Assessing potential efficiency gains in irrigated water use in New Zealand.

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Stuart Ford [1] Simon Harris[2] and Murray Doak[3]

Abstract

This paper reports a research project carried out on behalf of the Ministry of Agriculture and Forestry New Zealand designed to scope the issue of water efficiency in New Zealand and demonstrate where the most significant gains in efficiency can occur. The paper describes the efficiency framework developed based on the key areas of allocative, technical and dynamic efficiency. The areas of significant gains based on the theoretical analysis are tested against three community irrigation schemes. Although the case study findings support the theoretical conclusions there is a significant range of potential areas of improvement according to the nature of each case study.

Key Words: Technical, allocative, dynamic efficiency, framework, case studies.

This paper is based on a contract research report commissioned by MAFPolicy which is as yet unpublished. Copies of the full report will be available from the authors once publicly released by MAFPolicy.

1 Introduction

1.1 Background

Developing well-informed sustainable development policies and enhancing the environmental performance of the sectors are key objectives in the MAF Strategic Plan. On-going improvement in water use efficiency is a key sustainable development outcome as it can potentially provide more water for other uses and users thereby providing optimal economic outcomes, and also reduce the potential for nutrient leaching thereby reducing environmental impacts.

The New Zealand National Sustainable Water Programme of Action (SWPoA) has water use efficiency as a key objective of the programme, but as yet has not defined a specific work programme that examines the various policy drivers for improving efficiency, how they currently operate and the interactions between them.

The purpose of this work was to provide a scoping document that can inform the policy development process by providing a background understanding to the total concept of water efficiency, identifying and demonstrating where the greatest efficiency gains are to be made and the possible approaches that can be used to achieve this.

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[1] The AgriBusiness Group, Christchurch New Zealand. stuart@agribusinessgroup.com
[2] Harris Consulting , Christchurch New Zealand. simon@harrisconsulting.co.nz
[3] MAFPolicy, Christchurch New Zealand. Murray.Doak@maf.govt.nz

The project goal was;

"To scope the issue of water efficiency in New Zealand and identify and demonstrate where the most significant gains in water efficiency can be made for New Zealand and the necessary approaches to achieve those gains."

The methodology adopted in this research was to first scope the issues by reference to the body of existing work and identify the greatest potential areas for efficiency gains in an analytical framework. The framework was then used in three case studies to demonstrate its use in identifying where efficiency gains can be made.

1.2 Efficiency

The term efficiency has different contextual uses. In economics three terms are typically utilised:

- **Technical efficiency** – the rate at which resources, capital, labour are converted into goods. More goods produced for a given set of resources equates to higher technical efficiency.
- **Allocative efficiency** – optimally allocating resources to the production of different sets of goods in such a way that the welfare of society is maximised[4].
- **Dynamic efficiency** – allowing the allocation of resources to change over time to reflect changing production possibilities and societal preferences.

In thinking about efficiency, we need to distinguish between the static and dynamic situations, as denoted by the first two terms and the third term above.

In the static situation it is important to understand that in any production system there is typically one resource that is more limiting than others. It tends to be the limiting resource which drives much of the resource users' behaviour around efficiency. Thus the farmer who has plenty of water on his property is more limited by their land area or labour considerations than by the amount of water. To the outside observer their behaviour will appear very inefficient because he will tend to over apply water to ensure that his land produces at the maximum level. The converse will also apply – when there is too little water for the area to be irrigated, behaviour will tend to become more efficient with respect to water, but perhaps less efficient with respect to land or labour practices.

Similarly when we look at allocation decisions at a static point in time when water is not scarce in a catchment, "first come-first served" is an efficient approach to allocating water. It has low transaction costs, and is guaranteed to allocate the water to the highest value land use, since the applicant naturally represents the highest value because no-one else wants it.

When the mix of resources available to a farmer changes to the point where water is the limiting factor, or when access to new water in a catchment becomes constrained, this current practice is no longer guaranteed to be efficient. Thus over time the dynamic aspect of efficiency becomes more relevant. The water rich farmer can purchase more

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[4] Allocative efficiency is related to but should not be confused with regional council allocation. Whilst regional council allocation relates primarily to a user, allocative efficiency relates primarily to uses of the water, and can operate at scales within the farm, between farming uses, geographically, and between farm, non-farm and environmental uses.

land, and some mechanism of redistributing water resources in scarce catchments becomes critical.

The two important points to note are:

- Efficiency is dependent on the context of the decision being made; and

- Efficiency will change over time as the context changes.

1.3 Framework

The irrigation system is a complex mix / matrix of the base resource, the policy/regulatory environment, and the on and off farm access, transport, application and production system. Each of these elements of the irrigation system brings sources of potential non optimality, or inefficiency, into the use of water.

This paper sets out a framework whereby the efficiency of water use can be assessed to determine where the greatest gains to society from more efficient use of water are likely to occur. This framework will be used to drive policy discussion and the priorities for government investment in the Water Programme of Action.

Figure 1 shows the key elements used to assess the efficiency of water use. Each of these elements subdivides into a range of further issues, but because of the need to trade off simplicity against specificity, and because data has often not been collected for further disaggregations, the figure forms a useful basis to frame discussion.

The key elements are based on;
- the efficiency of Allocation,
- Distribution and
- Use of water.
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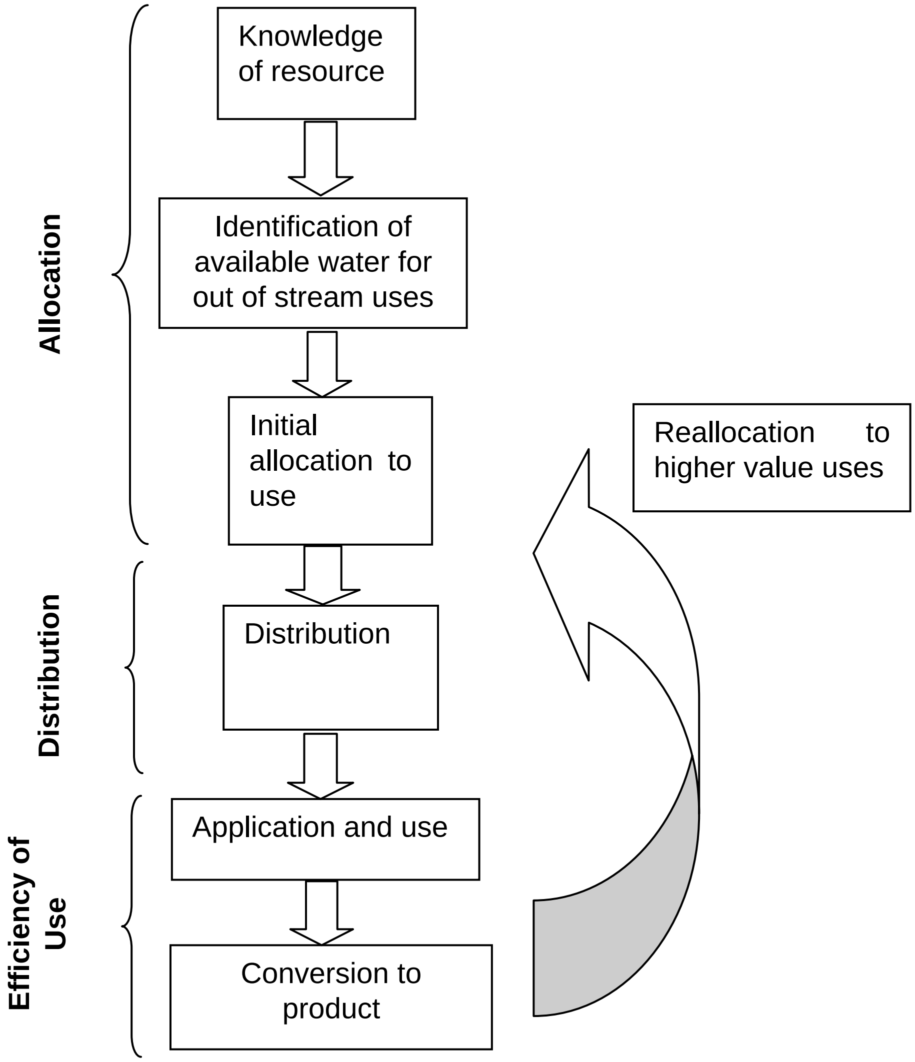
These are depicted in Figure 1.

Figure 1: Framework for assessing water efficiency



1.4 Conclusions

Conclusions on New Zealand irrigation efficiency considered in this framework is depicted in Table 1.

Table 1: Summary of Efficiency Framework

Category	Subcategory	Current Efficiency	Potential efficiency gains	Source
Water Source	Groundwater	Unknown but likely to be low.	High – up to 90% more water available in some catchments with less conservative approach	Improved understanding of resource – measurement, resource investigation, net use of water rather than gross.
	Surface	Moderate	Unclear	Generally good knowledge of resource, but still limited knowledge of takes.
Allocation	Nature of the Property Right	Moderate	Unknown	Problems with quality of title and flexibility. However it is unclear how much these are affecting investment decisions.
	Structure of the Allocation	Unknown	Unknown	Increasing size of A band in the Rangitata gave >50% increase in GDP – but would also require more water to be available from source
	Initial Allocation	Unknown - studies suggests that initial allocations are unlikely to be ideal	Unknown	
	Dynamic efficiency	Poor – limited ability for reallocation of resource.	Moderate – 12% to 22% reallocation potential	Transfer of water to higher value uses. Can overcome poor decisions in previous 2 allocation categories.
Distribution	Water access inefficiencies	Poor	Unknown but potentially significant	Anecdotal evidence of poor well and pump design
	Distribution	80% in best open canal, ~100% in piped systems.	20% losses from well maintained canal systems. However capital implications	Movement to piped distribution. Likely to be greater gains in poorly maintained canals.
Irrigation Use	Application	Poor – 24% - 96%	5 – 40% improvement	Improved irrigation design and management
	Overall	Poor – average pastureDM/water applied is 50% of potential.	100%+ in pastoral	Driven by better irrigation management, pasture management, farm system efficiencies. Some data suggests that DM production/mm PET is as little as 50% of potential
Water use decision making	Water use decision making	Unknown, likely to be poor	Modelling suggests 10% improvement from best management practice7	Use of sophisticated multi crop models, still under development.
Other Uses		Unknown.	10% - 20%	Little data – mainly from improved distribution and water savings by users in municipal systems

We consider the most significant areas for near term gains are (in order):

- **Irrigation application and use**
- **Knowledge of the source (groundwater)**
- **Dynamic Efficiency**
- **Distribution (well/pump and open canals)**
- **Water use decision making**
- **Other Uses (municipal)**

The case study assessment shows a significant amount of variability between studies but overall confirms the conclusions of the theoretical analysis as to the areas of most gains that can be made in use efficiency in the near term.

2 Theoretical Framework

This section scopes the theoretical framework developed for assessing the source of potential efficiency gains. The framework is summarised in Table 2.

Table 2: Efficiency Theoretical Framework

Category	Subcategory
Water Source	Groundwater Surface
Allocation	Nature of the Property Right Structure of the Allocation Initial Allocation Dynamic efficiency
Distribution	Water access inefficiencies Distribution
Irrigation Use	Application Overall
Water use decision making	Water use decision making
Other Uses	

Economic efficiency of resource allocation exists when the marginal benefit from the use of the resource is equal across all sectors (Dinar et al). This condition achieves maximum social welfare. Dinar then suggests a list of necessary criteria in order to achieve optimal allocation of a resource. These are:

- Flexibility in the allocation of supply.
- Security of tenure for established users.
- The real opportunity cost of providing the resource is paid by the user.
- Predictability of the outcome of the allocation process.
- Equity of the allocation process.
- Political and public acceptability of the allocation process.

By including items such as equity and acceptability, Dinar is taking a wider view of optimality rather than solely focusing on efficiency.

2.1 Efficiency in Identifying Available Water from the Source

The water source is the logical point to start. There are two main questions about efficiency in relation to the water resource:

- How good is the state of knowledge of the resource?
- Is the correct trade-off being made between the in stream and out of stream values associated with a water resource?

2.1.1 Knowledge of the Resource

Knowledge of the resource is a key efficiency question, because the better the knowledge the more efficient the decision on allocation of the resource. Harris and Skilton (2007) discuss a number of means by which poor understanding of a resource leads to inefficient decision making about abstraction. This can arise because poor understanding of the resource can lead to an incorrect estimate of availability for abstraction, but also because incomplete knowledge leads to conservatism in decision making based on the knowledge that is available. Conservative decision making as a result of incomplete / inadequate knowledge is driven by the primacy of the "precautionary principle" where the precaution is made in favour of no change to the resource rather than abstractive or alternative use.

In the case of New Zealand allocation authorities the authors note that this conservatism is explicitly embedded in the decision making process.

Knowledge of the resource is an important element of efficiency of use for water users in terms of designing and operating their water use infrastructure and production systems.

However it is never possible to have perfect knowledge of the resource. Even for very well specified resources, we cannot know how issues such as climate change and change in land use will affect the resource in future, and so effectively much of the allocation decision takes place under conditions of uncertainty.

2.1.2 Efficiency of Allocation Trade Offs

In relation to the second question regarding completeness of knowledge of the trade-offs between in stream and out of stream uses of the water, it is clear that there are a great number of different points of view, depending on the stakeholder concerned and the particular decision. However it is also clear that these decisions are made in a forum where no compensation between parties is applied for the trade-offs, and therefore no test is ever made regarding the willingness of different parties to pay or accept compensation for any change in aspects of the resource they value. Many stakeholders would argue that some of the values involved cannot be traded off, because of intrinsic values, the involvement of future generations, or non-substitutability. In the absence of a process to impute a price to all values involved, the decisions on in stream versus out of stream uses and values are made in a political and social process that can be influenced by factors other than the pure merits of the alternative arguments. In this environment it is not possible to determine whether efficiency is being achieved. At best we can assume that the process is fairly reflecting societal expectations, although there are a number of stakeholders who would strongly dispute this conclusion.

2.2 Efficiency in Allocation of Available Water

Once the allocation between uses has been determined then allocation decisions between competing parties for access to the designated resource must be made. Decision making on the allocation of variable resource has four key dimensions:

- The nature of the property right in water that is granted.
- The structure of the available allocation
- The initial allocation decision.
- The ability to re-allocate water to different uses.

2.2.1 Nature of the property right

The aim of a property rights regime is to provide the incentives for property owners to maximize the long term value of the resource, which should produce the most efficient outcome for society. The concept of efficiency of property rights takes into account the costs of negotiating rights, the costs of policing, the costs of establishment, and the costs of litigation. The set of property rights which minimises these costs is an efficient set.

Guerin (2002) uses a detailed breakdown of property rights based on Scott (1988). The characteristics of the property rights of key interest are:

- Flexibility: the extent to which the owner can change the mode or purpose of resource use without forfeiting the right.
- Divisibility – the ability to create joint ownership, to divide the asset spatially or by function, to construct temporal succession of rights
- Quality of title – enforceability, certainty, security, ease of establishing ownership. Defines how secure the property holder can feel that the specified property will continue to be available in the future.
- Exclusivity – specificity, excludability, how many other parties to agree with on use,
- Duration – permanence, length and arrangements for renewal
- Transferability – assignability, exchangeability, tradability

These categories are not completely independent or exclusive. For example the value of all the other characteristics is enhanced as duration increases (Scott 1988), and an increase in flexibility enhances the value of divisibility and transferability. Conceptually using the Scott approach the incentives are maximized when the right exists in perpetuity, is completely flexible, certain and secure, can be simply and freely transferred, and where others can be completely excluded from the use of the resource.

The authors considered there was potential to improve efficiency and reduce transaction costs by better specification of property rights. However no attempt was made to quantify the size of any potential gains in efficiency that could be made.

2.2.2 Structuring the Available Allocation

A regulatory authority makes a decision about how the available water will be allocated to users. The way they structure this decision determines key issues of priority and reliability for the users. Thus the regulator could decide to allocate all water on equal priority, give priority based on time of issue of the consent (last on - first off), or group consents into priority bands.

2.2.3 Initial Allocations

The issue of how initial allocations are made only becomes important when the water in a catchment becomes scarce. Until that point allocation on a “first come - first served” basis provides an adequate allocation process because each successive applicant represents the next highest value use. However once water becomes scarce, or will become scarce in the future, the allocation decision assumes greater importance. In the absence of a mechanism for reallocating water from existing uses / users to new more efficient uses / users, there are clearly some inefficiencies present in the actual distribution of water use compared with the ideal distribution of allocation.

2.2.4 Efficiency of Reallocation - Dynamic Efficiency

Dynamic efficiency arises when resources are able to move from lower value to higher value uses over time in response to changes in resource availability, societal preferences, and technological progress.

In the context of water, dynamic efficiency is most often seen as occurring with a system which allows for the transfer of water between users. While theoretically the transfer could also be achieved through a regulatory process, this is likely to have high transaction costs and little guarantee of best allocation of resources.

Potential benefits of water transfer include:

- Improvement in allocative efficiency with water moving from low value uses to those that are more highly valued by society.
- Improvement in dynamic efficiency allowing for changing needs and alternative uses.
- Creates an incentive to improve the technical efficiency with which water is utilised.
- The removal of political favoritism from re-allocation processes.
- Improved investment confidence.
- Deferment of investment in new and more expensive sources of supply.

Counsell and Evans (2005) identify the *first-in first served* allocation approach and its inherent inefficiencies in periods of excess demand as a key issue with the current arrangements for water allocation in New Zealand.

Section 136 (2) of the Resource Management Act (1991) allows water permits to be transferred provided transfers are allowed by a regional plan or upon application to the consent authority. Whilst many Councils’ allow for the transfer of water rights within their regional plans and consent processes, the transfer of permits is reportedly not widespread (Lincoln Environmental, 2000).

2.3 Efficiency in Distribution

The act of extracting water and delivering it to its point of use is a potential source of inefficiencies. There are elements of engineering efficiency in terms of losses of water in distribution and the efficiency of any energy use in the distribution system as well as efficiencies in closely matching the access and distribution of water in volumetric terms to accurately meet the demand from end use. This can arise through:

- Water access inefficiencies
- Distribution losses.

2.3.1 Water Access Inefficiencies

Water Access inefficiencies largely arise in groundwater abstraction with well and pump performance issues. These inefficiencies arise because pumps are poorly sized, poorly maintained, and because they may not use the latest technologies such as variable speed pumps. The level of inefficiency in accessing water is difficult to predict, because extensive surveys have not been undertaken. AquaLinc (2006) note that well efficiency is potentially a key area for reducing energy use, but that the relationships between well efficiency and well construction are poorly understood.

There may also be some access inefficiency issues associated with river diversion and gallery systems, and their ability to deliver the required volume and flow rate for efficient operation of distribution and application systems.

2.3.2 Distribution losses

The RITSO Society (2007) undertook a comparison of piped vs. open channel distribution systems. They indicated very limited losses from piped distribution systems, but losses in the order of 20% from open channel systems from seepage and operational losses.

In the Rio Grande region Fipps (2000) estimated that water savings from reduction of transportation, operation and accounting water losses in irrigation districts could increase water available from 70.8% to 90% of that entering the system.

2.4 Efficiency of Use

The efficiency with which users utilise water is determined by the ratio at which water is converted to a usable output. This efficiency can be very high – for example reported hydro generation system efficiency is around 90%[5] for water passing through their turbines. Vineyards, which deficit irrigate at certain times of year deliberately restricting water availability for the vines, have very high water use efficiency. These examples can be compared with an inefficiently run wild flood irrigation system, supporting low value pastoral production, where the efficiency of conversion to product is very low.

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[5] US Department of Interior, Bureau of Reclamation, Power Resources Office: http://www.usbr.gov/power/edu/pamphlet.pdf

2.4.1 Irrigation Efficiency

AquaLinc Research Ltd reviewed gaps in on farm irrigation efficiency in 2006 (AquaLinc, 2006). The discussion below is largely derived from their work. They divide concepts of efficiency into:

- Application efficiency – the percentage of water delivered to the field that is used by the crop. This is affected by both the amount of water delivered at each application, and the uniformity of application.
- Irrigation efficiency – related to the percentage of water delivered to the farm that is used beneficially.

Application efficiency can be defined by a number of terms. Commonly the ratio between water at the system uptake point that reaches and is stored in the root crop zone is preferred. (The denominator will be nearly identical for piped sprinkler systems, but for surface based canal delivered systems there may be significant losses between the farm boundary and the paddock that need to be taken into account).

There has been a wide range of application efficiencies measured both in New Zealand and overseas. Rout et al (2002) measured application efficiency for a range of different irrigator types. They report the results shown in Table 3.

Table 3: Application efficiency for different irrigator types (source AquaLinc 2006)

Irrigator Type	Average Application Efficiency (%)	Range (%)
Laser Level border(timber sill)	48	24 – 80
Laser level border (grass sill)	62	37 – 93
Contour Border (timber sill)	44	27 – 62
Travelling irrigator (Rotorainer 100)	85	76 - 96
Travelling Irrigator	67	62 – 70

McIndoe in AquaLinc 2006 collated data on expected water loss in spray irrigation systems to demonstrate where the major effort should be directed in improving on farm efficiency. This is reproduced below in Table 4.

Table 4: Expected water losses on spray irrigation systems (collated by McIndoe in Aqualinc 2006)

Source of Loss	Range	Typical
Losses from open race	0 – 30	10
Leaking Pipes	0 -10	<1
Evaporation in the air	0 – 10	<3
Blown away by wind	0 – 20	<5
Water in non target areas	0 – 5	<2
Interception by lands	0 – 3	<2
Surface runoff	0 – 10	<5
Uneven application	5 – 30	15
Excessive application depth	0 -50	10

Other data suggests that application efficiency is lower than might be expected in NZ. In some more recent measurement Thomas et al (2006) showed that despite a theoretical potential distribution uniformity of 0.9 for a centre pivot system, the best achieved in their tests was 0.8, and values as low as 0.67 were measured. For a K line system a value of

0.44 was measured, and for Roto rainers values of between .58 and .88 were measured. These authors concluded that most farmers do not know how efficiently irrigation water is being used, and that the information available strongly suggests that irrigation applications are not targeting crop or pasture demands. In this context Fipps is reported by Sanger[6] as finding that in Texas water measurement by itself reduced water use by 10%, and when combined with training water use was reduced by 20 – 40%

Little has been found in terms of irrigation efficiency in the New Zealand context – i.e. the returns per unit of water used. Clearly big differences exist in returns between different land uses, which can be related to the value of product, and this is discussed further in the section on dynamic efficiency and transfer of water between uses. Within land uses irrigation efficiency is affected by:

- Application efficiency (as discussed above)
- The nature of the plant, particularly the size of its rooting zone and its efficiency in conversion.
- The farm system efficiency in terms of converting the plant grown into saleable product.
- The quality of the product as it affects its value.

McIndoe (1999) found water use efficiency (WUE) of around 0.2kgMilk Solids (MS)/m3 of irrigation water applied on sprinkler irrigated farms, and 0.04 kgMS/m3 on border dyked farms. Martin et al (2006) cite a number of Australian studies measuring WUE for dairy pastures, with ranges between 0.022 and 0.124 kgMS/m3 of water supplied. The Australian studies showed that WUE is a combination of the efficiency with which water is used to grow feed, and the efficiency with which the feed is managed and utilised for conversion to milk solids. Martin et al (2006) reviewed a number of studies which address the relationship between water applied and milk solids (MS) produced on Canterbury dairy farms. They measured pasture production in paddocks on six dairy farms, and this data suggests that a reasonable benchmark for the most efficiently irrigated pasture is 20kgDry matter (DM) /mm of Penman PET. Data from other measured paddocks fell well below this benchmark – in come cases less than 10kgDM/mmPET. They suggest more even application of water, avoiding over application, better scheduling, and the potential for the use of more water efficient plant species such as lucerne and tall fescue.

Aqualinc 2006 ibid consider that the main loses within an irrigation system are due to uneven/excessive application depths and excessive application. They consider that good design can account for 5% – 40% efficiency improvements, and improved irrigation management can improve efficiency by 5% – 20%. They do note however that designing a system that is 100% efficient may not be economically viable. In particular the overall efficiency of the system needs to be assessed against capital costs, labour requirements, and operating costs (primarily energy requirements). Again this highlights the issue of total resource use efficiency rather than considering water use efficiency alone.

2.4.2 Water Use Decision Making

Within a farm system there are a number of allocation decisions which must be made relating to the use to which water is put. This is particularly true of mixed farming systems, such as cropping and sheep and beef systems. In these systems a complex

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[6] Environmental Defense unpublished report – available from this author.

decision process must be followed that trades off relative returns and relative efficiency of water use over time. These decisions are made at different time scales, from daily operations, seasonal decisions, crop type decisions, and wholesale changes to land use.

Current best practice in this area is generally based on irrigation scheduling advice to farmers from specialist consultants who undertake soil moisture monitoring and have a good knowledge of crop physiology and relative returns. The alternate to this involves a computer based modelling of optimum solutions. Considerable effort has been focused on this area historically. Linear programming techniques can be useful for pre season decisions on crop choice based on estimated available water, returns and system constraints (e.g. Matanga and Marino, 1979). However intra season decision making requires more dynamic optimization routines, and this has proven difficult. Past efforts such as Bright (1986) required a number of simplifying assumptions; however increases in computer processing capability have meant that new approaches can be adopted. Brown (2007) tested an optimization routine and showed an increase in pasture yield of 10% over a best management practice based approach. However this routine has yet to be tested in more complex farm systems.

Our conclusion in this area is that water use decision making is potentially a significant area for overall efficiency gain in terms of returns per unit of water applied. However the level of sophistication in both tools and irrigation systems means that it may be some time before these gains are able to be realized.

2.4.3 Efficiency in other uses

There is not a great deal of understanding in the New Zealand situation of the efficiency of uses other than irrigation related uses. This is because irrigation constitutes the majority of consumptive water use and has therefore been the subject of considerable attention. There is some information on efficiency in municipal water uses.

3 Case Studies

The purpose of the case study approach was to investigate and demonstrate the extent and nature of efficiencies that can be gained in different circumstances. The case studies chosen are three community irrigation schemes;

- Southern Valleys (SVIS) – Marlborough
- Opuha Dam – South Canterbury
- Balmoral Irrigation – North Canterbury.

Each scheme has been assessed in the efficiency framework developed in the previous section. Conclusions as to the most significant areas of near term gains are made.

The mix of outcomes that resulted from the assessment is demonstrated in Table 5 with potential gains explained in qualitative terms.

Table 5: Summary of Case Study Assessment

Category	Subcategory	SVIS	Opuha Dam	Balmoral Irrigation
Water Source	Surface water	Marginal if any.	Nil	Limited
Allocation	Nature of the Property Right	Nil	Nil	Some
	Structure of the Allocation	Moderate	Some	Limited
	Initial Allocation	Significant	Significant	Significant
	Dynamic efficiency	Significant	Moderate	Moderate.
Distribution	Water access inefficiencies	Nil	Moderate	Significant
	Distribution	Nil	Moderate	Up to 20% gains.
Irrigation Use	Application	Some gains possible.	Significant	10 to 20 % gains
	Overall	Some gains possible.	Significant	Up to 50% gains.
Water use decision making	Water use decision making	Moderate	Significant	Significant.
Other Uses		Nil.	Nil	Moderate

The case study assessment shows a significant amount of variability between studies but overall confirms the conclusions of the theoretical analysis as to the areas of most gains that can be made in use efficiency in the near term.

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