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Evaluation of the economic feasibility of water harvesting for irrigation in a large semi-arid tropical catchment in northern Australia

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ABSTRACT

There is interest by governments and private organisations in exploring alternative models of irrigation in parts of northern Australia where there has been little irrigation development to date. One alternative is 'water harvesting', which is defined here as the practice of pumping or diverting water during streamflow events and either applying directly to a crop or (more commonly) holding water in off-stream storage on a property for later use. This study presents a detailed farm-scale bio-economic analysis of water harvesting using river system modelling to represent the interactions between farm-scale returns, reliability of extraction and scale of development. In doing so the farm-scale viability of irrigation within a whole of catchment is assessed, and uses the Flinders catchment, a large, semi-arid tropical catchment in northern Australia as a case study. Extraction reliability varied spatially across the catchment and decreased with increasing total catchment extraction. The farm-scale profitability of water harvesting enterprises was found to be particularly sensitive to fluctuations in price, reliability of water extraction, discount rate, cost of storage and timing of crop-failure years. For crops requiring off-site processing, the existence of local processing facilities was a major factor. This study also highlighted that for irrigation developments based on water harvesting there is potential for serious mismatches between the timing of streamflow and time at which planting must occur.

For the cropping scenarios modelled here for the Flinders catchment it was found that mosaics of irrigation based on water harvesting and off-stream storage are unlikely to be profitable, and short to medium season crops provided the best return, although still negative. This is because land developed for irrigation of short to medium season crops returns no income for six or more months every year, while for permanent cropping the cost of constructing a storage that could provide water for irrigation throughout the year is prohibitively expensive. Assuming an optimal water storage to pump capacity ratio of 5, it was found that if an additional 240 GL of water were added to the existing 105 GL catchment entitlement, most new irrigators could extract their entitlement in approximately 70 to 80% of years, discounting any environmental or legislative issues that would need to be addressed. At these reliabilities, most high value crops would require high prices to be sustained through the entire investment period (for which there is no historical precedent), to acquire a return equal to inflation. The method and results presented in this manuscript would be useful to water planners and regulators to help inform water allocation, pricing decisions and policy initiatives, particularly where agricultural development may be based on water harvesting.

1. Introduction

In order to feed the world's population in 2050 it is estimated that growth in food production must increase by 70% (FAO, 2009). Given finite land and competing uses, much expansion of food production will have to come from intensification of agriculture, including irrigation (FAO, 2009). Given the worldwide depletion of groundwater resources (Konikow and Kendy, 2005, Shah et al., 2000) it is anticipated by some that there will be an on-going requirement for new water storage structures (ICOLD, 2015). However, the rate of large, dam-based irrigation projects has slowed worldwide because of high capital costs, exhaustion of prime storage locations and environmental concerns (Watson and Merton, 2013; Burney et al., 2013, Turral et al., 2010, Kingsford, 2000, WCD, 2000). Globally, significant

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public investment in irrigation appears to be in decline, while there has been increasing preoccupation with devolution of the management, ownership and responsibility for irrigation systems to farmers, with increasing investments expected in on-farm water storage (Turral et al., 2010).

An alternative to large in-stream dams is 'water harvesting', which is defined here as being the practice of pumping or diverting water during high streamflow events and either applying directly to a crop or (more commonly) holding water in an off-stream storage on a property for later use. Off-stream storages can take the form of ring tanks, turkey nest tanks or excavated tanks (see Lewis, 2002), and can be defined as farm scale or on-farm water storages (e.g. commonly 1000 ML to 8000 ML capacity (1 ML = 1000 m^3) on commercial farms in Australia) where all of the water is either diverted or pumped into the storage structure from an adjacent drainage line. An advantage of off-stream storages is that they are often considered to be less environmentally damaging than in-stream dams. This is mainly because in the absence of a diversion structure off-stream storages do not create a barrier to the movement of fish or the transport of sediment downstream (Vorosmarty et al., 2003; Syvitski et al., 2005). Such irrigation using small scale, on-farm extraction, conveyance and storage infrastructure continues to expand in many developing countries, especially those in Africa, the Indian subcontinent and south-east Asia (de Fraiture and Giordano, 2014). In northern Australia where the majority of rivers are unregulated (Petheram et al., 2014), mosaics of small scale irrigation integrated within existing pastoral properties is seen by some as offering potential to increase production from Australia's northern cattle herd (Gleeson et al., 2012), which is the dominant agricultural land use in northern Australia.

A relevant feature of northern Australian hydrology is the high seasonality and inter-annual variability of streamflow (Petheram et al., 2008). Increasing variability of irrigation water supply tends to reduce irrigation profitability because capital costs of storage, conveyance and irrigation infrastructure per unit area tend to increase (Connor et al., 2012). Intuitively, as upstream extraction increases, downstream extraction reliability decreases, and at some scale of development the reliability of water extraction may decrease to a point where it is no longer profitable for individual farms to irrigate. Hence the profitability of off-stream storage irrigation enterprises will vary across a catchment, and can only be properly assessed using a whole of catchment river system model.

Although numerous studies have assessed the economics of large, dam-based irrigation, and generally found poor returns to investment (e.g. Davidson, 1972; Fan et al., 2007; Molle, 2008), the authors could not find any studies prior to this work that comprehensively assess the economics of dispersed on-farm storages and irrigation (i.e. mosaics of irrigation with about 500 ha of irrigated land per farm) across an entire catchment using a semi-distributed river system model. Because in Australia the diversion or use of surface runoff requires a water 'allocation' to be purchased, (an allocation is an authority established under a catchment water resource plan to take water) a method for assessing the economics of on-farm irrigation across an entire catchment would be useful to water planners and regulators to help inform water allocation and pricing decisions.

This study combines a detailed farm-scale bio-economic analysis with river system modelling to represent the interactions between farm-scale returns and extraction reliability. In doing so it presents a method for assessing the farm-scale viability of irrigation within a whole of catchment context under varying levels of water entitlement; and tests the sensitivity of economic returns to the scale of extraction, and other factors affecting the reliability of water extraction as well as to a range of additional factors that influence potential irrigation returns in the northern Australian setting including: crop choice, discount rate, commodity price, size of storage and pump, distance to crop processing, and sequence of wet and dry years. The method is demonstrated for the Flinders catchment, in northern Australia.

2. Case study area

The Flinders catchment (~109,000 km^2) was selected to investigate the potential of water harvesting for irrigated cropping in northern Australia because it currently has low levels of water resource development (<2% of median annual flow), there has been a long history of interest in irrigation in the catchment and there is limited scope for large in-stream dams to supply large-scale irrigation developments (Petheram et al., 2013). Extensive grazing is the predominant land use in the Flinders catchment and irrigation is seen by local graziers and councils as being a way of enabling regional development and arresting the decline in rural populations (Brennan McKellar et al., 2013).

In the Flinders catchment 88% of rain falls during the wet season (November to April), with highest median monthly rainfall occurring during January and February (~85 mm). The months with the lowest median rainfall are July and August, with about 0.5 mm each. Potential evaporation also shows a seasonal pattern. During October to January, Morton's areal potential evaporation (Morton, 1983) exceeds 180 mm per month in most years. The climate of the Flinders catchment is comprehensively described in Petheram and Yang (2013).

The climate and soils of the Flinders catchment are potentially suited to a wide range of crops (Webster et al., 2013). The median annual discharge at the mouth of the Flinders River is 1241 GL (Lerat et al., 2013) and extensive flooding occurs in the mid-to-lower reaches in wet years (Fig. 1) with 95% of streamflow occurring during the wet season. Current annual water entitlements in the Flinders catchment are about 105 GL, although it is estimated that less than 30 GL is actually used annually.

Unless otherwise stated all hydrological analysis were undertaken over a 121 year time period (1890 to 2011) using daily gridded climate data from the SILO database (Jeffrey et al., 2001) — an enhanced climate 'data bank' containing datasets that are based on historical climate data provided by the Australian Bureau of Meteorology. Annual values reported in this manuscript are based on water years (July to June).

3. Materials and methods

The analysis necessitated the following discrete steps.

1. A financial analysis, also known as an investment analysis, to assess the gross margins required for an irrigation enterprise to be profitable for a range of reliability of water extraction values, three crop season lengths and different pumping and irrigation application infrastructure (Section 3.1). The end product is a relationship between the 'break even' gross margin and reliability of water extraction for crops of different season length (primary control on size of storage) and infrastructure.
2. A catchment scale hydrological assessment to investigate how different levels of extraction and rate of extraction (i.e. ratio of pump capacity to storage capacity) within a catchment impact on reliability of water extraction at different locations within the catchment. Using information from Step 1 the gross margins required to return a profit can be matched to their corresponding catchment scale entitlements based on the reliability of water supply. The likelihood of an irrigation enterprise being profitable can then be determined by comparing the break even gross margin to gross margins for specific crops.

3.1. Farm-scale financial analysis

Farm-scale irrigation developments require capital investment in the form of equipment and infrastructure. Financial performance is assessed by calculating the net present value (NPV) of the difference between costs and revenues occurring over the lifetime of the capital