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Minimum flow standards in the Williams River: an assessment of the impact on dairy farms

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Concern over river health has prompted the NSW Government to consider the imposition of minimum flow standards in the state's rivers. In the case of unregulated coastal rivers, which support a large dairy industry, the impact of these minimum flow restrictions may be quite significant. It is usually only during periods of low river flow that the farmers rely on river pumping for pasture production.

In this paper, a case study of dairy farms in the Williams River valley is presented. A simulation model is used which takes account of the effect of uncertain rainfall and irrigation access on soil moisture, and consequently pasture yields. This simulation model is linked to an optimisation model which determines how farmers best deal with deficits in fodder production. Some of the alternatives available include buying in feed, keeping reserves of silage on the farm and reducing milk production. The model is used to assess the impact of changing river access rules on dairy farm incomes. It is shown that the minimum flow standards result in a reduction in mean income, but also increase the skewness of income, by taking away farmers access to a drought relief strategy. However, an effective means of alleviating this increased riskiness is the use of long term drought reserves (pit silage). The net benefits of this option are assessed.

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1. Introduction

There is widespread concern about the deteriorating health of river systems in New South Wales. Many of the environmental problems in river management, including reduced in-stream water quality and degradation of ecosystems, are the result of intervention in the natural flow of rivers. The NSW government has taken a number of initiatives to address the problem of river health, one of which was the establishment of the Healthy Rivers Commission in January 1996. The Williams River was the first case study catchment to be examined by the Commission.

The Williams River is one of the many rivers that support the large coastal dairy industry in NSW[1]. These dairy farms use a combination of dryland and irrigated pastures, and high annual rainfall means that irrigation is only a supplementary source of soil moisture during dry periods. The small size of these catchments implies that the same weather patterns influence both rainfall on riparian farms and the headwater river flows. Consequently, while consumptive use of water by dairy farms is insignificant most of the time, the demand for access to river pumping represents a large proportion of the river flow during periods of low rainfall. This relationship can be seen in figure 1, which contains historical data on flows in the Williams river and volumes pumped by irrigators. The increased demands by irrigators during low flow periods jeopardises the maintenance of instream flows which are needed to ensure water quality standards to downstream users. In the case of the Williams River, the main downstream use of the water is for urban supply. It has been proposed that restrictions be placed on irrigation pumping during periods of low flow, in order to ensure minimum flow levels in the river. It is anticipated that the observation of minimum flow standards will improve river health in general, but in particular it should reduce the risk of algal blooms in Seaham Weir which is a major source of water supply for the city of Newcastle.

The Williams River flows through the shire of Dungog in the Hunter Valley. The main users of irrigation are dairy farms, which are located along the length of the river. A typical dairy farm has limited river frontage, with about 15ha of land suitable for irrigation, and a large proportion of the farm (around 40ha) under dryland pastures. Dairy farms in the Williams River are geared towards year round production of milk, with calving throughout the year, and a fairly constant demand for energy for milk production. Farmers use a combination of summer and winter yielding pastures which helps to even out the production of energy throughout the year. However, there is still a pronounced deficit of pasture in the colder months, and this is usually supplemented by purchased grain and hay, or with silage produced on the farm in the warmer months.

[1] About 80 per cent of dairy farms in NSW are located in the coastal statistical subdivisions.

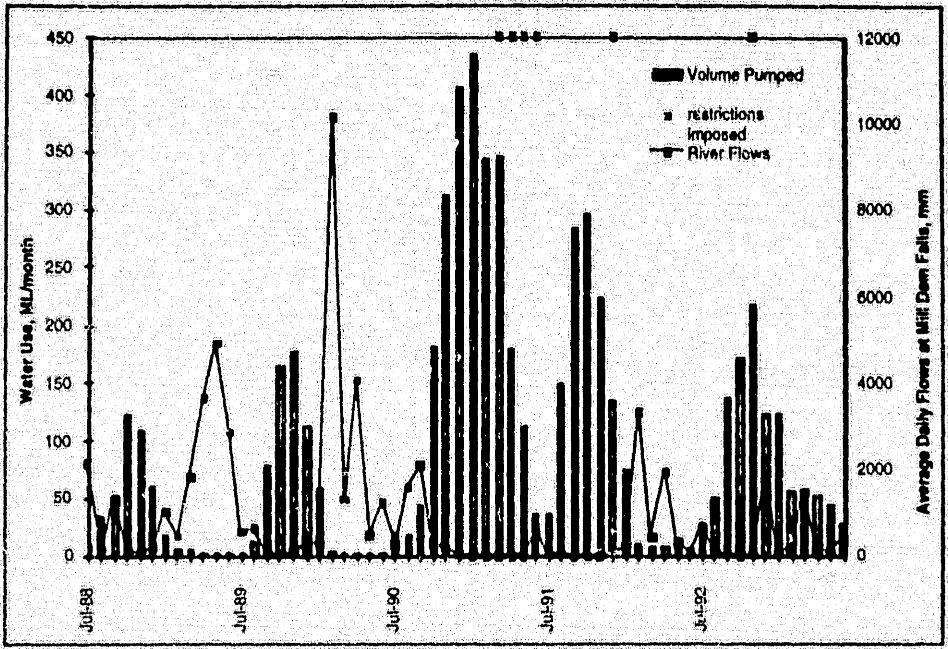

Figure 1: Historical evidence of high pumping under low flows

Source: DLWC, Newcastle

The aim of this analysis is to quantify the impact of alternative environmental flow rules on dairy farm incomes. By emphasising the impact of different soil moisture conditions on pasture productivity, it is possible to give a realistic estimate of the costs associated with having prolonged restrictions on river pumping. These are quantified by considering short term adjustments that the farm can make to maximise farm income. In addition, longer term adjustments to pasture management practices aimed at reducing risk are considered.

2. Model Description

The model is comprised of a series of modules which represent biophysical and economic elements in the farm production environment. These are:

- climate module
- river flow module
- soil moisture balance/pasture growth module
- dairy farm management module

Climatic and river flow modules

The climatic module is used to provide daily data on rainfall and evaporation. These are represented by look up tables which report an historical time series based on a user determined start and finish date. The river flow module looks up historical flows[2] at two gauging stations and determines, according to the minimum flow standard, whether or not irrigators are allowed access to river pumping. The outputs from these modules are simply rainfall, evaporation and access to river pumping. The modular approach implies that these components of the system could easily be substituted for more sophisticated statistical models of rainfall and hydrological models of river flow. For example, in other work being conducted at ABARE (eg. Brennan and Melanie (1997), Scoccimarro, Beare and Brennan (1997)), stochastic simulation is used to represent river flow modules.

Three alternative river access rules are examined in this paper. In the base case, it is assumed that irrigators always have access to irrigation water in low flow events. This represents the historical scenario where farmers have had access to water even after the river has stopped flowing, by accessing pools in the river. The most extreme scenario examined here is the restriction of access at the 80th percentile of natural flows. Zero access when flows are at the 80th percentile is a standard that being considered for NSW rivers state wide (Hassal & Associates 1996). The impacts of restrictions at this level are quite severe, an alternative scenario is considered where farmers are able to have restricted access to flows that occur between the 80th and 90th percentile, while having zero access to flows beyond the 90th percentile. These less severe restrictions are being considered for the Williams river farmers (J. Sayers, DLWC personal communication), and are more likely to be applied than complete restriction at the 80th percentile.

Soil Moisture Balance/Pasture Growth module

Climatic data is passed to a biophysical simulation model of soil moisture balance and pasture growth. Soil moisture balance is calculated for each pasture type according to equation 1.

$$(1) \qquad M_t = M_{t-1} + R_t + I_t - E_t$$

Where M_t is the moisture in the plant root zone, R_t is rainfall in mm, I_t is irrigation; and E_t is potential evapotranspiration, determined by pan evaporation multiplied by a crop factor.

Soil moisture capacity is determined by the plant root depth, multiplied by a soil moisture holding capacity (assumed to be 30 per cent). When irrigation water is available, pasture is irrigated to keep the soil moisture level above 50 per cent of capacity, however, soil moisture can fall below this level if the farmer is denied access to river pumping.

The model tracks the moisture index of each pasture on a daily basis, where moisture index is the moisture level divided by the maximum moisture level. This moisture index is used to represent a growth index for the pasture over that period. This growth index varies between zero and one and is multiplied by potential yield to determine the actual pasture yield in each month. The relationship between

[2] Historical data from these gauging stations were used to approximate natural flows by adding back estimated extractions by irrigators in low flow periods.

moisture index and the pasture growth index was obtained from the GROWEST model of pasture growth (Farrell) and the relationship is illustrated in figure 2.

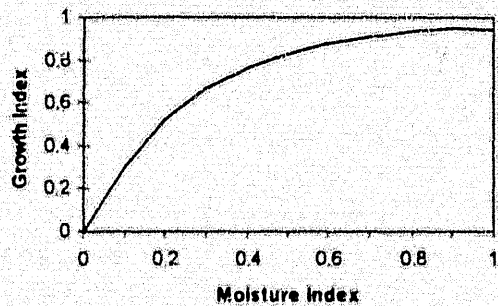

Figure 2: The impact of soil moisture on pasture productivity

Source: Farrell

The pasture growth module also examines planting decisions for annual pastures, and replanting decisions for pastures that die from soil moisture stress. The timing of annual planting is conditional upon rainfall and irrigation access, and late planting incurs yield losses. When there are extended periods of low soil moisture, pastures die and cannot be replanted until soil moisture recovers. Upon replanting, there is a delay time for pasture re-establishment before the pasture can be used productively in the dairy operation. The pasture growth model keeps an account of pasture establishment costs, and the total amount of energy produced in each season. This information is passed to the dairy farm module, as an input to the farm income maximisation problem.

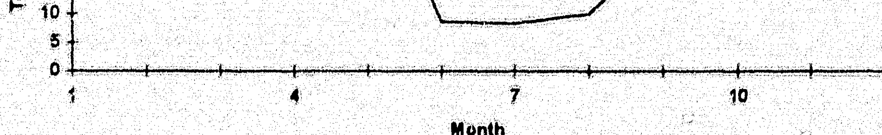

Figure 3: Seasonal pattern of pasture production on a typical farm

Dairy Production Decisions

A linear programming model is used to simulate dairy production decisions which are made on a seasonal basis, in response to realised climatic conditions. The parameters in the model, including objective function coefficients and left hand side constraints, are updated for each step of the simulation, and reflect seasonal conditions (including pasture production, potential benefits from fertilising grasses, fodder prices) and past farm management decisions (eg. available silage, the effect of cow nutrition on potential milk production).

The farmer's choices in any single period include the output of milk (which can be altered by reducing energy supply to those cows in the middle of the lactation cycle) and the purchase of fodder, as well as pasture management decisions. As irrigated area is restricted by topography and most irrigated area is planted to perennials, annual planting decisions are assumed fixed in the model. However, the farmer can increase pasture production by applying fertiliser to kykuyu and annual rye grass pastures, and this extra pasture yield can be used either to satisfy current nutritional needs, or to make silage. The potential yield benefits associated with applying fertiliser depend on moisture conditions. Farm income in any period is linked intertemporally because of the ability to carryover pasture production between periods in the form of silage. In the base runs, round bale silage is considered. This is the commonly used form of silage in the lower Hunter because it allows production in small quantities. It is used to store excess fodder produced in the warmer months, to be used as a source of winter nutrition. The seasonal pattern of pasture production on a typical farm is illustrated in figure 3. In the model, it is assumed that the value of producing round bale silage in summer and autumn is the discounted benefits associated with avoiding supplementary fodder purchases in the following winter and spring. This allows the production and carryover of silage to be treated in the current period decision framework. The round bale silage considered here is generally covered with plastic wrap and left out in the open, being intended as a temporary method of storage, and may deteriorate after one year. In the model, the age of the stored silage is recorded so that spoilage of silage more than a year old can be simulated. To avoid excessive levels of spoilage, it is assumed that farmers limit production of temporary silage, using a constraint in the linear programming model.

Another type of silage which is popular on larger dairy farms is pit silage, which involves burying the fodder. This form of silage has not been widely adopted in the lower Hunter because of the small scale of operation (N. Griffiths, Maitland Department of Agriculture, personal communication 1996). However, it has the advantage of durability, as pit silage can last for a number of years, which makes this form of silage suitable as a drought relief strategy. The use of this type of silage as a response to water restrictions is examined in this study. A description of how the pit silage decision is modelled is provided in section 4.

Assumptions used in the dairy farm module include costs of making and feeding silage, pasture production costs and grain and hay prices. These were taken from Department of Agriculture publications (Griffith (1989), Griffiths and Catt (1989)) and from ABARE's AADIS survey of farms in the Hunter Valley. The grain and hay prices are assumed to vary from a constant base according to seasonal conditions. Discussions with local Department of Agriculture staff revealed that hay prices doubled in the recent drought. This observation reflects the spatial correlation of seasonal conditions and the cost of transport. That is, in a drought hay production in local areas is affected and fodder must be transported from more distant regions. At the same time, all the neighbouring drought affected areas are competing for the same scarce supply of fodder. Because the supply of grain is likely to be more elastic, it is assumed in this model that grain prices are only affected by transport cost and bottlenecks in a drought, and that prices increase by 20 per cent in the worst drought. For less severe droughts, grain and hay prices are assumed to increase on a pro rata basis according to the severity of the drought.

3. Impact of environmental flow rules- current pasture management practises

Pasture production

The impact of the two river access rules on total pasture yield are compared against the unrestricted access case in figure 4, where "80th" refers to zero access at the 80th percentile flow, and "90th" refers to the where irrigators have zero access at the 90th percentile and restricted access between the 80th and 90th percentiles.

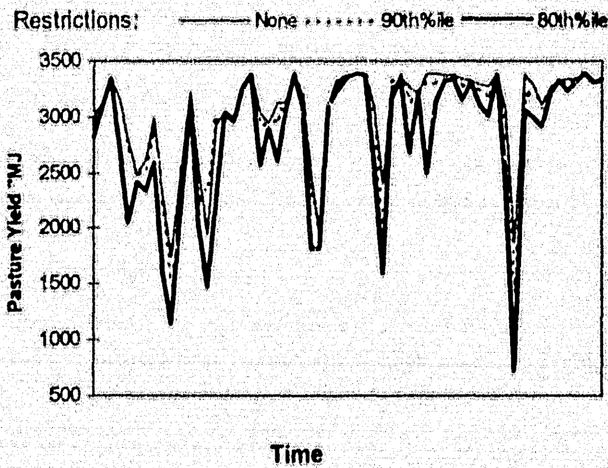

Figure 4: Impact of pumping restrictions on fodder production

As shown in this figure, there is considerable variability in total pasture production, even without pumping restrictions. This variability in yield reflects the impact of dryland pasture production. The balance between dryland and irrigated pasture production is demonstrated further in figure 5a and 5b. Irrigation access offers significant stability to the dairy farm during dry seasons by providing security of yield for the irrigated component of the farm. Removing access at the 80th percentile of flows means that farmers are less able to rely on irrigated pastures to provide a minimum level of fodder production. The costs of such restrictions are quantified below.

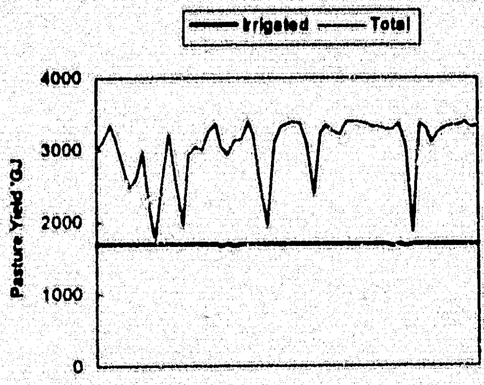

Figure 5a: Pasture yields with no irrigation restrictions

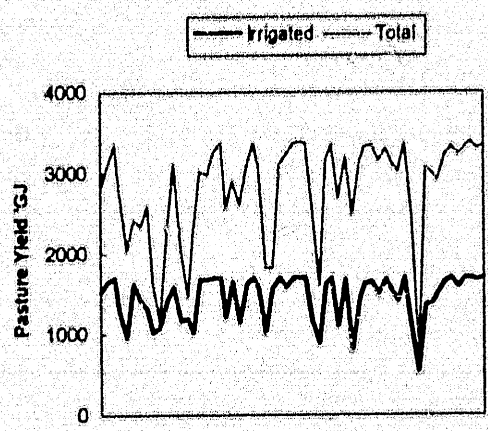

Figure 5b: Pasture yields with restrictions at 80th percentile

Impact of irrigation restrictions on farm income

The impact of restrictions on farm cash income (total cash receipts less total cash costs) are illustrated for the two extreme cases of no restrictions and 80th percentile restrictions in figure 6. Results are also summarised in table 1.The source of income instability in the no restrictions case is the variability in pasture production. As shown above, even with completely reliable irrigation access the farmer is dependent on some supplementary fodder purchases to feed the dairy herd, because of variability in fodder production from dryland pastures. The impact of removing irrigation access during periods when farmers rely most heavily on it (when dryland pasture growth is poor) is an increased variability in income and for the 80th percentile case, a significant reduction mean income.

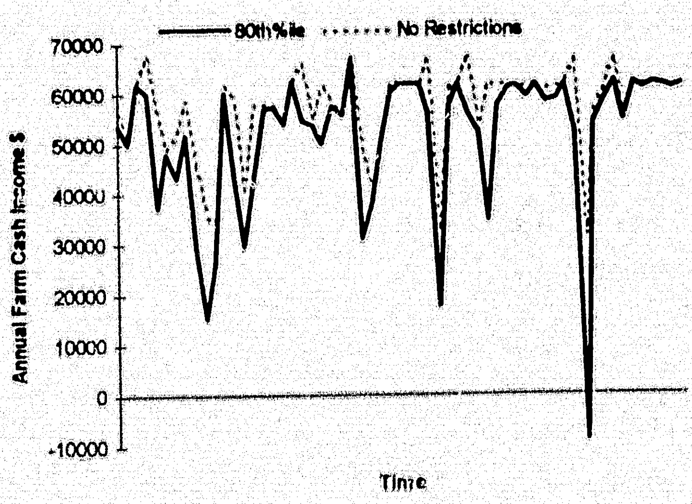

Figure 6: Impact of irrigation restrictions on farm cash income

The income levels demonstrated here indicate the farmer's best short term response to reduced pasture yield, as calculated by the dairy farm management module. The model's primary response to reduced pasture production is to purchase extra grain, as it is a cheaper source of energy than hay. However, due to requirements for a minimum level of fibre consumption (to maintain milk quality), the model solution is sometimes forced to purchase hay as a supplementary source of feed. The sources of nutrition in a drought year are illustrated in figure 7. The option to reduce milk production in response to fodder deficits was rarely chosen by the model. Even in a severe drought (80th percentile case) reduced milk production was only chosen to alleviate 3 per cent of total nutritional needs.

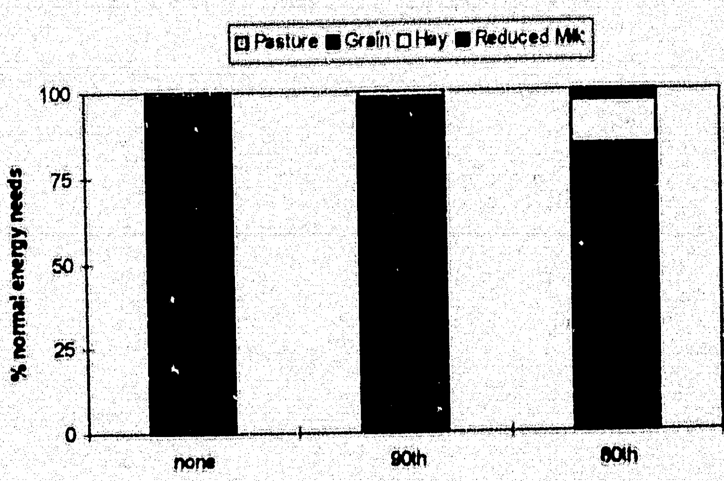

Figure 7: Sources of nutrition in a low production year

It can be seen from table 1 that the 90th percentile restrictions have little impact on mean annual income, but the more severe restrictions at the 80th percentile will reduce annual average income by 10 per cent. The examination of the impact on average farm income is misleading however, as much of the reduced income occurs as a result of very large reductions in income in drought years. The increased negative skewness in income is evident from figure 6, and in table 1 where the lowest income experienced over the 60 year simulation period is reported. The increased skewness in income brought about by the more severe 80th percentile restrictions could impact on farm viability, if a large adverse event exhausts farm financial reserves.

Also shown in the table is the mean annual cost associated with the restrictions, measured as a cost per irrigated hectare. There is a large difference between the 80th percentile restrictions, and the more lenient measure where farmers are allowed limited river access between the 80th and 90th percentile. This is because the more severe restrictions are likely to kill perennial pastures (rather than incur temporary productivity losses) and the lead time between replanting and production mean that the farmer relies on purchased fodder for extended periods. Since the difference in mean annual pumping between the 80th percentile case and the no restrictions case are about 1.4 ML per irrigated hectare, the short term annual costs of the 80th percentile restrictions are about $260/ml.

Table 1: Impact on Income -current management practises

Restrictions	Average Farm Cash Income	Difference c.f. no restrictions	per cent change	Cost per Irrigated ha	Worst Single Year Income
none	57 183				31 212
90th	56 085	1098	2	73	24 151
80th	51 621	5562	10	370	-8916

4. Impact of environmental flow rules- improved pasture management practices

Response to increased risk

The values shown in the previous section indicate the types of costs that the farmer can expect if he makes no adjustment to the increased risk he faces. However, given the magnitude of the increased risk, it is likely that he will consider changes to his farm management practises. One of these response may include investment in on farm water storage facilities, so that water can be extracted during periods of high flow and stored for later use. Discussions with DLWC officers have indicated that this option may be physically possible for some farmers but not others, and will involve significant investment costs. This option is not evaluated in this paper. An alternative method of risk reduction is to store fodder produced in years of high production as a drought reserve. While the type of technology currently used by farmers in the area (bale silage) would not be sufficiently durable to act as a drought reserve, pit silage can last many years. Pit silage has historically been unpopular in the area, because the scale of operation is too small to justify the cost of pits (at least for the purposes of intra-annual smoothing of fodder consumption). However, the impact of increased climatic risk may be sufficient to make the investment worthwhile.

In the following analysis, the use of pit silage as a response to increased climatic risk is quantified. Because pit silage is only produced in large quantities, the production and disposal of pit silage is modelled as a discrete decision. In order to examine the production and disposal of pit silage over a sequence of years it is necessary to determine an expected benefit (of silage) function which will prompt the model to produce pits in years of high production and dispose of them in years of low production. The expected benefit of pit silage is the expected benefit from avoiding high fodder prices in years of low production. These benefits will depend on the severity and duration of the drought, and the expected benefits are likely to be a declining function of the number of pits, as the first pit is more likely to be used than the next and so on. The estimation of an expected benefit function that results in an optimal smoothing of fodder consumption could be estimated using stochastic dynamic programming techniques, where the state variable is the number of pits available. There is no unique optimal rule however, as the expected benefits of the drought reserve will also depend on the risk preferences of the farmer, who may be willing to pay for a reduction in income variability. In this paper a more pragmatic approach is employed which searches over a range of expected benefit curves, to find a value that permits a smoothing of income without an excessive build up of pit production.

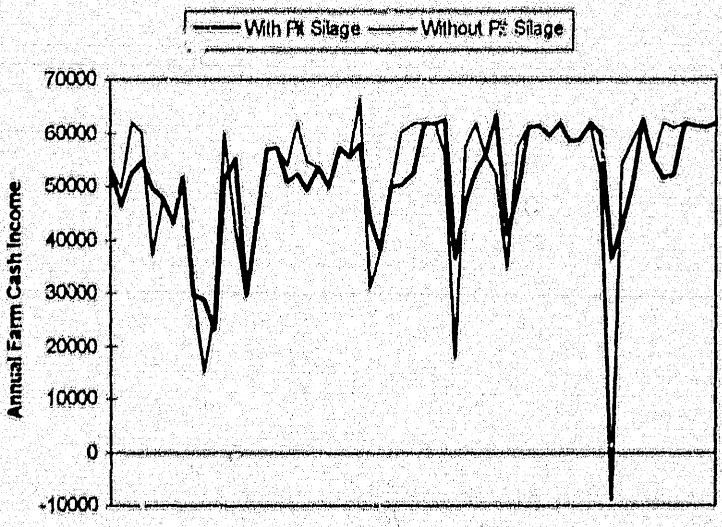

Figure 8: Impact of pit silage on income risk under 80th percentile restrictions

Annual farm cash incomes with and without pit silage for the 80th percentile restrictions case are illustrated in figure 8. It can be seen that the use of pit silage reduces downside risk considerably, although this comes at a cost of reduced incomes in high production years, when the costs of increased fertiliser use and pit production costs are incurred. Average annual income and the lowest recorded income for the 60 year simulation period are presented in table 2, for the alternative access rules with and without pit silage. The net effect of pit silage on annual average income is small, but there is a significant improvement in farm cash income during drought events when pit silage is used.

Table 2: Potential impact of pit silage production on farm income under alternative river access rules

River access rule	With Pit Silage	Without Pit Silage
Average annual farm cash income		
none	57 140	57 053
90th	56 046	55 911
80th	51 640	51 558
Lowest annual farm cash income		
none	34 131	31 212
90th	32 166	24 151
80th	23 007	-8915

Potential negative impacts

Strategic production of pasture in high rainfall years is achieved by increasing fertiliser use on grass pastures. In the 80th percentile case, this results in an increase in urea used in the catchment, averaging about 2 tonne per farm per year. One of the river health issues is that the nitrogen levels being recorded at Seaham weir are higher than the maximum standard recommended for protection of river health (Healthy Rivers Commission 1996). Whether this extra fertiliser use that results from an increased adoption of pit silage would have any impact on river health is not clear. However, the example illustrates the importance of anticipating the potential effects of proposed environmental regulations.

5. Regional impacts

The results of the analysis show that farmers can adjust to the increased riskiness brought about by the minimum flow restrictions by investing in pit silage. This option has the benefit of reducing the downside risk, but the impact on average income earning capacity is of a similar magnitude regardless of whether the farmer invests in pit silage. While there are other options that the farmer may use to respond to these increased risks (such as investment in off farm water storage), these options are expensive and may be more effective in reducing downside risk, rather than in improving average income of the farmers. The loss of annual average cash income at the farm and valley level are summarised in table 3, for the case where pit silage is used as a pasture management tool.

Table 4: Loss in annual cash income at the farm and valley level

River access rule	Per Farm	Valley level
90th	$1095	$60 170
80th	$5500	$302 500

6. Conclusions

The difference in income associated with allowing access to some water between the 80th and 90th percentile flows illustrates the importance of the Williams river as a drought relief strategy for dairy farmers. The difference between the 80th and 90th percentile scenarios examined here is due to the fact that the 80th percentile restrictions result in a loss in perennial pastures, while the more lenient restrictions (allowing limited access between the 90th and 80th percentiles) allows farmers to keep their pastures alive, even though they suffer temporary yield losses. The increased riskiness in production resulting from the water restrictions may encourage farmers to consider alternative drought relief strategies such as the use of pit silage evaluated here.

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