The economics of polypiping artesian bore water distribution

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Abstract

The water of the Great Artesian Basin is an important resource for the grazing industry in the semi-arid and arid areas of the Basin. The initial development of the Basin was a 'free for all' in an open access environment. State governments now license bores to restrict the use of water, but enforcement varies across states. The most widespread use of the water from the Basin is for stock water. In some sub-basins users of stock water already compete with each other and with other uses of water. There are clear local externalities with neighbouring bores but the extent of extraction externalities of any bore on the entire Basin is probably limited. Most of the stock water is reticulated in bore drains. Replacement of the drains with a polypipe reticulation system (primarily a water saving technology) represents a major investment for users. The replacement decision is complicated by the necessity for unanimity among members of a Bore Trust and by financing constraints. As competition increases for the use of water, the pricing of water or the allocation of transferable water rights could provide incentives for the possible adoption of water saving technology.

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Introduction

The Great Artesian Basin provides some interesting resource economics problems. The major use of water in the Basin is in the provision of stock water over a wide geographic area in climates ranging from well watered to arid. From a production economics standpoint, artesian water is a key resource in the grazing production processes of the semi-arid and arid areas. The provision of a substitute resource would be very costly. While the total value of grazing in the semi-arid and arid areas is not high, the marginal value product of the artesian water resource use in grazing is probably quite high. In addition to the provision of stock water, a small amount of water is used for irrigation in Queensland and Northern New South Wales. Water is also used for town supplies and mineral and energy development in inland areas where no other supply is available.

There are current concerns with the 'sustainability' of the artesian water resource and a particular concern with replacing 'wasteful' flowing bores and bore drains with piped reticulation systems. Local externalities are associated with current the use of water and there is the possibility of basin wide externalities in the future. Graziers, through bore trusts, pay only for the maintenance of the bore and the bore drain reticulation system, and not the water itself. As the concerns have grown there has a move to restrict the use of water by licensing of bores, but little use has been made of pricing or transferable property rights to manage the resource. The tentative approach taken in this study is that the water in the Basin is essentially a stock resource with some flow characteristics[1]. Thus standard resource economic theory can be used to consider the current concerns.

At present there is a limited demand for the water from the Basin mainly due to its quality. The quality of the water seems generally to deteriorate with movement west and south through the aquifer. With the exception of small areas in Queensland and Northern New South Wales located at the edge of the recharge zone, water from the Basin is not suitable for irrigation and it is only used domestically where other water is not available. In the future it is possible that new technology and/or the demand by other industries and urban demand will increase the competition for water from the Basin.

History of development of the Basin

The Great Artesian Basin extends from the Gulf of Carpentaria, through western Queensland into New South Wales and across to the north east of South Australia and the Northern Territory (Figure 1) underlying about a fifth of the Australia continent. Much of the area is arid or semi-arid and the major land use is extensive grazing of sheep and cattle. Prior to the tapping of the Basin flocks and herds were confined to areas watered by natural water courses. Many of these water courses are very unreliable. The land use was very extensive grazing on large stations. Where set

[1] Sinclair Knight Merz (1995) p. 5 take the alternative approach 'Groundwater, like surface water, should be considered a sustainable natural resoruce, not a resource or some other element to be mined'

stocking was practiced, stocking rates were very low as the area around water could support few animals. Alternatively, animals had to be moved frequently between various sources of drinking water and feed.

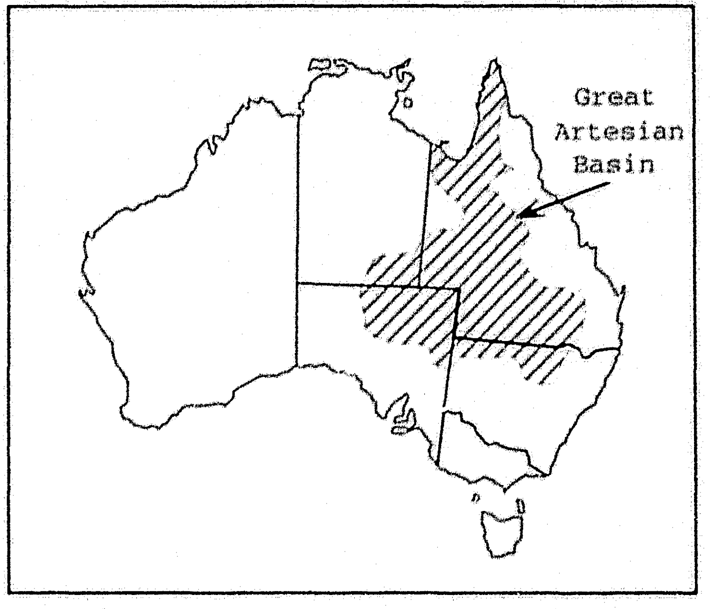

FIGURE 1 Location of the Great Artesian Basin

The discovery of the Basin in 1878 was followed by a period of rapid and uncontrolled development of the water resource from 1880 to the early 1900s in an open access environment. Many flowing artesian bores were drilled and the water was distributed in open earth drains. Sub-artesian bores were drilled and equipped with windmills, tanks and troughs. This development, combined with investment in fencing and other infrastructure allowed somewhat more intensive land use and the subsequent division of many of the stations into smaller family owned units.

At present the Basin provides the only reliable water supply available to most of the graziers, to some scattered mineral and energy industry sites and to a number of the towns of the region. Thus there are a variety of end uses and users scattered over a wide geographic area, separated by State boundaries.

There have been many concerns over the years that the Basin is over exploited. These concerns were first voiced only a few years after the initial development of the Basin and followed falls in the potentiometric surface of the aquifer. These concerns resulted in a series of Interstate Conferences on Artesian Water from 1912 to 1929, followed by considerable research efforts investigating the geology and hydrology of the Basin.

The current concern is again with the 'sustainability' of the resource, with an estimated average annual recharge of about 410 million cubic metres compared to an estimated average annual discharge of about 530 million cubic metres (Jacobson, Habermehl and Lau 1983). The issue of sustainability is discussed further below. According to Jacobson, Brown and Harrison (1983) inefficient and uncontrolled use of the water extracted from the Basin, mainly from flowing bores reticulating water into bore drains, results in only about 10 per cent of the discharge from the Basin actually being used. The development of new technology, especially in the manufacture of polypipe capable of reticulating hot water from artesian bores, has led to increased interest in the 'efficiency' of water use in the Basin. It is now technically possible to replace bore drains with polypipe and booster pump reticulation systems and some of these systems are in operation. This replacement has been encouraged by Federal and State Government action to rehabilitate artesian bores through Landcare programs.

Hydrology of the basin[2]

It is important to know something of the hydrology of the Basin before attempting to construct an economic analysis on which to make policy recommendations. The Great Artesian Basin was formed during the Mesozoic period between 65 and 240 million years ago. The aquifer system is comprised of multiple layers porous fractured sandstone confined between impermeable rocks on the bottom and by thick marine sediments on the top. In many areas multiple aquifers are separated by more or less impermeable layers of siltstone and mudstone. Surface water enters the aquifers from the recharge zones which are generally located in the higher rainfall areas of the Great Dividing Range in Queensland and New South Wales. During periods of the geological history of the Basin, rainfall in the recharge zone was much higher than it is today. This 'old' rainfall has largely contributed to the vast reserves of water found in the Basin now.

Water permeates down between the confining rock layers until it reaches the aquifer. As more water enters the recharge zone the level of the saturated zone rises and water is held under pressure in the aquifers. It is forced to the surface through bores and natural springs (see Figure 2). Some of the notable natural springs occur in mounds on the south western edge of the Basin near Lake Eyre. Water is heated in the aquifer and often has a temperature of over 50°C on emergence at a bore head.

The aquifers in the Basin vary in thickness from tens of metres to thousands of metres, with the top and bottom confining layers varying in height. Ridges, troughs and faults separate the Basin into a series of sub-basins. The Basin is tilted up to the north east, forms a large basin and then rises gently to the south west. The general movement of water is towards the south west, but this movement is very slow.

The upper level of the saturated zone in an aquifer is the 'hydraulic', 'piezometric' or 'potentiometric' surface. This is the level to which water would rise in a cased bore. The

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[2] This section draws heavily on Habermehl and Seidel (1979), Habermhel (1980), Hawke and Cramsie (1984) and Williamson (1984)

potentiometric surface is influenced by injections of water at the recharge zone and by extraction through springs and bores. Interestingly, it is suggested by the Australian Water Resources Council (1975) as water is extracted from the Basin and the potentiometric surface falls, recharge may increase.

A 'flowing bore' is produced where the potentiometric surface of water is above the ground level. After a bore is drilled, a conical shaped reduction in the potentiometric surface occurs around the bore. The fall of the potentiometric level reduces the pressure head of the bore. A drop in pressure results in (i) a reduction in the volumetric flow from an artesian bore or (ii) more seriously, a flowing artesian bore may become sub-artesian. A sub-artesian bore is produced where the potentiometric surface of water is above the ground level. Water from sub-artesian bores must be pumped to the surface. Pumping may be expensive due to the capital and operating costs of the pumping equipment. The reduction in potentiometric surface is most rapid after the initial tapping of a sub-basin due to the 'elasticity' of the aquifer.

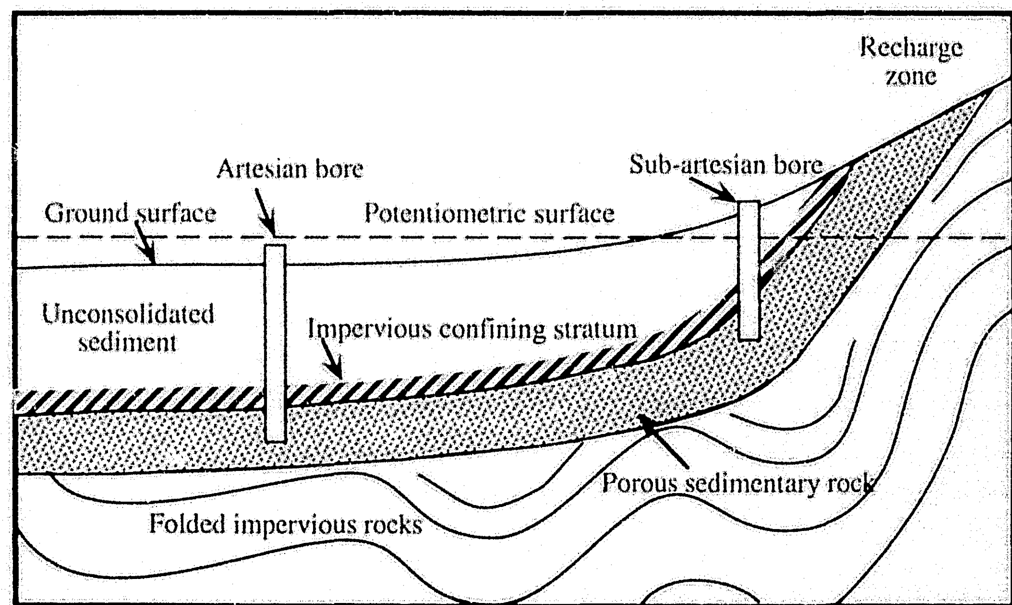

FIGURE 2 Illustration of the Great Artesian Basin

Since the widespread drilling of artesian bores about a century ago the potentiometric level has fallen at any point at which long term measurements have been recorded. There are clear local externalities with neighbouring bores over distances of a few kilometres. On the eastern edge of the Basin the flow rate of many bores has decreased dramatically and many have changed from artesian to sub artesian[3]. However the extent of extraction externalities of any individual bore on the entire Basin is unclear and is probably very limited. Attempts have been made to quantify these effects using computer simulation models (Seidel 1980).

[3] I have personally observed a movement of sevaral kilometres in the division between artesian and sub-artesian bores and a substantial decrease in the flow from bores in the area north of Moree over the past 40 years.

Bores and bore drains

Bores vary in depth and age. Many were drilled in the 1890s with another burst of activity during the 1930s. Many bores are over a thousand metres deep. All of the older bores were cased with metal or metal lined with concrete. The casing may deteriorate with age and in some situations the casing has corroded through. A similar problem arrises where water escapes between the bore hole and the casing. In both situations, artesian water has escaped, or is escaping, into upper level sub-artesian aquifers or into permeable layers of rock, gravel and sand through which it can percolate to the surface. Where artesian water escapes into the upper level sub-artesian aquifers, it may pollute the upper level water depending on the quality of the two sources of water. Where the artesian water seeps to the surface it may cause rising water tables and soil degradation ('scalding') due to the salts dissolved in the water. This problem can be remedied either by repairing the bore casing, or often, by blocking the bore at depth and drilling a new bore. Both remedies are relatively costly with each costing around $200,000.

Bore drains reticulate water from flowing bores in earth channels. Usually a flowing bore services a network of bore drains running through several properties. Livestock on the properties drink directly from the bore drain. Much of the water flowing from a bore is lost through seepage and evaporation in the drains.

There are a variety of problems associated with the drains in addition to the problem of water loss. The location of a drain is often constrained by topography as it must broadly follow a contour with a regular small fall from that contour. The constrained location means that stock may have to walk long distances to water thus reducing their productivity (see Squires and Wilson 1970; Squires, Wilson and Daws 1972; Squires 1981). The location of the drains may also impede other agricultural activity, especially farming. Drains have to be 'delved' at regular intervals to clear soil and vegetation that would otherwise result in blockages leading to water flowing out of the drain.

Land holders close to a bore head have a much more reliable and better quality water supply than those at the ends of the drains. This especially so where the flow of water from a bore has decreased over time. Originally the network of drains was developed to use all the available water and as the volume of water flowing for a bore decreases, it can no longer adequately serve the network of drains. Further, during wet periods bore drains act as drainage channels and land at the end of drains can become water logged and saline. Overflow from bore drains can also pollute natural water courses. This can be a problem where the quality of the bore water is particularly poor.

The drains also provide a means of spreading weeds and livestock diseases downstream. They also provide feral animals, especially pigs, with a distributed water supply increasing the difficulty of eradication.

Water reticulation by polypipe

Replacement of bore drains with polypipe has occurred in some areas and is planned for many others. Replacement can be planned so that a central bore or series of bores supplies water in many directions. As part of the replacement, bores that are unsatisfactory for one reason or another can be capped as fewer bores are required to supply water.

The diameter of polypipe required in the reticulation system is reduced by using booster pumps, as large diameter pipe is expensive. In the closer settled areas the booster pumps can be located near existing powerlines. In most cases water is supplied to concrete tanks to give a small reserve of stock water in case of system failure.

The advantages of polypipe reticulation over bore drains are fairly obvious (see Eigeland 1991). Artesian water is saved, the reliability of water supply is improved and water can be delivered to any desired point on a property. Operating costs are modest and comparable with the maintenance costs associated with delving bore drains. The major problem with the polypiping is the capital cost. Apart from bore rehabilitation, pipe and pumps about $1,500 per kilometre.

Institutional arrangements and the control of water in the Artesian Basin

It is well known that management of water supplies in Australia in under the jurisdiction of the States. In a few cases, special purpose institutions have been established to co-ordinate policy and/or manage where water management issues specifically cross state boundaries. Examples are the Australian Water Resources Council, the Murray-Darling Basin Commission and the Dumaresq-Barwon Border Rivers Commission.

The history of government involvement in water management originated with irrigation in Victoria with the *Irrigation Act* 1886 (Vic) and artesian water in New South Wales. The *Artesian Wells Act* 1897 (NSW) enabled groups of graziers to obtain Government assistance to a drill bore to supply their properties. The *Water and Drainage Act* 1902 (NSW) encouraged the formation of Bore Trusts to administer a bore (or series of bores) and the associated drain network. This period saw a rapid redistribution of land as large leasehold or freehold stations were divided into smaller units following the establishment of reliable water supplies.

The use of surface and underground water in New South Wales is now controlled under the *Water Act* 1912 (NSW), which developed from the *Artesian Wells Act*. In Queensland the *Water Act* 1926 (Qld) was based on the New South Wales Act, but was more narrowly focused on artesian water (Clark, 1979). Control is now under the *Water Resources Act* 1989 (Qld) (Sinclair Knight Merz 1995). The *Water Resources Act* 1976-79 (SA) was the first of the modern water Acts providing more administrative discretion in South Australia than in the past. This legislation has been replaced by the *Water Resources Act* 1990 (SA). The Northern Territory legislation is the *Water Act* 1992 (NT). Historically, the major thrust of the legislation was to ensure sound construction and maintenance of bores rather than control the use of water (Clark, 1979 p.159).

The administration of ground water resources is now under the control of the Department of Land and Water Conservation in New South Wales, the Water Resources Commission within the Department of Primary Industries in Queensland, the Department of Environment and Natural Resources in South Australia, and the Water Resources Division of the Power and Water Authority in the Northern Territory (see Sinclair Knight Merz 1995).

In New South Wales the Department of Land and Water Conservation is attempting to licence all artesian bores. The bores supplying water for irrigation are licensed. Users are charged $150 for the issue of the licence and an annual charge of $100 per bore. There is also a volumetric charge of 40 cents per ML. Many private and Trust bores supplying stock water are unlicensed but the flow of many of these bores is monitored from time to time. Other bores are licensed and the flow is monitored. The users of this water, mainly as members of Bore Trusts, do not pay for the water.

The powers of Bore Trusts in New South Wales are specified in Sections 52, 53 and 54 of the *Water Act* 1912 (NSW). The Trust has many of the characteristics of a club (for a review of club theory see MacAulay, 1995) with rate payers having responsibilities to, and deriving benefits from membership of the club. The Trust collectively undertakes functions that are beyond the capacity of individual members of the Trust. The Trust maintains the bore and drains and levies rate payers for the work. All rate payers in a given Trust pay the same rate for each hectare 'benefited' by a bore drain, regardless of the reliability and quality of the supply. The rates are very modest. Bore drains are sited and maintenance work is undertaken with the consent of the rate payers concerned. Easements are not held by the Trust and drains are essentially assumed to be temporary, although many have been in place for around 100 years. Replacement of bore drains with polypipe is obviously not mentioned in the Act[4], but administratively is assumed to be maintenance. It follows that the decision to replace the bore drains with polypipe requires the consent of all ratepayers in a Trust.

Economic questions

Economics of the extraction of the resource

Earlier it was assumed that the water in the Great Artesian Basin is a stock resource with some flow characteristics. This assumption is based on the author's very limited understanding of the hydrology of the Basin and the observation made by many authors that the movement of water in the basin is very slow. Williamson (1984) p. 40, for example, states that 'the rate of water movement...within the range of one kilometre every 100 years to one kilometre every 600

[4] There appears to have been some consideration of amendment of the Act to cover this replacement.

years...it is evident that the water issuing from bores may be up to several hundred thousand years old'

The economics of the extraction of an exhaustible resource have been well known since the famous paper written by Hotelling ([illegible]) on the subject. Extraction of artesian water has many of the characteristics of the simple exhaustible resource extraction problem posed by Randall (1987) chapter 15. Assuming away problems of ownership of the resource and any consequent resource rent, there is a marginal extraction cost (capital cost of bores and drains or pipes plus maintenance costs) which may rise over time as a given bore or bores in a sub-basin become sub-artesian (pumping costs) and a marginal user cost based on future demand for the resource. In the artesian water case however, there is no current market for the output, water, and hence no market price. Imputed prices could be determined from the derived demand for the input, water used in the farming (water for irrigation), grazing (water for stock), and mining industries ('industrial' water) producing outputs from the respective industries. In practice these implied prices could be estimated using mathematical programming models of representative firms in the respective industries using water from the Basin. A primary demand exists for water for urban use and it could be estimated by questionnaire or direct observational methods.

Aspects of the multiperiod extraction problem could be considered using multiperiod linear programming[5] or dynamic programming. These models could indicate optimal extraction rates and implicit prices over time under an essentially open access regime representing past policy, a situation where access was limited by policies such as the present bore licensing policy, or represent polices such as marketable water rights. The models could also shed light on the level of resource rents that might be extracted under alternative assumptions such as monopoly (perhaps government) ownership of the resource (see Zilberman, Wetzstein and Marra (1993).

If the water in the Basin is treated as a flow resource, the programming problem could be constrained so that water use would be less than or equal to the recharge of the aquifer. The policy options outlined above could be examined under this constraint. If the possibility of increasing the recharge rate as extraction is increased were included, some interesting non-linear activities and constraints might be added to the model.

The simple situation above is complicated by the existence of local externalities in sub-basins, at least. In most sub-basins water is only used for stock water with little competition between users. However in some sub-basins there is competition for the stock water. A good example is the use of artesian water for mining at Roxby Downs in South Australia. In this case there is competition for water between mining, stock water and 'environmental' water feeding the mound springs and their associated ecosystem (Pigram, 1986). The standard economic solution is the establishment

[5] These models might be broadly similar to the 'price-linked farm and spatial equilibrium programming models' proposed by Batterham and MacAulay (1994)

of a market for transferable rights to use water (see, for example, Randall 1981). This could include the creation of a property right for environmental water (Collins and Scoccimarro, 1995).

There are other examples of increasing competition for water in areas of New South Wales. In the Lightning Ridge area there is competition between town water, mining and stock water uses with the demand for town water and mining water, especially, increasing. At Moree, a growing tourist industry uses artesian water directly in spa baths[6] and competes with town water supply, irrigation and stock water. Thus it is possible that more competition for artesian water will occur in the future as either new industries (or urban areas) demand water of the current quality, or new technology is developed to improve the quality of the water. Thus transferable property rights and pricing solutions may become more important in the future.

Polypipe reticulation to replace bore drains

To take the simplest situation, if the decision to invest in a polypipe reticulation system were a purely private one, with a bore located on each property, a grazier could assess the likely costs and returns from the investment using net present value as a decision making criteria. Some graziers, especially in the arid zone, face this situation. The only externality the grazier would have to deal with a private production externality (the fall in the potentiometric surface) created jointly with other users in the sub-basin. The fall in the potentiometric surface leads to a reduction in the flow at the bore head and ultimately to the need to pump water. In an open access environment each user should recognise the production externality as they draw water from the same sub-basin. Voluntary agreements and/or amalgamation of users into Bore Trusts to internalise the production externality provides one solution. The group could voluntarily set limits on bore flow or limit consumption using pricing procedures or invest in the water saving technology.

A more common situation is where water users are already grouped in Bore Trusts and enjoy the economies of a bore shared among several graziers. These users face the production externality outlined above. They share the use of bore drains and experience a flow of externalities downstream. As discussed above, downstream users suffer problems associated with 'pollution' and unreliable water supply compared to the upstream users. Upstream and downstream users thus face different incentives when faced with a decision on replacing bore drains with polypipe. A further difficulty is the need for unanimity among members of a Bore Trust in the replacement decision. Different members of a Trust face different production, consumption and investment priorities and are subject to different financial constraints.

For the members of a Trust to make a unanimous decision to make the substantial investment needed to replace bore drains they must be convinced either that production benefits will make

[6] There is an associated waste disposal problem in this case.

their investment worthwhile, or that 'the government is going to step in' and force them to make the replacement for some 'environmental' reason. In the closer settled areas, on the margin between farming and grazing, the investment may be justified purely in terms of net private benefits associate with improved stock and cropping productivity (see Crisp, Kellaway, Madden and Batterham, 1994). The net private benefits are likely to be less apparent in the sparsely settled semi-arid and arid areas.

The financial constraints facing those individuals or Bore Trust members who wish to invest in the polypipe system are significant. In the area north of Moree the costs of a full scheme with water supply to each paddock have been estimated at about $25 per hectare on properties of ranging from 2,000 to 4,000 hectares. The individual graziers have to finance this cost as the Bore Trust has virtually no assets and no borrowing power[7].There may be some financial economies in setting up a scheme whereby Trusts borrow money for the work and amortise the cost in an addition to water rates. This mechanism is used by Shire Councils to finance the reticulation of town water[8]. The use of such a mechanism would obviously mean a very large increase water rates over the current charges. The water rate could be based on an annual connection charge (or a right) and on the use of water

Governments have taken a variety of actions to encourage Bore Trusts to replace bore drains with piped reticulation systems. Between them the Federal and State Governments pay 80 percent of the cost of rehabilitating a bore. In New South Wales, the Department of Land and Water Conservation has supplied a small subsidy by undertaking the design work associated with new reticulation systems. The government contributions presumably recognise externalities associated with the current use of water in the Basin.

Summary and Conclusion

The development of the Great Artesian Basin can be characterised as an initial period of a 'free for all' in a totally open access environment. This was followed by an initial period of concern about the rapid decrease in the potentiometric surface of the aquifer and the consequent reduction in water flow. State governments responded by attempting to set drilling and bore standards (presumably to reduce waste) and in some cases by licensing bores. Currently licensing provisions for bores are unevenly applied across state boundaries. In some cases the provisions of the license limit flow rates from bores and flow rates are monitored continuously or at random intervals. In other cases bores are not licensed although the flow may be monitored. In more extreme situations the location of unlicensed bores is unknown to State Authorities.

[7] Some graziers in New South Wales may be able to borrow through the NSW Rural Assistance Authority to finance the investment.

[8] The work by Crisp, Kellaway, Madden and Batterham (1994) included a survey of farmers and graziers in six Bore Trusts in the area north of Moree. It included questions on the financing of the investment in polypiping and a proposal that local Councils undertake and finance the work as part of their provision of water supply to the small towns of the region. All respondants were emphatically against such a proposal.

Concerns about the sustainabilty of the current use of water from the entire Basin have re-emerged. More needs to be known about the hydrology of the Basin before these concerns can be considered adequately in economic models. If there is a large resource with some relatively minor flow characteristics, it may be economically reasonable to 'mine' the resource. If water in the Basin is to treated as a flow resource, the hydrological characteristics of the flows must be known in order to specify the constraints required in an economic model. Economic models could consider competition for water for various end uses among the various sub-basins and show possible outcomes associated with the application of policy measures such as licensing of bores, volumetric restrictions, water charges and marketable water rights.

The most widespread use of the water from the Basin is for stock water. This water is an important input into the grazing industries of the semi-arid and arid areas of the Basin. Indeed it is difficult to see how the grazing industries in these areas could survive without artesian water. In some sub-basins users of stock water already compete with each other and with other uses of water in modified (by licensing of bores) open access environment.

In the past most of the stock water has been reticulated in bore drains which 'waste' water and are subject to some downstream externalities. Replacement of the drains with a polypipe reticulation system represents a major investment for most users. In many cases the replacement decision is complicated by the necessity for unanimity among members of a Bore Trust and by financing constraints. Further research is needed into institutional arrangements that might ease these complications. As competition increases for the use of water, the pricing of water or the allocation of transferable water rights will provide incentives for the possible adoption of the water saving technology.

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