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THE ROLE OF MANAGED AQUIFER RECHARGE IN DEVELOPING NORTHERN AUSTRALIAN AGRICULTURE

CASE STUDIES TO DETERMINE THE ECONOMIC FEASIBILITY

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ABSTRACT

Managed aquifer recharge (MAR) is a commonly used technique in many countries to artificially increase the recharge rate over the wet season and hence increase the groundwater storage available during the dry season. Considering northern Australia's long dry season and relatively short wet season, MAR has the potential to play a major role in water resource development.

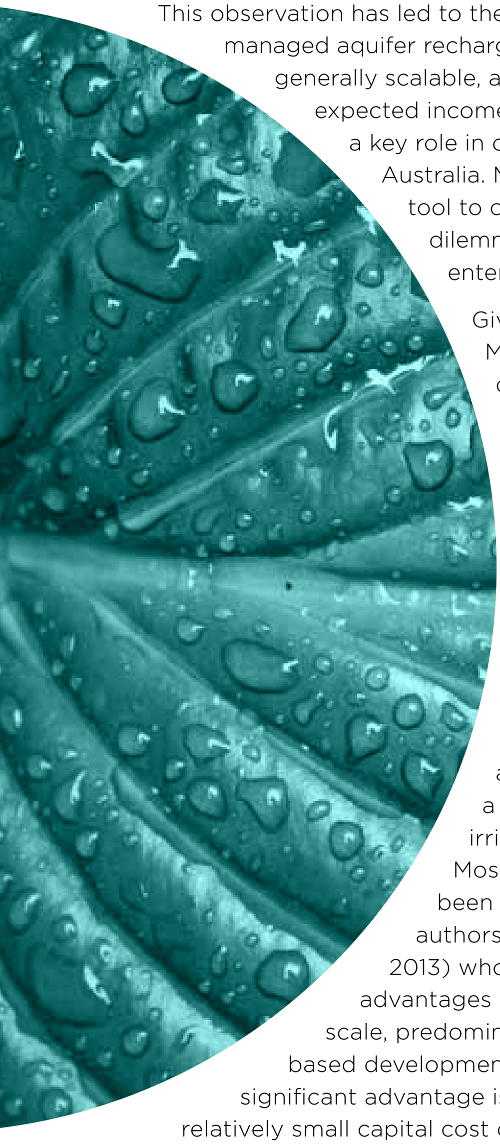
Shallow weirs, infiltration trenches and injection bores were considered as the main MAR methods. Five sites were assessed in the Pilbara and seven across the Northern Territory. After consideration of a range of factors such as the available source water, local hydrogeology, soil suitability and potential irrigation demand, most sites were considered technically feasible. A cost benefit analysis was completed on the feasible sites to determine the capital and operation and maintenance costs of water supply and on-farm benefits.

Preliminary costings estimated in the Pilbara show that with a weir, the annualised (levelised) cost to supply water to irrigate range between $77 and $282/ML. In the Daly catchment, preliminary costings show that, with a weir, the annualised costs to supply water for irrigation ranges between $166 and $575/ML. The calculated net benefit of fodder cropping is $110/ML, however, for horticulture (mango, Asian vegetables and melons) this ranges between $2,000 and $10,000/ML. The annualised costs suggest that MAR based irrigation schemes are more economically attractive for horticulture production.

INTRODUCTION

This paper describes a study to consider the role of MAR in developing irrigated agriculture in the Northern Territory (Daly catchment and Central Australia) and the Pilbara in Western Australia. The fundamental advantages of MAR based developments over conventional water sources (typically large dams) are the cost of transporting water, lack of evaporative losses, seasonal variability and the scalability of MAR projects. Conversely, impediments are believed to be primarily the economic feasibility rather than the technical feasibility. When compared to other water supply options, MAR can be attractive both economically and environmentally.

The perception of northern Australia of having abundant water resources, and hence huge potential for irrigated agriculture, has been around for decades. This has led to many large irrigation schemes, predominantly based on surface water development. However, most schemes fail for a variety of reasons. Ash (2014) and others point out that many of the irrigation schemes in northern Australia have failed because of cash flow. High initial capital costs (for example for large dams) require large returns to service the loans. Many of the failed schemes simply could not service the interest payments. In contrast, those schemes which started small and then slowly grew were able to meet their growing capital needs with gradually increasing income.



This observation has led to the thought that, as managed aquifer recharge (MAR) schemes are generally scalable, and can be sized to meet expected income flow, they could fulfil a key role in developing northern Australia. MAR could offer a useful tool to overcome the cash flow dilemma of private irrigation enterprises.

Given the scalability of MAR based irrigation developments, the implicit notion is that mosaic irrigation is preferred to large scale development. Mosaic irrigation is where individual relatively small scale irrigation developments are spread over large areas and hence in aggregate represent a significant area of irrigated agriculture. Mosaic irrigation has been discussed by several authors (e.g. Grice *et al.*, 2013) who point out the advantages over traditional large scale, predominantly surface water based development. Perhaps the most significant advantage is cash flow, whereby relatively small capital cost can be repaid by the income produced from irrigated agriculture. The mosaic concept allows the development to gradually grow in proportion to the income generation. The overall purpose of this study is to assess the technical and economic feasibility of small to medium scale water resource developments to support appropriate irrigated agriculture in specific locations in the Northern Territory and the Pilbara.

This study has been conceived in the context of four fundamental principles which control the technical and economic viability of irrigated agriculture in northern Australia:

1. **Transporting water is expensive**. Water is heavy. It is well recognised that pumping water is expensive and even long gravity fed systems require major capital investment and ongoing maintenance. Hence the goal in this study is to seek the lowest pressure pumping situations available and, as much as possible, to use the aquifer as the "pipeline". This generally means limiting the length of any supply channels to no more than several kilometres. It also means limiting pumping heads to less than 50 m ideally.
2. **Evaporation is very high.** Surface water bodies (dams, lakes, channels) in northern Australia lose a lot of water to evaporation. Evaporation rates of typically 3.5 m/year when the rainfall is only 0.5 to 1.0 m/year mean that any surface water body will lose a significant amount of water. This factor has driven the philosophy of storing as much water as possible underground where evaporation rates are effectively zero.
3. **Wet season variability is high**. There is considerable variation in the timing, magnitude and intensity of the wet season across northern Australia. A 'failed' wet season, where the actual rainfall over the months of December to April can be much smaller than the mean wet season rainfall, has significant impacts on stream flow (hence water supply) and agricultural water demand over the dry season. In the case of beef production this also controls the dry season dryland feed availability and hence fodder demand.
4. **The need for scalable water resource development.** As discussed previously a scalable development can address cash flow issues to ensure success in the long term.

These four principles have driven this project to be focussed on groundwater only, MAR and CWM (Conjunctive Water Management) as technically and economically viable options for Northern Australia. This suggests that mosaic type irrigation developments, rather than broad acre cropping, is likely to be preferred. However broad acre crops have also been considered where they appear to be feasible.

METHOD

Three principal MAR methods have been assessed:

Recharge Weirs

The purpose of a weir is to alter the characteristics of a channel and to create a pool of water for recharge to the underlying aquifer, while allowing excess flows to continue over the weir downstream. It is essentially a surface spreading technique that is aimed at increasing the contact area and residence time of runoff over the subsurface.

The purpose of this is to increase the total volume of water infiltrating the subsurface to enhance the total amount of recharge occurring to the underlying aquifer. Recharge weirs are commonly implemented in areas with permeable ground conditions that have a high infiltration capacity and the presence of a permeable unconfined aquifer. Figure 1 shows the concept for a typical recharge weir.

To minimise environmental impact the adopted design allows for rock ramps either side of the reinforced concrete structure to provide nature like structures providing fish passage and aquatic habit for local fauna through the simulation of a natural stream environment.

In general, recharge weirs are robust structures that require minimal maintenance and operative effort. General maintenance activities include the clearing of debris from the crest, removing fines from the upstream end of the weir, opening of the penstock valve to permit dry season/low flows and carrying out general repairs to the structure as required. The desilting process upstream is of particular importance as this is where the overflow is being pooled. Once pooled, sedimentation is likely to occur and be transported to the channel bed.

Infiltration Trench

The construction of infiltration trenches is an aquifer recharge technique that incorporates a shallow infiltration trench designed to capture stormwater or streamflow and allow it to infiltrate into the aquifer. This is achieved by enhancing the infiltration rate of runoff into the specific location of the trench. Even though relatively efficient at capturing runoff, the successful operation of infiltration trenches is heavily reliant on the hydraulic conductivity of the subsurface and the unconfined aquifer to be recharged.

Infiltration trenches are relatively low maintenance systems with the main mode of failure being the clogging of the system by fine grained sediments. This can be managed by introducing a vegetative strip to filter the runoff prior to infiltrating the trench.

Recharge Bores

Also known as injection bores, recharge bores are a subsurface technique commonly implemented in the managed recharge of aquifers. In comparison to surface spreading such as recharge weirs and infiltration trenches, injection bores are aimed at recharging deeper aquifers that are overlain by low permeability layers. The recharge technique involves the injection of water into the aquifer via bores that penetrate through the lower permeability layers. The primary mode of failure during the operation of recharge bores is either failure of the pumping/bore infrastructure or, pore clogging through the introduction of sedimentationor fines transported into the aquifer through the water being injected.

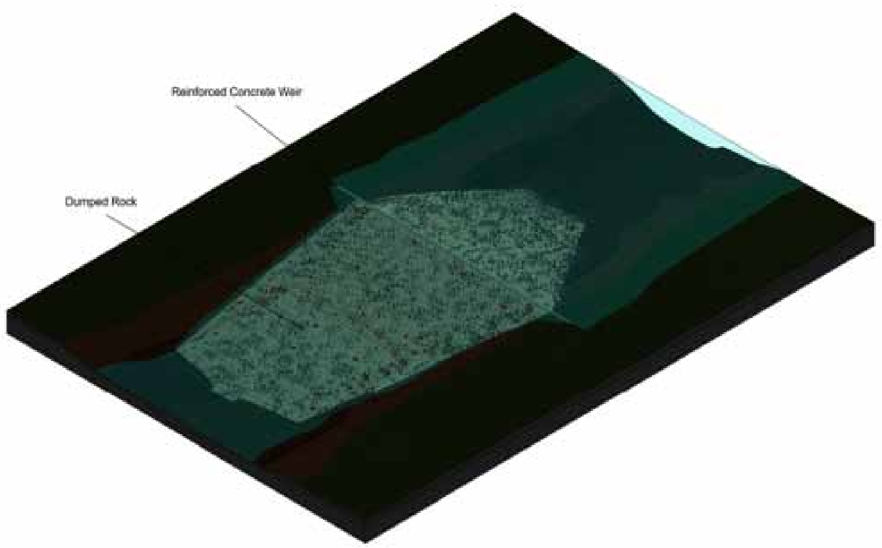


Figure 1. 3-D Concept of a typical Weir structure within an open channel

Site Selection

This paper focusses on the first phase of the study and involved undertaking a desk-top and limited field review to assess the relative merits of irrigation schemes supported by MAR/CWU at the identified locations in the Northern Territory and the Pilbara. This includes:

- Confirming the wet season flood harvesting potential
- Identifying sites with the greatest potential for MAR and CWU
- Confirming soil suitability
- Collating basic scheme level design features and high level costing information.

Phases two and three of the study involve detailed investigations and economic assessment of the most likely sites.

In the Northern Territory, seven areas were considered during Stage 1:

- Upper King River
- Lower King River
- Stray Creek
- Fergusson River
- Roper Creek and Elsey Creek near Mataranka
- Swim Creek in Wildman River catchment
- Ti Tree.

The location of these sites is shown in Figure 2.

Five sites were considered in the Pilbara:

- The lower Shaw River (downstream of "North Pole")
- Lower De Grey River (Upstream of Coolenar Pool to the junction of the Nullagine and Oakover Rivers)
- Lower Robe River (downstream of Pannawonica, including the area of the groundwater allocation plan)
- Fortescue River downstream of Opthalmia Dam and upstream of the Fortescue Marsh
- Weeli Wolli Creek downstream of the Yandi area mine dewatering discharge.

The locations of these sites are shown on Figure 3.

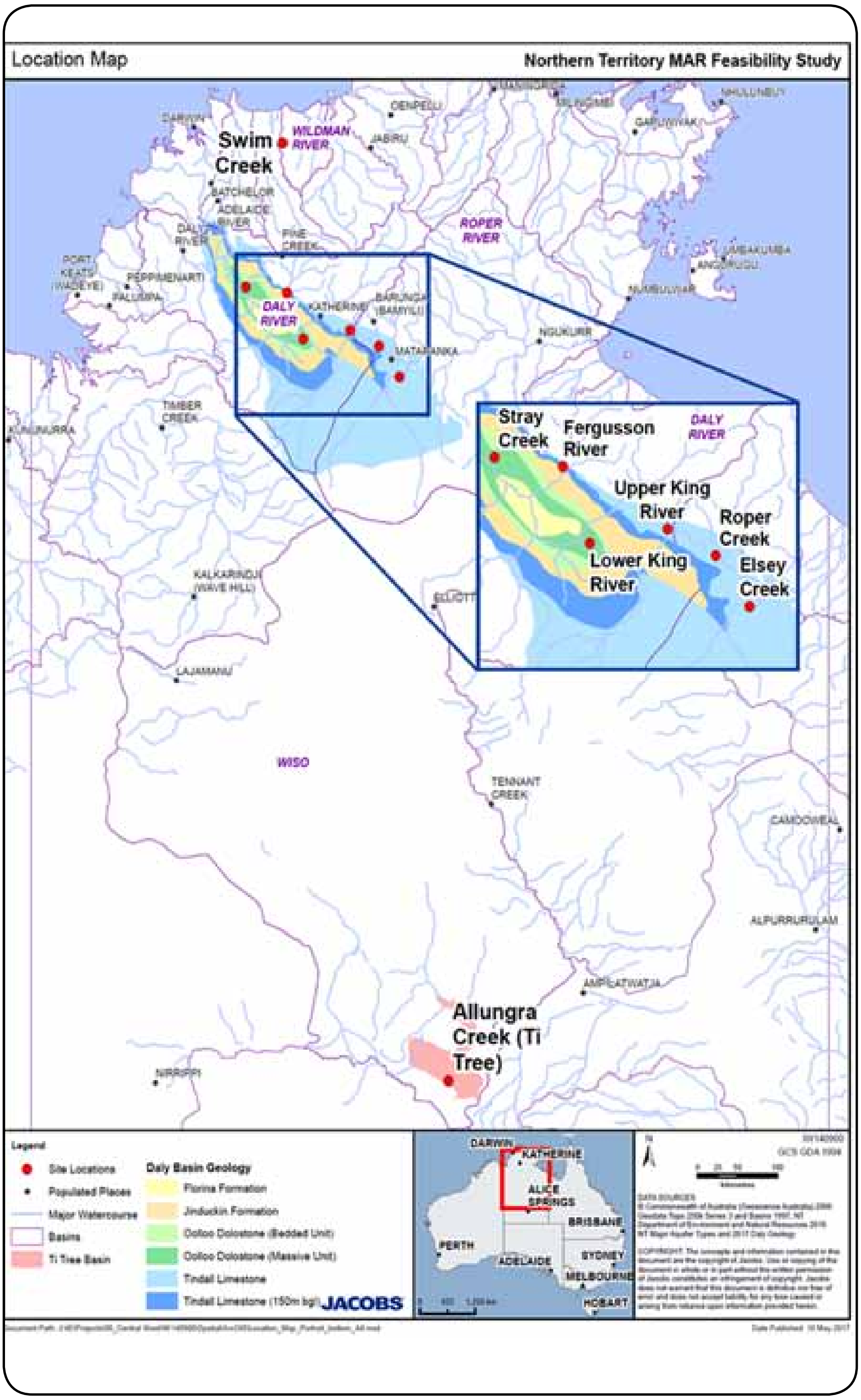


Figure 2. Location of sites in the Northern Territory

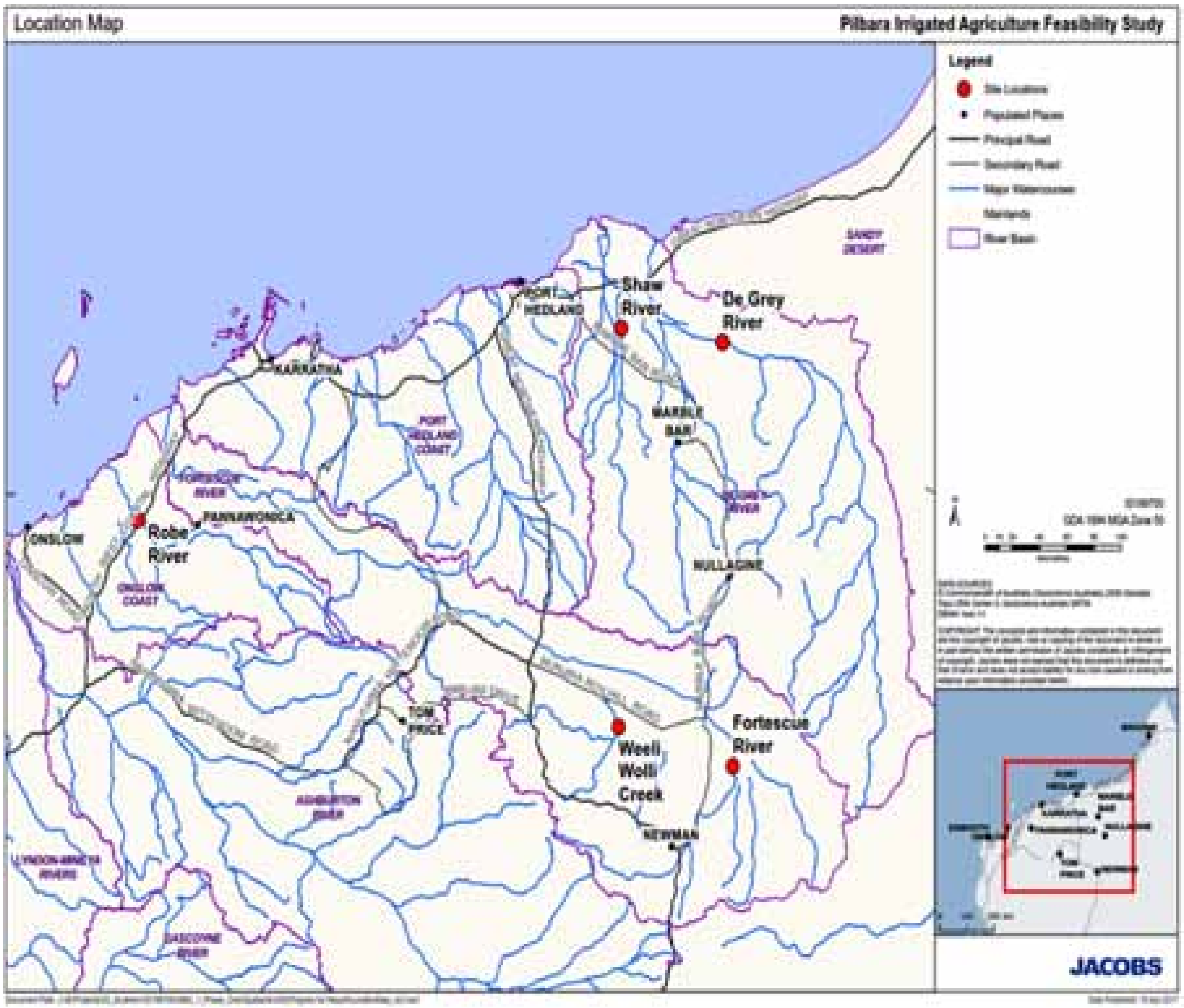


Figure 3. Location of sites in the Pilbara

RESULTS AND DISCUSSION

MAR is technically feasible at all 12 sites, although the volume of water that can be injected and recovered does vary. However the primary purpose of this study is to consider the economic viability of the resulting irrigated agriculture. Levelised costs (incorporating annualised capital and operation and maintenance costs) have been determined for all feasible MAR and CWU options, and net cash flow for specific crops have been assessed, as shown in Tables 1 to 4.

Table 1. Calculation of levelised cost for NT sites

	Upper King A	Upper King B	Lower King	Stray Creek	Fergusson A	Fergusson B	Ti Tree
Annual Volume of Supply (ML)	9,000	2,340	20,178	27,755	1,532	10,863	500
Annualised Costs							
Capex[1] ('000s)	$2,580	$1,710	$1,000	$1,290	$370	$2,570	$1,640
O&M ('000s)	$5,010	$1,290	$5,310	$3,730	$630	$5,420	$280
TOTAL ('000s)	$7,590	$3,000	$6,310	$5,020	$1,000	$7,990	$1,920
LEVELISED COST ($/ML)	$843	$1,282	$313	$181	$653	$736	$3,840

1. Discounted at 10% over 20 years

Table 2. Net cash flow for land use scenarios for NT crops[1]

Crop type	Area (ha)	NPV cash flow	Annualised cash flow	Water use (ML)	Cash flow ($/ML)
Mango	100	$5.2 M	$600,000	300	$2,000
Asian Vegetables	20	$2.0 M	$230,000	80	$2,900
Sandalwood	500	Unknown	unknown	5,000	Unknown
Melons	100	$35.0 M	$4,100,000	400	$10,000
Fodder crops	100	$1.4 M	$160,000	1,500	$110

1. Discounted at 10% over 20 years

Table 3. Calculation of levelised cost for Pilbara sites

	Robe	Shaw	DeGrey
Annual Volume of Supply (ML)	4,000	1,000	4,000
Annualised Costs			
Capex[1]	$135,307	$200,918	$111,146
O&M	$201,263	$81,435	$195,266
TOTAL	$336,569	$282,353	$306,412
LEVELISED COST ($/ML)	84.1	282.4	76.6

1. Discounted at 7% over 20 years

Summary of Northern Territory Sites

The cost to supply water using MAR in the Northern Territory sites was estimated to range from $181 per ML at Stray Creek to over $3,840 per ML at Ti Tree. The net cash flow associated with using water ranges between $100 per ML for fodder crops to $10,000 per ML for melons.

These findings demonstrate that MAR is likely to be feasible for all land uses apart from fodder cropping. Even the MAR scheme at Ti Tree, which is estimated to cost almost $4,000 per ML is economically justified given estimated cash flows for melons.

Of the Northern Territory sites that are economical, two have higher potential:

- Stray Creek weir
- Lower King River weir

Stray Creek

The downstream reach of Stray Creek where the creek flows over the northern Olloo Dolostone aquifer is considered to be the most prospective site. Analysis indicates that 5.5 GL could be recharged into the aquifer over the wet season with a single two metre high weir.

A series of five weirs could be used to recharge over 27 GL during the wet season. Assuming water demand is around 10 ML/ha, over 2,700 hectares could be irrigated. There is no shortage of suitable soils for irrigation in the Stray creek catchment. Within three km of the creek there are 9,000 hectares of arable soils, with an additional 14,400 hectares in the wider area.

The annualised (levelised) cost to supply irrigation water at Stray Creek is estimated at $181/ML. A range of horticultural development is economically feasible at this site with the calculated net benefit of mangos, Asian vegetables and melons of $2,000/ML, $2,900/ML and $10,000/ML respectively. Fodder cropping, with a net benefit of $110/ML, is not considered economic.

According to NT water policy, 20% of stream flow can be extracted for water supply purposes. The median annual streamflow is 570 ML/day and 20% of this is 114 ML/day. The recharge rate per weir is around 30 ML/day, which means under median flows, there would be three or four weirs operating over the wet season. When stream flow is lower than the median flow, one or two weirs would be required, or weirs would operate for short durations. When the stream flow drops below the 25th percentile, the recharge weirs may not be functional at all, which would mean there would be no additional groundwater recharge for every one in four years. The implications of seasonality and climate change will be considered further in Stage 2 of the study.

Further consideration would also be required to determine the implications of the Stray Creek Conservation area and potential regional impacts of changing this area from a groundwater discharge zone to a recharge zone.

Lower King River

The lower reaches of King River flow over the southern Oolloo Dolostone aquifer are also considered to be a prospective site for MAR. Analysis indicates that 10 GL could be recharged into the aquifer during the wet season with a single two metre high weir. Two weirs could be constructed on the Lower King River, recharging a total 20 GL over the wet season. Assuming water demand is around 10 ML/ha, around 2,000 hectares could be irrigated. The most suitable soils are located to the south of the King River, with at least 1,600 hectares of arable soil with few or slight limitations located close to the river.

The annualised cost to supply irrigation water around the Lower River is $313/ML. Similar to Stray Creek, a range of horticultural crops are economically feasible at this site.

The median annual streamflow is 610 ML/day and 20% of this is 122 ML/day. The recharge rate per weir is 56 ML/day, which means under median flows, both weirs could operate over the wet season. When stream flow is lower than the median, only one weir could be required, or both weirs would operate for short durations. When the stream flow drops below the 25th percentile, the recharge weirs may not be functional at all, which would mean there would be no additional groundwater recharge for every one in four years. The implications of seasonality and climate change will be considered further in Stage 2 of the study.

Other sites

A summary of the other sites in Northern Territory not recommended for further consideration is provided below:

- Recharge weirs on their own and in combination with injection bores were considered in the **Fergusson River** catchment. The annualised cost of suppling water ranged between $653/ML (recharge weirs) and $736/ML (recharge weirs and injection bores). This option is less attractive than Stray Creek and Lower King River.
- MAR was considered in the **Upper King River catchment** using surface water from both the King River and Roper Creek, together with Leach Lagoon for storage and injection bores into the Tindall Limestone aquifer. With an annualised cost of $843/ML using water from the King River and $1,282/ML using water from the Roper Creek, this option is considered less attractive compared to the Stray Creek and Lower King River.

- MAR was considered around **Ti Tree**, where groundwater extraction currently exceeds the sustainable yield of the aquifer. Recharge trenches were considered to capture surface flows in the Allungra Creek and its associated flood-out areas. However, with an annualised cost of $3,840/ML, this option is only economically feasible for melons.
- Recharge weirs were considered along **Roper and Elsey Creeks near Mataranka**. While technically feasible to recharge significant volumes into the Tindal Limestone aquifer with the Elsey Creek, suitable soils are not located in an area that would benefit from the additional recharge and there is a lack of understanding of the likely demand.
- A MAR scheme in the **Wildman River (Swim Creek)** would require groundwater development to occur first to lower groundwater levels during the dry season and create storage in the aquifer, before an MAR scheme would be effective.

Summary of Pilbara Sites

For the Pilbara sites, this study assessed an irrigation configuration using up to four, 40 Ha centre pivots located close to the river combined with a recharge weir. Preliminary costings were estimated which show that with a minimalist design weir, the annualised (levelised) cost to supply water to irrigate can range between $77 and $282 per ML pumped[1]. At the lower end of this, it is highly likely that this will be attractive for development, while at the higher end, the costs are not likely to be attractive. If the cost of a weir can be eliminated or substantially reduced, then the attractiveness increases significantly. Potential for managed recharge without a weir or at lower cost than has been assessed to date should be considered during Stage 2 of the project.

The calculated net benefit of the irrigation configuration tested is $76 per ML. This is a small benefit, which, when compared to the cost of water supply ($77 and $282 per ML pumped), makes the investment marginal.

The results indicate that three of the sites have potential for long term groundwater based irrigation that could be supported or augmented by managed recharge (MAR) from rivers, subject to the specific physical characteristics of each site. The other two sites appear not to be suitable for large scale groundwater extraction from the near river alluvial sediments, although a surface water source is present.

This makes them less attractive for MAR based schemes where the alluvial aquifer is used as the primary storage. They may still be suitable for irrigation when the availability of mine dewatering is considered and if other (deeper) aquifers are considered.

The three sites that have higher potential and are recommended for the Stage 2 assessment are:

- De Grey River
- Robe River
- Shaw River

A summary of the findings for these sites is as follows.

De Grey River

The De Grey River upstream from Coolenar Pool is considered to be the most prospective of the sites. Our analysis of the alluvial aquifer and modelled groundwater pumping indicates that the aquifer system is likely to support up to four centre pivots in close proximity and there is potential for multiple replicates of a four-pivot irrigation scheme along the length of the river. Hydrogeological conditions indicate that the alluvial aquifer is likely to be extensive and thick enough to support groundwater pumping of up to 4 GL per year at each irrigation site. Over the timeframe assessed, MAR via a weir could provide additional volume into storage. This is likely to be important in the long term viability of the sites but does not provide any additional benefits to the irrigation scheme within one season. Further, the economic assessment shows that it may be possible to break even with fodder crops and higher value horticulture should therefore also be economic and may be more attractive to investors.

Robe River

The Robe River in the vicinity of the Great Northern Highway is considered to be potentially feasible as there is sufficient alluvial aquifer system to sustain four GL or more of pumping, with MAR providing additional recharge that increases the sustainability of the scheme. Economic assessment has shown that with a narrow weir, this site could provide an economic irrigation scheme. Site inspections of the Robe River sediments have raised a concern that the infiltration rate through the river bed may be lower than needed for long term sustainability of intense irrigation. This aspect will need to be directly considered in the stage 2 studies.

Shaw River

The alluvial aquifer is thin beneath the Shaw River and is unlikely to be sufficiently transmissive to support extensive groundwater irrigation, with or without a weir. However, the far northern reaches of the Shaw are located where the alluvial system of the Shaw meets the De Grey and, in this area, the aquifer conditions are expected to be similar to those further upstream in the De Grey catchment and so should have at least the same potential as the De Grey River. At this stage, an irrigation scheme consisting of a single bore pumping 1 GL/year has been costed for comparison with other sites. A site for the stage 2 studies that is close to the confluence of the Shaw and De Grey Rivers would give the opportunity to assess the potential of both rivers and is recommended for further consideration in Stage 2.

CONCLUSIONS

Of the 12 sites selected for assessment, it is proposed that four be taken forward for further assessment. Although there are many technically feasible sites for MAR/CWU development to support irrigated agriculture, in many cases the levelised costs are high and consequently may not be financially sensible. Nonetheless this first phase of the study has identified significant sites that warrant further investigation. It is believed that MAR/CWU based irrigation development in Northern Australia is a technically and economically feasible approach.

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The PHADI project encompasses a range of biophysical resource investigations, economic analyses and regulatory reviews with the intent of de-constraining development. The project also includes practical irrigated systems research at the Woodie Woodie pilot site on Warrawagine Station in the East Pilbar

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