# Investment In Refurbishment Of Irrigation Channels – A Case Study Of The Stanbridge System In The Murrumbidgee Irrigation Area

A. Hafi[a]

[a]Australian Bureau of Agricultural and Resource Economics, Canberra, Australia.

Email: ahafi@abare.gov.au

**Abstract:** A model of on-farm water use and off farm water delivery is developed for the Stanbridge system within the Murrumbidgee Irrigation Area (MIA). For each channel reach in the model, a relationship is specified between the level of refurbishment investment and the resulting conveyance efficiency. The model is used to estimate the optimal refurbishment investment for each reach. Two methods of charging for the cost of refurbished infrastructure are analysed: uniform pricing where the differences in channel refurbishment costs and remaining conveyance losses between farms are ignored and efficient pricing that reflects the full cost of delivering water, including the refurbishment cost and remaining conveyance loss to each farm. The implications of alternative pricing options on aggregate net farm income are examined.

***Keywords:*** *Irrigation efficiency; Optimal investment; Water pricing*

## 1. INTRODUCTION

In recent seasons, reduced irrigation water availability, increased water demand from agriculture and for other purposes, and the high cost of investment in new dams and associated infrastructure in the southern Murray Darling Basin (MDB) have highlighted the need to make efficient use of existing water resources.

The potential benefits from further adoption of water saving technologies and practices were considered by Beare and Bell (1998) for the Murrumbidgee region. They found that over a thirty year period a 10 per cent increase in efficiency would lead to a benefit of around $254 million in the present value of farm revenues.

This paper reports on ABARE's ongoing research into the economics of refurbishing irrigation channels. Some important economic issues in refurbishing irrigation channels are considered first, followed by a discussion of the institutional factors that may influence investment decisions. A modeling framework, designed to estimate optimal investment in channel refurbishment, is outlined and preliminary results are presented for a case study of the Stanbridge system in the MIA.

## 2. ISSUES

The issue of optimal investment in channel refurbishment needs to be addressed for each reach as the benefits from refurbishment of a reach can accrue only to farms downstream of it. For equal conveyance loss rates and other conditions also being equal, the optimal investment per lineal meter for a downstream reach is likely to be less than that for an upstream reach as it potentially affects fewer farms. In an irrigation area, the spatial variability in the cost of refurbishment investment per megalitre (ML) of water delivered poses a question for the water authority on the selection of the method by which it could recover the cost of investment. The overall institutional setting that water authorities face affects the method of charging for investment in channel refurbishment. The water charging policy and the lack of well functioning water markets are two relevant aspects of the institutional setting.

Currently, irrigation water charging is based on the principle of full cost recovery for a region. Normally this is done through uniform pricing, where all farms share the total cost of delivering water to farms in the region equally, by paying the same price. This neglects differences in delivery costs including the cost of refurbishment investment associated with the spatial distribution of farms in the region. For example, farms located closer to the headwater are likely to have a lower delivery cost than farms further downstream.

A change in water charging policy from uniform pricing to one that reflects the actual delivery cost to each farm to recover the cost of refurbishment is also expected to create incentives for the efficient use of irrigation water on farm.

However, a well functioning water market is essential for introducing an efficient pricing regime.

These questions encompass a range of issues surrounding irrigation channel refurbishment and the recovery of the cost of channel refurbishment. Addressing these questions may assist policy makers, regional water managers and irrigator groups to determine the appropriate strategies to encourage the refurbishment of irrigation channels.

## 3. CURRENT STATE OF IRRIGATION CHANNELS IN THE MIA

There are over 1000 kilometres of supply and delivery channels within the MIA. The largest part (79 per cent by length) of the delivery channels is clay lined while approximately 18 kilometres of concrete lined channels are rated as of poor condition (Hafi et al., 2001).

Off farm delivery losses occur through seepage, leakage, evaporation and escapes from delivery channels. Seepage losses occur mainly from earthen and dilapidated concrete lined channels. Estimates of these conveyance losses in the MIA range from 13 to 30 per cent of water diverted. In the early 1990s, for example, approximately 30 per cent of diverted water has been lost in this manner (Bryant et al., 1992). On the low extreme, the estimates of these losses made by Sinclair Knight Merz (1995) and Neeson et al., 1995 indicate a loss of about 13 per cent of water diverted to the MIA.

## 4. MODELING FRAMEWORK

In order to address the issues identified earlier in this paper, a modeling framework was developed. The framework was used to simulate the behavior of farmers and regional water authorities toward the adoption of both on-farm and off-farm irrigation technologies within the limits set by the existing physical, economic and institutional environment.

Two versions of the model were developed to represent the incentives faced by farmers in the MIA in their use of land and water resources. Each version of the model is run with and without investment. The first version represents the conditions for optimal behavior by farmers as well as the water authority within a well functioning water market. In particular, water authorities in the first model are assumed to charge a price that reflects the cost of delivering water, including conveyance losses and the cost of refurbishing infrastructure, to each farm. When the model is run with investment scenarios, for each channel reach in the model, a relationship is specified between the level of refurbishment investment and the resulting conveyance efficiency. For each reach, the model condition for optimal investment is that at the optimum, the value of water saved by an additional unit investment must be less than its marginal cost. The second model also represents conditions for optimal behavior by farmers as well as the water authority, but subject to a uniform water price prevailing, regardless of the difference between farms in costs of infrastructure refurbishment and conveyance losses. When the model is run with the investment scenario, for each reach, the optimal investment levels obtained from the efficient pricing (first) model and resulting conveyance loss rates are assumed. The second model represents the uniform pricing currently practised by water authorities. Uniform pricing of irrigation water entails some economic losses and consequently this form of pricing is not economically efficient. In contrast, there are no economic losses with efficient pricing. The details of the two models are given in the appendix.

## 5. THE CASE STUDY AREA – STANBRIDGE MIA

The Stanbridge system comprises approximately 18 kilometres of irrigation channels/pipes of which 10 kilometres are unlined (earth), 6 kilometres are lined with concrete and 2 kilometres are piped. The system supplies water from the Gogeldrie branch canal of the MIA system to approximately 1200 hectares of farmland (513 hectares of horticulture and 680 hectares of broadacre). The channel system comprises 67 reaches of variable lengths, ranging from 20 to 1000 metres. There are 47 farms drawing water from within the channel system. At peak demand, water is diverted at around 80 ML a day to Lateral 123 from the Gogeldrie branch canal.

## 6. DATA USED

For each reach, engineering staff of Murrumbidgee Irrigation provided data about the water supply system and individual farms. The data used included the parameters of a series of relationships between conveyance loss rate and capital investment in channel refurbishment. These parameters were estimated in two steps. First, for each channel reach and peak flow rate the costs of refurbishment per lineal meter with different options were estimated using an engineering approach. Second, for each flow rate, these costs of refurbishment were related to corresponding conveyance loss rates. Some of these estimated relationships are presented in

Figure 1. The bulk of the data on cropping enterprises were obtained from data files used in a number of other models developed by ABARE (Hafi et al., 2001).

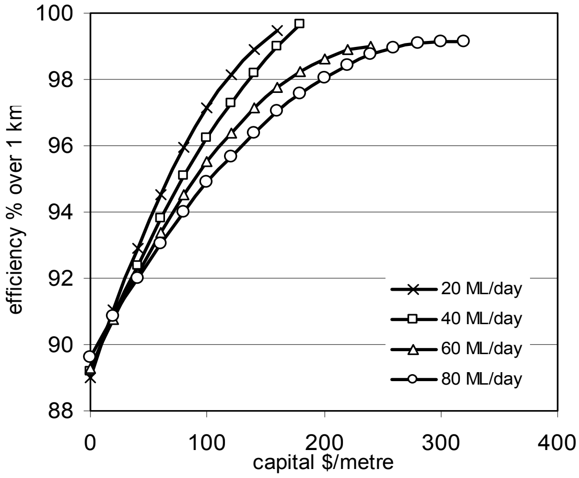


**Figure 1**. Conveyance efficiency at different capital investment level and peak flow rates

## 7. RESULTS AND DISCUSSION

### 7.1. Price of water

In the presence of conveyance losses the price of water increases with distance from source (Figure 2) until the water flow ceases. As the investment in channel refurbishment reduces the rate of conveyance losses, the increase in the price of water with the distance from source will be slower with investment than without investment. With investment, the difference in the price of water between any two adjoining channel nodes equals the cost of water lost in conveyance between these nodes plus the annual cost of refurbishment per ML.

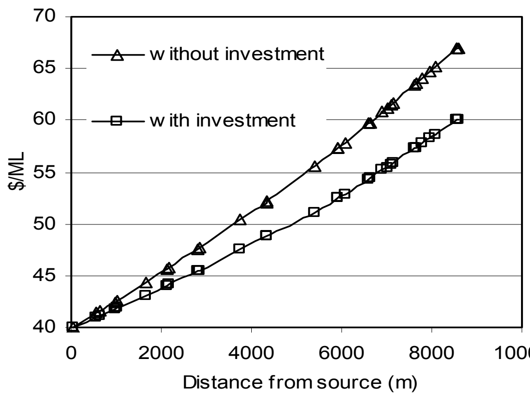


**Figure 2.** Price of water with efficient pricing

### 7.2. Optimal investment

At each location, the price of water and the rate of flow influence the profitability of investment in refurbishing irrigation infrastructure. This is because the greater the value of water flowing (price times the flow rate) through a location, the greater the benefit from preventing its loss at that point (Figure 3).

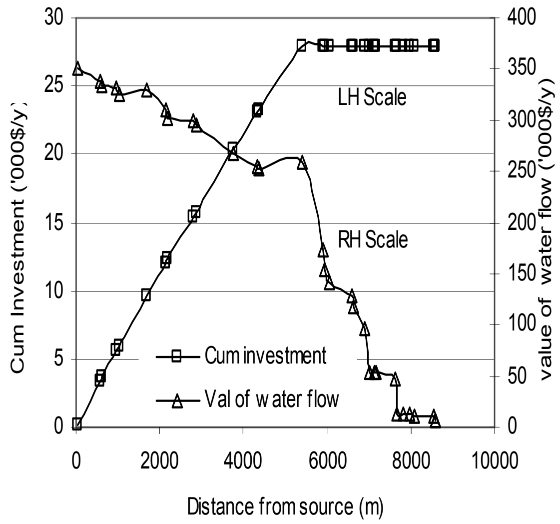


**Figure 3**. Cumulative refurbishment investment versus value of water flow, by distance from source

Moving downstream, as farms draw water and as water is lost in conveyance, the flow rates and thus the profitability of refurbishment investment declines. Even though the increasing price of water with distance from source increases the profitability of investment, the value of water flow declines with distance from source. Model results are that, it is not optimal to invest in channel refurbishment past 5.5 km from the source as the value of the water flow decreases sharply at that distance. For all reaches up to 5.5 km from source, the annual cost of optimal investments is estimated at $28,000 or $5.1 per metre. The annual cost of optimal investment per metre decreases from $5.9 near source to $4.6 at 5.5 km from source.

### 7.3. Benefits of investment

The benefits of refurbishment investment include the value of increased agricultural output produced with the use of saved water and revenue from the volume of saved water sold externally, if any. Assuming efficient pricing, at each downstream reach, the cumulative value of water saved exceeds the cumulative cost of investment indicating the profitability of investment (Figure 4).

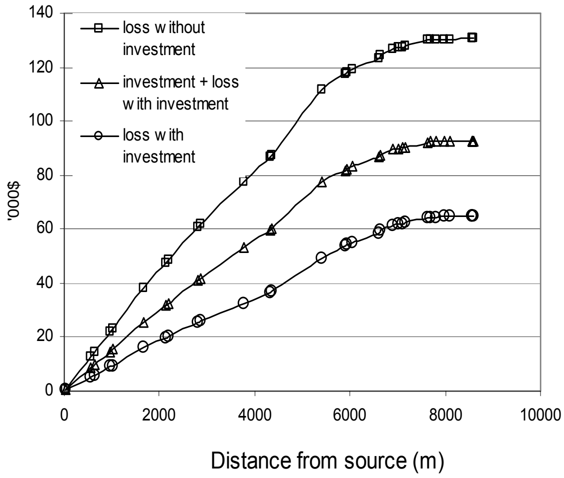


**Figure 4.** Cumulative value of water lost with and without investment

The increase in net farm income due to investment in refurbishment depends on the prevailing pricing regime. If uniform pricing is replaced with efficient pricing, the net farm income increases by $151,000 (or $3,200 per farm) per annum (Table 1). This potential increase in net farm income will be reduced to $83,000 (or $1,800 per farm) per annum if uniform pricing regime is maintained. However, these income gains from efficient pricing would come at some administrative cost. Under both pricing regimes, on average farms also earn income of $490 per farm and year by selling some of the water saved outside the system.

**Table** 1. Economic benefits of channel refurbishment ('000$/year)

| | Pricing regime | |
|---|---|---|
| | Efficient | Uniform |
| Net farm income | | |
| (a) Base[1] | 4223 | 4223 |
| (b) With investment[2] | 4374 | 4306 |
| (c) Change [(a)-(b)] | 151 | 83 |
| Incremental value of traded water | 23 | 23 |
| Incremental benefits | 174 | 106 |

**note**: **1**. with uniform pricing and no investment; **2.** optimal investment as determined with efficient pricing.

### 7.4. Charging for channel refurbishment

With investment, the difference in the price of water between any two adjoining channel nodes equals the cost of water lost in conveyance between these nodes plus the annual cost of refurbishment per ML (Figure 2). The annual cost of refurbishment per ML for farms located at different points increases with distance up to 5.5 km from source as downstream farms pay for the refurbishment of upstream reaches. The annual refurbishment cost per ML for farms located past 6km remains unchanged as refurbishment investment beyond this point is not optimal (Figure 5).

If uniform pricing is employed to recover the cost of refurbishment, the upstream farms are expected to pay a higher price while downstream farms pay a lower price.

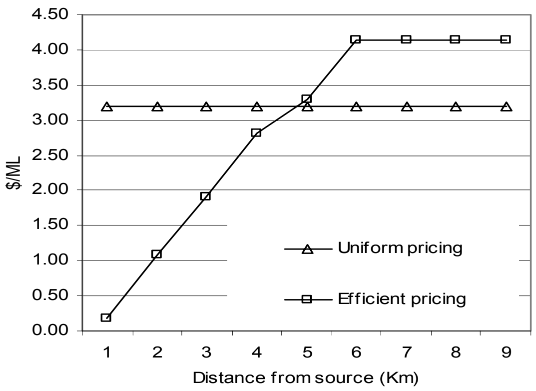


**Figure 5**. Charging for infrastructure refurbishment

## 8. CONCLUSIONS

A modeling approach to determine optimal investment in channel refurbishment has been presented in this paper. A key conclusion is that infrastructure and delivery pricing will impact on the optimal level of investment and subsequent water use.

With efficient pricing and when the water authority invests optimally in channel refurbishment farmers will pay lower prices and receive more water than without investment as conveyance losses are reduced. In the Stanbridge system, as the value of water flow decreases with distance from source, the model results are that it is not optimal to invest in channel refurbishment past 5.5 km from the source.

Charging a uniform price for delivery of water and infrastructure refurbishment to farmers in an area where the marginal cost of delivering water and infrastructure refurbishment differs between farms leads to a lower aggregate farm income compared with the outcomes under efficient pricing.

## 9. REFERENCES


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## 10. APPENDIX – A MODEL OF IRRIGATED AGRICULTURE IN THE STANBRIDGE SYSTEM – MIA

Because of limitations on space, a generalised form of the model developed for the Stanbridge system is reported here. However, the general form of the model presented here retains the key features that are required to address the issues associated with the investment in refurbishment of irrigation channels.

Each of the models covers an irrigation supply system with a number of channel reaches. Individual reaches are separated by nodes. Water is diverted to the system at source from a main channel. There are farms (one per reach) drawing water from the system. The farms are located at varying distances from the source as shown in Figure 6.

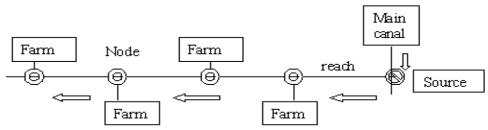


**Figure 6**. Spatial distribution of farms, channel reaches and the source of water

### 10.1. MODEL 1

Efficient water and land use and the corresponding efficient prices of water are obtained in model 1 as the solution to the problem of maximising the objective function (1) subject to the inequality constraints on volumes (2) – (5) and prices (6) – (10). The objective function represents, for the whole irrigation system, the annual gross margin on all farms plus the annual value of net external trade of Temporary Water Entitlements (TWE), less the sum of the annual value of water 'purchased' externally at source, annualized cost of refurbishment investment, rent to water at source and all annual land rents. The decision variables are the volume of water diverted from source and, for each reach, the annualized cost of refurbishment investment, for each farm, the area used for each crop and irrigation technology, and on the price side, the annual land rents, the rent of water at source and the prices of water along the channels. In the optimum, the value of the objective function must be zero.

$$\sum_{rnt} A_{rnt} P_{nt} + WS(VTWE - P^{w}) - WB.VTWE - Q^{11}P^{w} - \sum_{r} C_{r} - \Omega V^{2} - \phi V^{3} - \sum_{r} \Phi_{r} V_{r}^{4} \quad (1)$$

$$Q^{11} + WS - WB \le \Omega \quad (2)$$

$$WS \le \phi \quad (3)$$

$$\sum_{nt} A_{rnt} \le \Phi_{r}, \text{ for } \forall r \quad (4)$$

$$\sum_{nt} \frac{\xi_{n} - \eta}{\vartheta_{nt}} A_{rnt} + \varepsilon_{r} \left( \frac{C_{r}}{Q^{ir}} \right) \mu_{r} Q^{ir} + \sum_{j \in j_{i}, r' \in r'_{i}} Q^{jr'} \le Q^{ir}, \text{ for } \forall r \quad (5)$$

$$V^{2} \ge VTWE - V^{3} - P^{w} \quad (6)$$

$$V^2 \leq VTWE \quad (7)$$

$$V_r^4 + \frac{\xi_n - \eta}{\vartheta_{nt}} V_{ir}^5 \geq P_{nt} \text{ , for } \forall r,n,t \quad (8)$$

$$\left(1-\varepsilon_1\left(\frac{C_1}{Q^{11}}\right)\mu_1\right)V_{11}^5 \leq V^2 + P_m + \mu_1\left(\frac{C_1}{Q^{11}}\right) \quad (9)$$

$$V_{ir}^5 \geq (1-\varepsilon_{r'}\left(\frac{C_{r'}}{Q^{jr'}}\right)\mu_{r'})V_{jr'}^5 - \mu_{r'}\left(\frac{C_{r'}}{Q^{jr'}}\right)$$

$$\text{for} \forall j \in j_i, r' \in r'_i \quad (10)$$

Where $i$ and $j$ represent the nodes, $r$ and $r'$ represent the reach or farm assigned, $t$ the irrigation technology, $n$ the crop type, $V^e$ the value, or shadow price, associated with the volume constraint numbered $e$ (where $e$ = 2 – 5), $Q^{ir}$ the rate of water flow from node $i$ to reach $r$ (ML/day), and $A_{rnt}$ the area planted to crop $n$ with technology $t$ on farm $r$.

The parameters are: $P^w$, the external price of water at source (\$/ML), $VTWE$, the external value of temporary water entitlement, $P_{nt}$ the gross margin of crop $n$ adopting technology $t$ (\$/ha), $WS$, the volume of TWE sold out of the system (ML/year), $WB$, the volume of TWE purchased from outside the system (ML/year), $\mu_r$ the length of reach $r$ (metres), $\varepsilon_r\left(C_r/Q_r\right)$ the proportion of the flow rate lost per metre through evaporation and seepage along reach $r$ which is specified as an inverse function of annualized refurbishment cost, $C_r$ per ML of annual flow, $\eta$ the average rainfall (ML/year), $\xi_n$ the average evapotranspiration requirement of crop $n$ (ML/year), $\vartheta_{nt}$ the efficiency of application technology $t$ on crop $n$, $\Omega$ the flow of water diverted at source by the water authority (ML/year), and $\Phi_r$ the area of land available on farm $r$ (ha).

The model conditions (9) and (10) imply that at the optimum, in the presence of conveyance losses and when the water authority optimally invests in infrastructure refurbishment the value of water increases with distance from source until water flows cease. This is consistent with the formulation developed by Chakravorty and Roumasset (1991) for the efficient spatial allocation of irrigation water.

## 10.2. MODEL 2

The volume conditions for model 2 are identical to those of model 1.

However, the volume condition (5) and price/cost conditions (9) and (10) are replaced by (11) and (12) and (13), respectively.

$$\sum_{nt}\frac{\xi_n - \eta}{\vartheta_{nt}} A_{rnt} + \varepsilon_r^* \mu_r Q^{ir} + \sum_{j\in j_i, r'\in r'_i} Q^{jr'} \leq Q^{ir}$$

$$\text{, for } \forall\ i,\ r \quad (11)$$

$$V_{11}^{11} \leq V^2 + P^W + \frac{\sum_r C_r^*}{Q^{11}} \quad (12)$$

$$V_{ir}^{11} \geq V_{jr'}^{11} \text{ for } \forall\ j \in j_i, r' \in r'_i \quad (13)$$

Where, for each reach $r$, $\varepsilon_r^*$ denotes the conveyance loss rate obtained, after optimal investment from model 1 and $C_r^*$ the corresponding optimal annualized refurbishment investment (\$/ML). Optimal values for the farmers' and water authorities' decisions, subject to uniform water prices prevailing, are obtained by maximising (14) subject to inequality constraints in (2) – (4), (6)—(8) and (11) —(13).

$$\sum_{rnt} A_{rnt}P_{nt} + WS(VTWE - P^w) - WB.VTWE - Q^{11}P^w - \sum_r C_r^* - \Omega V^2 - \phi V^3 - \sum_r \Phi_r V_r^4 + \sum_{ir} Q^{ir}\left(\varepsilon_r^* \mu_r V_{ir}^5\right) \quad (14)$$

Criterion (14) has the same interpretation as criterion (1) above except for an additional term. This term is the sum over all nodes and reaches of the value of all seepage losses evaluated at the optimum uniform water price. The term can also be interpreted as the sum – over nodes and reaches – of the value of the *ad valorem* subsidy to a water user that is implicit in water charges set at a second best uniform price. Again in the optimum, the value of the criterion must be zero.