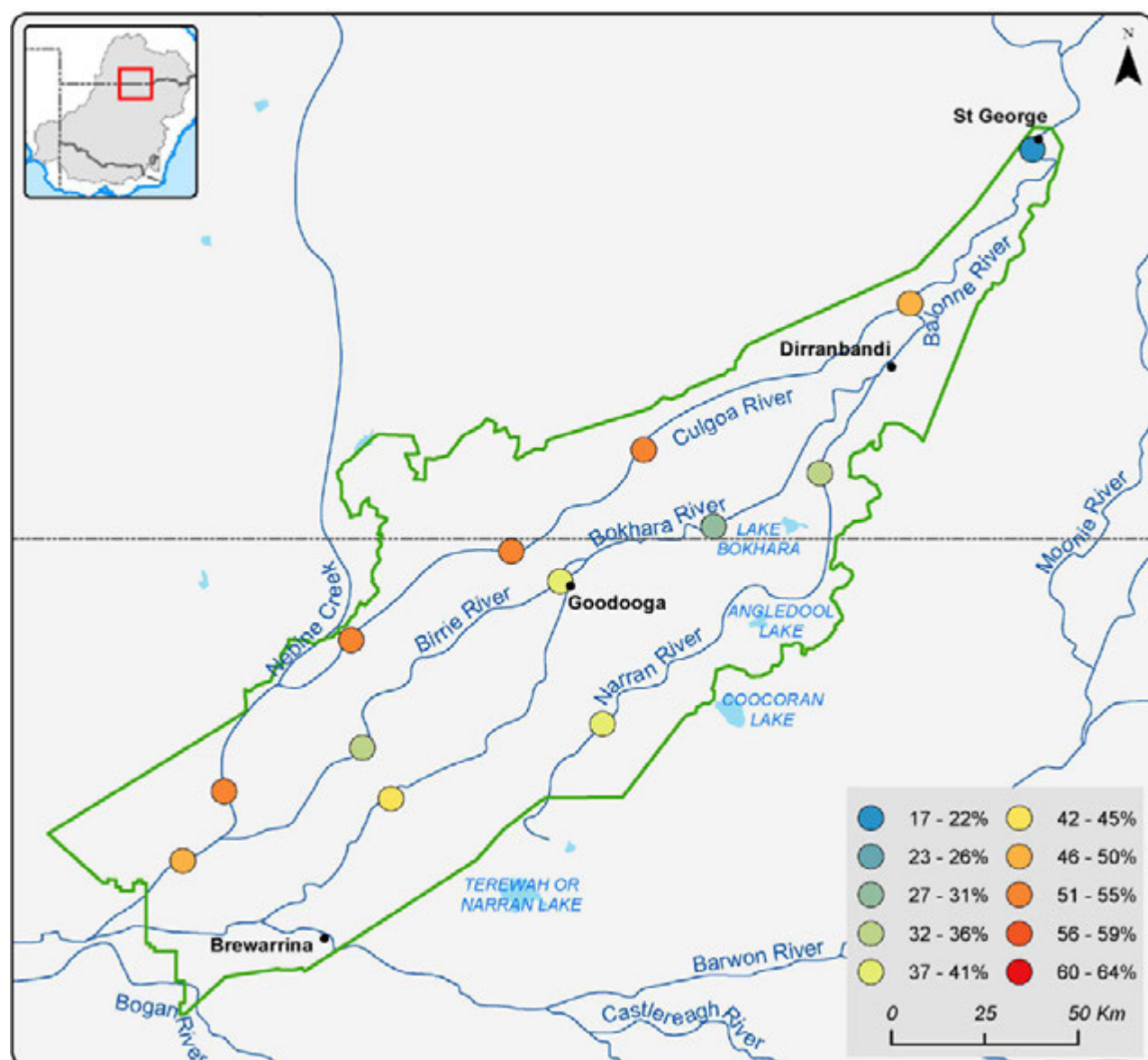


Figure 7: Distribution of flow reduction from Without Development to 390GL

Climatic conditions

The occurrence of flows is not evenly spread over the last century. The full floodplain grazing model runs over the 100 years until 2009. This period was selected based upon sufficient data on gauges and rainfall, as well as it being the period that the hydrology model has been run for. This period can be roughly broken up into three different climate periods. Until the early 1950s, there were very few large flows. Grazing methods were very different during this period to those used in the modern day. Due to the distances to markets, less technology, and the prolonged dry period, graziers would have likely had far less stock during this period. The second period ran for a decade until the 1960s when water availability was extremely high and flood records were set. Finally, the last period saw much more variation with years of both wet and dry. This final sequence most closely represents the experience of existing graziers.

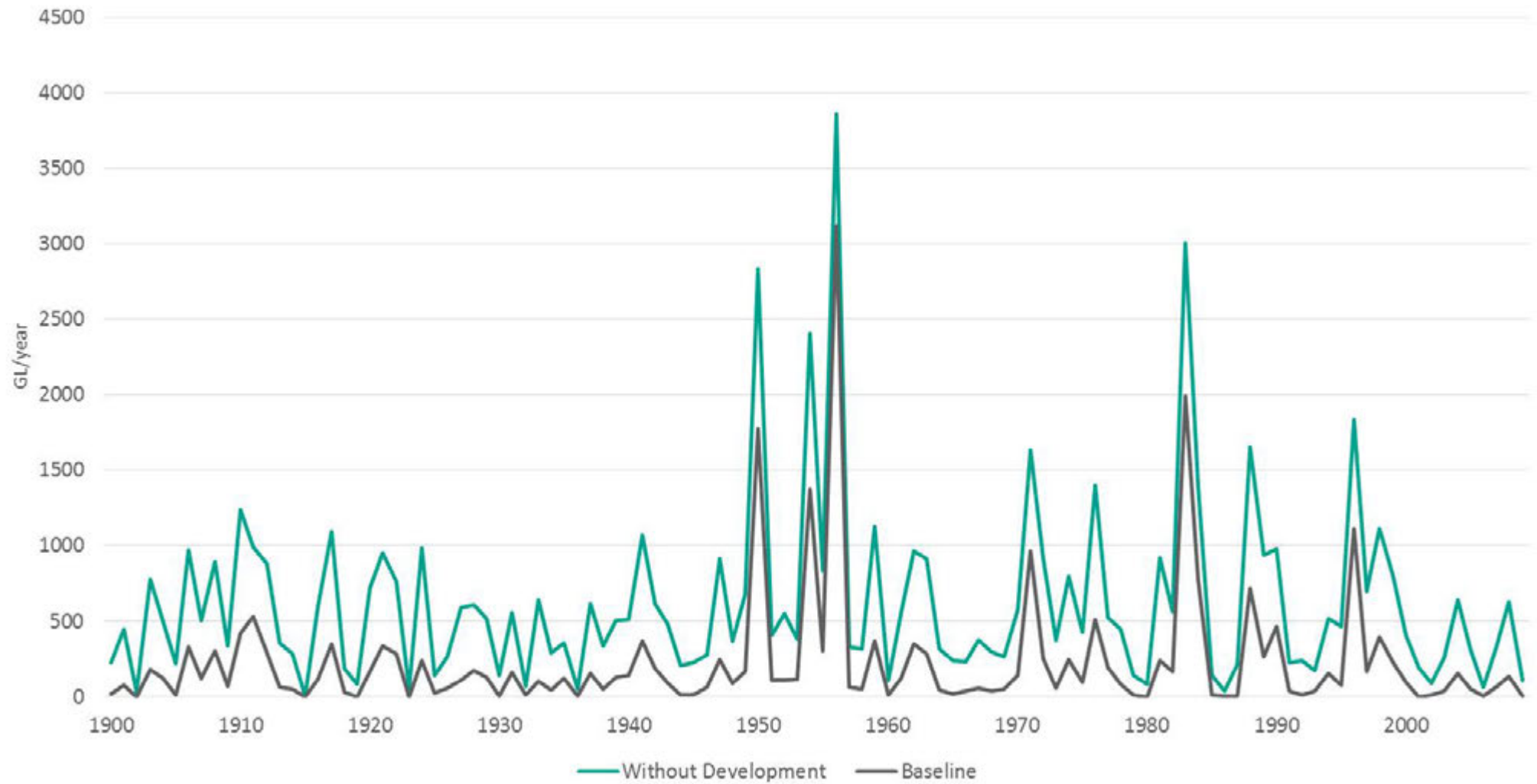


Figure 8: Annual gauge flows at the Culgoa at Brenda gauge

Water recovery in the Condamine-Balonne

The water recovery scenarios used in the Northern Basin Review are named in relation to the type and level of water recovery across the whole of the northern basin. Scenarios which have more water recovery across the whole of the northern basin do not necessarily assume more water recovery in the Condamine-Balonne catchment. Figure 9 gives the level of water recovery in the Condamine-Balonne catchment under each scenario. Even between scenarios with the same water recovery, modelled assumptions about the location and type of licence recovered will affect how much water reaches the floodplain. This, along with sequence and distribution of flow, explains why scenarios with more water recovery overall may not always deliver proportional benefits.

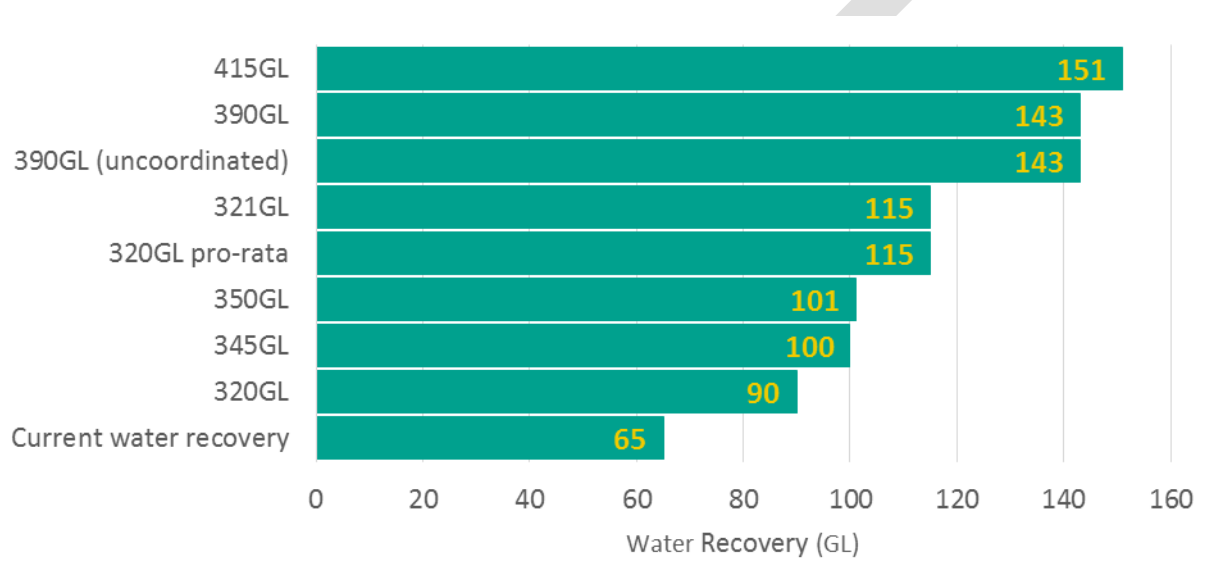


Figure 9: Water recovery in the Condamine-Balonne under each scenario

Building the model

The floodplain grazing system, as indicated above, is a complex system involving a range of flow types, seasonal conditions, grazer responses, and farm business models. This complexity means that linear modelling from a desktop study would be unable to capture sufficient detail to compare changed hydrology scenarios. Because of this, the MDBA had to engage closely with expert graziers to produce a more specialised simulation model.

It was impossible to directly link flow to inundation, to pasture response and finally to grazing outcome, as indicated in Figure 3 (above), due to the lack of data. To capture this process, the model was built as a simulation that combined many of these steps captured in seasonally based rules. Particularly, given that data only existed for a number of climate years – from the dry of the Millennium Drought to the widespread flooding of the 2010-2013 period – a model that was built relying only on available data would be prone to out-of-sample errors. That is, it would produce unusual results in types of climate years not covered in the data. This meant that further information and consultation with graziers was necessary to improve the model results.

The simulation rules were built by an iterative process of:

- consultation with graziers,

- composing a draft rule,
- comparing the rules behaviour to existing data,
- modifying existing rules to work in unison,
- bringing the rules back to graziers to discuss model performance,
- making further adjustments.

Repetition of this process allowed for refinement of behaviour both within the period where data existed for testing, but importantly also improved performance for all water years. This process also meant that each rule was built and validated from three points of evidence: a conceptual model of floodplain grazing, the data on production, and experience of current graziers. This also allowed for a gradual building of the model as rules were added and previous rules needed to be adjusted.

This process of consulting graziers, adjusting model behaviour, and comparing results with graziers identified several issues with the model. Primarily, it failed to respond to flow events in an increasing manner as well as failed to differentiate specific large flows over multiple days. This resulted in the creation of Rule 9 and Rule 10 (see Rule construction section below), as well as alterations to Rules 4, 6, 7 and 8. Additionally, since changes balanced effects over smaller flows, the buyback rule also had to be adjusted to prevent properties operating with negligible amount of stock in dry times.

As well as adjusting the rules that run the simulation, initial consultation with graziers highlighted important differences between properties that needed to be included in the model. The inclusion of model options around red and black soil, stock mix, and the use of supplementary feed were all identified as important components of the model that needed to be included.

The consultation process also identified variables that would affect model outcomes. Influential variables such as the price that stock sold for, or an estimated 'normal' amount of wool shorn from a merino were given as a range by various graziers. These ranges are given in the model. The effects of these variables on model results are given in the Sensitivity section (below).

Model design

The floodplain grazing model is used to consider the changes in flows, as described above, and how this affects production and earnings on the Lower Balonne Floodplain. The model simulates production and earnings by taking scenario outputs from the MDBA's hydrology model. It is built around the principle that the timing of flow and where a flow appears in a sequence are just as important as the volume of water.

The model attempts to evaluate differences in productivity across the whole floodplain rather than individual grazing businesses. Each business has a different combination of both fixed and variable costs. As the ratio of fixed and variable costs are affected by changes in flows – for example through farm amalgamation – estimating the full costs and benefits for specific properties would become unwieldy and complex across scenarios. As such, the model treats the floodplain as a single property with no subdivision and without fixed costs. It specifically accounts for labour costs, hence earnings per hectare estimates should not be attributed as profits to owner operators. Because of this, the model cannot be used to evaluate the effect of water recovery on specific businesses, nor can it be used to evaluate specific businesses' viability.

Instead, it estimates productive capacity changes of the floodplain as a whole. The model does not account for the time value of money or an internal rate of return, as these are both related to specific businesses. Net present value also discounts particular flows based upon timing, which is not informative when comparing the results of different flow scenarios.

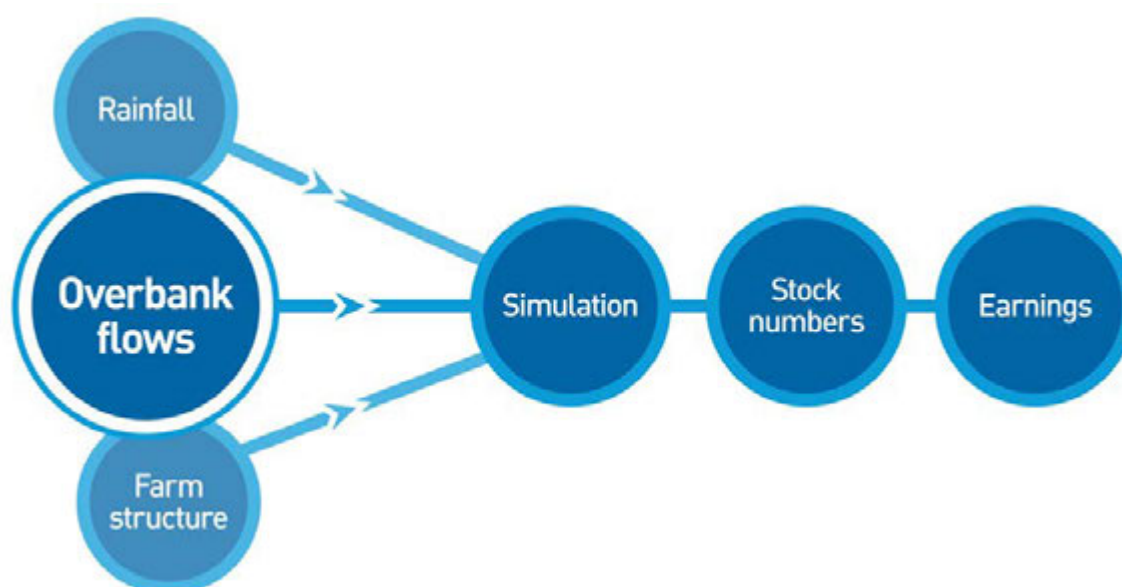


Figure 10: Basic model structure

The model calculates stock numbers – measured in terms of DSE per hectare – and resulting earnings each season. It calculates stock numbers based on the number of stock in the previous season, the rainfall and the overbank flows of the current season. These stock numbers are then used to calculate earnings.

The model also accounts for certain property specific factors when calculating stock numbers. The model can be varied based on stock mix, red/black soil division and the choice of whether or not to use supplementary feed. These factors have been added to the model to enable more disaggregated analysis if required, as the effect of flows on stock numbers and earnings will behave differently for each combination set. For instance, a principally red soil part of the floodplain, which does not flood, will produce fairly little – if any – variation in stock numbers based on changes in flow. Figure 13 and Figure 14 (below) show two model runs with the same model settings with different scenarios; while Figure 11 and Figure 12 show two model runs under the same water recovery scenario and different model settings.

The results of each model run are reported in terms of average annual DSE per hectare and average annual earnings per hectare. In some years, the model will produce significant differences between scenarios when there is a sequence of flow changes, in other years – particularly years of drought or only rainfall – the model will show no difference between scenarios.

This approach provides the flexibility needed to compare scenarios with the same model settings, or for different model settings to be used under a particular flow scenario.

Supplementary feeding

When conditions turn dry, if a property has more stock than existing feed supply can sustain, graziers can respond in two main ways. Either they can choose to destock the property completely or they can pay to import feed from elsewhere for the purpose of keeping stock in place. Some properties will grow feed on the property in wet years by forgoing foraging to shift feed to dry years. The management decision made about this will be different for each property for each dry period. There will also be differences across properties. The choice between whether to destock or to provide supplementary feeding will generally be based on how much stock remains on the property, how much feed there is on hand and prospects for pasture growth, the age of the herd, existing stock prices, existing feed prices, personal preferences, and farm financial condition. The decision is extremely important for grazing properties and is therefore modelled differently. Being caught by a long dry stretch with too many stock can be disastrous for grazing properties.

In both cases, as feed reduces, stock will progressively be sold off. Generally older, less productive animals will be sold off first to ensure a good breeding stock remains after the dry period. Younger animals also have a better chance of survival in dry periods. However, in both cases, it is better to sell-off as early as possible to maintain condition of stock and to avoid paying feed costs. There is no one best-decision in all cases. Two key determining factors will be the length of the dry period, the prevailing commodity prices and the circumstances on the farm.

In the case of a complete sell-off, graziers will generally receive lower prices as many properties likely to be destocking at the same time. Further, when wetter conditions return, and water and feed become more available, graziers must spend more to purchase back a (usually) young breeding herd in times when demand for stock is high. However, selling off completely makes more sense in prolonged droughts, when the ongoing costs of supplementary feed becomes unviable.

When graziers do choose to use supplementary feed to maintain animals on the property, there are three main benefits. Firstly, a property can maintain a good genetic stock to build on over time; secondly, the property is able to respond quicker to returning wet conditions; and thirdly, graziers avoid the added costs of completely restocking a property. However these benefits come with the cost of paying for feed to maintain animals. Usually supplementary feed will be kept at generally lower levels to save on costs, which usually results in little to no productivity as joinings (pairing rams and ewes for breeding) and high wool production becomes impossible. This is not the case for all properties. Generally, each property will maintain different levels of stock on supplementary feed. The use of supplementary feed is the traditional choice on the Lower Balonne Floodplain, although improved transportation and technology mean that properties are able to sell-off and buy-back at lower costs than in the past.

In practice, there are various gradations of supplementary feed and sell-off. Some properties maintain large stock numbers on supplementary feed, others sell-off completely, still others maintain very low levels of animals and avoid supplementary feed altogether. Additionally, graziers can use a range of feed levels.

This model also treats supplementary feed use in wet periods. In some cases, when there has been a lot of overbank flooding, supplementary feed can be used to boost nutrition lacking in pasture growth. This is represented in the model by increased success rates in breeding.

More than stock mix or soil type, whether supplementary feed is used has the most noticeable difference on results. This is because the other farm settings allow gradations while supplementary feed is treated as either being used or not used in the model. In reality, there are a myriad of strategies used to manage through dry periods with different outcomes for grazing businesses.

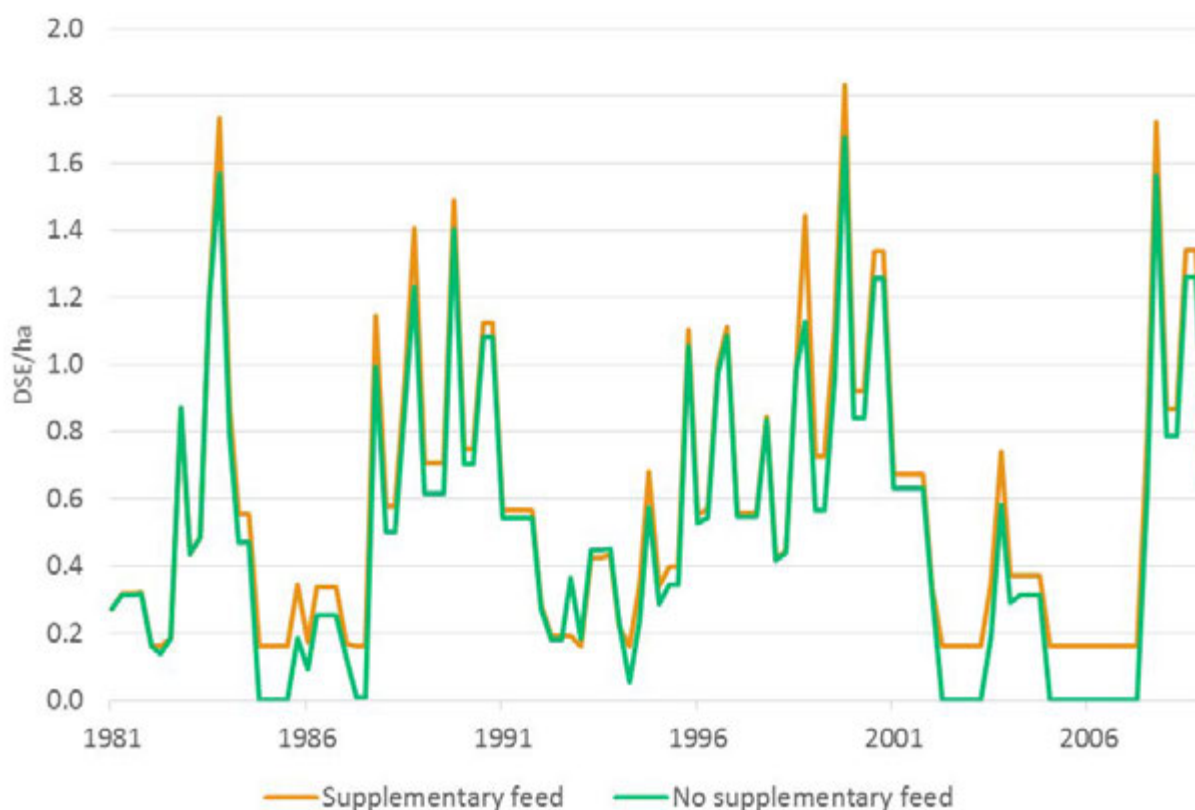


Figure 11: Stock numbers with and without supplementary feed

Figure 11 shows the difference, with the same water recovery scenario, between strategies based on supplementary feed and no supplementary feed. In the driest periods and wettest periods, there are noticeable differences between the two model runs. In the 1998-2000 period, the strategy with supplementary feed is providing better nutrition which results in better success in lambing rates. In very dry periods, such as 2000-2008 during the Millennium Drought, supplementary feed reduces or avoids the need to sell-off livestock. However, in most years, where water is not overly abundant or scarce, the two models will produce the same results.

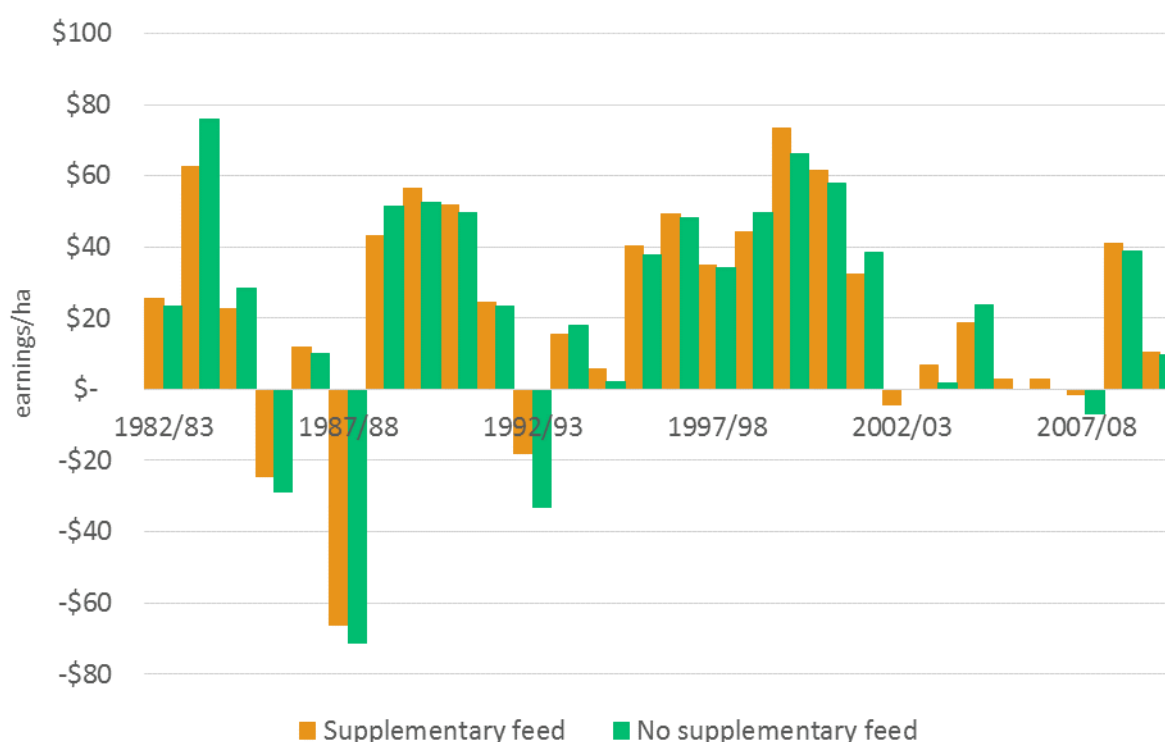


Figure 12: Earnings with and without supplementary feed

Figure 12 shows the earnings from the 'with supplementary feed' and 'without supplementary feed' model runs. In most years, each model run will produce about the same earnings. However in those years in high water, and the years before and after a sell-off, the difference is noticeable.

In a model run with sell-offs, there will be a big earning in the first dry year as all animals are sold from the property. This earning spike will then be followed by years of no cash flow while the property has no animals. Finally, in a year when wetter conditions return and where there is sufficient water to sustain animals, there will be large cash outlays to replenish animal numbers.

In model runs with supplementary feed, in all years there will cash flow, however in the dry years, the earnings will either be very low or slightly negative as costs of supplementary feed overtake the slim earnings. Generally, the supplementary feeding strategy appears to do slightly better over time.

See *Appendix B: Model Design* for a full discussion of the model approach and design.

Model tool

The model has been placed on the MDBA website along with this report. It includes a comparison tool that allows for model variables, and in particular the farm settings, to be changed. The tool allows users to explore the ranges of results that the model can produce. The Comparison tab features the red/black soil mix, the choice of supplementary feed, and the stock mix and choice over which two water scenarios to compare. On the Variable tab, the underlying model variables can be altered to compare variable sensitivities.

Model results

Figure 13 shows typical model output comparing the Without Development with the Baseline scenario. The model settings for this example do not use supplementary feed and has 100% black soil for both scenarios modelled. The inclusion of supplementary feed or increased red soil would generally reduce the variation in the model by raising the minimum or lowering the maximum respectively.

Figure 13 indicates that the differences between scenarios are not evenly spread across years. In some years, increased flows will produce double or more DSE/ha. In those years of rainfall without any overbank flows, such as through much of the 1920's; or in years of drought, as experienced in 2006, it can be seen that all scenarios will produce the same results. For years in which increased flows produce far more overbank flows – such as the period through 1997 – the results are much more divergent. Given that the Without Development and Baseline scenarios exhibit the shows the maximum difference in model output, all other scenarios and settings will produce results within this range.

The model runs for 100 years from 1909 until 2009. This period is modelled due to the availability of gauged rainfall data.

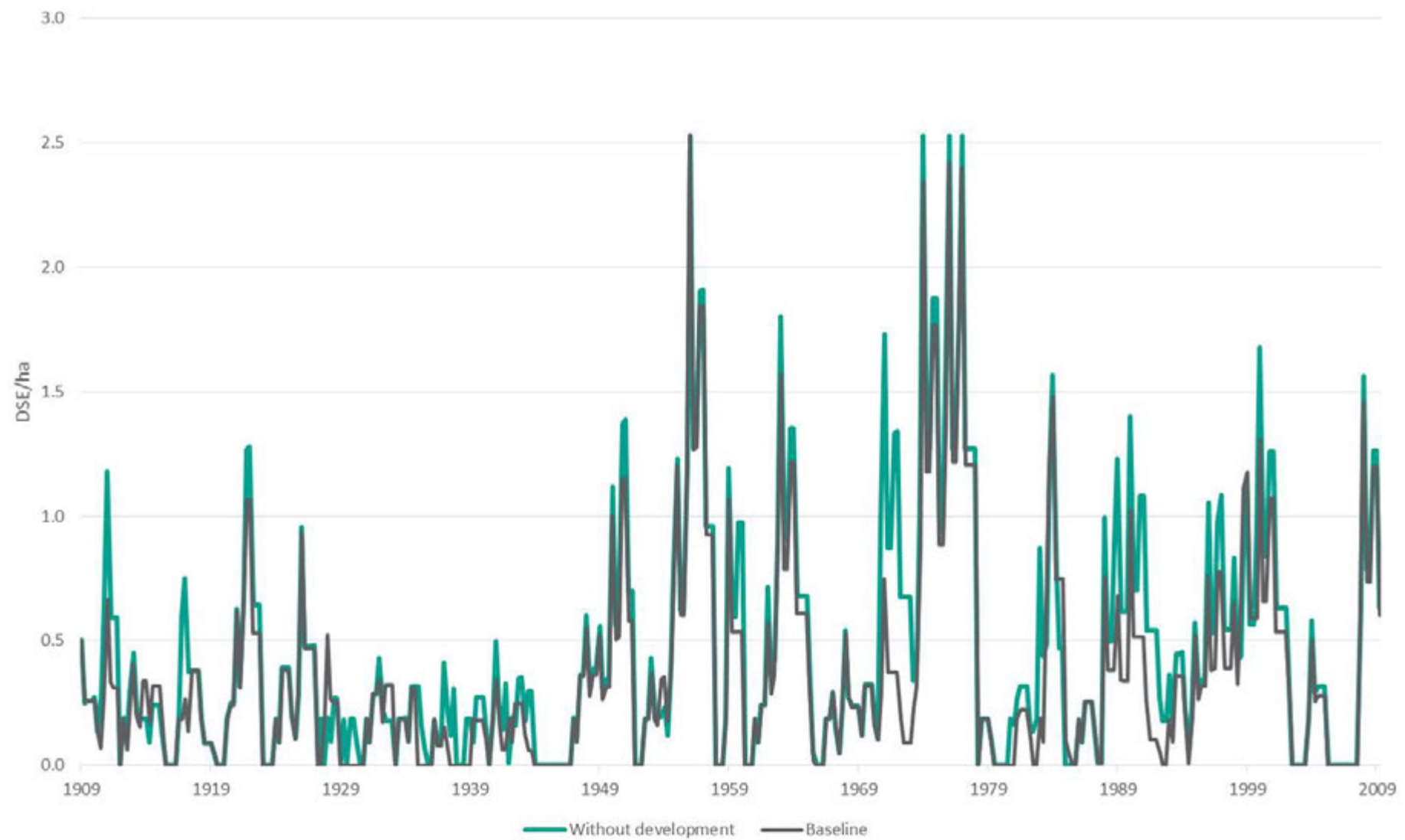


Figure 13: Modelled DSE/ha Without Development and Baseline

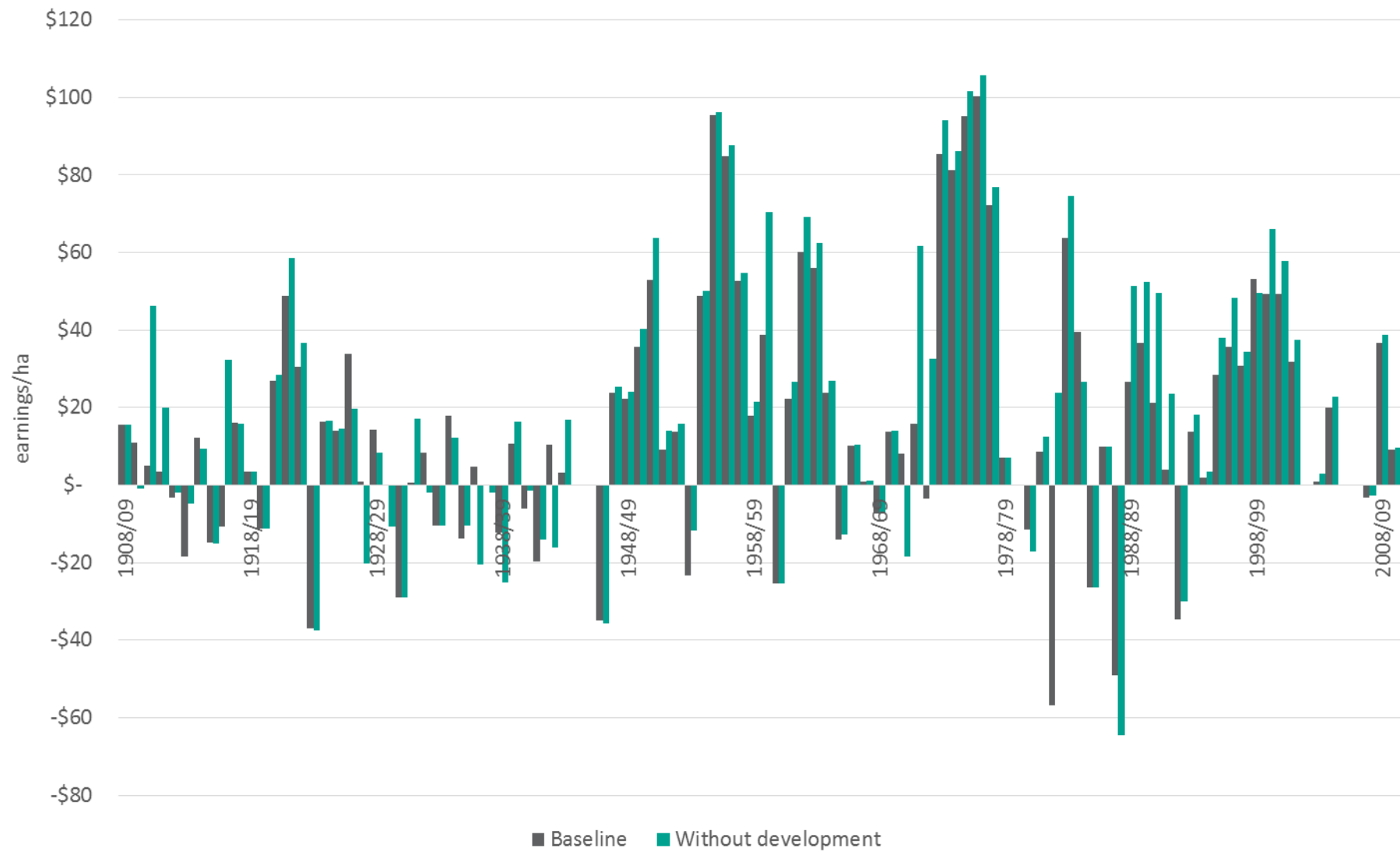


Figure 14: Modelled earnings/ha Without Development and Baseline

Figure 14 shows the annual earnings for the Without Development and Baseline scenarios. As for Figure 13, it shows results for a model run with 100% black soil, no supplementary feed and all sheep. In periods where stock numbers are similar between the Baseline and Without Development scenarios, earnings will be similar for both scenarios. Likewise, for periods where overbank flows make significant differences in stock numbers between the two scenarios, earnings reflect these differences.

Figure 14 also shows the costs associated with drought. In years where the property has been destocked, no earnings are recorded. However, the results also show that the years in which livestock are sold off will be high earning years, and years when restocking occurs result in large negative earnings. The balance between earnings and the costs associated with destocking and restocking is what determines the profitability of different stocking strategies. In periods without destocking, cattle will earn more in this model. However due to the cost of restocking, in periods with relatively more drought, sheep become the better earner due to lower stock costs.

Model results

The FPGM shows that as upstream development has reduced the volume of water reaching the Lower Balonne Floodplain, average stocking rates have dropped. There has been a similar effect on earnings. The figures below show results under a fixed set of model settings over the water recovery scenarios. These simple point-estimate results give a good indication of outcomes how the model performs with only changes in water recovery.

All subsequent results use the fixed model settings of equal amounts of agistment, sheep and cattle; and a proportion of black soil equal to that of the floodplain as a whole. Figure 15 and Figure 16 present results for with and without supplementary feeding strategies for each water recovery scenario modelled. The results show that as water is returned for the environment, stock and earnings are likewise returned to the floodplain. For example, compared with the Baseline (0.370 DSE/ha), Current water recovery restores around 10% of the drop in average stocking rates caused by upstream development (up to 0.378 DSE/ha), and the 350GL scenario restores 22% of the same reduction (up to 0.387 DSE/ha).

The difference in earnings is relatively larger. Water recovery increases the frequency of flooding events and reduces the length of dry spells. This reduces the number of times when stock is sold-off and brought back at losses. This means effects of water recovery are larger in earnings. In comparison with the Baseline (15.05 \$/ha), Current water recovery restores around 4% of the drop in average earnings per hectare caused by upstream development (up to 15.32 \$/ha), and the 350GL scenario restores 33% of the same reduction (up to 17.11 \$/ha).

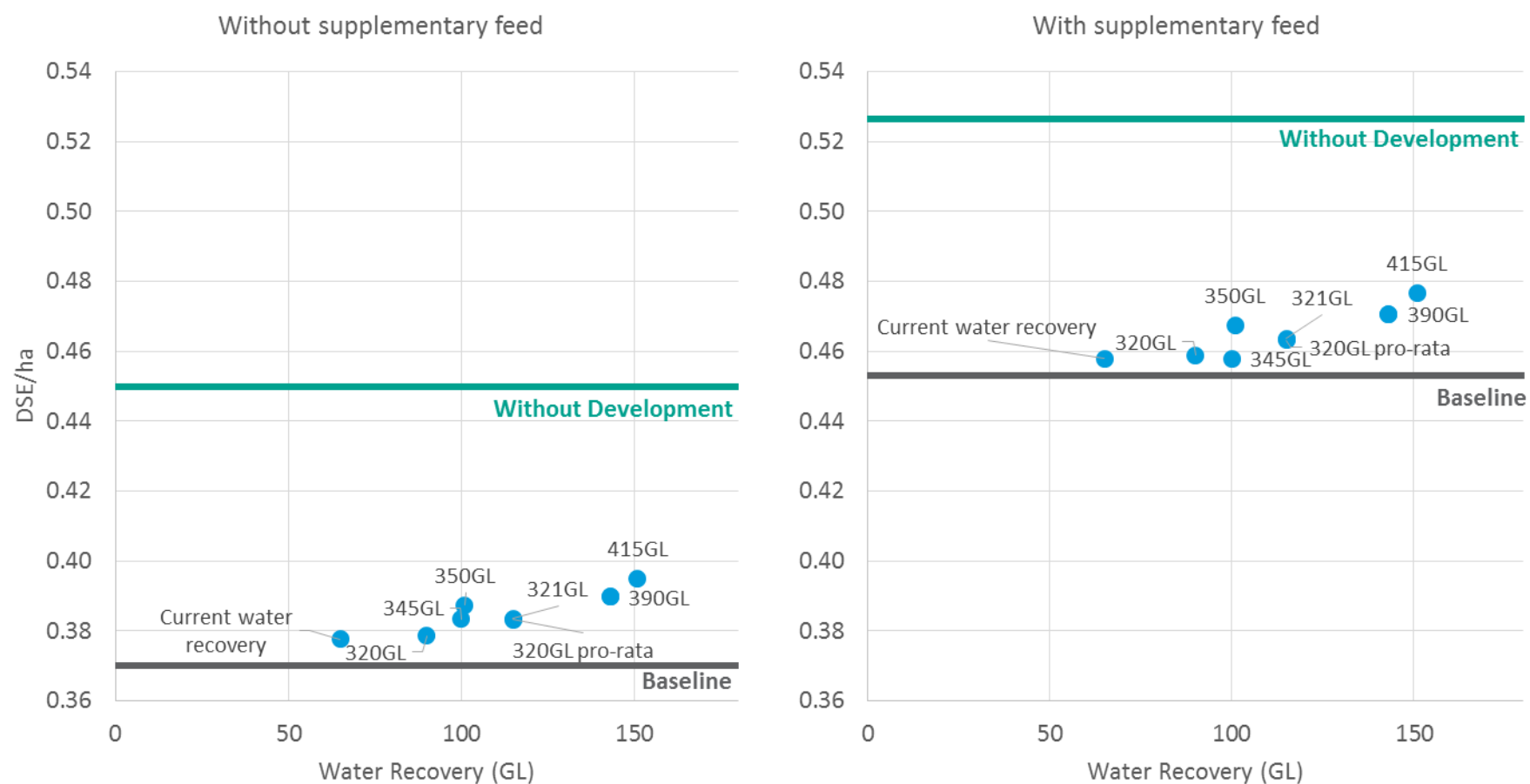


Figure 15: Fixed model settings DSE/ha results against water recovery in the Condamine-Balonne

The graphs above show the results with fixed model settings for with and without supplementary feed. Both strategies exhibit a similar pattern of increased stock numbers as more water is recovered. They also show that supplementary feeding properties naturally have more animals on average.

Table 1: Modelled stocking rates relative to Baseline

Stock Numbers per hectare (without supplementary feed)			
	Annual average DSE/ha	Change from Baseline	Proportion of the effect of upstream development which is returned
Baseline	0.370	0.00%	0.00%
Current water recovery	0.378	2.02%	9.52%
320GL	0.379	2.27%	10.73%
320GL pro-rata	0.383	3.46%	16.57%
345GL	0.383	3.48%	16.68%
321GL	0.384	3.55%	17.02%
350GL	0.387	4.48%	21.67%
390GL	0.390	5.08%	24.76%
415GL	0.395	6.35%	31.35%
Without Development	0.450	17.78%	100.00%

Stock Numbers per hectare (with supplementary feed)			
	Annual average DSE/ha	Change from Baseline	Proportion of the effect of upstream development which is returned
Baseline	0.453	0.00%	0.00%
Current water recovery	0.458	1.02%	6.37%
345GL	0.458	1.04%	6.49%
320GL	0.459	1.24%	7.75%
320GL pro-rata	0.463	2.16%	13.68%
321GL	0.464	2.26%	14.31%
350GL	0.467	3.01%	19.22%
390GL	0.471	3.71%	23.86%
415GL	0.477	4.91%	31.93%
Without Development	0.526	13.91%	100.00%

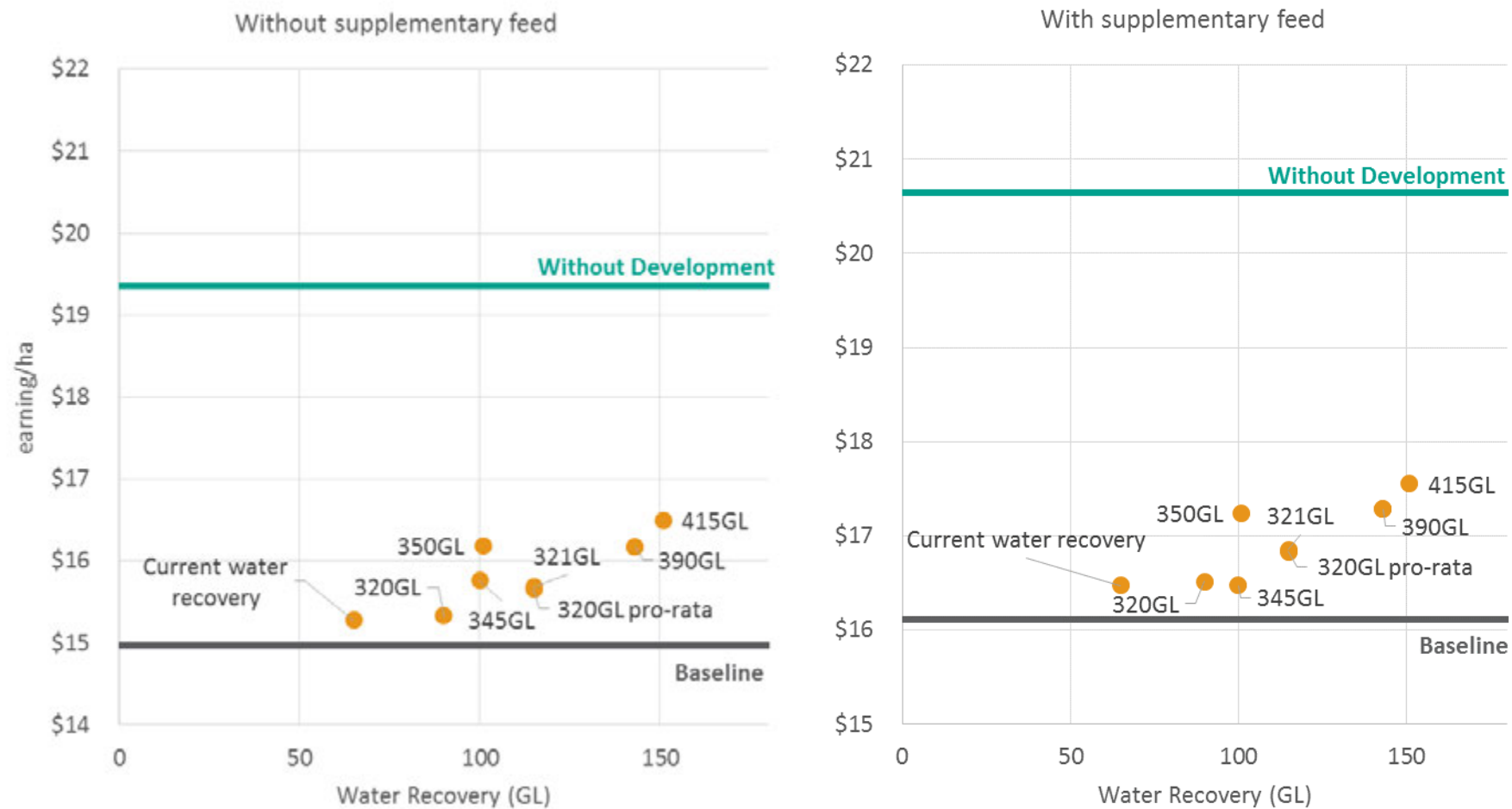


Figure 16: Fixed model settings earning/ha results against water recovery in the Condamine-Balonne

The above graphs show the earnings results for fixed model settings for with and without supplementary feeding. The pattern between scenarios is roughly similar to that of stock results. This also shows that using supplementary feed is only slightly better in terms of earnings than a strategy with no supplementary feed. One notable difference between these two strategies is evident for the 345GL scenario. Under this scenario a supplementary feeding strategy compared with no supplementary feed because of extended dry periods.

Table 2: Modelled earnings relative to Baseline for the 100 year average

Earnings per hectare (without supplementary feed)			
	Annual average earnings/ha	Change from Baseline	Proportion of the effect of upstream development which is returned
Baseline	\$14.96	0.00%	0.00%
Current water recovery	\$15.28	2.05%	7.13%
320GL	\$15.33	2.40%	8.38%
320GL pro-rata	\$15.66	4.42%	15.77%
321GL	\$15.68	4.56%	16.29%
345GL	\$15.76	5.06%	18.16%
390GL	\$16.17	7.47%	27.50%
350GL	\$16.18	7.52%	27.72%
415GL	\$16.50	9.28%	34.85%
Without Development	\$19.36	22.69%	100.00%

Earnings per hectare (with supplementary feed)			
	Annual average earnings/ha	Change from Baseline	Proportion of the effect of upstream development which is returned
Baseline	\$16.11	0.00%	0.00%
Current water recovery	\$16.47	2.19%	7.94%
345GL	\$16.48	2.21%	8.05%
320GL	\$16.52	2.45%	8.94%
320GL pro-rata	\$16.83	4.28%	15.88%
321GL	\$16.86	4.41%	16.41%
350GL	\$17.24	6.56%	24.96%
390GL	\$17.29	6.80%	25.93%
415GL	\$17.55	8.21%	31.77%
Without Development	\$20.65	21.96%	100.00%

Model variable sensitivity

The model results depend on the assumptions and input variables used. A full list of assumptions and rules are included in Appendix B: Model Design as well as a full description of the model itself. While the input variables and assumptions change results, the effects are usually relatively small. For example, an increase in the amount of wool shorn from a sheep will increase the values for all scenarios. The model normally assumes 5 kg of wool from each DSE of sheep, which results in a 29.34% difference in earnings between Without Development and Baseline. When the amount is pushed up to 5.25 kg per DSE, the difference changes to 29.23% between the same scenarios.

Another example where the results are slightly larger is the price earned for selling off sheep in dry conditions. Normally the price is \$85 per DSE, which results in a 29.34% difference between Without Development and Baseline. Some graziers suggested this price could be even lower at \$75 per DSE. Changing this variable changes the difference to 28.60% between Without Development (\$19.82 per hectare) and Baseline (\$15.41 per hectare).

A full account of variable sensitivities is given in the Sensitivity section in Appendix B: Model Design (below).

Results under recent climatic conditions: a 27 year simulation

As well as the 100 year simulation, which gives the best indication of how scenarios will perform over a full range of water availability conditions, a 27 year simulation (1982-2009) has been run to give a better understanding of the potential impacts on graziers under more familiar climatic conditions. The stream flows for the first half of the 100 year sequence until 2009 are far reduced from those in the middle and latter half as shown in Figure 8 (above). This is significant for an enterprise which is heavily reliant on streamflow (Figure 17).

This period from 1982 was modelled as it generally represents the experience of existing graziers and is closer to the period they were able to provide data for. While the 100 year simulation results are better for understanding results from returning water over the very long run, the 27 year simulation is more appropriate for understanding recent impacts on current graziers.

The 27 year period until 2009 was relatively wetter than the entire 100 year period, but is less wet than the 1950's, 1970's or early 2010's. However, it also incorporates the period of the Millennium drought in the 2000's.

This 27 years period had seen a number of changes which make it different in other ways to the whole 100 year period. As well as the changes in flow, the landscape, technology, business models and demographics of the area have also changed.

Grazing practice along with the reduction of water and the subsequent return of water from recovery has changed the types of trees and grasses that are growing or failing to grow on the floodplain. Some graziers noted that some plants and trees have started to grow in places where they had not been seen in living memory. The health of other plants, such as the lignum that lines the rivers, has declined with lower flows. The productivity of the land and the resulting conditions for grazing has been affected by these changes in plant life.

The business models of graziers have also changed over this period. Changing commodity prices, most notably the drop in the wool price in the early 1990's along with the recent increases

in the price of cattle, has meant a change in the stock mix on the floodplain from relatively sheep dominant to a more even mix between cattle and sheep. Additionally, the improvement of communication technology and transportation mean that graziers now do business with a much larger area around them. This has important implications for the relative costs of destocking and restocking, getting livestock to market, the costs of getting livestock to the area for agistment purposes as well as the towns where graziers go for agricultural supplies. These effects, separate from changes in water, have resulted in changes in business models over the 27 year period.

Finally the demographics of the floodplain have changed over the 1982 to 2009 period. The Mottell Reports from 1995 and 1996, for an area slightly larger than the current study area, estimate around 102 families in the Queensland portion and 390 families in the NSW portion of the floodplain living on agricultural properties. The number of families on agricultural properties at present is likely to be significantly lower due to a range of factors including reduced flows. During consultations, graziers suggested that in the past, graziers were required to live on their properties. However, multiple factors working together have led to a change in this requirement, resulting in property owners living away from their properties. Some of these factors are: farm amalgamations; labour saving technologies; the reduction in water availability and production opportunities; and changes in commodity prices.

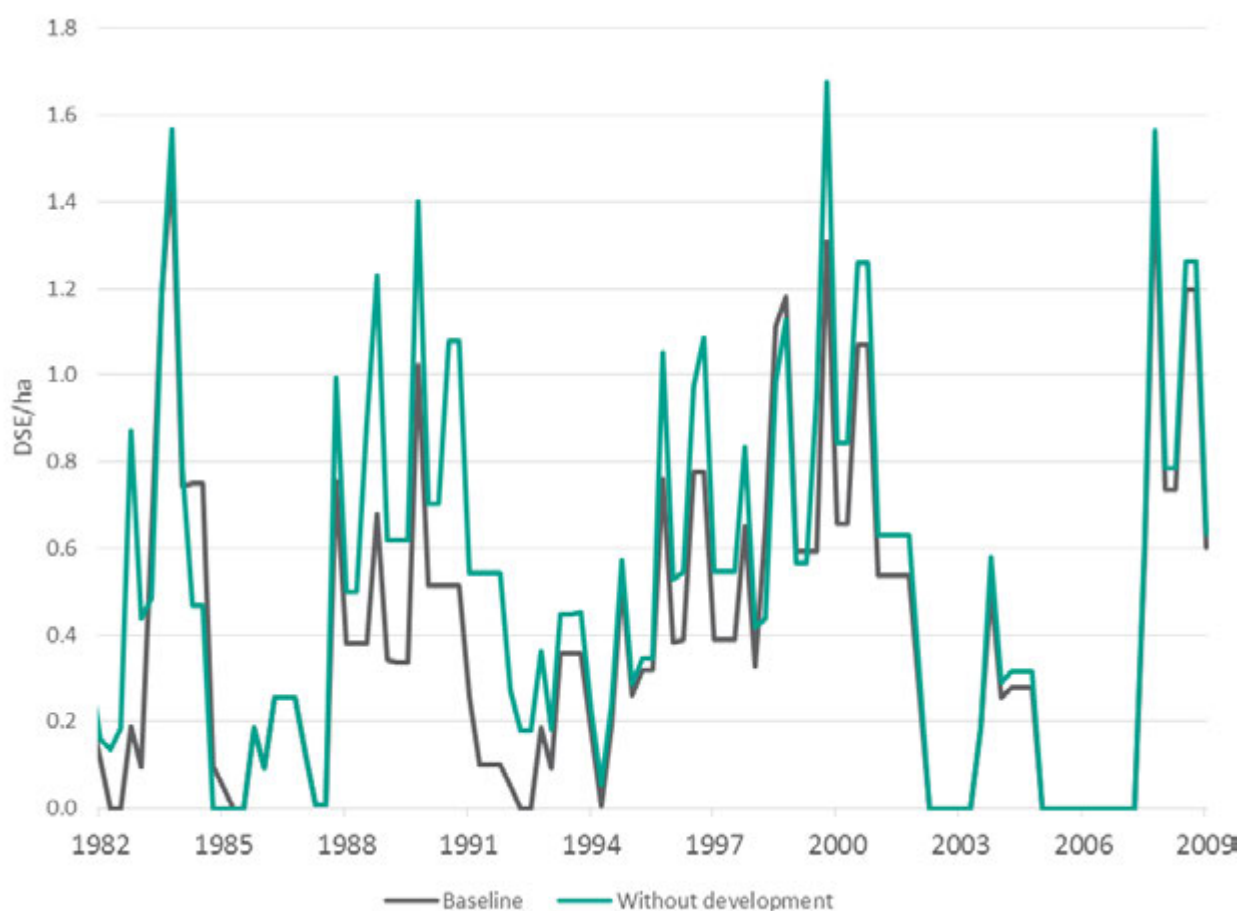


Figure 17: 27 year simulation results for changes in stocking rate

Table 3 lists the difference in stock numbers relative to the Baseline for each water recovery scenario. In general, the differences across scenarios are less for the 27 year simulation than for the 100 year simulation, though there is a larger difference between Baseline and Without Development.

Table 3: 27 year simulation stocking rate relative to Baseline (without supplementary feed)

Stock Numbers (DSE/ha)			
	Annual average DSE/ha	Change from Baseline	Proportion of the effect of upstream development which is returned
Baseline	0.364	0.000%	0.000%
Current water recovery	0.370	1.506%	5.360%
320GL	0.371	1.825%	6.513%
345GL	0.373	2.319%	8.320%
320GL pro-rata	0.373	2.405%	8.637%
321GL	0.373	2.459%	8.834%
350GL	0.388	6.251%	23.365%
390GL	0.392	7.122%	26.872%
415GL	0.409	11.043%	43.501%
Without Development	0.468	22.202%	100.000%

The difference in earnings between Baseline and Without Development is also slightly greater under the 27 year simulation compared with the full 100 years. Over the shorter period, the 350GL, 390GL and the 415GL water recovery scenarios all provide a marked increase in stocking rates and earnings compared with the other scenarios, as there are relatively more high-flow events in this period which favour scenarios that improve high-flows. This result holds regardless of the supplementary feeding strategy used

Table 4: 27 year simulation earnings relative to Baseline (without supplementary feed)

Earnings/ha			
	Annual average earnings/ha	Change from Baseline	Proportion of the effect of upstream development which is returned
Baseline	\$12.91	0%	0%
Current water recovery	\$13.15	2%	3%
320GL	\$13.20	2%	4%
321GL	\$13.27	3%	5%
320GL pro-rata	\$13.28	3%	5%
345GL	\$13.28	3%	5%
350GL	\$14.31	10%	19%
390GL	\$14.46	11%	21%
415GL	\$15.52	17%	36%

Earnings/ha			
Without Development	\$20.22	36%	100%

Model result characteristics

It is important to note that while the above results are for the floodplain as a whole, some properties may have experienced more or less significant changes. For instance, properties with all red soil will not experience any difference between scenarios as they do not experience any over-bank flows, while some properties with a dominance of black soils will experience differences twice as large as the average.

The results presented in also relate to a 100 year simulation covering a wide range of water availability conditions. However, the differences between scenarios is not evenly distributed in years or across properties.

For example it can be seen from model results that different hydrology 'regimes' existed roughly before 1940, between 1940 and 1980, from 1980 until 2000. Additionally the prolonged Millennium Drought, the high water years between 2009 and 2012, and finally the drought since 2012, have all had unique impacts on grazing systems that are different from the average over the 100 year period. Periods of relative dry are dominated by the cycle of sell off/buy on and/or supplementary feed, while relatively wet periods are dominated by larger production caused by overbank flows. It is important to note that the average production per hectare will be affected by the period selected while also hiding impacts of specific flow regimes.

This analysis also highlights that the average difference between two water recovery scenarios will not be reflected in each individual year's results. In droughts, differences between scenarios are often minor. The same is generally true in the periods with predominantly only rain. Flow changes between water recovery scenarios have the highest impact when flows that break a dry spell are restored or small flows are substantially enhanced. That is, it is the years in between the wet and dry extremes that differentiate between scenarios. This also means that the differences between scenarios can cluster in a series of years. For graziers, than means that in some short periods they may benefit significantly from assumed water recovery, much more than the average difference reported in the summary of results. The periods where flows are unchanged or impacts are minimal hide these larger differences that sit behind the average results.

The range of possible results from different model settings also suggest farm decision making can have a greater impact than changed flow alone. While the red/black soil division is fixed, the choice to use supplementary feed obviously has a relatively large impact on the average number of livestock kept over a long period. Supplementary feed also "flattens" differences in livestock numbers by setting a lower bound. Importantly, it is difficult to determine the extent to which changes in flows have had, or will have, impacts on these business choices.

Discussion

Water recovery and results

These results show that water recovery generally leads to improved results for both stock numbers and earnings. The beneficial effects of water recovery depend heavily on the period modelled. Scenarios which reinstate relatively more low-flow events will perform much better in dry periods, likewise for those that reinstate more high-flow events. This is evidenced by the relatively stronger performance of the 350GL, 390GL and 415GL scenarios in the 27 year simulations as each assumes water recovery that benefit relatively more in a wetter period. However, it is clear that water recovery unambiguously benefits floodplain grazing across the full range flow sequences.

These results also show that water recovered below Beardmore Dam, and in particular below St George will produce better results for the floodplain. The 350GL scenario performs relatively well compared with other scenarios which recover similar volumes of water. This scenario results in more stock and earnings relative to the 345GL scenario which has very similar total volumes recovered in the Condamine-Balonne catchment. However, it produces larger results for the floodplain because the water recovery is more targeted to benefit from the higher-flow events. Under that scenario the floodplain grazing benefits are comparable with the 415GL and the current target of 390GL scenario but with one third less water recovery in the Condamine-Balonne catchment.

Community

Upstream water development has affected floodplain grazing cash flows, seasonal employment opportunities, and possibly changes in the number of remaining households, which has impacted the surrounding communities, particularly Brewarrina. Reduced flows have added to the effect of other existing social and economic changes in the condition of these communities. The local communities, in particular Brewarrina, which have limited irrigated agriculture were once very dependent on grazing activity and associated seasonal and temporary work. The number of the grazing properties has dramatically decreased since the mid-1990s, in part due to reduced flows. While the decline in water is not the only factor affecting these communities, it has exacerbated underlying trends. The recovery of water as part of the Basin Plan will not dramatically improve the economy of Brewarrina and the surrounding communities, however it will have flow on positive effects for the community.

Conclusion

The results from the 100-year simulation suggest that water recovery can restore up to a third of the reduction in stock numbers and earnings due to upstream development. It appears that the 350GL, 390GL and 415GL scenarios will produce relatively similar positive results. These scenarios perform noticeably better than the other scenarios, which generally produce results not very different to those from the current level of water recovery.

The results are consistent with grazier advice that a greater volume of water, while generally producing better results as recovery goes up, is not the only factor affecting production outcomes. The locations, types of water recovered, and the way water is managed can have just as significant effects on environmental targets and floodplain grazing production in the Lower

Balonne as the volume of water recovered alone. Determining the types of water to be recovered, the rules around access to water, and the location of water recovery are outside the scope of this analysis and warrant further work.

The results from the 27-year simulation best highlight the magnitude of the potential benefits of water recovery. From the 'no supplementary feed' model highlights that water recovery can restore as much as 22% of the reduction in stocking rates and 36% of the drop in earnings caused by upstream water development. These are significant amounts for graziers. The analysis in this report also highlights that upstream water development has affected some properties more than others. Given that some places have lost more than half of all flows, large impacts are not unexpected. While the model does not account for individual businesses, it is likely that most properties on the floodplain have experienced some impacts.

While the results in this report are generally presented as averages across the entire floodplain, results on individual properties could be more significant. Graziers, by importing supplementary feed, help ameliorate the impacts of reduced water availability. However, a number of attributes will mean that some properties are more impacted by reduced water availability than others. The corollary of this is that some properties will benefit more than others from the increased flows associated with the water recovery scenarios. For example, properties better positioned to manage drier conditions with farm capital and supplementary feed; and those with more black soil (and therefore greater exposure to the benefits of overbank flows); will benefit more than the average property.

Also, this modelling work does not account for benefits that may be associated with opportunistic cropping on the floodplain following overbank flow events. Additionally, the geographic distribution of impacts is outside the scope of this analysis, although some graziers expressed during consultation that access to stock and domestic water is a very important issue on some parts of the floodplain.

It is likely that three decades of reduced flows, along with other changes, have meant that some households and businesses have stopped floodplain grazing in the Lower Balonne area. Returning water will not have the same effect as if the water was never removed from the area. By returning up to a third of potential stock and earnings to the floodplain, existing graziers would be in a better position to manage their future. This is likely to have flow-on benefits for the surrounding communities of the floodplain.

Appendix A: Notes

Acronyms

- DSE – dry sheep equivalent
- FPG – floodplain grazing
- FPGM – floodplain grazing model
- MDBA – Murray-Darling Basin Authority
- NBR – Northern Basin Review
- SDL – Sustainable Diversion Limit

Scenarios

Table 5: Scenario descriptions

Scenario Name	Volume across northern basin	Volume in Condamine-Balonne	Description
Baseline	N/A	N/A	The best estimate of water management operations prior to the Basin Plan. This scenario represents all entitlements, water allocation policies, water sharing rules, operating rules, and infrastructure as of June 2009.
Without Development	N/A	N/A	The best estimate of hydrology without development upstream of the floodplain. A comparison scenario.
Current water recovery	278 GL	65 GL	Represents the amount of water recovered in the Northern Basin as at December 2015, based on current planning assumptions and an estimate of 10 GL for expected future infrastructure-related recovery.
320GL	320 GL	90 GL	Represents water recovery at December 2015 (278 GL) supplemented with a further 42 GL recovered from the Condamine-Balonne, Border Rivers and Namoi catchments. Other catchments remain unchanged as they have already met their default contribution towards the shared recovery volume or have less influence on flows in the Barwon-Darling.
320GL pro-rata	320 GL	115 GL	Represents existing water recovery plus an additional 42 GL of recovery, but with a water portfolio re-balanced to ensure the NSW and Qld

Scenario Name	Volume across northern basin	Volume in Condamine-Balonne	Description
			contributions follow the default approach in the Basin Plan.
321GL	321GL	115 GL	A scenario designed using updated environmental, social and economic knowledge and the understanding we have gained from the other scenarios that resulted in more efficient environmental outcomes while minimising economic effects.
345GL	345 GL	100 GL	A scenario designed using updated environmental, social and economic knowledge and the understanding we have gained from the other scenarios that resulted in more efficient environmental outcomes while minimising economic effects
350GL	350 GL	101 GL	Represents a targeted water recovery — within Qld, recovery of the shared component has been targeted in the Border Rivers (rather than the Condamine–Balonne) based on relative connectivity with the Barwon–Darling — furthermore, recovery within the Condamine–Balonne has been targeted for the volume, location and entitlement types.
390GL (Northern Standard)	390 GL	143 GL	Represents the fully implemented Basin Plan as currently legislated. This scenario is the benchmark to compare with other scenarios tested as part of the Northern Basin Review.
415GL	415 GL	151 GL	This scenario represents a similar water recovery approach to the fully-implemented Basin Plan with a 25 GL increase to the water recovery volume.



Appendix B: Model Design

The model runs on the basic structure that the stock numbers in any one period is a function of the current season, the stock numbers in the previous period, and the overbank flows and rainfall over the previous two years as shown in Equation 1 where t is a seasonal (summer, winter, autumn and spring) time step. This general structure was derived from consultations with graziers. This reflects that overbank flows on the floodplain can have large lagged effects and are sequence dependant.

$Stock_t = f(Stock_{t-1}, Season_t, Overbank\ flows_{t...t-7}, Rainfall_{t...t-7})$

Model structure

The functional model takes the following form:

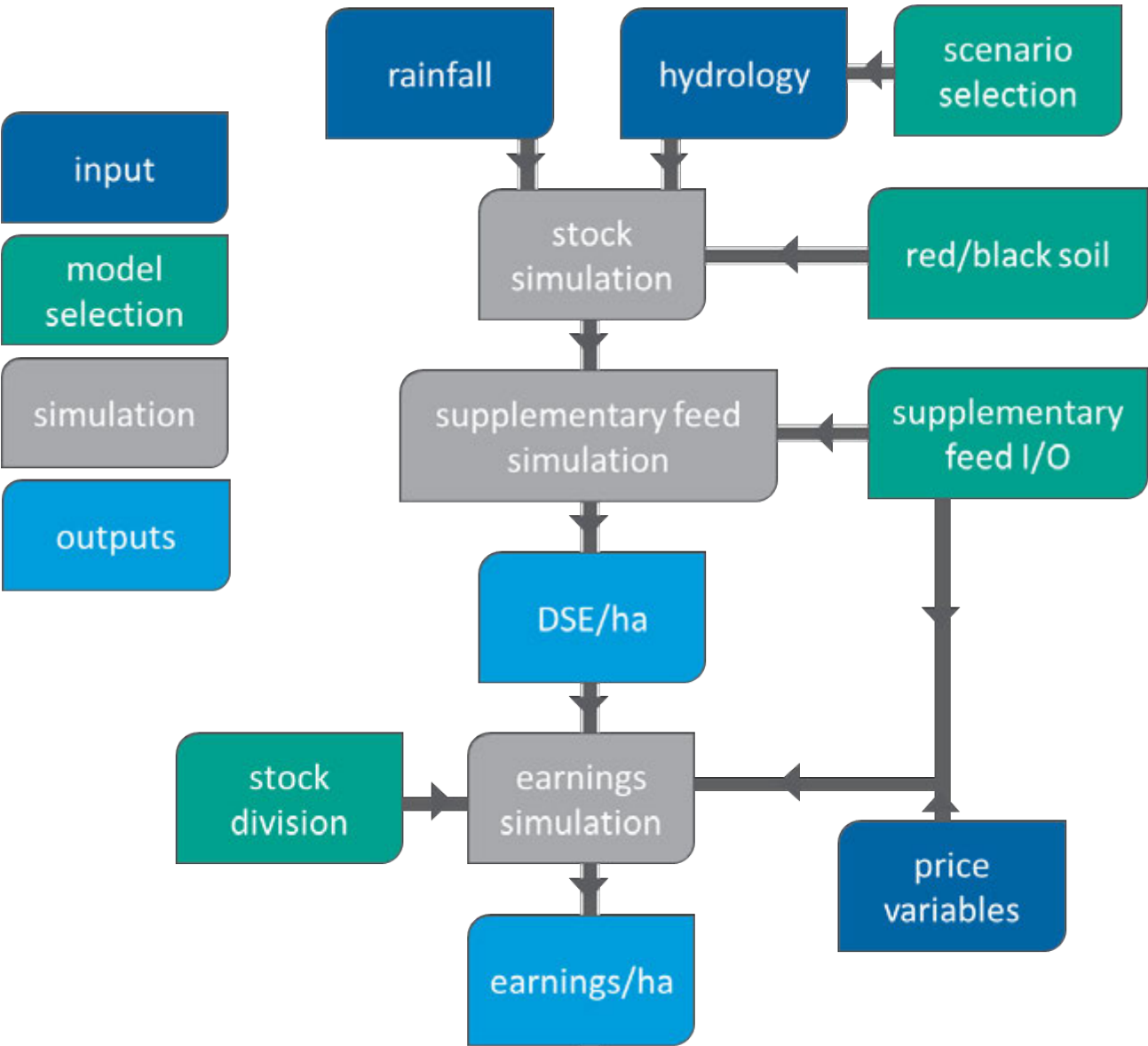


Figure 18: Model schematic

Model features

To capture this structure and features of floodplain grazing, and given the limited data, the model is built in Excel with the following features:

- Excel based
- Simulation based
- Computationally optimized model variables
- Seasonal
- Conditions are 'rules' based
- Primarily estimates carrying capacity and earnings separately
- Earnings estimated seasonally
- Separate training and model period

Excel based

The model was built in Microsoft Excel. The model relies heavily on the IF function to form the conditional rules.

Simulation based

The model is a simulation of stock numbers/carrying capacity expressed as DSEs. A simulation model was deemed necessary to capture the range of conditions faced by floodplain graziers, while also accounting for non-linearities of floodplain grazing systems. Figure 19 shows a stylised version of some of the complexity and non-linearities of floodplain grazing not adequately captured by more simple econometric models.

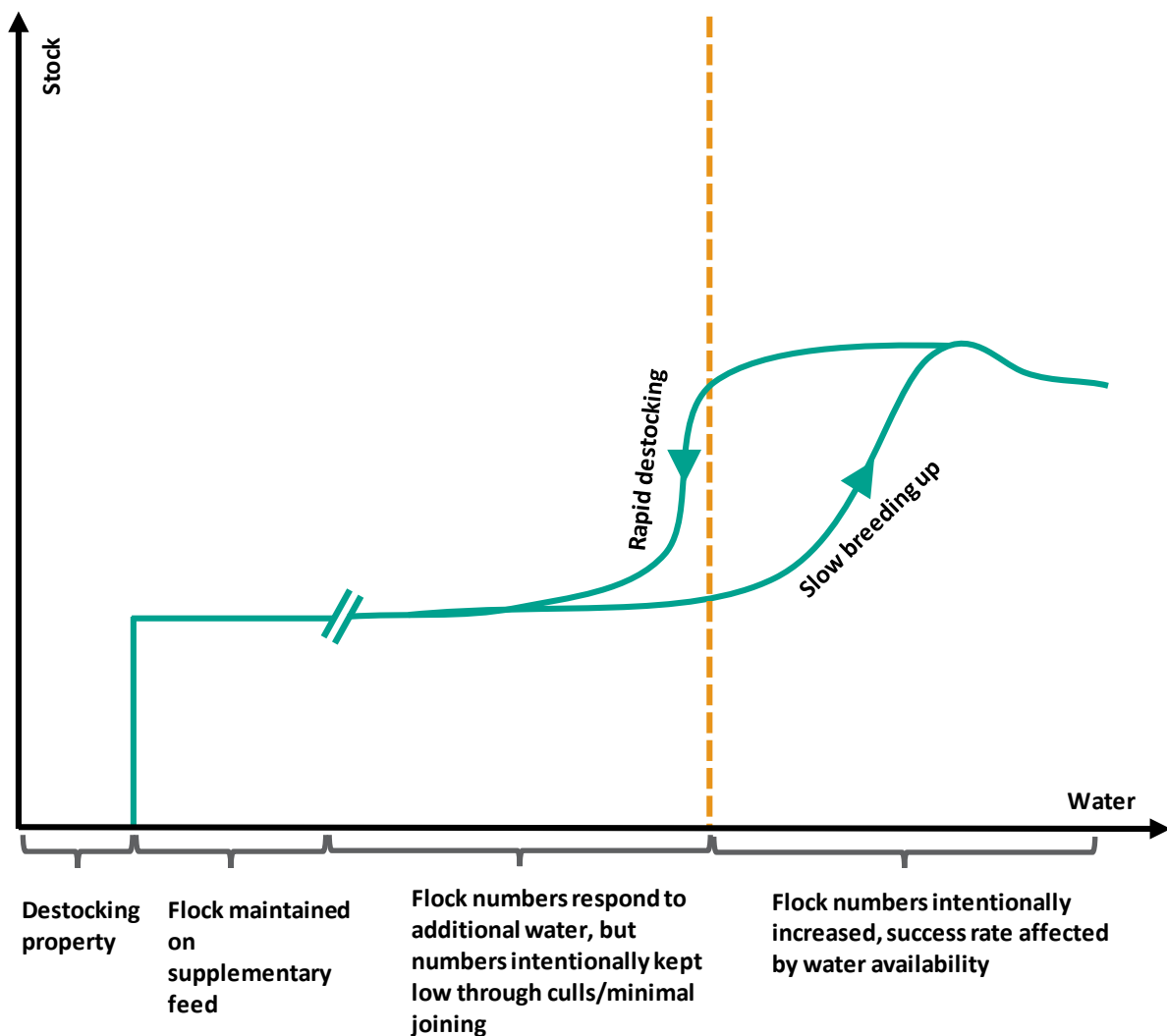


Figure 19: Stock response pattern

Computationally optimized model variables

The model variables were initially regressed against changes in DSE while those conditions were present in the training data. However, as rules have a combined and interacting effect in the model, the driving effects variables have been optimised using Microsoft Excel's Solver feature. This was run using the Evolutionary optimiser with generally tight limits because of potential non-linearities. The effects variables have been refined in an iterative process one-by-one rather than simultaneously due to limitations of the optimiser used. Results which 'broke' rules, such as equalling 0, were not kept over previous iterations. The target value was the coefficient-of-determination between model results and the training set, defined as:

$$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Conditional threshold variables and those that relate to supplementary feed were defined based on observation, weather and gauge data, farm data and interviews with graziers. These threshold values were not computationally optimised as this can result in thresholds which turn off rules altogether.

Seasonal

Stock numbers are generally recorded on an annual basis while hydrology and rainfall is reported on a daily basis. Seasonal estimates provide enough coverage of the range of water effects within a year. The model runs on a seasonal time step. This means periods are defined as winter until the 31st of August, spring until the 30th of November, summer until the 28th of February, and autumn until the 31st of May. This means that the same volume of water, from either rainfall or overbank flows, will have different effects depending on the season in which it occurs and in which part of the annual cycle the stock are in. For instance, joining only occurs after the longest day in summer, hence if a sell-off is forced to occur before this – such as due to extreme dry conditions and/or the declining availability of pasture feed – it will have significant effects in terms of end of year stock numbers.

Conditions are 'rules' based

The FPG model runs a number of 'rules' to determine stock numbers. There are eight primary rules and two additional rules to cover the effects of supplementary feed. Each rule is defined in terms of a change in DSE/ha. The DSE/ha at the end of each season is the sum of each rule-determined change and the DSE/ha at the end of the previous season.

Each rule typically has two parts: an 'if-statement' threshold variable that determines whether a condition or set of conditions are fulfilled which turn-on a rule; and effects variables that define the impact on DSE/ha when rules are triggered. Most rules have a seasonal condition and then an additional set of conditions that relate to water availability from either rainfall or overbank flows. The two rules which apply to supplementary feed have an additional true-false condition for whether or not supplementary feed is applied.

Estimates carrying capacity and earnings separately

The simulation model primarily estimates carrying capacity on a property, which is measured by DSE/ha. The question being asked is "what effect would water recovery have on potential future production?" This relates primarily to the estimation of changes in DSE/ha attributed to changes in the hydrograph. Hence, the core of the model estimates DSE/ha.

A second part of the model estimates earnings/ha. Given graziers face discontinuous earnings from having to sell-off and buy-on, as well as from the decision to turn to supplementary feed to boost production, carrying capacity does not have a linear relationship with earnings. As the carrying capacity aspect of the model is unable to attribute increases in stock numbers or decreases as purchases or sales, the model assumes the typical amount earned from a DSE of sheep, cattle and agistment. This rate is then applied to each quarter of carrying capacity. Even though these earnings are not, in reality, accrued to graziers in each quarter, these earnings can be taken as the grown meat and wool over that quarter of feed supply. Where rules can directly attribute earnings or costs to the change in stock, such as buy-on and sell-off rules, this is added directly.

Separate training and modelling periods

The stocking data collected from the consultations with graziers and from the Local Land Services was only available from the mid-1990s or early 2000s. This means that the data is only available for the period after development had already occurred upstream of the floodplain. This represents a significant limitation. Further, the model was trained over the period from early 2004 until 2013. This period was exceptionally dry and then exceptionally wet. However, the model runs for 100 years until 2009 which is largely in line with the hydrology modelling for the whole

Northern Basin Review. This means that some types of scenarios, particularly mid-level water years, had to be interpolated. This makes this model prone to out-of-sample errors relating to performance in conditions not represented in the data. However, minimising this risk has been a focus of grazer consultation to ensure the model performs to expectations.

Assumptions

1. There are several modifiers of the DSE model. The first is that the model will not allow DSE to decline below 0. Similarly the DSE is limited to stay below $1.1 \times$ maximum assumed DSE, which is assumed to be $2.3 \times$ the assumed property size; this in practice limits the model below 2.3DSE/ha , which aligns with grazier advice. However, in practice only the lower bound has any impact on the modelled results.
2. The model also has a 0-1 variable to account for the red-soil/black-soil division. This variable is a setting in the model selection. It turns on or off the effect of overbank flows as red-soil is – by definition – those areas not affected by overbank flows. This setting does not affect the ‘conditions’ as graziers, even with 100% red-soil, will observe overbank flows and will use this as a decision making variable. This is possibly non-linear in reality.
3. The model combines a range of gauge data across the floodplain and on different rivers into a single overbank variable. The variable used in the model is based on four gauges across the middle of the floodplain with one from each of the main rivers of the Lower Balonne Floodplain: the Culgoa, Birrie, Bokhara and Narran Rivers (see Figure 1, p. 3). While this captures general water availability over a season, it does not capture changes to the distribution of flows across the floodplain as development and water recovery can differentially affect flows down these four main branches of the Balonne River.
4. Models running supplementary feed assume a moderate amount of supplementary feed. In this case, this is sufficient feed to keep the number of stock at a minimum level with no stock losses over time. The model does not specify whether supporting stock during dry periods is necessarily done on-farm with supplementary feed or done off-farm with agistment elsewhere. However, this may not be enough feed to keep the animals productive (wool or lambing) through these dry periods. Additionally, it assumes that additional nutritional feed is applied during periods of relatively high wetness to increase lambing success rates.
5. The model assumes decisions about the stock mix (cattle/sheep/agistment) are not made on the basis of different commodity prices nor on changes in wetness. Under a single model setting, the stock mix is assumed to be exogenously fixed for the full duration of the model run (100 years).

Rule construction

The rules were constructed through a process of consultation, data evaluation and testing following these steps:

1. Consultation with graziers
2. Construction of training data
3. Identifying conditions in the training data
4. Specification of rules
5. Computer optimization
6. Testing against data

7. Testing with graziers.

The process began with consultation with a wide range of graziers from across the floodplain and by using different farm models to determine commonalities. Information on normal conditions, annual stock management patterns, extraordinary conditions and series effects was gathered. From these annual patterns, combined with data on end of year stock numbers, purchases, sales, breeding numbers, and agistment, we built a quarterly training set by attaching these events to their appropriate season based on a normal annual stock management cycle. This constructed training set could then be used to identify seasonal effects and seasonal conditions which could be used to construct the rules.

A minimum set of rules was derived to cover a sufficient range of conditions as simply as possible. The rules were generated by finding periods in which the conditions took place, both from the data and from direct grazer advice, and thresholds were identified from the input gauge and rainfall data. With contained conditions, the relationships between rainfall, overbank events, and existing stock numbers were defined either through linear regressions or through specific shifts in DSE/ha (in the case with limited data).

Once the rules were all defined, given they have strong interactions, the combined simulation was computationally optimized. Given that one rule can affect the performance of another, the rules were optimized together by targeting the coefficient of determination between modelled results and the training set. Using Excel's native Solver Optimizer, the model variables were optimized sequentially in an iterative process. The simulation was optimized to maximise the coefficient of determination between model output and the training data. This process was repeated until variables converged or the optimizer found extreme values. The model was optimized to a coefficient of determination of 0.87 before being taken to graziers.

The complete simulation and rules were then compared with existing stock data as well as confirmed through checks with graziers. This allowed both for a confirmation of rule performance and to identify deficiencies in the model behaviour. Given the training period does not cover all types of conditions, particularly mid-to-large overbank flows, the model's behaviour over the modelling period was compared with stock data and grazer experience to ensure reasonable simulation in all conditions. This resulted in an altering of several rules to improve performance in conditions not well represented in the training set.

This process was repeated to account for supplementary feed rules.

Rules

The DSE/ha simulation comprises eight general rules and two rules that apply on farms using supplementary feed. These take the form *if... then...*, utilising Microsoft Excel's IF function. The set of rules that drive the model are described below.

Rule 1: Sell-off rule

When the land becomes too dry, the property destocks completely. This takes into account the rainfall across the previous four seasons. Generally this is roughly equal to 170 mm/43 points/6.6 inches below seasonal averages. This rule is independent of season.

$$\text{Condition: } \sum_{t=-1}^{-4} (\text{rain} - \text{avg})_t < -1.682$$

$$\text{Effect: } \Delta \text{DSE} = -\text{DSE}_{t-1}$$

Rule 2: Buy-back rule

Reflects the presence of sufficient amounts of water either through rainfall or overbank flows to restock the property. This occurs after an overbank event or above 'average' rainfall conditions, which helps to account for a period of parched soil beforehand. If there are overbank flows as well, the scale of the buy-back is proportionally affected. This rule is independent of season.

Condition: $DSE_{t-1} < 0.08$, **AND**; $\sum_{t=0}^{-3} (rain - avg)_t > -0.5$, **OR**; $\sum_{t=0}^{-3} Overbank_t > 0.1$

Effect: $\Delta DSE = 0.08 + 0.005 \times \sum_{t=0}^{t-3} Overbank$

Rule 3: Winter rule

This is a general sell-off rule which covers the male lambs born plus a proportion of culled animals once they've been birthed and fed up to a saleable point. This roughly accounts for between 30-40% of the herd including births. This pattern is consistently applied each year.

Condition: Winter

Effect: $\Delta DSE = -0.498 \times DSE_{t-1}$

Rule 4: Spring rule 1

This is a response to rain conditions over the previous autumn, summer and spring being high enough for a small increase in the carrying capacity of the property. The increase is usually relatively small. However, the increase gets larger with more rainfall over the previous four seasons. This could be attributed to restocking in small amounts, agistment, or a second joining.

Condition: Spring, **AND**; $DSE_{t-1} \neq 0$, **AND**; $DSE_{t-1} < 0.75$

Effect: $\Delta DSE = 0.048 \times \sum_{t=0}^{-3} (rain - avg)_t + 0.035 \times \sum_{t=0}^{-1} Overbank_t$

Rule 5: Spring rule 2

While not strictly a 'spring' only event, this rule takes into account the rapid destocking that occurred in 2012/13, generally attributed to poor quality feed. This roughly happens when the two previous years had very large overbank events. This only occurs with a combination of poor feed quality and rapid drying. It occurs relatively infrequently – once or twice in a century – compared with other rules.

Condition: Spring, **AND**; $\sum_{t=0}^{-3} Overbank_t > 0.75$, **AND**; $\sum_{t=-4}^{-7} Overbank_t > 0.75$

Effect: $\Delta DSE = -0.143$

Rule 6: Summer rule

This accounts for when there is a large overbank flow and rainfall in the same period. This reflects an increase in carrying capacity associated with short-term conditions. The scale of the increase is a response to the level of the rainfall and overbank flows.

Condition: Summer, **AND**; $\sum_{t=0}^{t-3} (Overbank + rain)_t > 7$

Effect: $\Delta DSE = 0.026 \times \sum_{t=0}^{t-3} (Overbank + rain)_t + 0.108 \times Hiflo_t$

Rule 7: Autumn rule 1

This reflects the assumed natural increase in lambing that occurs after a spring/summer where overbank and rainfall events represent roughly average conditions, but lambing is scaled up with increasing water availability. This is the primary source of the increase in stock numbers.

Condition: Autumn, **AND**; $\sum_{t=0}^{t-1}(\text{Overbank} + (\text{rain} - \text{avg}))_t > 0$, **AND**; $DSE_{t-1} \neq 0$

Effect: $\Delta DSE = 0.026 + 0.153 \times \sum_{t=0}^{t-1}(\text{Overbank} + (\text{rain} - \text{avg}))_t$

Rule 8: Autumn Rule 2

This is a relatively small negative effect which winds back natural increases in years with 0 overbank flow events and with below average rainfall.

Autumn, **AND**; $\text{Overbank}_t + \text{Overbank}_{t-1} = 0$, **AND**;
Condition: $(\text{Rain} - \text{avg})_t + (\text{Rain} - \text{avg})_{t-1} < -1.6$

Effect: $\Delta DSE = -0.283$

Rule 9: High flow Rule 1

This captures the effects of especially large flows in summer and autumn.

Condition: Autumn

Effect: $\Delta DSE = 0.0134 \times \sum_{t=0}^{t-1}(\text{Hiflo})_t$

Rule 10: High flow Rule 2

This captures the effects of especially large flows in winter and spring.

Condition: Spring

Effect: $\Delta DSE = 0.0121 \times \sum_{t=0}^{t-1}(\text{Hiflo})_t$

Rule 11: Low-water supplementary feed rule

When water levels are sufficiently low and there are no overbank flows, a minimum stock is kept on the property on maintenance feed. This is 10% of maximum carrying capacity kept, with zero production from the animals. This applies in all seasons and works in conjunction with the rules above.

Condition: $DSE_{t-1} + \Delta DSE_x < 0.1$, **AND**; $\text{Supplementary feed} = \text{TRUE}$

Effect: $\Delta DSE = 0.07 - DSE_{t-1} - \Delta DSE_x$

Rule 12: High-water feed rule

When water levels from overbank and rainfall are sufficiently high, protein is added to supplement breeding success rates. This aims to ensure that reproduction increases DSE/ha by no less than 150%. This applies at the same time as the autumn increases. The costs are applied over two seasons, not just the season in which the new animals are added.

Autumn, **AND**; $\sum_{t=0}^{t-3}(\text{Overbank} + (\text{rain} - \text{avg}))_t > 0.8$, **AND**;
Condition: $\frac{\Delta DSE_x}{DSE_{t-1}} < 0.45$, **AND**; $\text{Supplementary feed} = \text{TRUE}$

$$\text{Effect: } \Delta DSE = 0.45 \times DSE_{t-1} - DSE_x$$

Earnings model

The earnings model converts carrying capacity, given as DSE per hectare, into earnings, given as dollars per hectare. Costs and earnings are applied in three ways to DSE per hectare: normal earnings, direct sales and purchases, and supplementary feed costs.

Normal earnings per DSE are calculated for agistment, cattle, and sheep separately. As it isn't clear from the rules whether changes in the carrying capacity respond to changes in agistment, buying more stock, breeding up, or additional joinings, these changes are unable to be turned directly into earnings and costs. For this reason, an annual earning per DSE is calculated and then applied according to the stock division to DSE each season. For sheep, the combined earnings include lamb, ewe and wool sales and best represent merino production. Cattle earnings include heifer, bull and yearling sales. Agistment is made at a flat fee. While these earnings and costs are applied per DSE per season, in reality these earnings are not realised each season. Hence, these earnings should be summed annually.

Several rules clearly indicate a sell-off or a buy-back. For these rules, changes in the number of stock are attributed directly as costs or earnings. Graziers were of the opinion that sell-off occurs during dry times when many properties try to sell stock which is when prices are depressed and conversely buy-on occurs when many properties are trying to restock. Additionally, graziers tend to sell-off the oldest and least productive animals first. Conversely, they buy productive ewes first, costing more per animal than those sold. For these reasons, they agreed the price difference for stock was at least double between the earnings from selling-off and the costs of buying-back.

Supplementary feed costs are applied according to the rule that they relate to. Supplementary feed costs associated with the low-water feed rule are applied per head in the seasons where the rule is in place. In these seasons, normal earnings are not credited. This reflects the supplementary feed being applied over these dry periods only being enough to keep stock on the property and not enough to allow sheep to produce earnings through wool or new joinings. Supplementary feed associated with the high-water feed is additional protein and nutrients which increases the success rate of a joining. For this reason, these costs are applied in the two seasons surrounding a summer joining. Normal earnings are applied in these seasons as well.

Data

Sources

While much of the model building was completed as a desktop model, the bulk of the structure and architecture of the model is based on consultation with experienced graziers from the Lower Balonne floodplain. These interviews were collected by the MDBA and its agents over multiple trips from September 2015 until July 2016 for consultation, data gathering, and results evaluation. Additionally, a teleconference was held to allow further consultation after rainfall made travel impractical.

Graziers targeted for consultation were generally:

- well-experienced, having managed properties on the floodplain over many years. Several were generational graziers having grown up on or having parents who managed properties on the floodplain;
- full time property managers having lived and worked on the floodplain as permanent residents;
- geographically disbursed across the floodplain; and
- from a diverse range of property types, soil types, management styles.

The tables that follow provide information about the different data sources that have been used in the FPG modelling. The sources of data include: mapping, geographical information, rainfall and hydrology, pricing variables, stock numbers, property-specific information, and reference material.

Table 6: Mapping data

Name	Source	Notes
Black/red soil comparison	<ul style="list-style-type: none"> • ASRIS. (2011). ASRIS - Australian Soil Resource Information System. http://www.asris.csiro.au. Accessed March, 2016 	
Map files for Figure 1, Figure 6, Figure 7	<ul style="list-style-type: none"> • Geoscience Australia © Topo 250K data (Series3) • Geoscience Australia © Topo 5 million data (2004) • Murray-Darling Basin Authority 	
MDBA LiDAR Area shape file	<ul style="list-style-type: none"> • Murray-Darling Basin Authority 	

Table 7: Model data

Name	Source	Notes
Gauge data	<ul style="list-style-type: none"> • NSW Department of Primary Industries: Office of Water. (2016) Real-time data http://realtimedata.water.nsw.gov.au/water.stm. Accessed April, 2016 • Queensland Government. (2016). Water Monitoring Information Portal. https://water-monitoring.information.qld.gov.au/. Accessed April, 2016. 	Gauges 422013, 422014, 422015, 422206, 422205, 422204, 422208, 422029, 422011, 422005, 422010
Hydrology outputs	<ul style="list-style-type: none"> • Murray-Darling Basin Authority, 2016 	Scenario outputs for gauges 422013, 422014, 422015, 422206
Overbank flow thresholds	<ul style="list-style-type: none"> • Dutta, D., Karim, F., Vaze, J. 2105. Determining Overbank Flow Thresholds for Different Flow Gauges. CSIRO 	
Pricing variables	<ul style="list-style-type: none"> • Multiple – directly through in-person and telephone interview • Also confirmed with local agricultural supply store • Meat and Livestock Australia. (2016). Market Indices. http://www.mla.com.au/Prices-markets/. Accessed May, 2016 	

Name	Source	Notes
Property specific details	<ul style="list-style-type: none"> Multiple – through survey instrument; or, through in-person and telephone interviews 	16 property owners with properties around the Hebel, Angledool, Goodooga, Weilmoringle, Talawanta, Collerina, Narran Lakes and Brewarrina areas.
Property specific stock numbers	<ul style="list-style-type: none"> Multiple – directly from property owners; or, with agreement from property owners from the NSW Local Land Services 	10 property owners, covering 15 properties
Rainfall	<ul style="list-style-type: none"> Bureau of Meteorology. (2016). Daily Rainfall. http://www.bom.gov.au/climate/data/. Accessed June, 2016 	Using the following stations: <ul style="list-style-type: none"> Angledool Station (048168) Brewarrina Hospital (048015) Brewarrina – Yappalee (048176) Collerina – Kenebree (048052) Goodooga Post Office (048046) Goodooga – Brenda (048014) Hebel General Store (044042) Weilmoringle (048025)

Table 8: Contextual information

Name	Source	Notes
Reference results	<ul style="list-style-type: none"> Mottell Pty Ltd 1995, <i>Flood Plain Resources Study Lower Balonne Flood Plain in New South Wales</i>, Mottell Pty Ltd, Swan Hill Mottell Pty Ltd 1996, <i>Flood Plain Resources Study Lower Balonne Flood Plain in Queensland</i>, Mottell Pty Ltd, Swan Hill 	Used in initial modelled and for results comparison purposes
Flow sequence analysis and environmental impacts	<ul style="list-style-type: none"> Murray-Darling Basin Authority 2016a, <i>Assessment of the environmental outcomes of water recovery scenarios in the Northern Basin</i>, MDBA, Canberra Australia (forthcoming) 	
Indigenous water values analysis	<ul style="list-style-type: none"> MDBA 2016b. Our water, our life – An Aboriginal study in the northern basin, Commonwealth of Australia, Canberra available at http://www.mdba.gov.au/publications/mdba-reports/aboriginal-study-northern-basin 	
Guide to the Proposed Basin Plan (Part 2)	<ul style="list-style-type: none"> MDBA (Murray-Darling Basin Authority). 2010a. Condamine-Balonne region: Lower Balonne River floodplain system and Narran Lakes. Guide to the Proposed Basin Plan. Volume 2: Technical Background - Part II. Commonwealth of Australia, Canberra. Available: 	

Name	Source	Notes
	http://www.mdba.gov.au/sites/default/files/archived/Condamine-Balonne-region.pdf	
Guide to the Proposed Basin Plan (Part 3)	<ul style="list-style-type: none"> Murray-Darling Basin Authority. 2010b. Guide to the Proposed Basin Plan. Volume 2: Technical Background - Part III. Commonwealth of Australia, Canberra. Available: http://www.mdba.gov.au/bpkid/guide/index.php (Appendices C to F). 	

Data processing

Data collected was transformed as described below. The three types of transformations were interpolation of gauge flow data, aligning the time steps of different types of data, and accounting for overbank thresholds in flow data.

Rainfall

Rainfall data sourced from the Bureau of Meteorology was transformed for use as an input for the model. A range of sites were chosen from across the Lower Balonne floodplain and were averaged to produce a single variable (see Table 7). All daily rainfall numbers which did not occur in a 7 day period totalling more than 10 mm were excluded. This aligned with grazier advice that these small events had no lasting impact. This variable was then converted to a seasonal time step.

It is important to note that rainfall data is one of the major limitations on the ability to push the analysis further back in time. It also had implications for geographical distribution of the data. Earlier dates, in the first half of the century, have less weather stations and data available. That is, a number of weather stations in the region were unable to be used for this study because the data did not go back far enough. Most of the weather stations selected for this study retained 100 years of data although some gaps occurred.

Gauge flows

Gauge flows in terms of ML/day were interpolated and summed seasonally for the purposes of training the model. Given the gauge data have periods of missing data, flows were interpolated from gauges above or below. For this reason, the values were linearly interpolated with various lags. From a range of models based on the various up or downstream gauges and various time lags, the linear models that provided the best estimates – based on a coefficient of determination – were used. Generally this filled fairly small ‘holes’ in the record. This information was then summed across the four gauges on each of the rivers of the floodplain, 422015 (Culgoa River), 422013 (Birrie River), 422014 (Bokhara River), 422206 (Narran River).

These were related to each of the following gauges:

- 422013 based on a 12 day lag from 422205 (upstream)
- 422014 based on a 14 day lag from 422205 (upstream)
- 422015 based on a 7 day lag to 422017 (downstream)
- 422206 based on a 3 day lag from 422205 (upstream)

Each of these gauges was then filtered by the relevant overbank flow threshold:

- 422013 at 4328ML/day

- 422014 at 1692ML/day
- 422015 at 5171ML/day
- 422206 at 4803ML/day

These values were summed to provide an overbank variable as an input to the model. This variable was then converted to a seasonal time step.

Hydrology flows

To use as an input, hydrology output for each water recovery scenario (see Table 5) was transformed for use. Similarly to the measured gauge flows, the modelled hydrology flows were filtered by their relevant overbank flow threshold, summed and converted to a seasonal time step.

High flows

Graziers suggested that particular flows with large volumes over multiple days have the most significant impact. A threshold of 20,000ML/day over the four gauges over four or more days was used to capture these flows. So that changes in both duration and volume were reflected in the variable, the area under a triangle formula was used as a simplification as follows: $Hiflo = 0.5 \times Duration \times Max\ volume$ for each event over this threshold. This variable was then summed to create the seasonal variable Hiflo which drove the model along with the rainfall-average and overbank flows.

Stock numbers

Stock numbers were used both in the training and testing of the model. As exact stock figures are not recorded by graziers on a seasonal basis, stock numbers were converted from annual reported numbers to seasonal estimates. This was completed by collecting additional information on lambing success rates, sales, purchases, periods of agistment, and other relevant changes in numbers. These were then used to interpolate seasonal results in conjunction with advice from the relevant graziers to ensure seasonal figures were realistic. Given limited data, this process was only possible for some properties. For testing purposes, the output of the seasonal model was tested against annual figures where seasonal numbers were unobtainable.

Red/black soil division

The proportion of red and black soils were derived by taking a cut of the Australian Soil Resource Information System using the MDBA LiDAR area, which suggests that about 74% of the Lower Balonne Floodplain is self-mulching black soil.

Pricing variables

Pricing variables were primarily obtained through consultation with graziers. These variables were defined in terms of a 'normal' year, so results are held fixed and not dominated by the large changes in the prices of meat and wool recently and over the last hundred years. Therefore, these values are based on heuristics rather than long-term averages given the large price regime changes in prices. The ranges on a number of these variables were produced by grazer consensus. These numbers were additionally compared to meat and livestock price indices where possible and were additionally presented to a local agricultural supply store manager with experience in floodplain grazing. It is important to note that some values, such as costs associated with working/mustering animals, vary according to property conditions such as property size or location on the floodplain.

The model sets different prices for buy-back and sell-off of stock around dry periods. Graziers describe this difference as relating to the general shortage of stock, wide spread demand, and need for high quality animals when coming out of drought; and conversely the overabundance of stock, wide spread supply, and selling off least productive animals first when entering drought. The model assumes a two-fold price difference between these values. Several graziers expressed that this could be even higher.

Sensitivity

Several parameters in the model have significant impacts on model outputs. In particular, grazier indicated various values for model variables, particularly around pricing. These differences are based on different heuristics of what typical values should be. The model's structure generally means that variables affect either price or stock numbers.

As there are a range of model settings, it becomes computationally difficult to explore the limits of variable sensitivities. Hence, variable sensitivity is given below as 'point' sensitivities with fixed model settings. These settings are given along with the resulting sensitivities. The sensitivities are given in terms of the difference between two scenarios, Without Development and Baseline, which will generally produce the largest differences.

Combinations of parameters were 'optimized' to maximise and minimise this difference within bounds. This process involved Microsoft Excel's Solver feature. These sensitivities were optimized within bounds defined either as $\pm 5\%$ or within ranges suggested by graziers. These ranges are listed in the model beside the variable they refer to.

Stocking variable sensitivity

Two input variables can affect the stock values. That is the starting stock (Starting assumed DSE), and the number of animals kept on the property on supplementary feed (Low-water feed rule). Starting stock tends not to have much impact, particularly over long periods. Over 100 years, this impact is negligible. The number of animals kept on supplementary feed, however, had a large impact on stock numbers and therefore the difference between scenarios. This difference also affects earnings results, which are reported alongside. Given supplementary feed is used to smooth stock numbers between periods of sufficient water, a high enough bound would result in 0 difference between all scenarios. The upper bound of 30% represents the highest amount from grazier consultations and is likely higher than most properties maintain.

Generally, however, since the model is driven primarily through water availability these variables have a limited effect on model results.

Starting DSE and minimum stock kept on supplementary feed sensitivities is shown in Table 9.

Table 9: Variable sensitivities for stocking numbers

	Scenario 1:	Scenario 2
Model run:	Baseline	Without development
Supplementary feed:	TRUE	TRUE
% black soil:	74%	74%
Stock division:		
Sheep	33%	33%
Cattle	33%	33%
Agistment	33%	33%

DSE/ha	S1	S2	Difference
Min	0.39	0.47	20.40%
Normal	0.37	0.45	21.62%
Max	0.37	0.45	21.71%

Earnings/ha	S1	S2	Difference
Min	\$15.25	\$19.16	25.66%
Normal	\$14.96	\$19.36	29.34%
Max	\$14.71	\$19.10	29.85%

	Lower Bound	Normal	Upper Bound
Low-water stock	0.05	0.07	0.3
Starting stock	1	3.1	14.26

Earnings variable sensitivity

In this model, pricing parameters do not affect the carrying capacity, so these variables are only reported in terms of differences in earnings per hectare. Scenarios run with supplementary feed and those without use different combinations of pricing variables. The variable sensitivities are tested separately for each. Without supplementary feed results are not affected by changes in the supplementary feed costs, but are affected by buy-on and sell-off costs.

Supplementary feed parameters

Given that pricing parameters scale both scenarios in the same direction and do not change the frequency of periods of supplementary feed, pricing parameters have relatively little impact on the differences between scenarios. However, they do affect the scale of results.

Table 10: Sensitivities for supplementary feed pricing variables

	Scenario 1:	Scenario 2
Model run:	Baseline	Without development
Supplementary feed:	TRUE	TRUE
% black soil:	74%	74%
Stock division:		
Sheep	33%	33%
Cattle	33%	33%
Agistment	33%	33%

Earnings/ha	S1	S2	Difference
Min	\$23.75	\$29.95	26.09%
Normal	\$14.96	\$19.36	29.34%
Max	\$9.67	\$13.10	35.48%

	Lower Bound	Normal	Upper Bound
Sheep earnings/DSE	\$54.40	\$77.08	\$117.53
Cattle earnings/DSE	\$67.69	\$80.68	\$97.20
Agistment earnings/DSE	\$0.48	\$0.50	\$0.80
Supplementary feed costs	-\$39.00	-\$42.00	-\$47.00

Destocking variables

Pricing variables relating to destocking affect the model in a similar way to those relating to supplementary feed. Hence, they also scale the results of both scenarios in the same direction. However, the results are slightly more pronounced than with supplementary feeding. It is important to note that the model is set to a 2 to 1 price difference between buy-on and sell-off prices. However, some graziers acknowledged that this amount could be greater at times.

Table 11: Sensitivities for without supplementary feed pricing variables

	Scenario 1:	Scenario 2
Model run:	Baseline	Without development
Supplementary feed:	FALSE	FALSE
% black soil:	74%	74%
Stock division:		
Sheep	33%	33%
Cattle	33%	33%
Agistment	33%	33%

Earnings/ha	S1	S2	Difference
Min	\$26.10	\$32.50	24.54%
Normal	\$16.11	\$20.65	28.14%
Max	\$10.27	\$13.84	34.77%

	Lower Bound	Normal	Upper Bound
Sheep earnings/DSE	\$54.40	\$77.08	\$117.53
Sheep sell-off/buy-back	\$75.00	\$85.00	\$100.00
Cattle earnings/DSE	\$67.69	\$80.68	\$97.20
Cattle sell-off/buy-back	\$45.00	\$50.00	\$60.00
Agistment earnings/DSE	\$0.48	\$0.50	\$0.80

Appendix C: Caveats

Data limitations

Not all farm idiosyncrasies have been accounted for. While the model settings take into account some of the variations between properties, a number of differences are not able to be explained within the context of the model. For instance, in some years one property may have a dramatic increase in stock numbers while another has a dramatic decrease. During consultations, some of this variation was explained by choices in timing, differences in farm conditions, farm capital requirements or other farm specific factors.

The Floodplain Grazing Model is a model of the entire Lower Balonne Floodplain. It runs off a combined overbank variable representing the main rivers of the floodplain. For this reason, it does not account for differences in flows between rivers. An increase in the flow down one river, with an equal decline in another river would not produce a result, but will have a significant relative impact between properties on each river.

Significantly, the model runs on a seasonal time step. This is significant in relation to flow sequences. The maximum height, number, profile, and duration of daily flows are all subsumed in a seasonal overbank flow variable. From consultation with graziers, it was made clear that the maximum flow of an overbank event, the duration, and the preceding conditions all have important impacts on where and how a flood moves across the floodplain. Additionally, the model will, in many cases, treat a series of small flows within a season as being equal to a single large flow of the same volume, which are known to have different impacts in terms of stock numbers. However, more precise information regarding areas flooded and how this relates to hydrology modelling was not available at the time of producing the Floodplain Grazing Model. A lack of data around areas inundated by flooding and pasture response means that a more precise modelling of the biophysical response of the floodplain is impossible.

Stock numbers, across properties, were gathered from different sources. Some figures were received directly from graziers while others were obtained from Local Land Services. In some consultations it was suggested that these numbers might not always be comparable, however no conversion factor was found.

Use limitations

Farm structure

Some properties on the floodplain also grow crops as well as running stock. Generally this is highly idiosyncratic, with some opportunistic cropping following overland flows and others running irrigation. This use, however, is relatively limited and only occurs when conditions are suitable. Only a couple of properties on the floodplain were identified that make significant earnings from cropping. The earnings from cropping are not estimated in this model, although it is highly likely that improvements in carrying capacity and earnings for stock also positively correlate with improvements in earnings from cropping. Changing licenses governing water access have also altered the crop production in a way that uncontrolled overbank flow could not have.

Over time, the intensity with which each property on the floodplain is utilised has changed. The Mottell Report from 1996 estimates several hundred grazi running active properties. That number is far fewer now. A large cause of this is farm consolidation, resulting in better productivity. Many

of the remaining graziers run multiple properties for their stock. However, some properties have either been left idle or are opportunistically grazed. This, in some cases, means there are absentee landholders who only move stock in when feed conditions are sufficient. These changes to the intensity of grazing are not considered in this model.

Although the model and outputs are measured in terms of DSE/ha, which is a common measure of stock feed requirements, it is important to note that the model does not take into account differences in feed preference in different types of stock. Graziers have suggested that sheep and cattle each have different feed preferences and there are some types of feed that are only consumed by one or the other. This suggests that the rate of trade-off between cattle and sheep may not be fixed, meaning it is likely that the maximum carrying capacity may only be reached with some combination of the two. The model does not account for these differences in feed preference in that it treats the trade-off as fixed.

The model also takes agistment as a fixed proportion of stock mix. In reality most properties will only take on agistment stock at certain times for relatively short durations. Agistment will also be used in support of regular operations, for instance, using earnings from agistment to fund stock purchase. It is likely that this managed approach with agistment stock would slightly alter the rate at which feed is used which would also affect stock numbers over time.

There are different supplementary feed strategies used across properties that are not accounted for in the model. Choices regarding the minimum stock kept on the property, as well as the level of supplementary feed per animal can both be varied. Both are significant in terms of stock numbers and profitability. As animals combine supplementary feeding with regular pasture feeding, the greater the numbers of animals kept on in dry times, the poorer the pasture response when water returns. This means that there is a trade-off between stock in dry times and stock in wet times. The nature of this trade-off is not explored in this model.

The amount of supplementary feed given to animals can be varied. With respect to differences in approaches to supplementary feeding, enough feed can be applied to keep animals productive even through drought, or animals can be kept on half rations accounting for some animal losses. Hence, the optimal feeding regime varies depending on the farm structure and on the length and extent of dry conditions. The number of stock kept on supplementary feed as well as the amount of supplementary feed used are not accounted for in this model.

Additionally, there are associated costs caused by water flows that are not accounted for in this model. Small flows can cause stock loss and localised damages. Large overbank flows can, in some circumstances, cause widespread capital damage and stock losses. Additionally, overland flow events also bear costs in terms of short-term feeding, labour costs, and impacts on red soil areas. These impacts, however, depend heavily on which parts of a property are affected by water as well as property specific factors and management. Limited information, as well as the differences between properties, means that these damages are not covered by this model. However, graziers suggested that, in general, damages incurred by flooding are able to be managed and that, overall, these impacts – relative to the benefits produced – are considered by graziers to be minor.

Some graziers indicated that in the short-term, the large floods can have more significant detrimental effects. A large flood, following reasonable rain, can swamp feed and cause it to die off and rot. Additionally, moving a large number of animals to a smaller area during flooding can

cause that country to become over grazed, which can reduce future productivity on these high ground areas. These shorter-term detrimental effects from large flooding are not explicitly modelled in the FPGM.

Geographical distribution

The model is not informed by the geographical distribution of stock, or by changes related to more or less water recovery. The model takes a sum of overbank flows across the four major rivers of the Lower Balonne Floodplain as indicative of water from overbank flows in a single season. However, this method fails to account for the differences in flows down each river. Some of the scenarios of the Northern Basin Review use different recovery assumptions which will affect the flows down each river. This is true particularly on the Narran River, where targeted recovery is important for reaching particular environmental targets.

Additional to the distribution across the floodplain, the model does not account for changes in distribution down the floodplain. As some water is extracted and other water is naturally lost, the amount of water reaching the lower reaches of the floodplain is different across scenarios. This is particularly important as several graziers noted that the larger flows required to deliver stock and domestic water to the lower floodplain are not occurring as often as they used to.

Farm financials

The model does not cover several important aspects relating to farm financials. It is not built to account for fixed costs associated with specific properties, does not account for the effect of commodity prices on business decisions, and does not account for access to finance or capital held on the floodplain.

The model outputs for earnings per hectare only cover those variable costs relating to a specific stock mix. It does not account for the fixed costs related to a specific property. For example, the cost of capital, providing for a household on the property throughout the year, and land taxes, are not included in the model. These fixed costs are specific to individual properties and hence are not calculated in this approach. As such, these results should be understood as relating to land productivity/carrying capacity and not the earnings of specific grazing businesses.

Similarly, this model does not account for farm financials. Access to finances, timing of cash flows, and the impact of prolonged periods of zero or negative incomes have all been raised as playing a significant role by graziers in consultations. These aspects of farm financials are all highly significant for the viability of individual businesses, as well as the wellbeing of graziers. However, these specifics of businesses will be highly different between properties and are outside the scope of this model.

The floodplain grazing model also does not incorporate the effects of commodity prices on business decisions. In consultations, graziers highlighted the importance of market conditions and commodity prices, of both stock and inputs, for business decision-making. After destocking the property from drought, the costs of acquiring new stock are as significant to the business decision as the return of water. This model assumes a fixed proportion of costs and earnings, and does not account for relative differences in price on decision making, although this is not specifically informative when comparing water scenarios.