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The Economic Cost of Weeds in NSW

A GrainGrowers Research Report

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Grain Growers Limited is Australia's only national, independent, member-based, financially sustainable and technically resourced grain producer organisation. We aim to build a more sustainable, profitable and efficient Australian grains industry for producers.

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Acronyms

ABS	Australian Bureau of Statistics
ABARE	Australian Bureau of Agricultural and Resource Economics and Sciences
CMA	Catchment Management Authority
DPI	Department of Primary industries
NRC	Natural Resources Commission
OEH	Office of Environment and Heritage

Executive Summary

Weeds result in lost value to an economy in which they are present. Losses due to weeds arise in the form of impacts such as reduced productivity and lost amenity value, health impacts and reduced environmental asset values. To reduce these losses, land managers engage in weed management. Such management will avoid **some** of the losses that would have occurred, but not all so there will be losses despite the management. Where management is undertaken the lost value to the economy due to weeds will be the residual losses that have not been mitigated and the value of the expenditure on management that is undertaken.

Previous studies of the lost value due to weeds for various jurisdictions have used the loss-expenditure approach to measuring economic impact or the economic surplus approach, and sometimes both. In this study both methods have been used and have been found to validate each other in terms of order of both magnitude and relativity. They are in the same order of magnitude and the economic surplus approach is larger which is as anticipated given that it incorporates price effects, that the loss-expenditure approach does not.

In previous studies of the economic costs of weeds, assessment has focused on the lost value on agricultural lands, with some incorporation of expenditure and effort on non-agricultural lands. This study also focuses on the costs on agricultural lands, which is appropriate because agricultural lands account for almost 80 percent of NSW's land area. In addition to the total cost of weeds estimated for agricultural lands in NSW, expenditure by public agencies on public non-agricultural lands, which account for the largest proportion of the balance of area in NSW, has been included. The total current annual cost of weeds in NSW is estimated to be in the range from $1,671 million to $1,903 million per annum, with an estimated mean value in the order of $1,800 million per annum. This comprises expenditure of $64.59 million by public agencies, and the balance as losses to producers and consumers due to weeds and weed management on agricultural lands.

Table E1: Summary of the estimated current annual costs of weeds in NSW ($'million)

	Low	Mean	High
	Expenditure on weed management and losses in output		
Agriculture			
Loss-expenditure estimate	1,311.49		1,649.30
Economic surplus estimate	1,606.55	1,732.91	1,838.64
		Expenditure only	
Public expenditure/non-agricultural land			
Public	64.59	64.59	64.59
Private	nq	nq	nq
Total (using the economic surplus estimate of losses to agriculture)	**1,671.14**	**1,797.14**	**1,903.23**

nq: not quantified

This total includes:

- The cost of labour, chemical and machinery on agricultural lands;
- The value of lost production on agricultural lands;
- The lost value due to price responses in agricultural markets; and
- The value of expenditure by public agencies on non-agricultural and agricultural lands.

This estimate is considered conservative because:

- Losses on non-agricultural lands are not included, eg. lost biodiversity, health impacts;
- Expenditure by private landholders of non-agricultural lands are not included;
- Expenditure by public agencies on non-agricultural lands may not be comprehensive;
- The losses in agriculture are calculated for the majority, but not all agricultural industries; and
- Some agricultural losses have not been included due to the variable occurrence and difficulties in assessing average estimates of impact, e.g. grain contamination and stock deaths resultant from weeds.

These costs have not been excluded because they are not considered important. In fact, there is increasing evidence to suggest that some of these costs, biodiversity losses for example, are likely to be considerable. However given uncertainty and in the absence of consistent and comprehensive biophysical data and resource valuations to parameterise the impacts, it has not been possible to incorporate them in this analysis.

From this study it is concluded that the costs of weeds in NSW is conservatively in the order of $1.8 billion per annum. Of the costs assessed, producers in the agriculture sector bear around 73 per cent of the burden of the weeds in NSW, consumers 23 percent and 4 per cent of the costs are public expenditure.

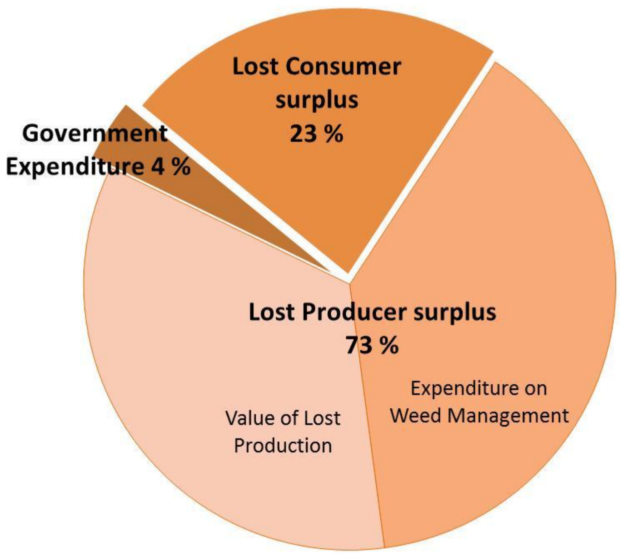


Figure E 1: Share of the estimated costs of weeds in New South Wales, by stakeholder

Such a cost is likely to prompt investigation of measures to mitigate any increases in the weed burden through new introductions (either from overseas or interstate) and identify worthwhile weed management strategies that can reduce the losses due to weeds and increase the efficiency of weed management expenditure. Any proposed expenditure should be subject to benefit cost analysis because it assesses if a proposal is worthwhile in the context of the economy and more or less worthwhile than other approaches to weed management. Evaluation of the *optimal level* of expenditure would be ideal going forward, however given the data needs and challenges with such analysis, especially at the state level, the principles of resource allocation that underpin the estimation of an optimal level should instead be adopted in expenditure decisions.

1 Introduction

A key aim of *NSW 2021*[1] was to achieve a reduction in the impact of weeds on production and natural assets, such as prime agricultural land and the reserve system, in New South Wales. Under the NSW Biosecurity Strategy, there is the intention to develop new biosecurity legislation that will address this aim by further enhancing the current risk-based approach to managing weeds (along with disease and pests).

With a view to informing the development of the new legislation, the Minister for Primary Industries requested the Natural Resources Commission (the Commission) to evaluate the effectiveness and efficiency of the current weed management arrangements in NSW. Among the components of the evaluation, the Commission identified the need to understand and quantify the baseline total economic impact of weeds in NSW.

This report was commissioned by the Commission to provide an assessment of the total economic impact of weeds in NSW. The report was completed in May 2014, and was specifically required to:

- Provide a review of, and assess previous studies of the economic impact of weeds and identify a method for application in the NSW context; and
- Using that method, undertake an assessment of the current annual economic costs of weeds in NSW.

All data, sources, results of analysis and findings and discussion resulting from this analysis are provided in the following chapters. In chapter 2 a review of the economics of weeds is provided along with a review of previous studies and the method adopted in this study.

The application of the method to agricultural lands and non-agricultural lands is detailed in Chapters 3 and 4. In chapter 5, the results of the individual analysis sections are presented in the context of each other and the total economic impact of the presence of weeds in NSW. The accompanying discussion details relevant caveats in interpretation and recommendations.

[1] Released in September 2011, *NSW 2021,* is the Government's 10-year plan which replaces the State Plan as the NSW Government's strategic business plan. It has aims to rebuild the economy, return quality services, renovate infrastructure, restore accountability to government, and strengthen our local environment and communities.

2 The economic impacts of weeds

2.1 Counting the costs of weeds: a conceptual basis

Weeds result in lost value to an economy through losses in productivity, amenity values, lost recreational values and a range of other impacts (see Appendix A.1 for a broader review). To mitigate these negative impacts, land managers engage in weed management activities, which require the commitment of resources. Jones *et al* (2000) applied the conceptual thinking of McInerney (1996), to the problem of weeds, and illustrated the trade-off that occurs between losses due to weeds and expenditure on weed management activities. As expenditure on weed management increases, you can *expect* the losses associated with the presence of weeds to fall.

Two approaches have been used to quantify the total costs of weeds to an economy. The loss-expenditure method incorporates estimates of unmitigated losses due to weeds and the costs of controlling weeds where resources have been committed to mitigating weed impacts. The second is the economic surplus approach which measures the lost economic surplus in affected markets when supply shifts due to increased costs of production and reduced availability of product in the market place. Both of these methods incorporate impacts on the economy due to weeds and expenditure on weed management, and accommodate the trade-off that occurs between the two types of costs.

Figure 1 provides an illustration of the opportunity costs and financial costs associated with weeds, given three different management scenarios. The costs of weeds will depend on the management which is undertaken, and the extent to which that management reduces the total losses due to weeds.

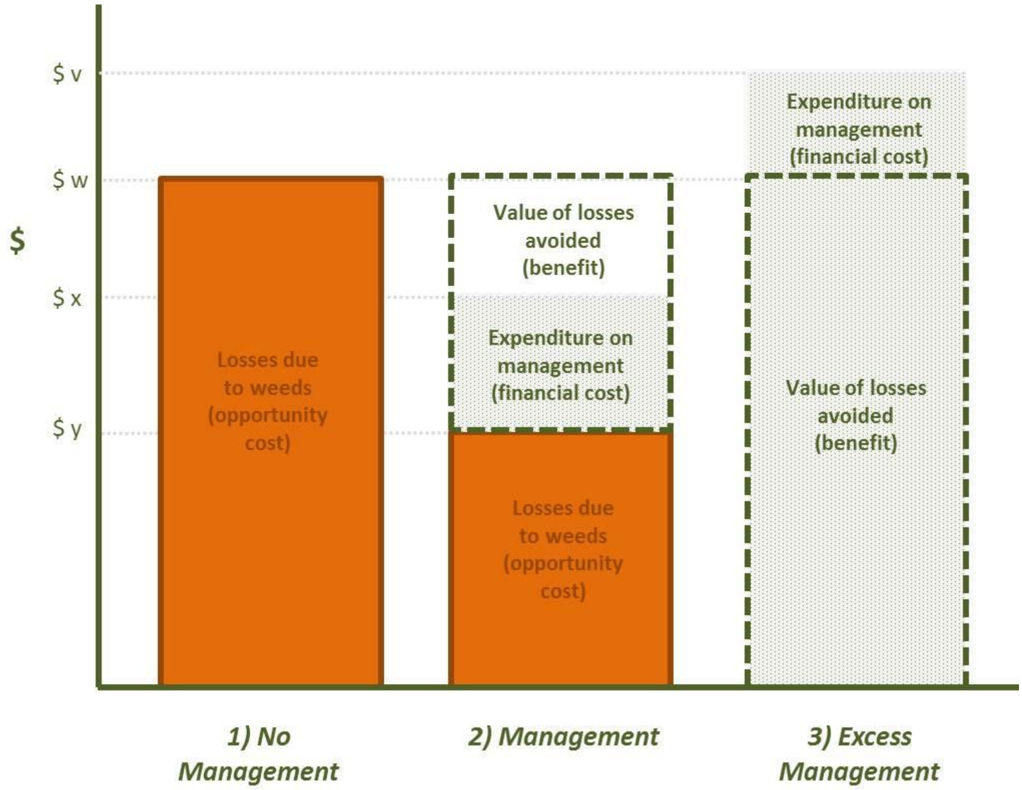


Figure 1: Accounting for the impacts of weeds: 3 scenarios

In the case of scenario 1), no weed management, the total value of lost productivity, amenity values and the like, could be estimated to be \$w. This is the total value that the economy loses because there are weeds present.

By contrast in scenario 2, weed management is undertaken. The weed management, if effective, will result in some of the losses due to weeds being avoided, but also a cost in terms of the cost of management. In this illustration, the losses that are avoided due to management are equivalent to \$w - \$y. The total lost value in the economy is the expenditure on weed management (\$x - \$y), plus the remaining losses due to residual weeds (\$y) that were not avoided, for a total economic loss of \$x. In this case the total cost of weeds to the economy happens to be lower than in the case of no management.

Now consider that a significantly greater amount of expenditure is committed to weed management, scenario 3. In this illustration, management which costs \$v leads to mitigation of the impacts of all weeds. The total cost of weeds to the economy is expenditure on management (\$v) plus the losses due to the weeds (now, \$0), for a total of \$v. In this case, the total cost of weeds to the economy is greater than in the case of no management. It is also shown as greater than the value of the losses avoided. As demonstrated by the scenarios, an estimate of the economic cost is a reflection of the economy's resources diverted managing weeds and the value not gained because of weeds, at a point in time, for a given amount of weed management effort.

The correct or optimal amount of management will be determined at the margin on the basis of the relationship between the value of the losses that can be avoided, compared to the cost of the management to achieve those avoided losses. There may be cases where total elimination of a weed is not economically rational, as will there be cases where no management is appropriate because there is little damage to be avoided. However, any decisions regarding the appropriate level of expenditure on weed management would need to be informed by knowledge of known or potential avoided losses. The effort, and consequently the expenditure, on weed management should be determined at the point where the marginal losses that can be avoided and the marginal costs of management are equated to the marginal benefits.

Clearly in scenario 2), the benefits of the expenditure are greater than the expenditure and so the total cost of weeds is lower than where no management was undertaken. In scenario 3), the expenditure is greater than the benefits achieved and so the total cost of weeds is higher than in the absence of management. To support decisions regarding expenditure on weed management, analysis of the optimal level of effort and expenditure would need to be undertaken. Such analysis focuses on the trade-off between costs (expenditure on weed management) and benefits (avoided losses attributable to the management). The optimal amount of weed management will be at the point where the marginal benefits are equal to the marginal costs, after taking into account the opportunity cost of the funds in alternative uses. This trade-off between costs (weed management expenditure) and benefits (avoided losses) and will be driven by the technical efficiency of weed management techniques and returns to weed management and will be characterised by decreasing marginal returns.

Plants that are considered 'weedy' may also contribute benefits to an economy (see Appendix A.1). The negative impacts of such plants must be considered, and therefore estimated, net of any benefits.

The following review, methodology and analysis in this report have been completed in view of delivering an ***estimate of the current annual economic costs of weeds, given the current level of management***. The review does not focus on the efficiency of management practices, the total losses of weeds in the absence of weed management or whether the current annual cost of weeds in NSW is higher or lower than it would be in the absence of expenditure in weed management.

The estimate of the current annual economic costs of weeds given the current level of management is useful to policy makers on a number of levels. In particular it:

- Provides a context to the problem of weeds with respect to other costs to the NSW economy.
- Can provide a baseline for the assessment of the cost changes over time. The cost of weeds to the state will change over time. Given a consistent methodology which accounts for real rather than nominal values, the change in the total cost of weeds over time can be assessed. Importantly, due the trade-off relationship between expenditure and losses, an assessment of either independently can in no way be used to compare changes in the total costs of weeds over time.
- Could be used to assess past and plan new weed management strategies. The value of state wide weed management strategies and legislation could be assessed in the context of how a proposed strategy has or would change the level of total costs to the state over time. Key to such assessments is the need to forecast what would have happened, or will happen, in the absence of the proposal. Given the high level nature of the estimate and the inherently uncertain nature of weed populations, incorporation of uncertainty in such assessments would be imperative.

2.2 Previous studies of the economic impact of weeds

There is a range of studies that have considered the annual economic impact of weeds. In the main, these studies relate to the costs and losses that result from the presence and spread of a particular weed species. For example, an estimate of the cost of the presence of Paterson's curse in Australia found the annual cost to sheep and cattle producers through lost productivity in pastures, control costs, and wool contamination to be $250 million (Lloyd, 2005). Similarly, the cost of blackberry control and lost production across Australia was found to be at least $70 million (Weeds CRC, 2006).

The problem of assessing the total impact of the collective presence of weeds across a broad geographical area has also been undertaken a limited number of times. These include Combellack (1987), Jones *et al* (2000), Sinden *et al*. (2005) and Ireson (2007). Combellack and Sinden *et al* provided an economic assessment of the total cost of weeds to Australia, while Jones *et al* estimated the total cost of weeds to just the grains industry across Australia and Ireson *et al* estimated the annual cost of weeds to Tasmanian pasture and field crops. Common to all of these studies is an emphasis on the costs of control (expenditure) and lost production (residual losses) in agricultural industries.

Combellack assessed the costs of control and gross losses of production in agriculture, as well as some direct costs to management of weeds in national parks, railways, forestry establishment, aquatic areas and industrial buildings and found the cost to be $2,096 million (1987). Jones *et al* estimated the collective impact of the range of weeds that affect Australia's winter cropping industry. The study used a survey of farmers to derive estimates of expenditure on weed management and yield losses due to residual weeds. These estimates were incorporated within a loss-expenditure analysis and then used to calibrate an economic surplus model. The study estimated there to be $1,333 million per annum lost economic surplus. Ireson *et al* (2007) used estimated production losses and the cost of herbicides but not associated labour as the basis for an estimated annual cost of $58 million (2007) to the state of Tasmania.

Sinden *et al* used a loss-expenditure analysis accompanied by an estimate of the total change in economic surplus resultant from the presence of weeds in agriculture in Australia. The stochastic surplus analysis, estimated the total annual cost in lost surplus to range from $3,554 million to $4,532 million, with a mean of $3,927 million. The study also estimated the direct costs of control, though not losses, on indigenous lands, in national parks and natural environments and on other public lands. The total costs estimated as lost surplus in agriculture and direct costs of controlling weeds on non-agricultural lands across Australia were found to range from $3,554 million to $4,532 million with a mean total of $4,039 million.

Such large costs are not a phenomena isolated to Australia. The direct costs and production losses from plant invasions in agriculture in New Zealand were estimated to be $100 million in 2002 (Williams & Timmins), while more recently, the cost of pastoral weeds alone have been estimated to cost the New Zealand economy $NZ1,200 million per annum ($NZ1,000 million in farm production losses + $NZ200 million in control costs) (Bourdôt, 2012). The total annual cost of weeds in the United States was estimated to approach $US15 to $US20 billion dollars (Ashton and Monaco, 1991) while a more recent, though still dated, study estimated the costs to be $US34.5 billion on the basis of direct costs and production losses from agriculture and some limited environmental losses (Pimentel, 2002).

A range of estimates of costs and losses for particular weeds specifically in NSW and/or particular industries have been undertaken. For example, the costs of blackberry control and value of lost agricultural production in just central western NSW was found by Vere and Dellow to be $4.7 million per annum (1986), while Serrated Tussock was found to cost the state of NSW $40 million per annum in reduced livestock carrying capacity (Jones and Vere, 1998). Only one estimate of the collective presence of weeds in NSW has been identified. An estimate of $1,200 million is cited (Montoya, 2012) as the annual lost value of production and control costs, though no review of the methodology has been possible. In another study, the total expenditure on herbicides used to manage weeds on agricultural lands in NSW was reported to be $475 million, however this is not accompanied by an estimate of losses due to residual weeds or broaden the scope of expenditures included in the cost assessment (ABS, 2007).

Common to the reviewed studies of the economic impact of weeds is estimation based on the expenditure on weed management and the residual losses from weeds left unmanaged given current management: the loss-expenditure approach. Almost entirely, these studies have focused on losses in agricultural systems with this regard. Where the studies have focused specifically on agriculture this is appropriate, and where analyses have been of the collective impact of weeds in a geographic area, this has been consistent with agricultural lands accounting for the great proportion of that area. The surplus approach to estimating costs has only been used by Jones et al (2000) and Sinden *et al* (2005), but again in both, the focus is on the costs on agricultural lands.

Some studies have supplemented estimates of loss on agricultural lands with estimates of expenditure on weed management on non-agricultural lands. Pimentel *et al* (2002) and Sinden *et al* (2005) for example have quantified the costs of managing weeds on public lands or which threaten environmental resources, but no studies have incorporated losses in environmental values in a comprehensive way. This is due primarily to incomplete understanding and quantification of the total values of the underlying environmental assets, and furthermore to the difficulties assessing the rate of decline in those values due to weed invasions.

2.3 Methodology adopted for assessment of the costs of weeds in NSW

The loss-expenditure approach to estimating the cost of weeds requires the calculation of the increased cost of production due to the presence of weeds, and an estimate of the lost production that occurs because weeds are present but not managed (residual weeds). These are estimated and aggregated across the relevant jurisdiction.

The surplus approach to estimating the total economic impact of weeds, as used by Jones *et al* (2000) and Sinden *et al* (2005), incorporates the losses resultant from a supply shift, that incorporates both increased costs and opportunity costs (losses from residual weeds) of production, in the supply function (from $S_{\text{without Weeds}}$ to $S_{\text{with Weeds}}$) as illustrated in Figure 2. A price response is included due to the upward sloping demand function and so the losses are borne:

- By producers in the market because weeds restrict their output from being greater than it would have been in the absence of weeds (output is Q_1 instead of Q_0); and
- By producers who spend more on producing their remaining output than they would have in the absence of weeds (cost of the marginal unit of production increases from P_0 to P_W);
- By consumers who have access to less product for consumption (production available for consumption is Q_1 instead of Q_0); and
- By consumers in the market paying more for their consumption (the market price is P_W instead of P_0 assuming a competitive product market).

The combined impact of these is a loss in total economic surplus generated by the market. The loss is represented by the combination of areas $a_3 + a_4 + a_6 + a_7$, as shaded in Figure 2[2].

[2] Losses are the *difference* in economic surplus (a proxy for economic welfare) without weeds (areas $a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7$) and with weeds (areas $a_1 + a_2 + a_5$), a loss equivalent to the area ($a_3 + a_4 + a_6 + a_7$).

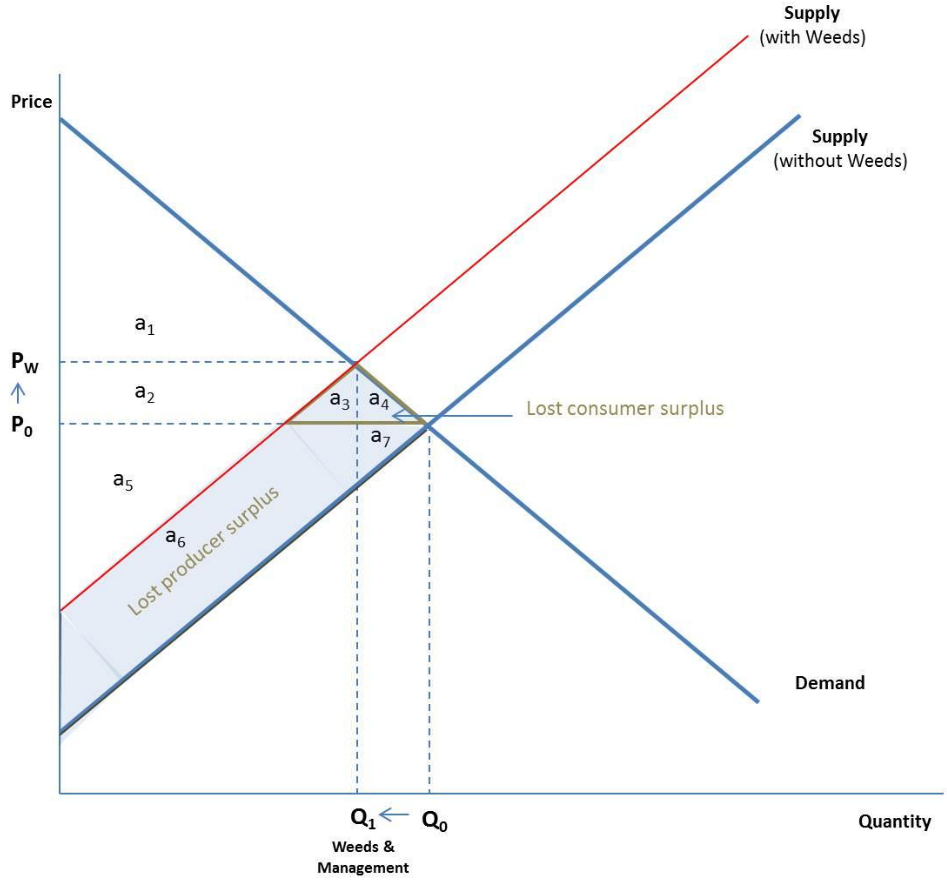
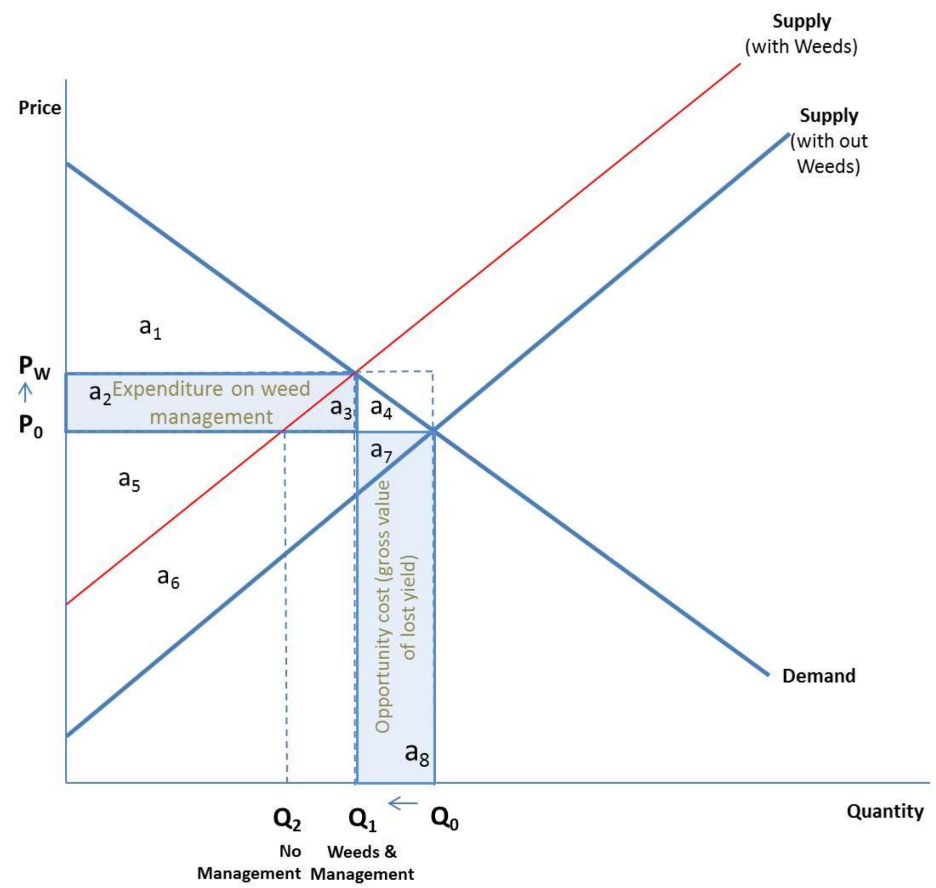


Figure 2: The impact of weeds on economic surplus

Shown in Figure 3 are the two ways that the total costs using the loss-expenditure approach have been undertaken in past studies. In Figure 3a), the two shaded areas are consistent with the approach used by Combellack (1987), where expenditures were included and opportunity cost (lost production) was measured as *gross losses*. Area's a_2 and a_3 reflect the total expenditures (increased cost of production per unit multiplied by the number of units produced, Q_1) and area's a_7 and a_8 reflect the opportunity cost (the value of production without weeds multiplied by the production foregone because of the weeds).

Meanwhile, in Figure 3b the shaded areas are consistent with those measured by Sinden *et al* (2005) in their loss-expenditure analysis, where the opportunity cost was measured as *net losses* (i.e. lost gross margin for the quantity foregone, area a_7). The approach used by Sinden *et al* has been adopted in this study because accounting for net losses will not overestimate the losses and also recognises that where weeds are present and no production is undertaken, expenses will also not be outlaid. However, it is also recognised that the change in gross margin approach to accounting for opportunity costs may underestimate losses, where costs of production are outlaid, and losses due to weeds prevail.

a) Opportunity cost measured as gross losses (lost revenue)



b) Opportunity cost measured as net losses (lost gross margin)

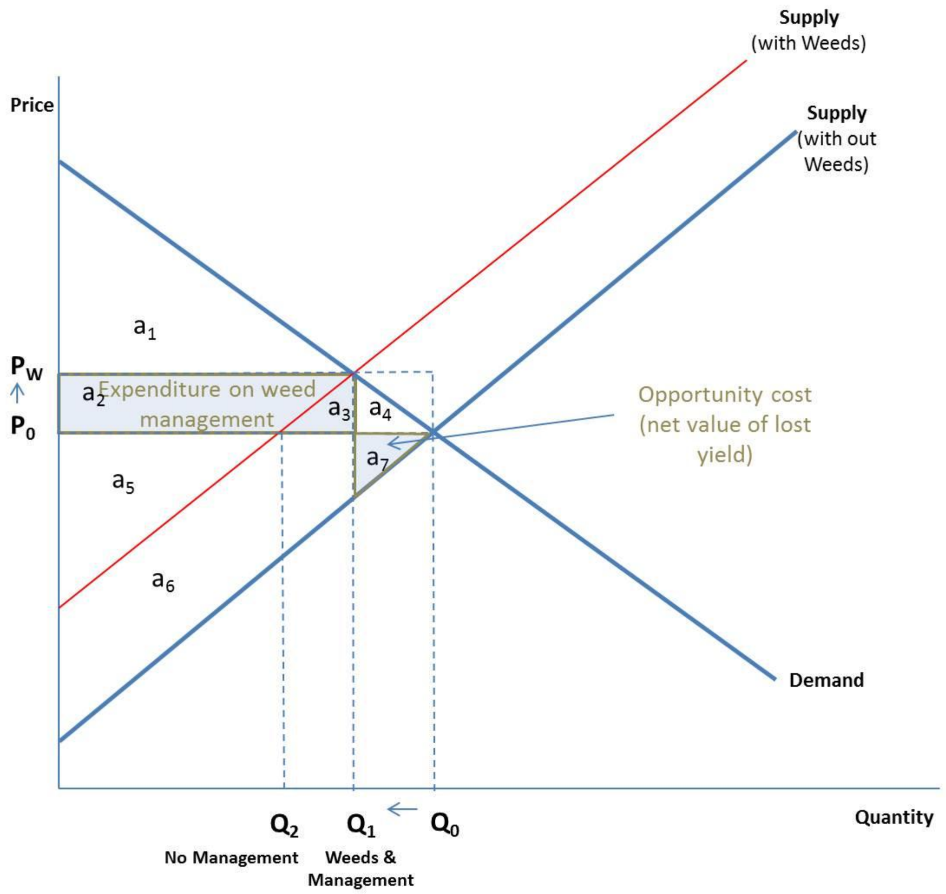


Figure 3: Loss-expenditure estimates in the context of economic surplus estimates

As illustrated in Figures 2 and 3, the magnitude of the areas used to estimate the costs will vary depending on whether the economic surplus or the loss-expenditure approach is used (and if net or gross losses are assessed in the loss expenditure approach), the nature of the supply and demand functions and depending on the supply and demand responses of the given market. As such, the cost estimates from the two different approaches are unlikely to coincide, and the difference will be dependent primarily on the nature of the supply and demand responses. However, you could expect the two estimates to deliver estimates in the same order of magnitude and that the economic surplus approach estimate would be higher given that it includes price effects. Each of the approaches has a number of challenges, most fundamentally:

- The loss-expenditure approach may overestimate losses where opportunity costs are measured as gross losses (as per Figure 3a), but may underestimate opportunity costs where losses are measured as net losses (see Figure 3b).
- The economic surplus approach requires the supply and demand responses of the relevant markets to be observable, and often supply and demand elasticities are approximate, not available or are dated and assumptions must be made about the functional form of the supply and demand functions which may or may not be realistic.

The following method has been used in this study. It is based on, and is comparable in most regards, to the approaches used by Jones *et al* (2000) and Sinden *et al* (2005), in that it adopts a loss-expenditure approach where losses are accounted for as net losses *and* then these estimates are used to derive the supply shifts for each relevant agricultural market and estimate the resultant change in economic surplus (that is areas $a_3 + a_4 + a_6 + a_7$).

The method has four steps:

1. Loss-expenditure analysis for agriculture. Data on expenditure on weed management were obtained from a range of sources including ABARES, ABS and the NSW Department of Primary Industries. Data on losses is based on industry consultation and estimates from the literature, applied to representative gross margins. All losses have been considered as losses net of benefits. That is, net of any benefits that the weed plants may offer to production (e.g. some weed plants may offer stock feed benefits at some stages of the year or at low densities). The combined costs are aggregated using ABARES and ABS data on farm numbers and farm sizes for NSW;

2. Economic surplus analysis for agriculture, including stochastic analysis. Data to describe the NSW markets for the range of agricultural industries (price and quantity data and elasticities estimates) were sourced from ABARES, ABS and the literature. These data were incorporated within a stochastic surplus simulation in the Solver™ platform. The supply shifts were estimated using the per hectare data from the loss-expenditure analysis and uncertainty was incorporated via the use of a range for each of the supply shift values[3].

[3] The supply shift factor, *K*, was estimated as total per hectare costs/average yields per hectare/equilibrium price. Given uncertainty regarding this important variable, it was incorporated as a stochastic element with a triangular distribution, which accommodated the range of loss estimates sourced in the loss expenditure analysis from the literature and industry consultation.

3. <u>Analysis of direct control costs on non-agricultural land and by public agencies.</u> Costs on non-agricultural land were assessed as the direct costs of control, using the budgets of the range of agencies involved in the management of non-agricultural lands in NSW. Data have been reviewed to consider potential double counting given that in some instances data were available only by funding agency rather than management agency. Estimation of the direction of efforts and funds towards weed management was required in some instances where funds were directed to projects with multiple natural resource management aims (e.g. a riverine management project may have weed management, salinisation and erosion aims). *Expenditure by public agencies on agricultural lands and related activities have also been included here due to difficulties in most cases apportioning agency funds between activities on private and public lands.*

4. <u>Review and discussion.</u> The results of each independent section (steps 1 to 3) have been reviewed in the context of the total economic loss to the state of NSW each year. In this step, the interpretation of the results and the implications for planned management and assessment was also documented.

Steps 1 and 2 above are focused on losses on agricultural lands, which account for almost 80 per cent of the area of NSW (see Table 1). The impact of weeds on conservation areas, which account for a further 13 per cent of NSW, are analysed as part of the analysis of direct control costs on non-agricultural lands. 'Urban' and 'other lands' which account for the bulk of the remaining land area are also considered in Step 3.

Table 1: Area of NSW by landuse

Landuse	**Area** (million ha)	**Proportion of total area** (%)
Cropping [a]	8.57	10.64
Grazing [a]	53.66	66.65
Horticulture [a]	0.15	0.19
Intensive Animal Production [a]	0.02	0.02
Mining and Quarrying [a]	0.13	0.16
Urban [a]	0.79	0.98
Forestry [c]	2.18	2.71
Conservation Areas [a,d]	7.12	8.84
- Indigenous lands [b]	*0.01*	*0.01*
- National Park [b]	*5.23*	*6.50*
- State Conservation Area [b]	*0.54*	*0.67*
- Other Area [b,e]	*1.34*	*1.66*
Other [a,f]	7.89	9.80
Total land area of NSW	80.51	100.00

Data sources and notes: a. DPI data (Landuse_V1_1), **b.** OEH data (Estate_2013_V2), **c.** Forestry Corporation of NSW data (LegalSF), **d.** DPI data (**a.**) includes Conservation Area that seems to include OEH data (**b.**) and Forestry Corporation data (d.), **e.** Other Area includes CCA Zone 1, CCA Zone 2, CCA Zone 3, Historic Site, Karst Conservation Reserve, Nature Reserve, Regional Park, **f.** Other land use includes Conservation Area, Power generation, River and drainage system, Special category, Transport and other corridors, Tree and shrub cover, Wetlands.

3 Economic impact of weeds on agricultural lands

3.1 Introduction

The impact of weeds on agricultural lands has been estimated firstly using the loss-expenditure approach and then the economic surplus approach. The results of these analyses are now presented.

3.2 Loss-expenditure analysis

Using the loss-expenditure approach[4], the costs of weeds on agricultural lands is estimated to be within the **range $1,312 million to $1,650 million per annum**. To estimate this, the agriculture sector in NSW was disaggregated into 11 sub-sectors. These sub-sectors were selected as they represent the majority of agriculture in the state and they are consistent with the available data[5]. The number of farms in each of these sectors, their average size and indicative gross margins, has been used as the basis on which to estimate the financial costs attributable to weed management and the opportunity cost of weeds in terms of lost production from residual weeds. The sub-sectors, along with the results of the analysis are shown in Table 2.

Table 2: Estimated losses & expenditure attributable to weeds & weed management

	Opportunity costs ($'million)		**Expenditure** ($'million)		**Total** ($'million)		
	Value of lost production		Chemical & machinery for its application	Labour			***Expenditure** (as % of total)* [a]
	low	*high*			*low*	*high*	
Grain	58.24	77.65	223.54	28.15	309.93	329.34	*79*
Dairy Cattle	11.75	17.63	4.23	1.21	17.19	23.07	*27*
Beef Cattle	27.12	54.24	34.60	24.36	86.08	113.20	*59*
Grain-Sheep/ Grain-Beef	75.61	151.22	182.57	47.14	305.32	380.93	*67*
Sheep-Beef	68.57	137.14	45.47	44.46	158.50	227.07	*47*
Sheep	122.19	244.39	58.77	61.89	242.85	365.04	*40*
Cotton	29.71	44.57	45.50	1.24	76.46	91.31	*56*
Sugar	1.79	3.58	3.50	0.19	5.48	7.27	*58*
Rice	9.16	11.00	91.63	1.68	102.48	104.31	*90*
Fruit	0.20	0.41	4.36	0.17	4.73	4.94	*94*
Vegetables	0.34	0.69	1.97	0.16	2.47	2.82	*81*
Total	**404.69**	**742.50**	**696.14**	**210.66**	**1,311.49**	**1,649.30**	***53*** [b]

[a] calculated on the basis of the average industry value of lost production, [b] calculated as a weighted average by industry land area

[4] Where residual losses are estimated as *net losses* (lost gross margin returns).
[5] Including from the Australian Government Department of Agriculture agency ABARES, ABS and from the NSW Government Department of Primary Industries.

The 11 agriculture sub-sectors do not represent all agricultural production in NSW. A range of industries such as chicken and egg production and other intensive industries have not been included as their intensive nature limits exposure to the impact of weeds. Other industries have been excluded on the basis of their size and/or lack of reliable data. On this basis, the results in Table 2 can be considered conservative. The following sections provide a review of the estimates in Table 2, by loss and type of expenditure.

3.1.1 Expenditure on chemical and machinery used for its application

ABARES Farm Survey crop and pasture chemical data for the period 2008 to 2012 (ABARES, 2014) coupled with NSW DPI gross margins (2012, 2013) have been used to derive the per hectare costs of herbicide. Where current data were not found to be available, costs estimated in previous studies were adopted and indexed to 2012 using the ABARES Cost of Chemicals index (ABARES, 2014). Five-year average costs have been used where possible to allow for seasonal variance in the necessity of weed control activities. These costs were aggregated on the basis of the number of farms and average farm size per industry sub-sector.

The cost of operating machinery to apply the chemicals was estimated on the basis of machinery use in various NSW Department of Primary Industries gross margins (2012, 13), and costed using the Departments estimated operating costs ($76.36/hour, NSW DPI, 2012). Where insufficient data were available, a standard hour/hectare rate was adopted, as detailed in Appendix A.2. These costs include fuel, repairs and maintenance, but not labour for operating the machinery, or any allowance for fixed costs. These costs, estimated on a per hectare basis were also aggregated using the number of farms and average farm size per industry sub-sector.

The combined expenditure on herbicides and cost of operating machinery for weed management activities to agriculture in NSW is estimated to be **$696.14 million per annum** as shown in Table 3.

3.1.2 Expenditure on, and value of labour, used for weed control activities

Application of herbicides using machinery or manually and a range of other non-chemical approaches to weed management require labour. This is an additional cost due to weeds on agricultural lands in NSW. Data from ABS (2007) on the total average number of days of effort put towards weed management has been used as a basis for estimating the total cost of labour directed to weed control activities. ABS estimated an average of 31 days per 1,000 hectares for agricultural lands in NSW. This was allocated across the sub-sector industries on the basis of total land areas occupied by farms. It is recognised that this is an average estimate of effort across industries which will have varying labour intensity in the management of weeds. The total cost on the basis of an average wage rate of $20/hour (NSW Farmers, 2012) and an 8 hour day, is estimated to be **$210.66 million per annum** (Table 4).

Table 3: Expenditure on Herbicide & Machinery, by industry sub-sector

Industry sub-sector	Machinery cost ($/ha)	Chemical cost ($/ha)	**Total ($/ha)**	**Total by sub-sector ($ million)**
Grain	9.16	30.22	39.38	223.54
Dairy Cattle	3.82	13.50	17.32	4.23
Beef Cattle	3.82	3.23	7.05	34.60
Grain-Sheep/ Grain-Beef	3.82	15.39	19.21	182.57
Sheep-Beef	3.82	1.26	5.07	45.47
Sheep	3.82	0.89	4.71	58.77
Cotton	3.82	177.75	181.57	45.50
Sugar	3.82	85.43	89.25	3.50
Rice	3.82	266.00	269.82	91.63
Fruit	3.82	123.03	126.84	4.36
Vegetables	19.09	41.42	60.51	1.97
Total				**696.14**

Table 4: Estimated cost of labour used in weed control on agricultural lands in NSW

Industry sub-sector	**Labour cost ($ million)**
Grain	28.15
Dairy Cattle	1.21
Beef Cattle	24.36
Grain-Sheep/ Grain-Beef	47.14
Sheep-Beef	44.46
Sheep	61.89
Cotton	1.24
Sugar	0.19
Rice	1.68
Fruit	0.17
Vegetables	0.16
Total	**210.66**

3.1.3 Estimates of the opportunity cost of residual weeds

Despite efforts to manage weeds, there will be losses due to residual weeds. These will result because of the efficacy of methods used and the relationship between the marginal cost of managing weeds and the marginal benefit of doing so. In some instances it does not pay to manage all weeds, even though they still impose costs.

In this section, the costs associated with these residual weeds are reported. This cost has been estimated using the same 11 agricultural industry sub-sectors. The losses that occur despite standard weed management practice (i.e, those practices accounted for in sections 3.1.1 and 3.1.2 above) have been identified as percentages of lost yield/productivity. Given uncertainty in estimates, and a range of circumstances across the state, a range of lost yield/productivity percentages has been adopted. These have been applied to the representative gross margin[6] for each industry sub-sector, to calculate the difference in gross margin with and without the additional yield (the net opportunity cost), and aggregated on the basis of the number of farms and average farm size (adjusted for the productive area, given not all hectares on a property will be in productive operations at any one time).

Table 5: Estimated annual residual losses (opportunity costs) due to weeds in NSW

Industry sub-sector	Yield loss attributable to residual weeds (%)		Opportunity cost of residual weeds ($/ha)		Additional not costed opportunity costs	Total losses by industry sub-sector ($'million)	
	low	high	low	high		low	high
Grain	6	8	11.40	15.20	Grain contamination	58.24	77.65
Dairy Cattle	2	3	53.48	80.22	Stock deaths	11.75	17.63
Beef Cattle	5	10	6.14	12.27	As above	27.12	54.24
Grain-Sheep/ Grain-Beef	5	10	8.84	17.68	Stock deaths and grain contamination	75.61	151.22
Sheep-Beef	5	10	8.50	17.00	Stock deaths	68.57	137.14
Sheep	5	10	10.88	21.76	Stock deaths and wool contamination	122.19	244.39
Cotton	10	15	118.57	177.86	Very occasional vegetable matter discounts	29.71	44.57
Sugar	5	10	45.60	91.20		1.79	3.58
Rice	2.5	3	26.98	32.38	Grain contamination	9.16	11.0
Fruit	1	2	5.95	11.90	Will vary by crop type and harvesting mechanism, but weeds may lead to additional sorting requirements.	0.20	0.41
Vegetables	1	2	10.53	21.06	Will vary by crop type and harvesting mechanism, but weeds may lead to additional sorting requirements.	0.34	0.69
Totals						**404.69**	**742.50**

[6] On the assumption of constant variable costs per unit of output, the value of a percent change in yield will be the same if calculated as a percent change in gross margin.

The opportunity cost due to residual weeds, have been found to range from around **$400 million to $750 million** as shown in Table 5. The key yield loss data used to estimate these losses are also shown in Table 5. These and the corresponding estimates of loss reflect uncertainty which is, primarily, related to seasonal conditions. Full data and assumptions used are provided in Appendix A.2.

3.2 Economic surplus analysis

Calculation of economic costs as changes in economic welfare is a widely used approach, where the metric economic surplus is used to quantify economic welfare (Griliches 1958, Alston 1991, Tozer & Marsh 2012, Mitchell 2014). The following details an estimate of the change in total economic welfare that results from weeds, as the change in surplus (ΔES) that occurs in the range of markets in which NSW agricultural production is traded. Economic surplus comprises consumer surplus and producer surplus so that a change in economic surplus is calculated as $\Delta ES = \Delta CS$ (change in consumer surplus) $+\Delta PS$ (change in producer surplus).

In terms of Figure 2 of Chapter 2, this assessment estimates the lost surplus areas a_3 and a_4 (change in consumer surplus, ΔCS) and a_6, and a_7 (change in producer surplus, ΔPS). The standard approach to surplus estimation, as documented by Alston (1991), has been used:

$$\Delta CS = P_W Q_W Z(1+\frac{1}{2}Z\eta)$$

$$\Delta PS = P_W Q_W (K-Z)(1+\frac{1}{2}Z\eta)$$

and

$$Z = \frac{K\varepsilon}{(\varepsilon+\eta)}$$

where

P_W = equilibrium market price

Q_W = equilibrium market quantity

ε = absolute value of the elasticity of supply (slope of the supply function)

η = absolute value of the elasticity of demand (slope of the demand function)

K = vertical supply shift

Z = percentage change in price arising from a supply shift

This method was applied to 20 industries that represent the majority of agricultural production in NSW. The data used to calibrate the model are provided, with sources, in Appendix A3. The consumer and producer surpluses for each of the 20 markets were calculated and then summed to provide an estimate of the losses due to weeds and weed management in agricultural production in NSW.

The vertical shifts in the supply functions, *K,* were estimated using the per hectare cost data estimated in section 3.1, calculated as a per unit (Q) value using average yields for the same period, divided by the equilibrium price. *K* is a key driver of any estimates of surplus. As such, it was introduced to the model as a stochastic variable. This stochastic model was simulated within Solver™, using a triangular distribution around the variable *K*.

3.2.1 Total loss of economic surplus due to weeds

The total cost of weeds in NSW, calculated as a change in economic surplus, was estimated to be between **$1,607 and $1,839 per annum, with a mean of $1,733 million per annum**. This comprises losses in producer and consumer surplus across the 20 agricultural industries incorporated in the model. The losses by industry are shown in Table 6.

Table 6: Change in economic surplus due to weeds in NSW, $'million

Industry	Mean Values			*Range*	
	Change Consumer surplus (CS)	Change Producer surplus (PS)	Change in Economic Surplus (CS+PS)	*Minimum ES Value*	*Maximum ES Value*
Wheat	19.43	270.26	289.69	*284.49*	*298.60*
Oats	1.78	13.15	14.93	*14.32*	*15.35*
Barley	5.60	41.08	46.68	*45.23*	*48.23*
Canola	3.25	24.01	27.26	*26.19*	*28.01*
Lupins	0.63	4.70	5.33	*5.096*	*5.46*
Field peas	0.19	1.43	1.62	*1.53*	*1.64*
Chickpeas	1.94	14.42	16.36	*15.64*	*16.74*
Sorghum	1.63	12.04	13.67	*13.13*	*14.04*
Maize	0.55	3.92	4.47	*4.40*	*4.72*
Sunflowers	0.16	1.20	1.37	*1.31*	*1.41*
Soybeans	0.18	1.32	1.50	*1.46*	*1.56*
Cotton	25.28	36.55	61.84	*58.77*	*65.94*
Rice	2.47	15.27	17.74	*16.79*	*18.28*
Sugar	0.58	3.80	4.38	*3.56*	*4.64*
Dairy	8.77	21.77	30.50	*22.50*	*41.37*
Wool	153.49	239.38	392.87	*356.22*	*427.14*
Lambs/mutton	161.43	162.51	323.94	*293.51*	*357.40*
Beef/veal	30.65	442.26	472.91	*437.00*	*482.19*
Fruit	0.63	2.60	3.24	*3.12*	*3.25*
Vegetables	0.76	1.86	2.62	*2.26*	*2.69*
Totals	**419.39**	**1,313.53**	**1,732.91**	***1,606.55***	***1,838.64***

3.3 Annual costs of weeds on agricultural lands in NSW.

Two previously used approaches to estimating the cost of weeds on agricultural lands have been used in this study. The first, the loss-expenditure approach, resulted in an estimate of annual cost ranging from **$1,312 and $1,650 million per annum**. This approach has been undertaken as a 'bottoms up 'approach, starting with the number of farms and per hectare expenditures. It does not include price effects so you would anticipate it to be lower than the estimate of loss using the economic surplus approach.

The economic surplus approach was used to estimate the annual losses to be between **$1,607 and $1,838 million, with a mean of $1,733 million**. These losses reflect the losses to producers and consumers. It has been assessed on the basis of the impact of weeds on industry markets, prices and quantities so is a 'top down' approach.

Both of these methods confirm the order of magnitude of the cost of weeds to NSW given current management practices, but both are considered conservative because:

- Not all agricultural industries and lands have been included;
- Net losses, rather than gross losses, have been used to estimate the opportunity cost of lost yields/productivity;
- A conservative approach to the identification of yield loss parameters has been taken in consultation and review of the literature;
- There is a range of losses that cannot be confidently quantified, such as grain contamination and stock deaths; and
- There are additional costs of management that cannot be confidently quantified, including management strategies to avoid herbicide resistance, rotations and the use of genetically modified varieties.

4 Costs of weeds on non-agricultural lands

Non-agricultural lands comprise a range of both private landholdings and public landholdings (Table 7). On both of these there are likely to be losses (opportunity costs) associated with the presence of weeds as well as expenditure to mitigate the impacts of weeds.

Private non-agricultural landholdings include urban lands used for homes and businesses, and regional landholdings not used for agricultural production, such as mining, forestry or indigenous lands. Public non-agricultural landholdings include urban lands used for parks, sporting fields, conservation lands, nature reserves and other lands managed by the state, public agencies, local councils and trustees.

Table 7: Private and public non-agricultural lands

Private landholdings	Public landholdings
Private urban and non-urban lands (homes and businesses)	Public urban lands (e.g. parks, nature reserves, sporting facilities)
Mining	Conservation areas (e.g. nature reserves, wetlands)
Private forestry	National parks and state forests and reserves
Indigenous lands	Travelling stock routes

4.2 Expenditure on weed management on non-agricultural lands

Review of literature and data sourced from the Natural Resources Commission have been used to provide the following estimates of expenditure on these non-agricultural lands.

4.2.1 Urban areas

There are some 790,000 hectares of urban lands in in NSW (Table 1). Weed management activities on these lands will range from control of lawn weeds and invasive plants in home vegetable gardens to weed control in local parks, sporting fields, roadsides, local reserves and conservation areas. Some of this weed management will be voluntary, and some will be required in compliance with the *Noxious Weeds Act 1993*. Some will be undertaken by private landholders and other by the local control authorities (normally the local government councils).

Local control authorities are responsible for resourcing activities to ensure compliance with the *Noxious Weeds Act* and are responsible for both the management of noxious weeds on public lands, and the compliance of private landholders with the *Act*. The combined expenditure on these activities in NSW in the 3 years to 2012/13 is estimated to be $45.5 million or an average of $15.2 million per annum[7]. A substantial part of this expenditure will be related to enforcement of the *Noxious Weeds Act* by way of surveillance and issuing weed orders. Some part of this will be related to agricultural lands, rather than urban lands. Despite this, the entire budget is included here because it has not been possible to apportion it between agricultural and non-agricultural lands and its inclusion here does not make a material difference to the total cost estimates as interpreted in this report.

Expenditure on public lands within urban areas by local government councils that is not related to compliance with the *Noxious Weeds Act 1993* is likely to be highly variable based on region, landholder and seasons. A 2011 submission to by the Local Governments and Shires Association of NSW to the NSW Government estimated that councils in NSW collectively spend up to $30 million per annum on weed management (Montoya, 2012), some $15 million more than the $15.2 million reportedly spent by them on their local control authority responsibilities. The additional expenditure by local governments/local control authorities is recognised, however not included in this analysis as it has not been possible to verify its extent.

Analysis of expenditure on private lands within urban areas has not been undertaken due to the highly variable likely costs and lack of existing data on which to base the analysis.

4.2.2 National Parks

There are 5.23 million hectares of natural lands gazetted as national park in NSW Table 1). The National Parks and Wildlife Service (NPWS) is reported to have spent $54.7 million on weed management activities in the period 2010/11 to 2012/13[8]. This equates to an estimated average of $18.2 million expenditure on weed management annually.

4.2.3 Other public lands and public expenditure

Weed management activities on a range of other public lands is undertaken by a wide range of agencies, with funding from a number of sources. By source, estimated annual expenditure on weed management in NSW is shown in Table 8. Some part of this will be related to agricultural lands, rather than public lands. Despite this, the entire budget is included here because it has not been possible to apportion it between agricultural and non-agricultural lands and its inclusion here does not make a material difference to the total cost estimates as interpreted in this report.

The true value of expenditure on weed management by public agencies is considered to be likely higher than $31.19 million. The possibility of being able to attribute CMA base level funding is just one element that would facilitate greater understanding of the public resources expended on weed management.

[7] Figures taken from the Weed Action Program annual reports provided to DPI by the regional project teams, cited in NRC (2014).

[8] Data from Office of Environment & Heritage, December 2013 as cited by NRC (2014).

Table 8: Annual public expenditure in NSW (*excl NPWS*)

Funding source	Source	$' million (per annum)
DPI Weed Action Plan	DPI provided $29 million through the Weed Action Program for the years 2010/2011 to 2012/2013, an average of $9.7 million annually[a]. This is in addition to the expenditure reported by LCAs.	$9.7
Catchment Action NSW	Nine of the eleven CMAs provided over $2.7 million from 2010-11 to 2012-13.[a] Additionally, a significant portion of the approximately $74 million allocated by Catchment Action NSW to CMAs in this period was spent on integrated land management projects with a weed management component [b]. It is estimated on the basis of apportionment across the state-wide CMA objectives that in the order of $7-8 million (10 per cent) of this would be a reasonable estimate of the proportion directed to weed management activities.	$3.6
Caring for Our Country	$13 million of funding for Caring for Our Country projects were identified as being primarily focused on weed management funded from 2009-2010 through 2011-2012[c]. A significant portion of the $141 million in base-level funding to CMAs was also spent on weed management[b] however there has been no consistent basis on which to apportion this.	More than $4.3
Public Reserves Management Fund	Crown Lands Division spent $585,000 to fund over 166 weed management projects in 2011-2012[d].	$0.59
Biodiversity Fund	Biodiversity Fund Round one projects primarily focused on weed management totalled $8.6 million and an additional $30 million for projects with a significant weed component. The majority of projects were funded over 3 – 6 years. The annual average is estimated to be in the order of $8.6 million. Available data suggests that related cash and in-kind contributions may be in the order of $6 million per annum however there are no definitive records on which to report this.	More than $8.58
Environmental Trust	Environmental trust funding provided an estimated $10.3 million from 2010-2011 through 2012-2013 for weed management projects, an average of $3.4 million annually[f].	$3.40
Forestry Corporation of NSW	Forestry Corporation of NSW spent $1.02 million on weed control in 2010/11 [g].	$1.02
	Total	**More than 31.19**

[a] NRC (2014). Two CMAs were unable to provide data for the report. The estimate of average annual expenditure has therefore been inflated by a pro-rata average equivalent in recognition of the gap in the data.[b] NRC (2014) [c] Review of Caring for our Country 2011-12 Community Action Grants Successful Projects. It is recognised that not all of the funding may be expended in the 2012 year, however on the basis that other projects from previous funding rounds will still be operating, the 2011/12 funding round is considered a reasonable indicator. [d] New South Wales Parliament Legislative Council. General Purpose Standing Committee No. 5 (2013). "Management of public land in New South Wales", NSW Parliament Legislative Council, Sydney, NSW, cited in NRC (2014).[e] NRC (2014). [f] Data provided by OEH, October 2013, cited in NRC (2014). [g] New South Wales Parliament Legislative Council. General Purpose Standing Committee No. 5 (2013). "Management of public land in New South Wales", NSW Parliament Legislative Council, Sydney, NSW, cited in NRC (2014).

4.3 Lost value on non-agricultural lands

Losses, or opportunity costs, due to weeds on non-agricultural lands will vary significantly, from lost production values in the case of forestry or home gardens, to lost cultural values on indigenous lands and reduced amenity opportunities in nature reserves and lost biodiversity in national parks.

Estimation of these losses due to residual weeds has not been undertaken in previous comprehensive studies due primarily to the difficulty and high cost in doing so accurately. In particular, and primarily in relation to environmental assets, there is insufficient information on the asset values associated with such lands, marginal physical impacts of weed invasions on such lands and the marginal economic losses. This is because no markets exist for these environmental assets. Valuation of the losses on non-agricultural lands is further complicated by the high variance in the types of lands and land uses within the 'non-agricultural lands' land use category.

Sinden *et al* (2004) econometrically assessed the annual benefit of weed control in terms of biodiversity protection, using a defensive expenditure approach. Their analysis found the benefit of each saved threatened species to be $68,700 per annum. Coutts-Smith and Downey (2006) estimated the number of species in NSW threatened by weed populations to be 419. When combined, such data may provide the basis on which to consider the lost values on conservation and other natural lands. At its most basic, it is possible to postulate that the total annual environmental value lost due to weeds is $28.8 million. However, this figure on its own is unlikely to be accurate because:

- the per species annual value is based on expenditure undertaken, which is assumed to be reflective of total community value for the species. In reality this value is likely to represent a lower bound on possible value per threatened species;
- there are no data to indicate the extent to which weeds have reduced the total value of a threatened species. There is no indication of the remaining proportion of a threatened species, and additionally how this relates to minimum thresholds for species survival and annual rates of change; and
- losses related to threatened species alone would not capture all losses in biodiversity, amenity and use values on non-agricultural lands.

No verifiable and consistent data relating to lost cultural values on indigenous lands, lost production on forestry lands or home gardens or reduced use values associated with national parks and reserves was identified in the scope of this project.

4.4 Total cost of weeds on non-agricultural lands

The total cost of weeds on non-agricultural lands has been estimated as the expenditure by public agencies on public lands, which were in the order of **$64.59 million** in 2012, as per Table 9. In this case, public expenditure by agencies, in relation to for example the Weed Action Plan and CMA activities on farms, have also been included as there has been no basis on which to apportion total expenditures to agricultural and non-agricultural lands. Further, the expenditures are normally contributing to environmental asset management rather than agricultural productivity measures, and are a smaller part of the total expenditure.

No measures of private expenditure, or bases on which to estimate private expenditure, on non-agricultural lands have been identified and therefore these are not included in this assessment. Insufficient data were available to estimate the private and public losses on non-agricultural lands, so these are also not included in this assessment.

Table 9: Expenditure and losses due to weeds on non-agricultural lands

	Expenditure	**Losses**
	($ million)	
Private non-agricultural lands		
	nq	nq
Public expenditure / non-agricultural lands		
Local government / local control authorities	15.20	nq
National parks	18.20	nq
Other Public lands and public expenditure	31.19	nq
Total	**64.59**	

nq: not quantified

Expenditure of $64.59 million is considered to underestimate the costs on non-agricultural lands because it does not include private or public losses on non-agricultural lands and it does not include private expenditure on non-agricultural lands. Further, recorded public expenditure is unlikely to be comprehensive. Full disclosure of weed management expenditure by local councils and local control authorities would contribute greatly to understanding the costs of weeds on non-agricultural lands.

5 Conclusions

5.1 The results and their interpretations

The total annual current cost of weeds in NSW is estimated to be between $1,671 million and $1,903 million, with a mean value of around $1,800 million. These are calculated on 2012 values and are considered indicative of the costs that would be borne in the current year. As shown in Table 10, the total includes the impact of additional expenditure and losses in agriculture and expenditure by public agencies on public lands.

This means that on the basis of current weed management practices and weed populations, $1,800 million is lost to the economy each year in terms of expenditure that could have been diverted to other uses (instead of expenditure on management) and value of production that could have been produced if it was not for the weeds (opportunity costs (lost production)). It does not measure the cost of weeds if management was not undertaken, but rather measures the costs given current management. In terms of Figure 1, it is the value $x in scenario 2.

Table 10: Current annual cost of weeds in NSW ($'million)

	Low	**Mean**	**High**
	Expenditure on weed management and losses in output		
Agriculture			
Loss-expenditure estimate	1,311.49		1,649.30
Economic surplus estimate	1,606.55	1,732.91	1,838.64
		Expenditure only	
Public expenditure/non-agricultural land			
Public	64.59	64.59	64.59
Private	nq	nq	nq
Total (using the economic surplus estimate of losses to agriculture)	**1,671.14**	**1,797.14**	**1,903.23**

This total includes:

- The cost of labour, chemical and machinery on agricultural lands;
- The value of lost production on agricultural lands;
- The lost value due to price responses in agricultural markets; and
- The value of expenditure by public agencies on non-agricultural lands (including public agency expenditure that may be directed to on-farm projects).

The results of this study can be compared to the estimated cost of weeds in Australia completed by Sinden *et al* (2005) because of the consistent method used however in doing so it should be recognised that:

- fruit and vegetable markets were not included in their economic surplus estimate; and

- the estimate by Sinden *et al* was calculated in 2002 terms, whereas this estimate for the cost of weeds in NSW has been estimated in 2012 terms.

Of the total estimated cost, agricultural producers are estimated to bear around 73 per cent of the burden of the weeds in NSW, consumers 23 percent and 4 per cent of the costs are public expenditure on weed management activities, as illustrated in Figure 4.

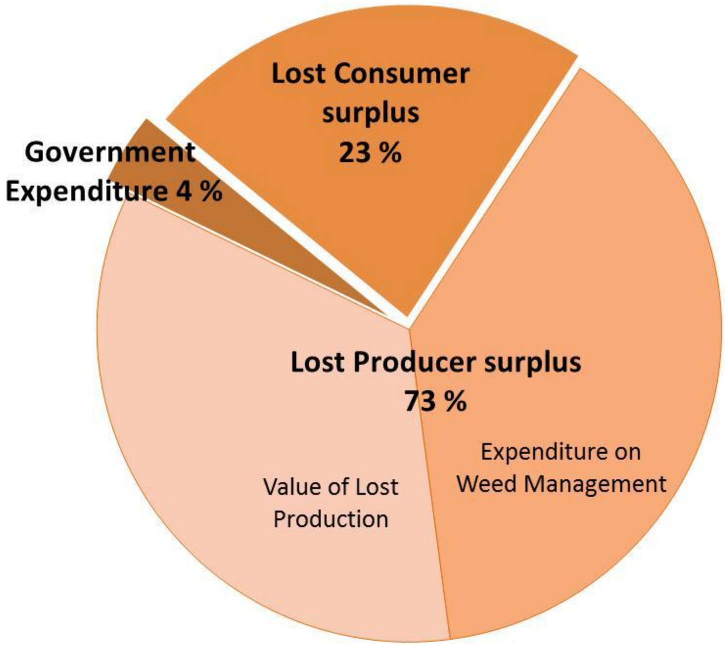


Figure 4: Share of the estimated costs of weeds in New South Wales, by stakeholder

Within agriculture, the annual cost of weeds in NSW is greatest for the livestock sector at up to $900m million per annum followed by the cropping sector at $700 million (Table 11). While the cropping sector has generally higher per hectare expenditure on herbicides, machinery and labour to manage weeds and losses due to residual weeds (refer to section 3.2), losses in the livestock sector of NSW are higher due to the number of livestock farms and hectares operated in NSW.

Table 11: Summary of losses and expenditure by industry groups ($'million)

	Low	High
Cropping (grains, rice, sugar, cotton)	647.0	722.7
Livestock (dairy, beef, sheep)	657.28	918.85
Horticulture (fruit, vegetables)	7.21	7.75
	1,311.49	1,649.30

5.2 Strengths and weakness of the results

The estimate of the cost of weeds in NSW is based on the total costs associated with production on agricultural lands using the economic surplus approach and the expenditure on public lands by public agencies. This figure is considered conservative because:

- Losses on non-agricultural lands are not included;
- Expenditure by private landholders of non-agricultural lands are not included:
- Expenditure by public agencies on non-agricultural lands may be incomplete;
- The losses in agriculture are calculated for the majority, but not all agricultural industries;

While conservative, and potentially considered a lower bound estimate, this is a strength in that the cost is not an overestimate of the problem of weeds. Further, the estimate of costs to agriculture, which accounts for by far the largest proportion of the estimate, is confirmed by the two approaches to estimation: the top down approach of the economic surplus calculations and the bottom up approach of loss-expenditure calculations. The two approaches estimate costs of the same order of magnitude and the loss-expenditure estimate is lower than the economic surplus approach as you would expect given that the economic surplus approach includes price effects.

The absence of opportunity costs on non-agricultural lands is the biggest weakness of the results, and this is driven by the paucity of information relating to values. However, in the absence of key data and knowledge to drive estimates of lost biodiversity values, for example, attempts to include these opportunity costs would be misleading.

5.3 Implications for expenditure decisions

The estimate of current annual costs can provide the basis for monitoring changes in the total current annual costs of weeds over time. Given the same methodology, assessment over time could be undertaken to recognise changes in the costs of weeds. Such changes at a state level are unlikely to be discernible at small increments such as annually, but over time there will be material changes in losses and expenditure as new weeds emerge and weed management practices and efficiencies change. Additionally, input and output prices will change over time due to inflation and to changes in the value of the underlying lost productive values (i.e. changes to $/tonne). These should be incorporated if a new current annual cost of weeds is estimated. However, to assess real changes in expenditures and costs, in separate time periods, the expenditure and costs should be assessed in the same base year values.

On their own, a change in the value of expenditure, or a change in the losses, over time does not provide a basis for comparing how the annual costs of weeds are changing over time. This is because of the tradeoff relationship between expenditure and losses. As expenditure increases, you can expect losses to fall, and vice versa. This is further complicated by the fact that increasing expenditure does not result in a comparable linear change in avoided losses. As such, any comparisons over time must be mindful that increased expenditure does not necessarily indicate an increased cost of weeds: increased expenditure may (but also may not) correspond to greater avoided losses due to weeds, and the opposite applies in the case of reduced expenditure.

The current annual cost of weeds cannot alone provide an indication of the return on investment in weed management activities. However, the expenditure (the costs of management), if compared to the benefits (avoided losses), can provide the basis for identifying the return on investment. The value of avoided losses has not been estimated in this study. In terms of Figure 1, this benefit cost approach would be the comparison of the expenditure on weed management, $x-$y in Scenario 2, with the value of the avoided losses, $w-$y in Scenario 2. Where the expenditure is less than the avoided losses, the management expenditure would be deemed to have been (or anticipated to be in the case of *ex ante* considerations) worthwhile, and vice versa.

However, to go to the next step and identify the optimal level of expenditure, that is the level of expenditure which minimizes total costs of weeds in the context of alternative uses of expenditure funds, the marginal value of avoided losses and the marginal cost of management must be set equal. Such analysis requires detailed analysis of weed management techniques and efficacy, the 'dose-response relationships' associated with weed management. It also requires that analysis is undertaken in recognition of the dynamics of weed populations over time and space. For this reason, such analysis has been limited to date to individual weed species populations, and then it has often been demonstrative analysis due to insufficient data. In the case of state wide management decisions, application of this type of analysis is unlikely to be possible, however, the principals of marginal returns that lie behind such analysis can and should be considered in expenditure decisions.

5.4 Recommendations

This study has found the costs of weeds in NSW to be in the order of $1.8 billion per annum and such a cost is likely to prompt investigation of measures to mitigate any increases in the weed burden through new introductions (either from overseas or interstate) and identify worthwhile weed management strategies that can reduce the losses due to weeds and increase the efficiency of weed management expenditure. Any proposed expenditure should be subject to benefit cost analysis because it assesses if a proposal is worthwhile in the context of the economy and more or less worthwhile than other approaches to weed management. If possible, evaluation of the optimal level of expenditure would be ideal going forward, however, in the absence of such analysis being possible the principals sitting behind it should be adopted in expenditure decisions.

Specific recommendations regarding the outputs of this study are that:

- the study should be updated in 5 to 6 years to assess material changes and accommodate changed values, using the same methodology;
- research on the value of environmental assets and weed invasion impacts should be supported;
- investigation of the variance in weed burden/losses in productivity by location in NSW could be undertaken to assist in increasing the accuracy of weed cost assessment (as well increasing the possibility of more effective targeted R&D and management outcomes); and
- private expenditure on weed management on non-agricultural lands be investigated.

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Appendices

A.1 Impacts of weeds

Weeds have the effect of damaging the quantity and quality of outputs from the systems they invade (Cousens and Mortimer, 1995) as they compete with desired plants (either exotic or native). Introduced plants, which have become invasive, impose considerable impacts on agricultural industries, in natural areas and amenities available to society. There are 1,386 species of plants identified as weeds in NSW (Coutts-Smith and Downey, 2006).

The impacts of invasive plants vary significantly from species to species. The most widely addressed are those where plants become invasive in agricultural systems. These impacts include reduced food production through reduced productivity of crops and pastures (reduced quantity and quality), and increased management to control the invasions. In cropping systems in NSW, weeds such as heliotrope (*Heliotropium europaeum)*, panic grasses (*Panicum* spp), Johnson grass (*Sorghum halepense)* and wireweed (*Polygonum aviculare*) are widespread and can lead to significant loss of yield, and diversion of significant resources for management and containment of the weeds.

Poisoning of, and injury to, pets and livestock is a further impact that can result from the invasion of some plants. St John's Wort (*Hypericum perforatum*), for example, reduces the productivity of sheep through reduced general health, capacity to lamb and reduced wool quality, but can also cause death. Similarly stock, especially horses and pigs, are susceptible to poisoning by Paterson's curse (*Echium plantagineum)*. A consequential impact in agricultural systems is that increased chemical management can lead to an increased risk of herbicide resistance, which, if it results, has wide spread implications.

In natural areas, weed lead to the creation of exotic monocultures which results in loss of native biodiversity and contribution to the extinction of native flora and fauna, spoilt landscapes with loss of tourist appeal and reduced possible use of, and quality of, natural areas for recreational purposes (Cousens and Mortimer, 1995: Groves et al., 2001; Odom, 2002). In NSW, Lantana (*Lantana camara* L.), bitou bush (*Chrysanthemoides monilifera* subsp. *Rotundata)*, blackberry (*Rubus fruticosus* agg), kikuyu (*Pennisetum Clandestinum)* and Scotch broom (*Cytisus scoparius)* are noted as the weeds most widely responsible for loss of, or threat to loss of biodiversity (Coutts-Smith and Downey, 2006). Invasive plants, including these, have been found to be the primary source of threat to 419 threatened plant and animal species and ecological communities in NSW (Coutts-Smith and Downey, 2006).

A key and immediate impact for many individuals is allergic reactions to invasive plant populations. Privet (*Ligustrum sp.)* and Parthenium weed (*Parthenium hysterophorus*) are two notable examples of invasive plants in NSW which can create impact with severe respiratory and dermatitis effects for humans (and animals) (Blackmore and Gray, 2012; NSW DPI Invasive Species Unit, 2012). Additional impacts from weeds can include the blockage and pollution of waterways resulting in increased management needs and decreased water quality, increased risk of bushfires and creation of shelter for feral animals and spread of associated disease.

It must be recognised, however, that not all of the impact of weedy species are negative. This is linked to the fact that more than 70 per cent of weedy species in Australia are thought to have been introduced intentionally (Kalisch Gordon, 2008). Reasons for the introduction or favourable impacts of, exotic species include (Kalisch Gordon, 2008: Ligenfelter, 2014):

- soil stabilisation;
- provision of habitat and feed for wildlife,
- nectar for bees;
- their aesthetic qualities;
- to add organic matter;
- source of pasture;
- provide genetic reservoirs;
- contribute to human consumption; and
- provide employment opportunities.

The benefits of weedy species such as Paterson’s curse are well known with respect to the apiary industry. The benefits of a plant such as prickly acacia (a weed of national significance) are even noted and include drought insurance, improved stock condition and better fleece weights (Montoya, 2012).

The negative, and to a lesser degree the positive, impacts of weeds over time are characterised by uncertainty and compounding impacts as weed populations spread. The rate of spread varies between different species, primarily because of the coincidence of the specific spread vectors, suitability of environments to which they spread and the intrinsic features of the plants. Uncertainty surrounding weed spread presents difficulties in identifying the most efficient approach to management. However, the compounded impacts over time as weed populations spread means that management is essential to avoid long term significant costs to the community.

A.2 Data used to derive loss and expenditure on agricultural lands.

Appendix Table A.2.1: Industry data used to assess expenditure and loss on agricultural lands

Industry sub-sector	Farms (no.)		Average farm size (ha)		Average farm size adjusted for production area (ha)[h]	Gross margin ($/ha)	Data source
Grain	2,435	a	2,331	a	2,098	190	NSW DPI (2012) Average of gross margins reported for wheat production
Dairy Cattle	842	a	290	a	261	2674	NSW State Average, reported in Dairy Australia (2012)
Beef Cattle	5367	a	915	a	824	123	NSW DPI (2012) Average of gross margins for beef enterprises in NSW
Grain-Sheep/ Grain-Beef	5,428	a	1,751	a	1,576	177	Average of gross margins used for grain, beef cattle and sheep
Sheep-Beef	2,648	a	3,385	a	3,047	170	Average of gross margins used for sheep and beef
Sheep	2,199	a	5,674	a	5,107	218	NSW DPI (2012) Gross Margin for indicative flock type: merino ewes (20 mic) with 75% merino Rams, 25% to Terminal sire)
Cotton	382	b	656	e	656	1186	NSW DPI (2012) Average of gross margins reported.
Sugar	490	c	80	c	80	912	Per tonne gross margins reported by Welsman (2011) times by average yields in NSW (114t/ha)
Rice	849	d	400	f	400	1079	NSW DPI (2012) Average of rice gross margins reported.
Fruit	3,436	b	10	g	10	595	NSW DPI (2003) Gross margin for Washington navels production in NSW with updated price and cost data is used as a proxy. Orange production dominates fruit production by volume in NSW (ABS, 2012)
Vegetable	1,302	b	25	g	25	1053	NSW DPI (2013) Average of gross margins reported for fresh winter, fresh summer and processing potato. Potato production dominates vegetable production by volume in NSW (ABS, 2012)

Data sources and assumptions:
a ABARE, Agsurf, 2014, b ABS, 2011-12 c NSW Sugar (2014) (number of hectares of sugar should allow for 10 ha fallow, 36% 1 yr sugar and 64% 2 yr sugar, annualised) d NSW Rice Marketing Board, 2014 e Cotton Australia, 2011 f DAFF (http://www.daff.gov.au/agriculture-food/crops/rice) g Derived from ABS, 2011-12 h Adjusted for productive area on the basis of ABARES reported land areas to avoid double counting.

Appendix Table A.2.2: Data used to calculate opportunity costs (losses) by industry sub-sector

Industry sub-sector	Yield loss attributable to residual weeds (%)			Opportunity cost of residual weeds ($/ha)		Opportunity cost of residual weeds Industry sector ($million)	
	Low	High	Source	Low	High	Low	High
Grain	6	8	Based on Jones *et al* (2000). Residual losses are not anticipated to have changed significantly. Increases in herbicide resistance are coupled by increased capacity to manage other weeds, including through changed management practices. (pers comm. Dr Michael Southan, January 2014)	11.40	15.20	58.2	77.6
Dairy Cattle	2	3	Pasture losses, estimate used by Sinden *et al* (2005), has been adjusted down relative to other pasture systems due to the intensive nature of pasture management in dairy and reflects reduced stocking rates/performance.	53.48	80.22	11.8	17.6
Beef Cattle	5	10	Productivity losses based on pasture losses reported by Sinden *et al* (2005), which included an allowance for losses on extensive range lands across Australia. This estimate has been adjusted to reflect the composition of grazing lands in NSW and reflects reduced stocking rates/ performance.	6.14	12.27	27.1	54.2
Grain-Sheep/ Grain-Beef	5	10	As above	8.84	17.68	75.6	151.2
Sheep-Beef	5	10	As above	8.50	17.00	68.6	137.1
Sheep	5	10	As above	10.88	21.76	122.2	244.4
Cotton	10	15.0	Adjusted down from the range used by Sinden et al (2005), in view of gains made with chemical application efficiency and use of Round Up ready GM varieties.	118.57	177.86	29.7	44.6
Sugar	5	10.0	Pers comm, Peter Macquire, NSW Sugar, 2014	45.60	91.20	1.8	3.6
Rice	2.5	3	Range of 10% around Sinden *et al* (2005), in the absence of industry data.	26.98	32.38	9.2	11.0
Fruit	1	2	Based on Sinden *et al* (2005).	5.95	11.90	0.2	0.4
Vegetable	1	2	Based on Sinden *et al* (2005)	10.53	21.06	0.3	0.7
Total						**404.7**	**742.5**

Appendix Table A.2.3: Data used to calculate expenditure on machinery and chemical costs

Industry sub-sector	Machinery costs			Chemical costs			Chemical & machinery costs - Total	
	Machinery input (hr) [a]	Machinery cost per hour [b]	Machinery cost ($/ha)	Reported Crop & pasture chemical cost [c]	Herbicide chemical (% of total) [d]	Herbicide cost ($/ha)	$/ha	Industry sub-sector totals [e]
Grain	0.12	76.36	9.16	34.74	0.87	30.22	39.38	223.5
Dairy Cattle	0.05	76.36	3.82	15.88	0.85	13.50	17.32	4.23
Beef Cattle	0.05	76.36	3.82	3.80	0.85	3.23	7.05	34.60
Grain-Sheep/ Grain-Beef	0.05	76.36	3.82	18.11	0.85	15.39	19.21	182.57
Sheep-Beef	0.05	76.36	3.82	1.48	0.85	1.26	5.07	45.47
Sheep	0.05	76.36	3.82	1.05	0.85	0.89	4.71	58.77
Cotton [f]	0.05	76.36	3.82	177.75	1.00	177.75	181.57	45.50
Sugar [g]	0.05	76.36	3.82	89.93	0.95	85.43	89.25	3.50
Rice [h]	0.05	76.36	3.82	266.00	1.00	266.00	269.82	91.63
Fruit [h]	0.05	76.36	3.82	123.03	1.00	123.03	126.84	4.36
Vegetables [h]	0.25	76.36	19.09	41.42	1.00	41.42	60.51	1.97
Total								**696.14**

Data sources:
a Derived from representative gross margins identified in Table A.2.1
b NSW DPI (2013)
c Average crop and pasture chemical expenditure reported by farm type for the 5 years to 2012, by ABARES (2014)
d review of representative gross margins was undertaken to ascertain the likely proportion of chemical expenditure that would have been for weed management, compared to pest and disease management.
e Aggregated on the basis of total number of farms and farm size reported in Table A.2.1
f based on Sinden et al (2005) and indexed to using ABARES chemical cost index (2013)
g based on Sinden et al (2005), indexed to using ABARES chemical cost index (2013) and then confirmed with NSW Sugar (pers comm, Peter Macquire, February, 2014).
h herbicide costs sourced from direct interrogation of representative gross margins.

Appendix Table A.2.4: Data used to calculate labour cost

Industry	Days per 1000 ha [a]	$/hr [b]	Industry sub-sector totals [c]
Grain	31	20.00	28.15
Dairy Cattle	31	20.00	1.21
Beef Cattle	31	20.00	24.36
Grain-Sheep/ Grain-Beef	31	20.00	47.14
Sheep-Beef	31	20.00	44.46
Sheep	31	20.00	61.89
Cotton	31	20.00	1.24
Sugar	31	20.00	0.19
Rice	31	20.00	1.68
Fruit	31	20.00	0.17
Vegetables	31	20.00	0.16
Total			**210.66**

Data sources:
a Average number of days per 1000 hectares reported by ABS (2007)
b Approximate mid-point of range reported for Farm and Livestock Hand labour rates in NSW (NSW Farmers, 2012)
c Aggregated on the basis of number of farms per sector, average hectares per farm and an average working day of 8 hours per day.

A.3 Data used to calibrate economic surplus model

Appendix Table A.3.1: Industry data, calculated parameters and changes in surplus

	P ($/unit) [a]	Q (tonnes)[b]	Z [c]	Min K [d]	Most likely K [d]	Max K [d]	Elasticity of supply (ε) [e]	Elasticity of demand (η) [f]	Change consumer surplus ($'million)	Change producer surplus ($'million)	Change in economic surplus ($'million)	Range: Minimum ES Value	Range: Maximum ES Value
Wheat	209	6750200	0.013456	0.196795	0.201846	0.206896	0.25	3.5	19.4312	270.2563	289.6875	284.4918	298.5951
Oats	150	278400	0.040807	0.328186	0.340061	0.351936	0.3	2.2	1.780607	13.1465	14.92711	14.32415	15.34867
Barley	166	1423600	0.023127	0.186369	0.192728	0.199087	0.3	2.2	5.604447	41.0783	46.68275	45.22729	48.22663
Canola	370	496880	0.017353	0.139672	0.14461	0.149547	0.3	2.2	3.251202	24.00591	27.25711	26.19123	28.01195
Lupins	200	97320	0.031463	0.252842	0.262193	0.271543	0.3	2.2	0.633593	4.697691	5.331284	5.095859	5.460289
Field peas	284	29340	0.022338	0.179456	0.186146	0.192837	0.3	2.2	0.190703	1.432471	1.623173	1.534111	1.644205
Chickpeas	545	293040	0.012	0.096515	0.100001	0.103487	0.3	2.2	1.941798	14.42075	16.36255	15.64031	16.73521
Sorghum	161	866200	0.011546	0.092845	0.096217	0.099588	0.3	2.2	1.630634	12.03893	13.66957	13.13234	14.04392
Maize	192	168200	0.016627	0.133607	0.138555	0.143503	0.3	2.2	0.546766	3.919874	4.46664	4.399853	4.715278
Sunflowers	480	33060	0.010162	0.081637	0.084682	0.087726	0.3	2.2	0.163058	1.204834	1.367892	1.311248	1.406079
Soybeans	360	35120	0.014095	0.11324	0.117462	0.121684	0.3	2.2	0.180974	1.318962	1.499937	1.456241	1.560769
Cotton	2500	518380	0.019108	0.044309	0.047132	0.049956	1.5	2.2	25.28314	36.55317	61.83631	58.77452	65.93518
Rice	389	408805.3	0.015238	0.103654	0.108361	0.113067	0.36	2.2	2.467049	15.27257	17.73961	16.79237	18.27769
Sugar	310	2235440	0.000832	0.005115	0.005913	0.006712	0.36	2.2	0.576793	3.801456	4.378249	3.563479	4.636465
Dairy [g]	43	1.06E+09	0.000191	0.000484	0.000697	0.00091	1.13	3.0	8.726869	21.77429	30.50116	22.50374	41.37239
Wool	7200	120272	0.159456	0.369716	0.407499	0.445282	0.9	1.4	153.4948	239.377	392.8719	356.2178	427.1353
Lambs/mutton	2680	207174	0.247773	0.448383	0.499137	0.54989	1.38	1.4	161.4303	162.5108	323.941	293.5138	357.3977
Beef/veal	1997	438023.4	0.034217	0.487659	0.513258	0.538857	0.1	1.4	30.65471	442.2564	472.9111	437.0026	482.1931
Fruit [h i]	600	703004	0.00151	0.007386	0.007551	0.007716	0.2	0.8	0.637373	2.598758	3.236131	3.119639	3.253589
Vegetable [h i]	520	726323	0.002011	0.005957	0.006536	0.007115	0.4	0.8	0.760243	1.86282	2.623063	2.260431	2.688719
								Totals	**419.3863**	**1,313.528**	**1,732.914**	**1,606.553**	**1,838.638**

Table continues over the page (Data sources and Assumptions)

Data sources and Assumptions:

a Five-year average unit prices sourced from ABARES, 2013.

b Five-year average quantities for NSW sourced from ABARES, 2013. Quantities of meat have been derived from reported NSW livestock sales, adjusted for a conversion rate to quantity in meat.

c Calculated.

d Estimated as per unit increases in supply using data sourced on labour costs, chemical and machinery costs and a range of observed and assumed losses.

e Assumed as per Sinden et al (2005) with the exception of fruit and vegetables where elasticities have been assumed.

f Assumed as per Sinden et al, with the exception of wheat where the elasticity of demand has been revised down to reflect the changes in the market since the original study was undertaken, including increased exposure to international markets, and for fruit and vegetables for which Sinden et al did not have estimates. The elasticity of demand estimates for fruit and vegetables are derived from Andreyeva et al (2010).

g Units are litres.

h Prices are proxy prices due to insufficient available data to calculate a weighted average fruit or vegetable price. These prices are the price of naval oranges and potatoes for fruit and vegetables respectively.

i Quantities sourced from aggregation of fruits and vegetable production reported by ABS (2012).

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