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Is dilution the solution for water pollution? An economic analysis.

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Abstract

High nitrate concentrations have been reported within Canterbury aquifers due to agricultural intensification. Reducing nutrient loadings to groundwater by a reasonable degree is difficult for industry because of the anticipated cost of effective mitigation technologies. A novel alternative is to decrease nitrate concentration through increasing the amount of water present in the aquifer through the use of Managed Aquifer Recharge (MAR) in combination with some minor farm-level mitigation practices. However, this poses a difficult economic problem that involves balancing the benefit of lowering nitrate concentrations in groundwater, improving reliability of groundwater availability for future irrigation, the capital cost of MAR infrastructure, and the cost of source surface water to use in the dilution. This study presents a dynamic economic analysis that weights these alternative sources of value. Overall, it is shown that a MAR scheme is of positive value to both the environment and economy, with an average benefit: cost ratio of four, and around \$76m of income and 170FTE of employment gain per annum at regional level.

Keywords

Economic analysis, Managed aquifer recharge, Mitigation, Nutrient loading.

Introduction

Non-point source pollution (NSP) mainly due to the agricultural activities can have detrimental impacts on the environment (Doole, 2012), particularly grazing that has been implicated with nutrient outflows to waterways through leaching and runoff (Bouwman et al., 2011). Reportedly, 85% of ground water beneath European Union farm land exceeds target threshold for nitrate (CEAS, 2000), dairy farm activities in the USA is a key source of excessive nitrate in water sources (Almasri and Kaluarachchi, 2004), and water pollution due to excessive nutrient leaching from farming also not uncommon in New Zealand (Monaghan et al., 2007). A number of policy measures to control NSP have been discussed in the literature (Sakar, 2008) however none of these has so far been effective in controlling NSP pollution mainly due to the difficulty in monitoring the source of pollution (Woodward, 2005). Profitable nutrient mitigation practices and technologies can be useful in this situation (Pannell, 2008) however the lack of effective profitable mitigation practices is a main concern in New Zealand farming context (Doole and Paragahwewa, 2012).

Recently, managed aquifer recharge (MAR) has been evolved as a potential mitigation tool for water pollution linked to the nutrient leaching (Golder, 2014). MAR is a general term used to describe a wide range of tools aimed at artificially recharging a targeted aquifer. These tools are primarily intended to supplement the existing natural recharge processes such as rainfall and river seepage. In practice, for catchment-scale NSP issues, these MAR tools would need to be encompassed into an overall Groundwater Replenishment Scheme (GRS) structure with the goal of developing, operating and maintaining recharge activities. In this context, MAR represents the dilution of nutrients in groundwater which assists in the achievement of the target concentrations (Golder, 2014). However, it is important to note that replenishment of groundwater is also used to offset the over allocation of groundwater and to help stabilise and restore spring-fed surface water bodies in a catchment. The timing and amount of water added to achieve quality outcomes will also provide benefits toward the goals of providing reliable irrigation supplies and increasing minimum flows in rivers and streams.

Water banking in aquifers found to be cost effective in urban water supplies in Perth in Australia (Gao, et al., 2014). Recently Medgal et al., (2014) have discussed the institutional and policy reforms adopted by the Arizona Water Bank Authority in the USA to enhance the supply reliability of water through water banking. An economic assessment by Malivia (2014) indicates that the benefit of MAR could be considerable due to its ability to increase the volume of stored water and potential water quality improvement through natural aquifer treatment processes. However, the general lack of ample

economic analysis of MAR systems restricts its implementation at wide scales (Maliva, 2014). As far as we know there is no economic assessment of MAR under the New Zealand biophysical and farming conditions. This study is the first such economic assessment considering a proposed GRS using MAR program in the Hind catchment in Ashburton District in Canterbury Region in New Zealand.

Methods

We have employed the standard project analysis techniques and assessed the cost-benefit ratio (CBR) and the net present value (NPV) measures of MAR at catchment level. The assessment was based on the Hinds catchment specific net farm profit (NFP) data provided by Macfarlane Rural Business Ltd. (Everest, 2013), and costs data for MAR (Goulder, 2014). A 30 year project planning and implementation period was considered for the assessment and 8% discount rate was used to indicate the value of MAR from business perspectives. The catchment level impacts data are then used to assess the regional level economic impacts of MAR using the Social Accounting Matrix (SAM)-based Input-Output (SAMI-O) model that we developed for this study.

Case study area

The Hinds River catchment which consists around 132,000ha of farming area (Table, 1) wedged between the Ashburton and Rangitata rivers drains approximately 350km of predominantly lowland foothills and plains. The North Branch and South Branch are the major tributaries and these converge at Mayfield to form the main river (Fig, 1). For number of years the Hinds catchment has been dominated by sheep, beef, deer and arable, with some dairying, however in the last 10-15 years land use has been changing. The arable farms were traditionally, and still predominantly are, concentrated on the deeper soils near the river margins and on the lower plains, atop of the drained swamp. Sheep, beef and deer, were historically distributed across the remainder of the plains, dominated by breeding ewes, and most farms finishing lambs. The significant increase in land converted to dairy from arable and sheep, beef and deer has seen an increase in the number of non-finishing stock (dairy replacements) to be grazed both during the summer and in the winter, leads to a widespread dairy support farming industry (Everest, 2013). The demand for dairy support has not only absorbed irrigated land, but has also absorbed dryland farms on both the plains and the foothills. The intensification of land use has seen reductions in drainage volumes and run-off through improved irrigation efficiency. This results in gradual increase in the concentration of contaminants, particularly nitrogen, in water resources and decrease in supply reliability of

irrigation water in the some irrigation schemes in the catchment (Table, 2). The environmental Canterbury- the regulatory organization in the region is therefore in the process of water quality and quantity limit setting process for the catchment and one of the main measures suggested for this process is the Hinds catchment GRS.

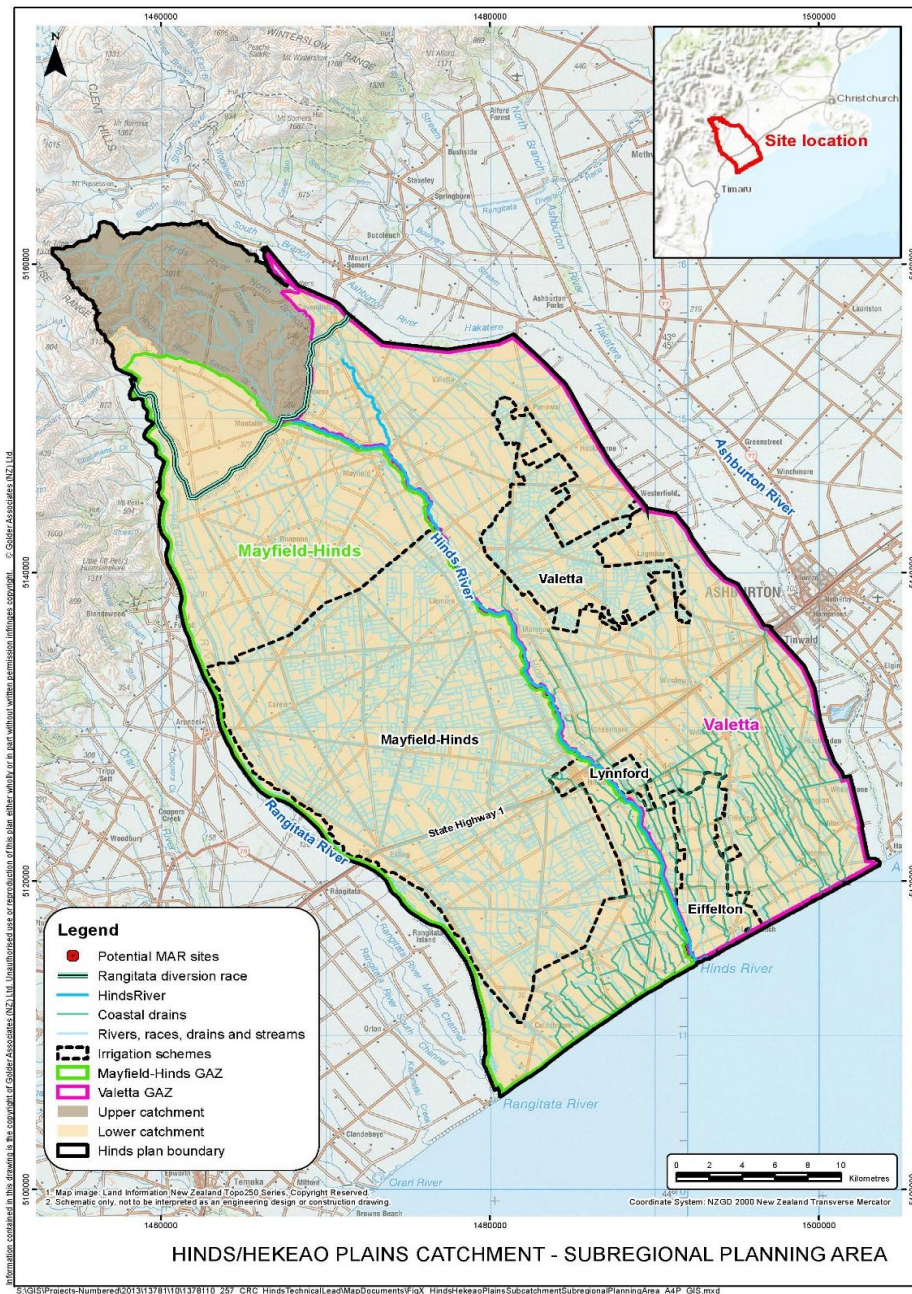


Fig 1: Map of the Hinds plan area.

Table 1: Land area (ha) under different farm Types.

Land Type	Area (ha)
Arable	27,331
Dairy	43,852
Dairy Support	10,813
Sheep, Beef & Deer	50,089
Total	132,085

Source: ECan (2013).

Table 2: Supply reliability of main irrigation schemes in the catchment.

Irrigation Scheme	Area (ha)	Supply Reliability (%)
Valetta groundwater supplies	3,600	80
Hind River Surface Water	333	40
Lowland drains surface water	3,336	80

Source: ECan (2013).

Assessing the benefits of MAR

MAR can be beneficial through improving the water availability and through enhancing the water quality by diluting accumulated nutrients in ground water systems (Maliva, 2014). In this study we have accounted for both of these benefits. The value of increase in water availability was estimated by considering the value of increase in the supply reliability of irrigation water in the different irrigation schemes in the catchment (Table, 2). The value of water quality improvement was assessed by considering the forgone cost of farm level nutrient mitigation practices that alternatively farmers would have to adopt to improve the water quality.

Value of increase in supply reliability of water

The financial return to an increase in irrigation supply reliability due to the MAR was estimated from irrigation pasture/crop response estimates. The relationship between pasture dry matter production and amount of irrigation was derived using data (1949-84) from the

Winchmore flood irrigation trials (Rickard & McBride, 1986; Richard, 1972; Schipper et al., 2013) which are located in the same region as the Hinds catchment. By employing this experimental data, the relationship between pasture dry matter (DM) production and the amount of water was estimated using a Bayesian smoothing algorithm (Upsdell, 1992). The initial model fitted was:

$$\text{DM} = \text{function}(\text{water availability}) + \text{function}(\text{Year, Trial, Treatment}) \quad (1)$$

The terms in Year, Trial, and Treatment are included to allow for the correlations that these terms induce in the data. Third order interactions were needed in the model as judged by the Akaike Information Criterion (AIC). The curves with irrigation consisted of a straight line up to water availability of 1000 mm with water availability having no further effect at higher values (figure, 2). It was decided to restrict our region of interest to water amounts less than 1000mm, where a simpler equation was adequate. Furthermore, water availability and dry matter (DM) production provided a good fit in this region as judged by the AIC. The non-linear parts were non-significant ($p > 0.05$). The resulting equation was:

$$\text{DM} = 8.4 (\pm 0.8) \times \text{water availability (mm/year)} + 2153 (\pm 687) \quad (2)$$

(Figures in parentheses are standard errors)

We need only the coefficient of the water availability term when employing equation (2) to describe pasture production on farms in mid-Canterbury. This coefficient is the change in production $= 8.4 (\pm 0.8) \times$ the change in water availability (i.e. the change in supply reliability of water). We use this relationship to estimate the additional pasture production associated with irrigation in the Hinds catchment area.

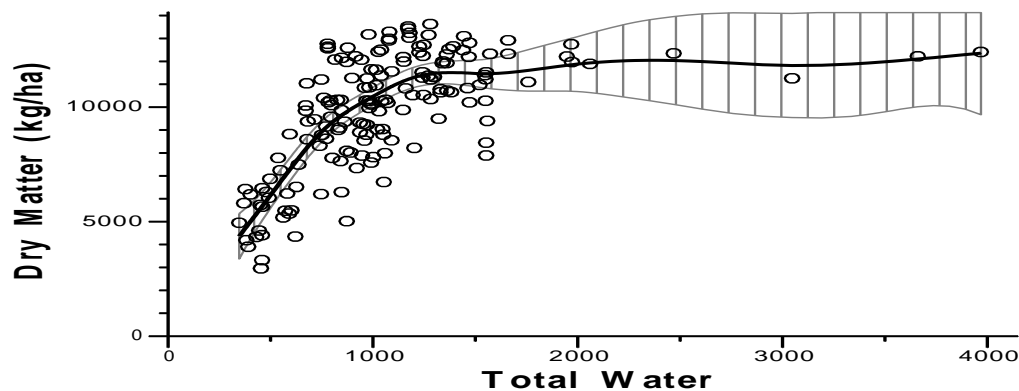


Figure 3A: Dry matter as a function of total water availability (rainfall and irrigation (Circles are the data positions)).

For this calculation, we assumed that the optimum supply reliability level is 95% and we estimated the value of lost pasture volume in terms of costs incurred by the amount of additional supplementary feed required. We also used the data provided by MRB on current pasture yield for different farming systems (dairy = 13,917Kg/DM/ha/Yr: dairy support = 11,833 Kg/DM/ha/Yr) for this assessment. We assumed that lost pasture yield due to the lack of water would have to be provided through supplementary feeding. The current price of supplementary pasture is assumed as \$0.21/kgDM (MPI, 2014) and also assumed price to be increasing by 5% every 5 years during the 30 year assessment period. We then estimated the potential range of yield loss across the catchment, considering dairy farms as having the highest DM production and dairy support farms as having the lowest DM production. We derived catchment level average income gain using this relationship.

Assessing the value of water quality improvement

Catchment scale water quality modelling scenarios (Scott, 2013) indicate that none of the on – farm mitigation practices representing good management practices (GMP) come close to achieving the water quality target, even if irrigation does not expand and MAR is used to increase water availability in the system. The modelling also shows that it is unlikely that the water quality target will be met without MAR unless all farm types adopt the highest level of on-farm mitigation practices. In this assessment we therefore assumed that if MAR is not implemented, all type of farmers in the catchment have to adopt the most advanced levels of mitigation practices (AMP). In other words, we have assessed the costs and benefits to the catchment with and without MAR (Table 3). The NFP values (Table 4) provided by MRB (Everest, 2013) was employed to assess the forgone cost of not implementing the advanced mitigation practices at farm level.

Table 3: Cost and benefit criteria for MAR.

	Costs	Benefits
With MAR	MAR establishment and operation	Reliability gains Avoided cost of the most advanced mitigation practices
Without MAR	Advanced mitigation practices (AMP) cost	Costs avoided due to not establishing MAR

Table 4: Farm level NFP with current and advanced mitigation practices (NZ\$/ha).

Farm type	NFP (current)	NFP (AMP)
Sheep & Beef 1(dry land)	171	34
Sheep & Beef 2 (irrigated)	7	1
Arable 1 (process crops-irrigated)	419	195
Arable 2 (small seed- irrigated)	530	414
Arable 3 (conventional-irrigated)	263	-318
Arable 4(conventional-dry land)	170	32
Dairy Support (irrigated)	319	70
Dairy Support 2 (part irrigated)	492	-37
Dairy 1(system 5)	884	111
Dairy 2 (system 4)	835	59

Source: Everest (2013).

Assessing the cost of MAR

All the cost figures involved in establishment and operation of MAR are given in Table 5. We have used these data to estimate the present value of cost (PVC) of MAR using standard project analysis techniques. This assessment was carried out for different price ranges of water. The price of water was determined from a range of potential water sources from ‘free’ (\$0/m³) through to \$0.14/m³ (Golder 2014). We have also used the average water price of NZ\$0.09/m³ for our estimations employing 8% discount rate to reflect the cost as a private investment.

Table 5: MAR cost and water requirements for staged programme development (in 10 years).

Stage	Year	Activity	Recharge Rate (m ³ /s)	Estimated MAR Costs (NZ\$)	Land Costs (NZ\$)	Total Costs (NZ\$)
Stage 1	2014-15	Pilot Programme Start	0.5	351,500	Lease	351,500
Stage 2	2016	GWRP Development	0.8	563,000	55,000	618,000
	2017		1.1	80,008	5,000	85,008
	2018		1.4	447,500		447,500
	2019		1.7	447,500	25,000	472,500
	2020		2.0	188,500	2,500	191,000
	2021		2.4	487,500	25,000	512,500
	2022		2.8	228,500	2,500	231,000
	2023		3.2	527,500	25,000	552,500
	2024		3.6	389,500	7,500	397,000
	2025		4.0	466,000	10,000	476,000
				4,177,008	157,500	4,334,508
Stage 3	2026 - 2040	GWRP Operation	4.0	694,400		
Total Programme Cost						5,028,908

Source-Golder (2014).

Assessing the value of regional scale impacts of MAR

In the regional level impact assessment we used a socio accounting matrix input-output (SAMI-O) excel based model that we developed for this study. We used the model to capture and understand the Canterbury Regional economic structure in terms of how the industries are linked and interdependent on one another. This modelling approach captured the impacts of

changes in an economy and what is being produced on the wealth of that economy (West 1992). Generally the direct value of a sector is measured in terms of its Gross Domestic Product (GDP) contribution to the economy. To develop the SAMI-O the Canterbury Region socio accounting matrix (SAM) was obtained from Market Economics Ltd, a company that generates SAMs from the Statistics New Zealand 2006-07 supply tables, using the ANZSIC96 industry definitions¹. The SAM database is a comprehensive, economy-wide dataset showing payments and expenditures between industries. The “social” aspects of the SAM captured how households earn and spend their incomes. The SAM included the industries that are of interest in this study, namely horticulture and fruit growing, livestock and cropping farming, dairy cattle farming, and other farming. However, they were not disaggregated to the level of farm types being considered in this study such as irrigation water based dairy. Another database used in the model is the employment number (as of March 2004) by industries in the region (Department of Labour, 2004). This was the most recent available employment data at industry-level. This served as baseline employment numbers by industry. The industry structure, however, as represented in the SAM, has not changed dramatically since 2004 and thus this will not have any significant impact on the assessment. The impact of changes in catchment level farm earnings due to MAR was captured in terms of linkages and interdependency between the industries as represented in the SAMI-O database.

Results

Value of increase supply reliability of irrigation water

The highest impact on pasture growth (Table, 6) and therefore the highest income gain at farm level (Table, 7) is obviously shown in the areas covered by the irrigation schemes with the lowest supply reliability of water (such as that from the Hinds River that has reliability of around 40%). This farm level gain implied that the catchment level total gain due to the increase in reliability will range from \$2.2million (assuming the whole area is under dairy support) to \$2.9million (assuming that the whole area is under dairy farming) under the current land use scenario (Table, 8).

¹Statistics New Zealand has only recently released 2006-07 Supply Use Tables (and an Input-Output Table) based on ANZSIC06 industry definitions.

Table 6: impact of reliability of water on dry matter production.

Under baseline scenario	Dairy (tDM/ha/yr)	Dairy Support (tDM/ha/yr)
Farm-level pasture production at baseline reliability	12.1	10.4
Valetta Hearing Consent (80% reliability)	8.6	7.8
Hinds River (40% reliability)	12.1	10.4
Lowland Drains surface (80% reliability)		
Pasture Production at 95% reliability	13.9	11.8

Source: estimated based on the experimental data (AgResearch Ltd.).

Table 7: Farm level income changes due to increase in reliability of water.

Under solutions package	Dairy	Dairy Support
Income gain at farm level at 95% reliability (\$/ha/year)		
Valetta Hearing Consent	371	283
Hinds River	1,112	849
Lowland Drains surface	371	283

Source: own computation based on the data provided by Everest (2013).

Table 8: Net potential gain (NZ\$m) at catchment level (assuming whole area is under dairy or dairy support).

Under baseline scenario (no farm level mitigations)	Dairy	Dairy Support
Potential gain at areas (3600ha) Valetta Hearing Consent	1.3	1.0
Potential gain at areas (333ha) Hinds River water surface	0.4	0.3
Potential gain at areas (3336ha) Lowland drains	1.2	0.9
Total across the catchment (\$m)	2.9	2.2

Source: own computation based on the data from Everest (2013).

Cost of MAR

The present value of the cost (PVC) of MAR is around NZ\$ 0.83/ha/year if water is available free for the scheme. When water is priced, PVC varies from NZ\$ 8-34/ha/year averaging around NZ\$22/ha/year (Table, 9). The main cost component of the MAR is water cost (estimated PVC is NZ\$84.5million) followed by operational cost (estimated PVC is NZ\$2.9), and cost of land with estimated PVC of NZ\$0.27million.

Table 9: Present value of the cost of MAR (NZ\$/ha/year @ 8% Discount rate).

MAR completion	Water Free	Water Price		
		@NZ\$0.03/m ³	@NZ\$0.09/m ³	@NZ\$0.14/m ³
10 years	0.83	8.0	22.2	34.1

Source: own computation based on data from Golder (2014).

Total net benefit of MAR

The catchment level average net present value (NPV) of MAR is estimated to be NZ\$449million (at water price of NZ\$ 0.14/m³). The average benefit cost ratio is estimated to be at least 4, indicating high returns to MAR (Table, 10).

Table 10: Estimated benefits of MAR at catchment level.

Benefit and cost (\$ millions) at 8% discount rate	Water Price			
	Free	@(NZ\$ 0.03/m ³)	@(NZ\$ 0.09/m ³)	@(NZ\$ 0.14/m ³)
Present value of benefits	536.4	536.4	536.4	536.4
Present value of costs	3.3	31.5	88	134.6
Net present value	533.1	504.9	448.5	401.5
Benefit-cost ratio	164	17	6	4

Source: own computation based on data from Golder (2013).

Impact of MAR at Regional level

Total regional level income gain due to the MAR at average water price is estimated to be around 76\$m/year which includes 57m\$ of industry production income and 20\$m of value added income to the region. The total employment generation in the region is around

170FTE/year which consists of 80 jobs within industry and 70 jobs due to flow on impacts of agricultural activities in the catchment (Table, 10)

Table 11: Economic impact of increased reliability at regional level at baseline farm practices.

	MAR impact at catchment and regional scale
Total average gain (\$m/year) at the catchment level due to the MAR	14.9
Industry production income (\$m/year)	56.8
Direct impact (\$m/year)	15.0
Flow-on impact (\$m/year)	41.8
Value added income (\$m/year)	19.6
Direct impact (\$m/year)	1.3
Flow-on impact (\$m/year)	18.4
Total regional income gain (GDP/year)	76.4
Total employment (number of job FTE/year)	170
Direct impact (number of job FTE/year)	80
Flow-on impact (number of job FTE/year)	90

Source: Own computation based on SAMI-O model simulations.

Discussion

The present value of the cost of MAR is estimated to be around NZ\$88million. The main cost component of the MAR is the cost of water - which is estimated to be around 97% of the total cost. The operational and land cost of MAR is around 1.8% and 0.14% respectively. In accordance with the other studies (Gao,et al.,204; Maliva, 2014), our assessment of the MAR also shows that farm, catchment, and regional level economic benefits are considerable. The average net present value (NPV) of MAR is around NZ\$449 and the benefit cost ratio is at least 4 indicating a considerable return for the investment. The value addition of MAR to the

regional economy is estimated to be around NZ\$76million/year, and the employment generation to the region is around 170FTE jobs per year.

Overall, this study highlights that the dilution of ground water through the use of managed aquifer recharge would be economically attractive to mitigate increasing nutrient loadings to aquifers. In particular, this reflects the threat posed by increasing farm intensification in the irrigated areas of the South Island and the lack of cost-effective farm-level mitigation practices.

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