10 Irrigated agriculture: *development opportunities and implications for northern Australia*

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Maize crop, Katherine
Photo: Peter Thorburn CSIRO

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1. KEY POINTS

1. Northern Australia's soils have been highly weathered by millennia of monsoonal rain. They are typically low in organic carbon, have low water holding capacity and are highly erodible. These traits unite to provide soils that are susceptible to surface sealing and have low infiltration rates which, combined with the north's high rates of solar radiation and evaporation, confer on crops a low water use efficiency. In the north's severely water-limited environment, this poses a strict limitation on the expansion of irrigated agricultural development.

2. While there is potentially *ca* 17 million ha of soil suitable for annual crops, and as much as *ca* 32 million ha suitable for forestry, there is probably only water sufficient to exploit *ca* 60,000 – 120,000 ha, or <1.0% of this potential via irrigation. Rainfall is not sufficient to support crops in large tracts of northern Australia. Water, rather than soil, is the resource that limits irrigated agricultural development in northern Australia.

3. The available water resource may be sufficient to enable a two- to four-fold increase of northern Australia's existing irrigated cropping industry. Within 20 years a doubling of its size could increase gross regional product by $185 m (136%), create an additional 1,400 full-time equivalent jobs and increase regional population by 2,200 people.

4. Groundwater appears to be the source of water most likely to sustain new development of irrigated agriculture. Whereas surface water favours development of a small number of centralised irrigation schemes (such as the Ord River Irrigation Area), groundwater is best suited to supporting a larger number of small scale and widely dispersed irrigation developments; often called 'mosaic' irrigation.

5. The application of mosaic irrigation is logically attractive but largely untested. Its advantages over larger schemes include the potential to reduce salinity, erosion and runoff. Its small scale makes it within reach of private investors, which may induce capital and operating cost efficiencies that can escape larger public schemes. Its small scale also makes it well suited to the adaptive management that may be required in the north: the costs of 'learning by doing' are probably more bearable than in larger schemes.

   The potential disadvantages of mosaic style irrigation development include the possibility that it reduces water use efficiency through enhanced advective losses. Its distributed nature may mean that it less able to provide for industry 'hubs' around which the soft and hard infrastructure that support new industries can develop. On the other hand, its distributed nature may help the already well-established beef industry to increase productivity and capital efficiency, by improving the amount, quality and timeliness of feed supply.

   It is not clear whether biodiversity and conservation values are enhanced or reduced by the use of a smaller number of larger irrigation schemes or a larger number of distributed activities.

6. Humans have practised irrigation for 5,000 to 7,000 years. It has rarely been sustainable, though it has been variously acceptable, desirable and necessary. The problems of irrigation – including salinisation, local-scale waterlogging, nutrient depletion and the degradation of surrounding landscapes through water depletion – usually take a long time to become evident and, though examples of it are rare, even longer to ameliorate.

It is possible that the ‘problem’ of irrigation is less that it is not sustainable than that we persistently pretend that it is. Positing irrigation design and management on the assumption that it is sustainable may lead us to conceive and operate it in ways that do not maximise its many benefits or minimise its various disadvantages.

Whether or not irrigated development proceeds, and whether or not it occurs via large schemes or irrigation mosaics, it is critical that it does not repeat *all* of the errors of previous irrigation developments. *Some* of the impacts of irrigation are unavoidable as they are inextricably linked with consumptive water use.

2. PROLOGUE

Australians have long dreamed of substantial agricultural development in the north of our continent. In the historical public mind, its abundance of soil and water have been wasted and, 'if we don't use them, someone else will'. Surely northern Australia has the potential and, given the spectre of global food shortages, perhaps even the duty to be the Nation's new food bowl?

Public perceptions are not always well informed. The nature, extent and current uses of soil and water are dealt with elsewhere in this report and suggest that the northern landscape supports a multitude of uses and values (Indigenous livelihoods, tourism, fishing, mining, terrestrial and aquatic conservation, amongst others.). It is not being 'wasted'. Furthermore, the north already contributes significantly to the world's larder. If northern Australia were a country, it would be the world's seventh largest beef exporter [Calculated from (1).] The story of agricultural development of the north is therefore variously one of outstanding success, unrealised potential or over-reach, depending on one's point of view.

3. INTRODUCTION

This chapter describes cropping in northern Australia from a land and water perspective. It draws on a brief history of its irrigated agriculture before outlining its current status and potential development trajectories, based largely on opportunities and constraints as they are currently applied and understood[1].

It explores the positive and negative impacts of these possible trajectories, outlining methods by which benefits can be maximised and negative outcomes minimised. We conclude with a brief summary of critical knowledge gaps.

As in southern Australia, irrigated agriculture is economically and socially significant in many parts of northern Australia. In most other ways, however, northern Australia is fundamentally unlike Australia's traditional cropping areas. Profound differences exist in the climate, soils and history of the existing southern and potential northern cropping regions.

The south's comparatively moderate climate enables the majority of its crops to be grown profitably without irrigation. This has not proven feasible at any comparable scale in the temporally arid north, where the yield of dryland crops is typically 2 to 5 times lower than that of irrigated crops (2). The soils of the south, while not of uniformly high standard, tend to be newer, less weathered and therefore more nutritious than those of the north. Notwithstanding these stark biophysical distinctions, it is the different histories of the north and south that provide the most telling contrast.

Substantial development of the south occurred much earlier than in the north. Consequently, the north has had a shorter period in which to 'find its feet', and to build the hard and soft infrastructure required to support a significant non-grazing agricultural industry. More importantly, it means that the south was developed by and for a different society. That society was unashamedly and, some argue, necessarily pro-development. It was willing to promote wide-scale landscape transformation,

[1] We have not, for instance, taken into account a range of unforeseeable future technological developments that may enhance agricultural potential. We are similarly unable to estimate the costs and hence attractiveness or rationality of irrigating the landscape. The possibilities for both are excessively wide and subject to unpredictable change.

and to subsidise the inputs and infrastructure required to initiate it and the markets required to sustain it in its infancy (3).

Society has changed markedly since the years of widespread agricultural development in the south. In the 20^{th} Century, agriculture's contribution to the Nation's gross domestic product (GDP) contracted ten-fold, from 30 to 3% (4). As a consequence, popular and political support has diminished and, where attention was once paid only to the 'upside' of agriculture, its negative consequences now command closer scrutiny. Experience with the widespread and irreversible degradation of the Murray-Darling's waters and surrounding landscape has made society wary of agricultural developments, particularly those based on irrigation. Changes in domestic political paradigms and international agreements have made direct and indirect subsidy of agriculture less attractive. Evidently, this present study of agricultural development in the north must swim against, rather than with, the tide that supported agricultural development of the south. So it is not possible to simply compare future development in the north with that which has occurred in southern Australia. Land that was suitable for agricultural development in 1900 would not be deemed suitable for agricultural development today; society would not support the financial, physical or social costs required to subdue it.

But if we were to go back in time, and consider a scenario where we developed the north before the south, in the 1800s rather than the 2000s, how would it differ? This analysis would not be concerned with impacts on the environment, sustainability or the potential impacts on (or perhaps even existence of) other people or industries. Tourism, so significant today (*ca* $2.8 billion p.a. in northern Australia), did not exist. Prior ownership by Indigenous people was not widely recognised. The fate of the colony would have hinged on the success of the agricultural enterprise, so technical obstacles and the means to overcome them would have been identified. Much of the north's vast water resources and tracts of land would be available for agricultural production, and society would seek to mobilise the economy and its full technical armoury to achieve it.

According to the figures presented elsewhere in this report by Wilson et al., up to 18 million hectares of northern Australia has soil that is potentially suitable for agricultural production. Realising that potential would require vast reserves of fertiliser and the storage, transmission and application of enormous volumes (*ca* 200,000 GL; 100% of that annually flowing down the north's waterways (5)) of irrigation water. Even if that were technically feasible, in today's society, it is unlikely to be cost-effective or acceptable on environmental or other grounds. Consequently, this chapter does not consider the unconstrained potential of the north.

Our analysis is necessarily incomplete. It does not explicitly explore the potential for expansion of rainfed or dryland agriculture, which currently comprises about half the cropping area in northern Australia. The potential for this has been explored in detail elsewhere (6) and the significant advances that continue to be made in dryland cropping (2), and which may support expansion of that industry, are beyond this report's terms of reference.

The authors know that it is not possible to foresee with any considerable accuracy the arcs of actual future development in the north. Entrepreneurs exist to prove so-called 'experts' wrong. The vastness and variability of northern Australia provide ample opportunity for the development of innovative methods for profitably undertaking irrigated agricultural enterprise, using methods not foreshadowed here.

4. A BRIEF HISTORY OF AGRICULTURAL DEVELOPMENT IN NORTHERN AUSTRALIA

4.1 A general history

From about 1880 a wide range of crops was tested in northern Australia, with many showing promise, but only peanuts, tobacco, cotton and rice persisting. Peanuts were the biggest success prior to World War II, occupying some 600 hectares prior to the outbreak of war (7).

Immediately after World War II there was a strong political will to 'develop the north', and a review of previous cropping failures identified the causes of failure as (8):

- environmental: a formidable climate, unsatisfactory soils, floods and droughts, widely varying topography
- economic: isolation from markets, transport costs, the lack of marketing
- social: unattractive social and living conditions.

From the end of World War II there have been six large scale agricultural developments in northern Australia. Some regard them as failures because they did not meet the unrealistic expectations of the time. The reasons for their failure read rather like a washing list of 'traps for young players', and reflect the 'frontier' nature of the enterprise. They included: poor agronomic practices; poor administration; severe climatic hazards; poor agronomic knowledge of the soils and crop responses to the environment; unreasonable production targets; inefficient labour use; poor site selection; lack of sufficient water; poor water control leading to erosion; soil nutrient deficiencies; high costs due to isolation; excessive capital expenditure; use of unsuitable soils; and unrealistic expectations for market price (9). Not all of these difficulties have diminished with time.

Socio-economic limitations to agricultural development are evident in small, dispersed populations that have a limited tradition of agricultural knowledge. Regionally, agriculture depends on skilled and experienced practitioners who have access to communications and agricultural transport infrastructure to provide contact with markets and agribusiness support networks. Gone are the days when farmers could grow a crop and sell it to a monopoly statutory marketing authority. These socio-economic impediments to agricultural enterprise are exacerbated by fluctuating political support for northern industries, poor social facilities and an uncomfortable climate (6).

The post World War II review of agricultural development in northern Australia suggested that success would require demonstration of stable production, adequate and regular markets, organisation of transport and marketing and government assistance to provide a standard of living to sustain a 'virile population' (8). Further analysis of the six major attempts at irrigated agriculture in northern Australia suggested that success required expansion through smaller developments, coupled with a research program focused on the potential broad-scale (i.e. whole of system) agriculture problems, allowing operators to use adaptive management to learn-as-they-go, use resources efficiently and minimise economic and climate risk (9). These are remarkably similar to the pointers for success provided by the Daly River Management Advisory Committee in their chapter of this report.

4.2 The Ord River Irrigation Area

The Ord River Irrigation Area is the north's largest irrigation scheme and, hence the primary source of irrigated agricultural experience in the region. We explore its history to learn from its successes and pitfalls.

The Royal Commission of 1940 identified 40,000 ha of potentially irrigable land in the Kimberley. Agreement between the WA and Commonwealth Governments led to the completion of the main Ord River dam, with a capacity to irrigate 70,000 ha, in 1971. Roads and infrastructure were built, farmers were recruited and cotton was first planted in 1963, supported by the smaller Diversion Dam, completed in 1963. Twelve thousand ha of cotton had been established by 1973. Increasing production costs, mainly due to pests, and marketing difficulties had put most farmers on the scheme into serious financial difficulty and cotton production stopped in 1974. Through the 1980s the range of crops expanded, horticultural crops were added, marketing improved, farming became financially profitable, and the farmed area increased. Production and marketing strategies focused on crops with high value per unit weight (to reduce transport costs) and other crops that could be produced out of season were grown for domestic and international markets (10).

Lake Argyle, formed behind the main dam, became a tourism asset (and a Ramsar site because of its wetland values), and its water was also used by the Argyle diamond mines. The agricultural potential of the area remained unrealised, however, and in 1990/91 the total area cropped was only 4,400 ha, 6.3% of the potentially irrigable area. Between 1958 and 1991 the Scheme incurred a net combined private and public loss of $497m at zero discount rate. It also represented a heavy subsidy of farming enterprise, with the public loss totalling $511m and the private benefit $14m at 1991 prices) (10). Correcting for inflation, 2009 equivalents are a combined public private loss of $687.2m, a private benefit $18.8m, and a public loss of $668.2m.

Davidson had predicted the economic failure of the Ord River Irrigation Area and the reasons for it, in 1965 (11):

> *it would be cheaper to pay people to live in the area and do nothing, than to subsidize farming in the region.* (page 279).

His predictions proved correct for the first several decades of the scheme, but more recent analysis has shown that the Ord scheme has more recently become economically defensible, and even attractive. Hassalls and Associates in 1993 estimated a positive internal rate of return to combined public and private investments of between 3% and 5% for the period 1959-2021 (10). Their estimates of the internal rate of return for the period 1991-2021 were between 36% and 61%. These very favourable estimates were based on what they saw as much better prospects for the scheme resulting from the new production and marketing strategies then being adopted.

Since then the Ord Irrigation Area has spread to 15,500 ha growing a range of field and horticultural crops. The gross value of agricultural production in 2007-08 was $96m. We have not been able to obtain an economic analysis of the Ord Irrigation Area between 1991 and the present, but the WA Government is investing $220 m, and the Commonwealth Government $195 m in Phase 2, while acknowledging past failures in the Ord as well as the Murray Darling Basin (12). Favouring success are proximity to Asian markets, and the availability of land, water and pest-resistant crops. Against these advantages are set large distances for inputs and outputs, pest and disease threats, storm risks, and salinity hazard. The Scheme is expected to spread to 28,000 ha and, at this scale, may support local processing industries.

The past failures and more recent successes of the Ord River Irrigation Area provide obvious lessons for future development of agriculture in northern Australia. Major errors of judgement were made early in the investment process. The results from small experiments on research stations were seen as sufficient to justify investment in a large project. Resources were committed irreversibly without pilot projects to test the soundness of the investment. Dissenting opinions – Davidson was not alone (outlined in the Cook-authored chapter of this report) – were ignored or actively suppressed by organisations and individuals paid to act in the public interest.

The most important lesson, though, is not contained in the specifics of the Ord experience. It is that each generation of decision makers faces uncertainty, and that we must expect the unexpected. We can, however, narrow the odds. We do know that the world's population is increasing, fossil fuel reserves are declining, water resources in many countries are over-allocated, and the area of arable land may be declining because of degradation. These changes in the availability of resources are expected to be magnified by climate change (13).

With that in mind, we can prepare ourselves for an uncertain future by recognising that:

- there is often a long lag between a cause, such as a land use change, and an effect – such as salinisation of soils. In the Goulburn Broken catchment the lag has been 130 years (14)
- many impacts are cumulative – for example breakdown of soil structure under cultivation
- most impacts interact with each other, often with surprising results
- some changes are marked by thresholds, so the system can appear to function normally until a threshold is crossed. Threshold changes can be irreversible on a human timescale. Water table level is an example.

An alternative history of agricultural development in northern Australia is provided in the Cook-authored chapter of this report.

5. CURRENT STATUS OF IRRIGATED AGRICULTURE IN NORTHERN AUSTRALIA

The quantity and value of irrigated agriculture in northern Australia is small by national standards yet it is significant in its contribution to the regional economy.

5.1 Northern Australia, total

The current value of irrigated agriculture in northern Australia is in the order of $160 million annual production, which represents around 0.8 per cent of the regional total economic activity. Employment currently generated by irrigated agriculture, directly and indirectly, is estimated to be approximately 1,700 full-time equivalents (ftes). This represents around 1.3 per cent of the region's total labour force. Environmental impacts, and conflicts and synergies with a wide range of interests (Indigenous, tourism, recreation, conservation, mining and fishing) are all small because the irrigated area is also small (*ca* 34,000 ha; <0.03% of northern Australia).

The value of agricultural production is dominated by perishables such as mangoes and melons ($40 and $32 million respectively) with sugar, ornamentals, vegetables and fodder production worth about $15 million annually each (15) (16). Sandalwood is currently worth almost $60 m. By way of contrast, beef cattle production in northern Australia is worth in the order of $1 billion annually ($750 million in northern and north western Queensland, $190 million from Northern Territory and $60 million from Western Australia) (15) (16) (17).

Irrigated production accounts for about half the area devoted to cropping in northern Australia (34,000 ha) (18), yet it provides over 75% of the value of agricultural production (19). Furthermore, within the irrigated area, the value of production is not closely related to the land devoted to it. Fruit and vegetables each occupy only 5% of the area (Table 1), yet respectively contribute 26% and 49% of the total value of irrigated production. Crops and pasture, by contrast, occupy 80% of the area yet contribute only 25% of the value of irrigated production.

Table 1 Summary of irrigated agricultural production area in northern Australia, 2005/06[a]

Irrigated Agriculture	Northern Australia ('000 ha)	State components ('000 ha)			Australia ('000 ha)
		WA	NT	QLD	
Cereal crops cut for hay	0	0	0	0	61
Cereal crops for grain or seed	1	1	0	0	286
Cereal crops not for grain or seed	0	0	0	0	28
Cotton	0	0	0	0	270
Fruit trees, nut trees, plantation or berry fruits	11	1	5	5	139
Grapevines	0	0	0	0	183
Nurseries, cutflowers or cultivated turf	0	0	0	0	15
Other broadacre crops	2	1	0	1	55
Other crops	0	0	0	0	14
Pasture for grazing	3	0	0	3	814
Pasture for hay and silage	2	1	0	1	217
Pasture for seed production	0	0	0	0	39
Rice	0	0	0	0	102
Sugar cane	9	5	0	4	210
Vegetables for human consumption	2	1	0	1	109
Vegetables for seed	0	0	0	0	5
Total crops	30	10	5	15	2,546
Tropical forestry[b]	4	4	0	0	4
Total	**34**	**14**	**5**	**15**	**2,550**

[a] Due to confidentiality, excludes some area of irrigated agriculture that was not published. Total area may be understated.
[b] Principally sandalwood for 2007/08.
Source: (18) (20).

At the time of the 2006 ABS Agricultural Census, approximately one-third of agricultural businesses (including livestock) in northern Australia were actively involved in irrigation, that is, almost 900 farms (Table 2).

Table 2 Irrigation activity in northern Australia, 2005/06[a]

	Northern Australia
Agricultural businesses (n)	2,329
Agricultural businesses irrigating (n)	888
Area of agricultural holding ('000 ha)	94,409
Area irrigated ('000 ha)	32
Volume applied (ML)	192,536
Application rate (ML/ha)	6.0

[a] Includes livestock and livestock products but excludes forestry products.
Source: (18)

Total agricultural water use in northern Australia is only 2% of Australia's agricultural total (Table 3). Approximately 223 GL of water was used to irrigate crops in northern Australia in 2005/06, 65 per cent in WA, 28 per cent in QLD and 6 per cent in NT. The average rate of application was *ca* 6.5 ML/ha, which is thought to be a considerable underestimate. Sugar cane (41 per cent of irrigated water use in northern Australia), tropical forestry (18 per cent) and fruit and nut trees, plantation and berry fruit (18 per cent) accounted for the majority of the water used for agriculture in northern Australia.

Table 3 Water use by crop type, 2005/06

Irrigated Agriculture	Northern Australia	State components (GL)			Australia
	(GL)	WA	NT	QLD	(GL)
Cereal crops cut for hay	0	0	0	0	139
Cereal crops for grain or seed	12	12	0	0	695
Cereal crops not for grain or seed	0	0	0	0	59
Cotton	0	0	0	0	1,735
Fruit trees, nut trees, plantation or berry fruits	41	3	14	23	630
Grapevines	0	0	0	0	633
Nurseries, cutflowers or cultivated turf	0	0	0	0	82
Other broadacre crops	12	9	0	2	167
Other crops	0	0	0	0	29
Pasture for grazing	10	0	0	10	2,888
Pasture for hay and silage	5	4	0	1	799
Pasture for seed production	0	0	0	0	140
Rice	0	0	0	0	1,253
Sugar cane	91	66	0	24	1,057
Vegetables for human consumption	12	9	0	2	417
Vegetables for seed	0	0	0	0	15
Total crops	182	104	14	63	10,737
Tropical forestry[a]	41	41	0	0	41
Total irrigated agriculture	223	145	14	63	10,779

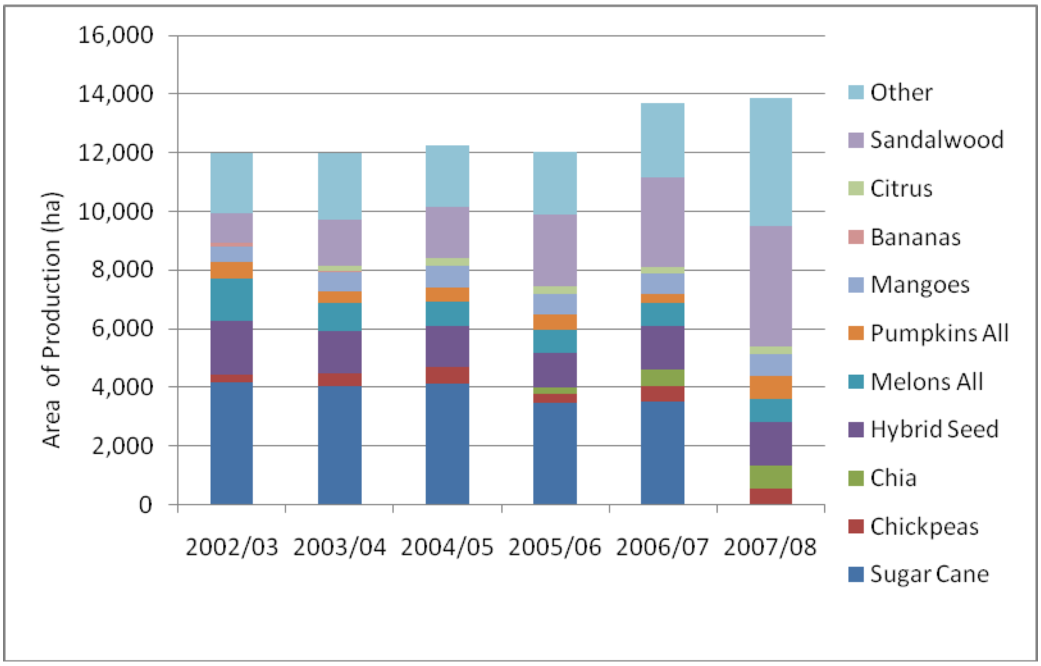
[b] Principally sandalwood for 2007/08.
Source: (18) and EconSearch analysis.

5.2 Ord River Irrigation Area

The largest area of irrigated agriculture in northern Australia is the Ord River Irrigation Area (ORIA), situated on the silty floodplains of the lower Ord River in northern WA, approximately 450 km from Darwin, the nearest large centre. The ORIA had almost 14,000 hectares of land under irrigation in 2007/08 (Figure 1) (21). The current area under irrigation is referred to as Stage One of the ORIA. The Government of Western Australia approved Stage Two of the ORIA in 2004, which involves the development of an additional 30,000 hectares of land (22).

The Ord River irrigation scheme is often referred to as a failure. However, farmers have adapted from the early stages of development and are now growing crops that suit the environment and markets. A significant change in recent years has been the cessation of sugar cane production (in 2007/08). This followed closure of the sugar mill at Kununurra that was not able to operate competitively due to depressed sugar prices and insufficient throughput for efficient mill operation.

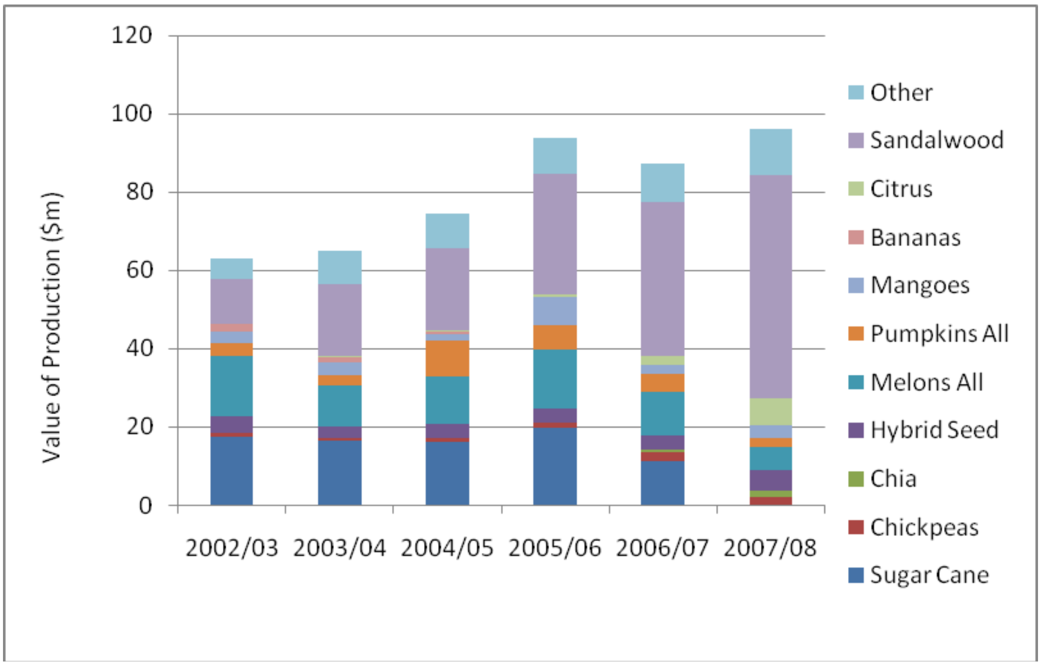
Figure 1 ORIA cropping area, 2002/03 to 2007/08



Source: (21)

The value of crops grown in the ORIA is illustrated in Figure 2. The introduction of sandalwood has been a success for farmers in the ORIA. Sandalwood is a high value, low volume product that delivers high returns (23). The value of sandalwood from the ORIA has grown from almost $12 million in 2002/03 to approximately $57 million in 2007/08 (Figure 2) (21).

Figure 2 Value of ORIA crops, 2002/03 to 2007/08



Source: (21)

5.3 Other irrigation areas

The Katherine-Douglas-Daly-Area (KDDA) is situated within the Daly River catchment in the NT. Development in the area is restricted to two areas, one near Katherine and the other at the intersection of the Douglas and Daly Rivers. The KDDA has an irrigated area of approximately 2,200 hectares (22). Most agricultural industries in the Northern Territory are in a developmental stage with low irrigated area, crop production and grower numbers. Most production systems are still evolving (24). Horticulture is the dominant agricultural commodity in the NT and has seen rapid development over the last 10 years.

In the Mitchell catchment in northern Queensland there is a small area of irrigated agriculture (ca 9,000 ha), situated in the Upper Walsh part of the Mareeba-Dimbulah Irrigation Areas (MDIA). Irrigated agriculture is limited to this area because of the geographical distribution of the soil type, reliability of water supply, and human settlement. Crops grown include peanuts, avocado, banana, grass seed, stone fruit, coffee, tea tree, sugar cane, navy beans, citrus, mango, macadamia nuts and grapes (25).

Although the Lower Burdekin is not situated within the defined region of northern Australia, for the purpose of this report it is worth mentioning as it is one of northern Australia’s largest irrigation areas with 80,000 hectares of land under cultivation. The region has a long history of growing sugarcane and is northern Australia’s most established irrigation area (22).

There are small areas of irrigated horticulture near Broome and Derby. Developments of irrigated agriculture have also occurred on pastoral leases throughout northern WA. These developments have generally been less than 100 hectares and of secondary significance in the overall operation (a requirement under the terms of a pastoral lease). There has been increasing interest from pastoralists to diversify their operations and this will inevitably lead to more agricultural development on these stations (26).

6. CROPPING IN THE NORTHERN AUSTRALIAN ENVIRONMENT

6.1 Soils

Most of the potentially arable soils in northern Australia are infertile relative to those of southern Australia (27). Northern Australia’s ancient soils have been highly weathered by the millennia of monsoonal rain occurring since they were formed. Amongst the traits that are difficult to ameliorate with management, they are typically low in organic carbon, have low water holding capacity and are highly erodible. These traits combine to provide soils that are susceptible to surface sealing, have low infiltration rates and, consequently, support crops with low water use efficiency. As a partial consequence, opportunities for enterprises based on rainfed crops utilising stored soil moisture are limited and many have proven to be only marginally economically sustainable (6). Amongst the traits that can be ameliorated by management, the soils of northern Australia are particularly deficient in macronutrients such as nitrogen (N) and phosphorous (P) (6). Utilisation efficiency of these nutrients is likely to be lower in the north than in the south because, amongst other things, intense rainfall tends to favour loss through leaching, gaseous emission (N) and erosion (P).

The low water and fertiliser use efficiencies furnished by northern Australia's generally poor soils increase the cost and risk of crop production and its off-site impacts.

A more comprehensive description of soils is given in the Wilson *et al*. chapter of this report.

6.2 Climate

Northern Australia's rainfall is highly seasonal. Over 90% of the rainfall is received in the wet season (November to April) and rainfall in the dry is small and unreliable. High intensity thunderstorms are common in the early wet season and cyclones, which result in several days of continuous very heavy rainfall, can occur during the wet season. Despite the ready availability of rain, the wet season is not favoured for production of most crops in most of the north. The high and protracted wet-season rainfall causes myriad production problems that include waterlogging, flooding, difficulty with farm traffic, direct crop damage, erosion and – because roads are often cut during the wet – difficulty in transporting inputs and produce. Irrigation of dry-season crops is the favoured production method where possible.

In the dry season, during which most irrigated crop production would occur, high solar radiation levels in northern Australia promote high growth and yield. A location such as Katherine receives *ca* 25% more solar radiation each day during a May-October growing season than a southern wheat belt location such as Merredin (WA). This can considerably increase the growth and yield of fodder crops (that are harvested before the plant senesces), but needn't (for reasons outlined below) provide for higher grain crop yields. Unfortunately, high levels of solar radiation also promote high soil temperatures (40-60°C) that are lethal for seeds and seedlings (28). Overcoming this difficulty exercised the minds of agricultural scientists during the 1970s, and their solution involved the use of mulches and minimal tillage (6), both of which are still recommended today (2).

The north's high temperatures are well above those that could be considered optimum for production of most crops. Given adequate water and nutrients, most crops can survive temperatures >40°C, but even tropical crops such as maize reach maximum yield at temperatures <25°C (29). The reduced yield per crop that can be expected of many traditional 'terminal' crops (i.e. those that are harvested when the crop is mature) may be offset by the ability to grow more than one crop during each dry season, because high temperatures make crops develop more quickly. For example, while a typical 'southern' wheat crop might take 24 weeks from sowing to maturity, a crop grown in Katherine can reach maturity in as little as 8 weeks (P Thorburn, pers. comm.). While two or even three crops per year may sound more attractive than one, it also requires increased expenditure on the 'fixed costs' of crop production such as planting and harvesting. It also leads to longer periods of bare soil, which promote wind and water erosion.

High temperatures and high solar radiation together promote evapotranspiration, or the loss of water from crops, soils and surface waters. Evapotranspiration rates in northern Australia are about 50% higher than those experienced in most southern cropping regions (30). If crops are to survive, some of this 'lost' water must be replaced. If crops are to produce viable yields, this water must be replaced regularly so that the crop does not experience drought. In a northern Australia location such as Katherine, the annual average point potential evapotranspiration is *ca* 3000 mm[2], whereas in a southern wheat belt location such as Merredin (WA) it is closer to 2000 mm (30). Given that crops do

[2] This means that, without rainfall, a 3.0 m deep dam would evaporate entirely within a year, via losses of about 8 mm per day. (This figure does not include seepage losses). Katherine receives about 1200 mm rainfall each year so, roughly speaking, a 1.8 m dam would be empty in a year, even if no water were taken from it.

not grow all year, 1500 mm (15 ML/ha irrigation) is a useful rule of thumb for the irrigation required for 1-2 annual crops each year in the north. A lesser amount (6-10 ML/ha) may be required for a single crop. A typical 'southern' food crop requires about 5 ML/ha (31). The use of high efficiency irrigation methods, such as subsurface drip irrigation, would reduce these figures somewhat.

It is important to note that regional figures for farm water use are scant in the north compared with southern farming regions (31). Notwithstanding that scarcity, the available figures suggest that areal farm water use figures are 80% higher in the northern catchments than the average for Australia (31) – a reflection of the punishingly high rates of evapotranspiration that are inescapable in the north. The chapter by Cresswell et al. describes the difficulties that the northern climate imposes on water storage – either on farm or as part of a public scheme.

While water can generally ensure the survival of crops in highly evaporative environments, it cannot guarantee that they will produce crops of yield or quality sufficient to secure a viable enterprise. Identifying individual crops suitable for the north is beyond the scope of this report. Suffice to say that the quality of many fruits and vegetables is compromised by high evaporative demand, which makes them wilt even in the presence of adequate water supply.

The warm, moist and high-nutrition conditions favoured by crops are, unfortunately, very much the conditions that favour the multiplication of agricultural pests and diseases. These are not usually identified as present before a crop has been introduced to an area but, once a considerable food source has been created (i.e. a crop) the various pathogens and insects that generally infest crops make their presence felt. The consistently warm climate of northern Australia enables insects and pathogens to multiply rapidly and also to evolve resistance to treatment more quickly than occurs in cooler climes. It was through this means that insect pests caused the collapse of the Ord's cotton industry in the 1970s (6). Furthermore, if irrigated production extends through the full duration of the dry season, the ability to kill off pathogens by depriving them of food is diminished which, for many pests and diseases, creates a reservoir for disease in the next season. The north's climate naturally favours the growth of insects and diseases, and 'solutions' such as genetically modified crops are not a panacea so much as an additional tool for dealing with them.

The introduction of food into a landscape also seems to attract macro-pests, such as cockatoos and magpie geese (the latter are often blamed for the failure of the Adelaide River rice industry in the 1950s). Control measures against these pests have a greater impact on humans (i.e. stress relief) than they do on the incidence of pest damage. Bird pests are likely to be more common in the north than the southern cropping regions, at least in part because the more intact northern landscape supports a greater number of birds and bird species.

6.3 Greenhouse gas emissions

Accounting for the greenhouse gas emissions of irrigated agriculture is beyond the scope, and especially resources, of this report. A few brief observations, based on preliminary analyses, will suffice.

1. Increased irrigation development based upon clearing of existing savanna is likely to make a significant contribution to greenhouse gas emissions, based on existing Kyoto Protocol reporting standards (32). The act of clearing is likely to contribute an average of >100 CO_2-e t/ha (CO_2-e = Carbon dioxide equivalents).

2. Annual cropping is unable to recoup this emission of CO_2-e because biomass that it harvested each year can only be counted in one year. Annual crops assimilate a maximum of 10-20% of that emitted though clearing and, through use of chemicals and fertilisers, contribute further to CO_2-e emissions.

3. Standing carbon plantings (i.e. unharvested forest) and bioenergy plantings have the potential to sequester carbon once carbon uptake has exceeded emissions from clearing. When taking into account fossil fuel offsets, bioenergy production provides ongoing carbon mitigation whilst woody carbon plantations plantings will reach a maximum value when matured.

7. IRRIGATED AGRICULTURAL ENTERPRISES THAT MAY BE SUITABLE FOR NORTHERN AUSTRALIA

The development of a sustainable and resilient irrigated agriculture industry in northern Australia would be greatly assisted by access to a wide range of crops. This would significantly reduce risk by reducing exposure to a narrow set of inputs and markets, and unpredictable climatic events.

There are many possibilities for irrigated agriculture in northern Australia, including:

- annual crops: short lived, shallow rooted requiring intensive planting, management and harvesting practices
- perennial crops: medium to long term crops requiring intensive planting and establishment activity followed by regular management and harvesting
- forestry: long term tree species requiring initial intensive management followed by a long, relatively undisturbed period and a short term intensive harvesting period
- improved pasture: mixed perennial grass and legume with intense establishment activity and ongoing management practices varying from low management intensity grazing to high management intensity mechanical biomass removal.

The land suitability for these ‘crops’ across northern Australia is considered in detail in the Wilson et al.-authored chapter of this report.

For a more detailed account of specific crop and pasture options and practices in northern Australia, we direct the reader to *Striking the Balance* (2), which provides an excellent overview of the crop husbandry required in the north.

7.1 Annual crops

A range of annual crops has been identified as suitable for northern Australia. New crops are no longer being invented so, not surprisingly, the main prospects tend to be ‘standard’ tropical crops such as grain sorghum, maize, rice, cotton, mungbean, soybean, sesame, peanut and horticultural crops such as melons, pumpkins and other vegetables (2). These crops are not an unknown quality in Australia - we currently grow 750,000 ha of sorghum, 70,000 ha of maize and 50,000 ha of rice (33) - though the expertise and markets available to support northern Australian cropping industry are unclear. These crops might be expected to consume about 10-15 ML/ha of irrigation water, especially if grown in rotation with peanuts.

7.2 Perennial crops

Perennial crops likely to be suitable for northern Australia include horticultural tree crops such as mango, banana, citrus, papaya, lychee and other tree fruits. These crops generally produce perishable products and, consequently, reliable and rapid market access is vital. Due to the seasonality and perishability of most horticultural crops, price is highly sensitive to supply. This may present an opportunity for northern Australian suppliers to seize higher-priced markets - the warmer northern climate should enable them to commence harvest earlier in the season than other Australian producers. This capability has been exploited by Northern Territory mango growers, who are routinely the sole sellers for a number of weeks prior to the arrival of fruit supply from the Atherton Tablelands, Burdekin and Bowen. These crops might be expected to require a total of 5-15 ML/ha irrigation water.

7.3 Forestry

Forestry production in northern Australia has historically been hampered by termites, slow growth rates caused by lack of water and low soil fertility (34) and problems with stand maintenance. The water requirement of forest plantations in the north is unclear. It is generally accepted that they require irrigation during the first few dry seasons following establishment (35). In order to support commercially attractive rates of growth, and to reduce the incidence of termite attack, more sustained irrigation, perhaps of the order of 10 ML/ha, would be required. Prospective species such as African mahogany, that appear to be well adapted to the tropical savanna, can meet unforseen problems such as a pronounced sensitivity to cyclone damage (36). The tropical savanna is consequently considered marginal for most timber plantation forestry (34). Perhaps because of these long-standing limitations, the industry does not receive the R&D support provided in countries such as Indonesia, where tree breeding continually improves productivity and timber quality. As a consequence of this and the natural limitations posed by the north, production of timber may remain a boutique industry (35).

The cultivation of trees in the landscape needn't be restricted to timber plantation forestry.

Sandalwood is grown in both the Ord River Irrigation area and in the area to the north of Richmond, Qld. The introduction of sandalwood into the Ord River Irrigation Area (ORIA) has been a success; it is a high value product that delivers high returns to growers (23). Of the 13,000 hectares of irrigated farming land in the ORIA, there were almost 2,000 hectares of commercial Indian sandalwood plantations (2005). Annual planting area totals approximately 200 hectares (37). The Queensland DPI markets approximately 500 cubic metres of sandalwood each year (38). Production from other sandalwood growing countries, such as India, Indonesia and the Pacific islands has quickly declined because of over-harvesting, forest clearance for agriculture, disease and illegal logging operations. This provides Australian sandalwood growers with clear market advantages.

Pongamia is an Australian native plant with prospects as a bio-fuel source. The plant is drought tolerant, fast growing and can be first harvested from 5 to 6 years after planting. It is expected the plant will achieve bio-diesel yields of 2.5 to 3.0 tonnes per hectare. The pongamia plant fixes nitrogen, reducing the need for fertiliser. According to the NT department responsible, 'if Pongamia plantations can be successfully established on less arable land, with minimum fertiliser use and variable summer rainfall, then there is a significant potential for a renewable fuels industry in the NT' (39).

Chia, originating from Mexico, produces an oil seed which is rich in omega 3. Chia production began a few years ago in the ORIA as trials but the region has now become the largest producer of chia in the world. Approximately 750 hectares was grown in the ORIA in 2008, with the majority exported to the US (40).

Agroforestry appears to have maintained its Cinderella industry status in southern Australia for the last several decades, but may be better suited to the north. It has the ability to combine grazing with shade and shelter, protection from wind and water erosion and a measure of biodiversity preservation. Bush foods provide $14m annual retail turnover in Australia, and there may be commercial opportunity for cultivation of suitable species such as quandong, native figs and acacia (34). The extent to which agroforestry or bush foods would rely on irrigation is unclear.

7.4 Pastures and fodder crops

Irrigation opportunities exist for improved pastures and fodder production. The beef industry is very well established in northern Australia, and has overcome many of the problems of critical mass that beset other industries. Intensification of beef enterprises via production of a higher volume and quality of feed using irrigated pasture and fodder production has been identified as a major goal of the industry (see the Cribb et al. authored chapter of this report). It can improve profitability by supporting higher growth rates, greater control of turn-off condition, the potential to provide year-round supply and, hence, better use of capital. Intensification may also reduce greenhouse gas emissions from cattle. The northern beef herd emits about 4% of the nation's greenhouse gas equivalents, and as much as 17% (2.3 Mt CO_2-equivalent) of those of the Northern Territory (where it is the third largest emitter) (41). These figures could be significantly reduced by the availability of higher quality feed. Compared with common tropical forages (e.g. Rhodes grass), provision of higher quality forage can reduce methane gas emissions by *ca* 50% per head per day; provision of grain can reduce methane production per unit feed intake by up to 30% (42). Both these opportunities require the production of food close to the point of consumption, to minimise currently prohibitive logistics problems and costs. On-farm production using irrigation provides an attractive solution, and is likely to require 5-15 ML/ha of irrigation water.

8. POSSIBLE DEVELOPMENT TRAJECTORIES FOR IRRIGATED AGRICULTURE IN NORTHERN AUSTRALIA

As outlined in the 'Introduction' and 'Cropping in the northern Australian environment' section of this chapter, further development of agriculture in northern Australia is highly likely to depend on irrigation. Irrigated agriculture, in turn, is critically dependent on the availability of suitable and coincident soil and water supplies (as well as the supporting hard and soft infrastructure alluded to above).

8.1 Narrowing the possibilities for irrigation potential

Objectively establishing the quantity and quality of the potentially available land and water, and their coincidence, is a difficult task for an area as great and varied as northern Australia – particularly in a static analysis such as this. The reasons are several.

1. The 'land and soil resources' chapter of Wilson et al. in this report identified areas that are potentially suitable for agricultural production. The potential areas were very large in extent (*ca* 18 million ha). The knowledge required to reduce this 'potential' area to a 'workable', 'sensible' or 'actual' level (by taking into account flood risk, cost-effectiveness, etc) does not currently exist. The current mapping at scales of 1:250,000 to 1: 1,000,000 falls well short of the 1:50,000 scale resolution required to identify the areas requiring more detailed survey for farm planning.

   The 'farmable' subset of suitable soils is likely to be a fraction of the 18 million hectare total, and its extent and location and particular deficiencies are not known. This makes it impossible to clearly identify a development trajectory for irrigated agriculture, based on the soil resource.

2. If all of northern Australia's 200,000 GL annual average streamflow (5) were made available for irrigation, it could support *ca* 13.3 million hectares of fully irrigated agriculture (assuming an annual irrigation requirement of 15 ML/ha) or *ca* 20 million ha of less productive irrigated agriculture (assuming a 10 ML/ha requirement, with crops receiving less than their full water requirement, or land being rested for longer periods).

   This assumes that all of the north's annual streamflow would be available for diversion. This is highly improbable. Society is unlikely to support the obliteration of every northern river. Even if it were, it would need to find a way to store that water and protect it from evaporation so that it could be transmitted to the farming zone, without loss. Even if these conditions could be met (they can't), it is unlikely that society would be prepared (or able?) to fund the infrastructure required.

   How many rivers is society prepared to alter? By how much is it prepared to alter them? How much money is it prepared to spend on infrastructure to enable water capture and transmission to support irrigated agriculture? Without answers to these questions, it is not possible to objectively identify a development trajectory for irrigated agriculture, based on the surface water resource.

3. The precise extent and location of groundwater potentially available for use by agriculture is unclear because groundwater data for northern Australia are sparse (5). A detailed account of the best-available water accounts can be found in the Northern Australia Sustainable Yields Project drainage division reports (43). Unfortunately, these do not make it possible, from a groundwater perspective, to identify a development trajectory for irrigated agriculture, because abstraction of groundwater for irrigation impacts on other uses of water. The negotiations to determine how much may be available for irrigated agriculture have yet to occur.

Clearly, objectively quantifying the irrigated agricultural potential of northern Australia is made difficult by the high degree of uncertainty surrounding the biophysical, social and economic factors that govern development. We would be better placed to provide advice on the potential for irrigated agriculture development if the development parameters were more tightly specified.

8.2 Focusing on the probabilities of irrigation potential

Let's cast the above uncertainties to one side, and use a different approach to estimating the irrigated agricultural potential of the north. We'll examine what may be technically feasible based on estimates of water and soil availability derived from this report.

8.2.1 A whole of northern Australia, groundwater recharge area based approach to estimating irrigation potential

A groundwater recharge area approach to estimating the area of land with irrigation potential does not use site-specific data; it simply uses a known ratio between extraction area (groundwater) and application area (irrigated land) to assess land-water relationships. It helps to assess whether land or water is the most likely limiting resource.

Hydrologically sustainable groundwater-based irrigation in northern Australia (i.e. that which doesn't permanently deplete the groundwater resource, and thereby 'cut its own throat'; but which doesn't take account of other uses) requires a recharge area that is "several orders of magnitude greater than the irrigated area" (44). This occurs because, in much of northern Australia, aquifer recharge rates are low and the recharge areas required to support concentrated extraction are often of an intermediate to regional scale.

If we take a bold approach, assume that several orders of magnitude means "three", and ignore the distribution of that water and its other uses, then this provides for a maximum of 120,000 ha of irrigated land (i.e. 1/1000th of the *ca* 120 million ha study area).

The soil mapping produced by Wilson et al. (this report) shows that this would not provide for irrigation of all the class 1+2 soil *potentially* suitable for production of irrigated annual crops (16.8 million ha), forestry (32.4 million ha), improved pasture (16.8 million ha), perennial crops (6.0 million ha) or rice (3.6 million ha). For all crops, therefore, using a recharge-area assessment and a 3rd order of magnitude relationship between recharge and extraction, water rather than soil is the factor limiting crop production.

A more precautionary approach would use a 4th order of magnitude multiplier (1/10,000th of the study area) and determine that groundwater could support 12,000 ha of irrigated agriculture (ignoring other uses). Under this assumption, the availability of water would pose a far greater limit to crop production than the availability of suitable soil. And that doesn't take into account competition for groundwater from other uses.

8.2.2 A regional, groundwater prospectivity based approach to estimating irrigation potential

The groundwater prospectivity approach is more spatially explicit than the recharge-area based approach for estimating irrigation potential because it is based on the mapped assessment of ground water. Consequently, it is possible to overlay the regional availability of water with the regional availability of soil to arrive at an estimate of the area with irrigated agriculture potential.

Analysis of Figure 15 in the 'water resources' chapter of Cresswell et al. (this report) shows that the Daly, Wiso and Georgina groundwater provinces have 'high' prospectivity, and could be expected to deliver around 100 GL per annum. Assuming an irrigation requirement of 10-15 ML/ha, each province could support 6,700 – 10,000 ha of irrigated agriculture. Together they could sustain 20,000 -30,000 ha of irrigated agriculture.

The soil mapping produced by Wilson et al. (this report) suggests that there is sufficient class 1+2 soil in each of the Daly and Wiso provinces to effective utilise this water for each of the annual crop, perennial crop, forestry and improved pasture categories of production. In the Georgina province, the intersection of suitable soil and water suggests that 6,700-10,000 ha of irrigated forestry may be possible. In none of these provinces is a high proportion of soil suitable for flooded rice production.

A similar analysis shows that the Canning, Ord-Victoria, Pine Creek, McArthur and Great Artesian provinces are of 'medium' prospectivity and could be expected to deliver 10-100 GL of groundwater annually. Together, therefore, assuming an irrigation requirement of 10-15 ML/ha and a mid-point availability of 45 GL per province, each province could support 3,000-4,500 ha of irrigated agriculture, or a total of 15,000-22,500 ha.

The Canning province has a marked imbalance of available soil and suitable water. It has >4 million ha of class 1+2 land (*ca* 40% of its area; Table 4.4; Wilson et al. chapter) potentially suitable for all crops except rice, yet groundwater water sufficient for only up to *ca* 4,500 ha.

The Ord-Victoria and Pine Creek provinces are also characterised by a significant water limitation. Its *ca* 1 million ha of potentially suitable soils overly groundwater resources sufficient to support only *ca* 4,500 ha of irrigated crops (annual crops, improved pasture, forestry and perennial crops, but possibly not flooded rice), or 0.5% of their area.

McArthur province's 2-3 million ha of potentially agriculture-suitable (class 1+2) soils overly groundwater sufficient to irrigate only 4,500 ha, or about 0.2% of its area. For the Great Artesian province, the *ca* 700,000 ha of class 1+2 annual crop soils overly groundwater sufficient to irrigate only 0.6% of their extent.

Analysis of the 'low' prospectivity provinces – Halls Creek, Bonaparte, Arafura, Mt Isa-Cloncurry and Tasman – indicates that each could provide around 10 GL of water annually. This equates to *ca* 670-1000 ha in each province or a total of 3,300-5,000 ha, assuming an irrigation requirement of 10-15 ML/ha. As with the provinces outlined above, this provides water sufficient to irrigate only a very small (<0.2%) proportion of the regions' class 1+2 agricultural soils.

Using the prospectivity method, we estimate that the area of potentially groundwater-irrigable land in northern Australia to be around 40,000-60,000 ha. This constitutes around 0.4% of northern Australia's potentially class 1+2 annual cropping soils, and approximately 1%, 2%, 0.2% and 0.4% of the class 1+2 soils for perennial crops, rice, forestry and improved pasture, respectively.

Crop production in northern Australia is limited by water, not soil.

As outlined above, northern Australia currently supports *ca* 34,000 ha of irrigated agriculture, about 14,000 ha of which is irrigated using surface water from the Ord scheme. One interpretation of this is that *ca* 20,000 ha is already being irrigated using groundwater, meaning that there remains the capacity to add a further 20,000-40,000 ha of irrigated agriculture that uses groundwater. If this were to eventuate, it would enable the area of irrigated agriculture to approximately double. The economic consequences of this expansion are explored in Section 11.1, below.

8.2.3 A surface water based approach

As outlined above and in the 'Water Resources' chapter of this report (Cresswell et al.), the ability to use surface water for irrigation in northern Australia is constrained by the great difficulties of capture and storage loss. Both these constraints are highly dependent on the location and configuration of surface water storages. Figure 12 of the 'Water Resources' chapter shows that there are currently 23 surface water storages across northern Australia with capacity >1 GL. Beyond the Ord River Irrigation Area, for which expansion is already planned, the prospects for increased irrigated agriculture based on surface water storage are limited. A few calculations will help to illustrate the point.

A stored volume approach

The current total surface water storage capacity in northern Australia is *ca* 11,170 GL (Figure 12, Cresswell et al., this report). If we exclude the Ord River Dam, which is already accounted for in irrigated agriculture (and for which there are limited opportunities for similar storages in the north), the volume drops to *ca* 1,170. Assuming that all this water was available for agriculture (and it isn't – much is lost via evaporation and is used for other purposes, such as domestic supply), it could support *ca* 80,000 – 120,000 ha of irrigated agriculture. As outlined above, this is sufficient to irrigate only a very small proportion of the potentially suitable agricultural soils. Irrigated agriculture in the north is likely to be water rather than soil limited.

A divertible volume approach

This analysis is provided for completeness only. The uncertainties surrounding the diversion of existing flows are so great as to render the analysis quantitatively suspect, but qualitatively instructive.

Figure 14 of the 'Water Resources' chapter of this report shows the 'divertible volume' of northern Australia's surface waters, by catchment. These represent the maximum volumes of river flow currently occurring that might be available for other uses, such as irrigated agriculture. In most instances they have been identified by State and Territory jurisdictions as maximum possibilities. The extent to which they could become reality is unknown, as is the fraction of the divertible volume that could be made available for irrigated agriculture. There are many and great questions about the technical, social and economic capacity to and desirability of accessing 'divertible' water.

If all the divertible water were available for use – and there is *absolutely no* prospect for this; evaporation losses alone could be expected to reduce the volume by at least 25% - then there is a maximum of *ca* 47,000 GL of water available for irrigation (we have assumed the upper bound of divertible volume – e.g. 5000 ML in the 2500-5000 ML class – is available). This would provide for irrigation of *ca* 3-4.5 million ha, or around 25% of the potentially class 1+2 annual cropping soils.

Even when unrealistically large volumes of the north's water resources are notionally diverted to agriculture, there is a clear water rather than soil limitation to expanded irrigated agricultural development.

9. IRRIGATION SCHEMES

Large irrigation areas have many attractions, most of which are related to scale efficiencies. The ability to concentrate irrigation within large 'schemes' provides efficiency for hydrological engineering and the 'hard' (communications, transport, accumulation and storage facilities, etc.) and 'soft' (labour, expertise, etc) infrastructure required to support industry.

As outlined above, and elaborated in the 'water resources' chapter of Cresswell et al., the majority of northern Australia is unlikely to be well suited to large irrigation schemes. Even where suitable soil exists in considerable area, the water resources required to irrigate them effectively to their full extent do not exist. The capacity to usefully build dams is limited in most regions by topography (it's too flat) and high rates of evaporation (surface water losses are high). Where topography is suitable, rainfall is usually prohibitively low. Groundwater reserves are, in many cases, either too small or too sensitive to support widespread irrigation. Those within the Daly and Georgina regional aquifers are the most obvious exceptions.

These difficulties needn't preclude the development of irrigated agriculture in northern Australia. Smaller scale, and more widely distributed, irrigation systems - irrigated mosaic agriculture - have been suggested as an attractive development option for northern agriculture (26).

9.1 Mosaic agriculture

Irrigation mosaics are small patches of irrigation are dispersed throughout a region, rather than concentrated in a smaller number of larger contiguous areas. While there has been little scientific study of the benefits and impacts of mosaic irrigation, its logical appeal suggests that it warrants further investigation. Here we present that which has been reported about irrigated mosaic agriculture, with an emphasis on comparison with larger scale 'irrigation scheme' agriculture.

9.1.1 Biophysical considerations

Salinisation

All water contains solutes, or dissolved material other than water, such as minerals and salts. Irrigation increases the concentration of solutes in soil by delivering more water than would naturally occur, and through the addition of chemicals such as fertiliser. This areal concentration is exacerbated by the concentrating effect of evaporation. If concentrated solutes are not removed from the soil they eventually reduce plant production via salinisation. This risk is particularly pronounced when irrigation causes a rise in the local watertable, ensuring that the solutes delivered in irrigation water, those added via crop husbandry and those mobilised in the soil by rising water are in contact with plant roots, and liable to further concentration by enhanced evaporation. This process is called irrigation salinity. It can occur rapidly, as evidenced by its appearance in the Ord River Irrigation Area within 30 years of irrigation commencing (45).

The key to reducing the likelihood of irrigation salinity is to dispose of solutes, either by deep flushing (leaching) or by drainage to surface water, both of which are essentially polluting processes. Reducing watertable rise through judicious application of irrigation water is another method. Designing irrigation systems that naturally reduce water table rise is another, more permanent, contribution to a solution.

Mosaic irrigation can reduce water table rise and, hence, salinity risk, compared with the same area of irrigation occurring in a contiguous block (46). The placement of the irrigation patches needs to be designed to ensure that their size and distance from each other enables each patch to act as a separate entity. If patches are too large or too close, the patches will tend to behave as a larger single block, obviating the salinity advantages of mosaic irrigation. Optimum design parameters are site specific, and readers are referred to Cook et al. (2008) (46) for further details.

The smaller size and 'mobile' nature of irrigation mosaics mean that they can be positioned to avoid salinity risk and, if necessary, move once salinity risk becomes realised, much more readily than larger capital intensive irrigation 'schemes'.

Water use efficiency

Water use efficiency is intrinsically low in much of northern Australia, because of its combination of high rates of evapotranspiration and soils of low water holding capacity and low infiltration rate. Low water holding capacity and infiltration rates make the application of high volumes of irrigation water ineffective and damaging (especially via erosion). Instead, water must be applied to crops frequently and at low rates. This reduces water use efficiency by maximising the presentation for water for evaporation, a problem that will beset large irrigation schemes and distributed mosaics with equal nuisance.

Rates of water application, though low, will in many instances exceed the capacity of bores to supply them (2). As a consequence, even groundwater-based mosaic irrigation will, in many instances, require turkey's nest balancing reservoirs to maintain water supply for continuous irrigation. This reduces water use efficiency by exposing to evaporation water that was previously protected.

Evapotranspirative losses via advection, the process whereby water moves from moist to dry air, may be 10-20% greater in mosaic irrigation than in larger irrigation schemes (47). Given the already high rates of potential evapotranspiration in the north, this increase in evapotranspiration could increase irrigation requirements by as much as 1.5 - 3 ML/ha.

Countervailing the greater advective losses of mosaic irrigation may be its capacity to occur only at those sites in the landscape where soil (e.g. greater depth, higher infiltration rate) and topography lend themselves to high water use efficiency.

It is not clear whether extraction, transmission and application losses of water are higher or lower using larger central schemes or smaller distributed systems.

Erosion

Large-scale irrigation schemes are likely to promote wind and water erosion compared with mosaic irrigation, a feature that may be important for managing the generally highly erodible soils of northern Australia.

Pollution

Agricultural activity of virtually any description poses off-site risks. These risks are increased by irrigation because it changes water balances and supplies the medium by which contaminants are carried off-site. The most likely contaminants are agro-chemicals and fertilisers (especially N & P) and sediments (perhaps containing them) fostered by erosion.

The presence of increased nutrient levels in northern rivers is of potentially great concern. A large number of northern rivers and estuaries provide the conditions (warmth, inoculants) for production of toxic blue-green algae – their growth is limited only by a lack of nutrients (48). The supply of N and

P could lead to algal blooms and their attendant impacts, which include health risks posed by affected (49):

- drinking water: nausea, gastroenteritis, paralysis, etc.
- swimming water: eye irritation, hayfever symptoms, promotion of skin tumours, etc.
- fish: ingestion leading to neurotoxin-associated death
- irrigation water: toxins may render irrigation water unsuitable (toxic to livestock, etc) for several months

The risk of algal blooms being caused by agricultural pollutants is arguably greater under 'scheme' than mosaic irrigation because of the reduced likelihood of excessive irrigation and erosion fostered by the user-pays operation of mosaic systems.

Biodiversity conservation

It is not clear whether biodiversity and conservation values are enhanced or reduced by the use of a smaller number of larger irrigation schemes or a larger number of distributed activities. In addition to the regional specificity implied by the question, there is little or no data to support an unequivocal assessment. Several, countervailing, issues arise:

- Irrigation mosaics will tend to be located on more productive soils, and nearest water sources; precisely the locations that support the highest biotic values (50). By this means, widespread application of mosaic irrigation could endanger regionally-important ecosystems. By the same token, however, larger scale schemes are unlikely to be sited where soils are poor and water scarce.
- The distribution of mosaic systems may make them a more widespread and hence risky source of pests such as weeds and insects, both of which commonly emanate from agricultural, and particularly irrigated, enterprises.
- The distributed nature of irrigation mosaics may require a greater network of supporting infrastructure, such as roads, than larger centralised schemes. In frequently flooded landscapes such as those of the north, infrastructure of this type can alter flow regimes, with consequences for both terrestrial and aquatic biota. Further details can be found in the 'Terrestrial' and 'Aquatic' ecology chapters of this report.

It is important to recognise that the influence of irrigation systems spreads well beyond their surface boundaries. Irrigation, by definition, takes water from one place and concentrates it in another, leading to problems caused by both accumulation and deprivation of water. The influence of a 300 m radius mosaic irrigation 'circle' of 30 ha spreads well beyond its 300 m radius. The influence on watertable height can extend for several kilometres, and can take many years to become apparent (46). Consequently, it is possible for relatively small mosaic irrigation circles to substantially alter local area hydrology (surface and subsurface) and ecology (both terrestrial and aquatic) even if they are planned to minimise hydrological overlap (46). Given the time-lags involved, it is not sufficient to use adaptive management to respond to problems of this nature when they become evident – they are predictable and should be dealt with by planning using science-based knowledge.

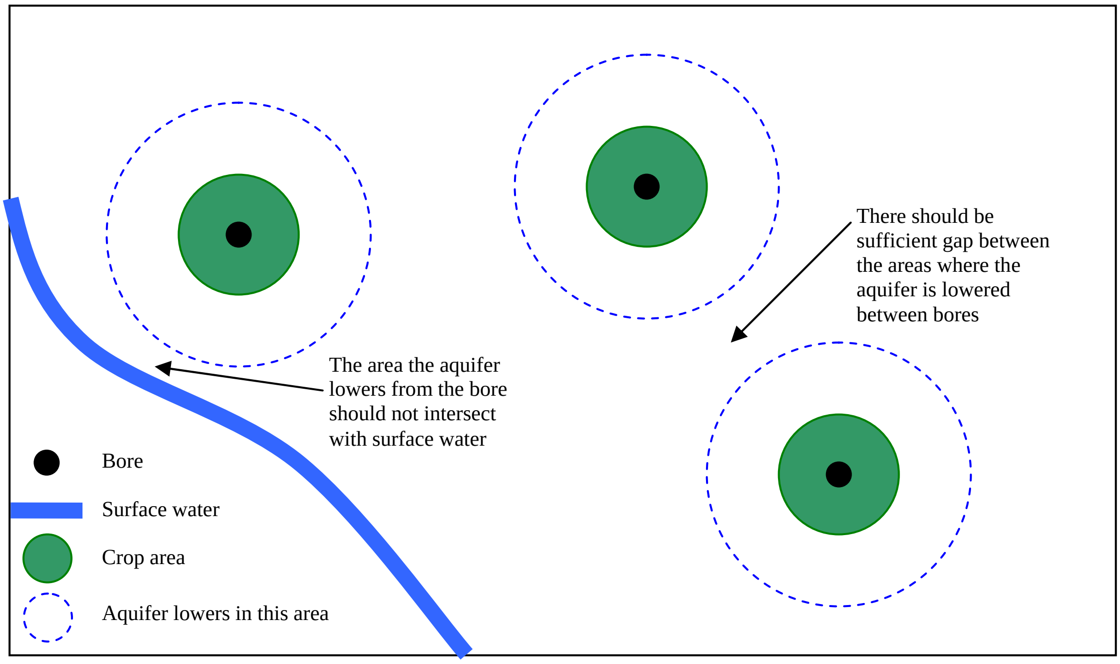


Figure 1: Bores need to be a sufficient distance from connected surface water and from each other based to minimise local-regional scale impacts. Source: this chapter.

9.1.2 Socio-economic considerations

The Food and Agriculture Organisation of the United Nations (FAO) 'guidelines for irrigation planning' give prominence to the socio-economic aspects of irrigation development, citing them as a major indicator of success or failure of irrigation schemes and enterprises (51).

Furthermore, FAO draws a greater distinction between public and private irrigation schemes than it does between large and small schemes. Public irrigation schemes tend to have for their impetus government planning, finance and implementation. In most cases, farmers receive a subsidised service. In private irrigation systems, even though government may facilitate development or provide incentives, it is usually left to farmers to make investment decisions, and to pay for, operate and maintain systems, and to bear associated risks (51).

This distinction further highlights the importance of socio-economic conditions in determining the success or otherwise of irrigation enterprises; in many instances they are more important than physical (i.e. engineering) considerations.

This has particular application to mosaic irrigation agriculture, where the socio-economic conditions differ widely from those for irrigation schemes.

Cost efficiency of irrigation

Public irrigation systems tend to be supply driven, and may incorporate broader social or political objectives, whereas private irrigation is essentially demand-driven and seeks financial objectives. These characteristics fundamentally influence the approach applied to irrigation investment. Capturing the advantages of both approaches requires that the features that make successful private irrigation self-sustaining be applied to public irrigation investments. This requires that farmers be involved in planning decisions, contribute towards capital costs and accept full responsibility for funding operations and maintenance (51). This is assured in privately-run mosaic systems but is frequently incomplete or lacking in public irrigation schemes, which significantly reduces their cost-effectiveness.

FAO argue that a contribution by users towards the capital cost of irrigation schemes indicates demand and commitment, both of which are prerequisite for the sustained success of a system (51).

A corollary of the above is that, because mosaic irrigation may be based on user-pays principles, with owners incurring both the capital and variable costs of irrigating, there will be a natural tendency to scale irrigation infrastructure more appropriately (and flexibly) and to irrigate more frugally than occurs in public schemes. In addition to fostering cost effectiveness, this also implies enhanced enterprise resilience and greater water use efficiency.

Administration

According to the World Bank, there is no evidence to suggest any systematic differences in success between small or large irrigation schemes (51). They argue that where there is a low capacity to plan, implement or manage a larger scheme that smaller developments are preferred. On the other hand, they also argue that there are many examples of small distributed schemes that have failed, possibly because widespread distribution overstretches logistics and staff capability.

FAO argues strongly that sustainable irrigation development hinges on implementability, which requires that the implementation of the project is matched to local institutional capability, and that commitment to the project be based on stakeholder participation and local ownership (51). This is ensured in owner-operated mosaic systems, but in centralised schemes is not guaranteed even by heavy up-front investment.

Groundwater management

The distributed extraction occurring under mosaic irrigation can foster conditions that encourage excessive groundwater removal. Distributed extraction carries the risk that the total volume and timing of extraction across an area is not coordinated or known: the tyranny of small decisions (52). This, combined with the time lags that occur between local and regional groundwater impacts, means that excessive extraction may not become apparent until significant adverse effects (i.e. interruptions to river base flow) have occurred (46). This problem can be overcome using a combination of regulation, hydrological knowledge and real-time monitoring of groundwater extraction and height.

On the other hand, even in unregulated systems, irrigation mosaics may discourage over-extraction because each extraction point is, depending on the water yield of bores and groundwater transmissivity (ML/h), a ‘locally private’ resource that each ‘owner’ would seek to preserve. The extent to which this occurs is highly dependent on rates of lateral replenishment of depleted groundwaters, and it would be risky to rely on it as a prophylactic against over extraction.

Critical mass

The centralisation of production enabled by large irrigation schemes can provide the conditions required to develop critical industry mass. Through improved capital utilisation and reduced supply and marketing risks, industry ‘hubs’ can promote the private investment that sustains industry. ‘Centralised’ production can increase volume and enhance production logistics, improving the conditions under which secondary industries such as food processing can occur. Importantly, industry 'hubs' tend to find it easier to attract and maintain the soft infrastructure (skills, networks) that help to sustain vibrant and sustainable industries. The distributed nature of mosaic irrigation will prejudice against the development of critical industry mass.

9.1.3 Sustainability considerations

Humans have practised irrigation for 5,000-7,000 years. It has rarely been sustainable, though it has been variously acceptable, desirable and necessary. The problems of irrigation – including salinisation, local-scale waterlogging, nutrient depletion and the degradation of surrounding landscapes through water depletion – usually take a long time to become evident and, though examples of it are rare, even longer to ameliorate. Many of the world's major valleys (e.g. Indus, Nile, Murray-Darling, Jordan, Rio Grande, Tigris-Euphrates) are being irrigated, with progressive, visible and in some cases critical decline, but without commensurate remedy (53).

It is possible that the 'problem' of irrigation is less that it is not sustainable, than that we persistently pretend that it is. Positing irrigation design and management on the assumption that it is sustainable may lead us to conceive and operate it in ways that do not maximise its many benefits or minimise its various disadvantages.

Perhaps agriculture can learn elements of sustainability from the mining industry.

It is possible that if we were to conceive of irrigated agriculture as literally unsustainable (in the sense that it is extractive and irreversibly alters the landscape – like mining; but necessary and acceptable or desirable – like mining) that we may manage it more productively and with lower impact. As described in the 'mining' chapter of this report, the mining industry has, through a combination of learning and regulation, significantly reduced its environmental footprint and enhanced its social benefits in the last 20 years. In the environmental sphere, it has achieved this by recognising its impacts, planning for them, managing to reduce them during mine operations and undertaking activities that ameliorate them when extractive operations have ceased. Attitudes sustaining this behaviour have been supported by regulation.

The distributed and potentially mobile nature of mosaic agriculture may present an opportunity to directly mimic some of the sustainable elements of mining that are not possible with larger, 'fixed' irrigation schemes or developments. It is possible that the temporal and spatial movement of irrigation mosaics (perhaps on a rotational basis), preceded by planning and followed by targeted ameliorative activity, may reduce the impacts of irrigated agriculture and increase their broad-sense sustainability. Of course, the converse may also be true – and at significant cost. This challenging concept may be worthy of further investigation.

Whether or not irrigated development proceeds, and whether or not it occurs via large schemes or irrigation mosaics, it is critical that it does not repeat *all* of the errors of previous irrigation developments. *Some* of the impacts of irrigation are unavoidable, as they are inextricably linked with consumptive water use.

Excellent guidelines, based on analysis of the successes and failures of irrigation schemes around the world are readily available, and easy to comprehend (51). Implementation of 'best practice' is clearly more difficult than comprehension, but is likely to enhance the long-term performance of irrigated agriculture in the north. That will enhance both the industry and the landscape and society upon which it depends.

10. REQUIREMENTS FOR AGRICULTURAL DEVELOPMENT

10.1 Infrastructure

A major impediment to agricultural development in northern Australia has been lack of transport and other infrastructure. The concentration of Australia's major markets in the distant southern capitals reduces the competitiveness of producers in the north (54), and has been identified as one of the biggest challenges to achieving sustainable and viable irrigated industries in northern Australia (11).

All agricultural inputs, such as fertiliser, chemicals, seed and machinery components have to be freighted into the region because of the lack of industry and major suppliers, adding to the cost of production. The horticultural industries are impacted significantly by distance to markets because they require high cost refrigerated transport for interstate and export markets. Most heavy agricultural inputs are still transported in by road, even with the recent arrival of the railway in the NT (22).

Regular international air freight out of Cairns and Darwin allows for fresh perishable products to be transported to some Asian markets. There are some large regional business centres and communities that did not have regular air services in 2007/08. These included Katherine and Tennant Creek regions in the NT and the Kimberley region in WA (55).

Capacity constraints for northern Australian ports will also hinder export growth. While this will have the greatest effect on the mining industry, it could also impact on the development of irrigated agriculture. Limited port capacity could constrain the industry and not allow it to grow beyond the domestic market (12).

The mineral boom in northern Australia over the last 10 years has resulted in major economic development. This includes over $30 billion spent on mining and related infrastructure from 2005 to 2008. This investment is already in place and the related economic development and population growth could provide flow-on benefits for agriculture in northern Australia (54).

10.2 Skills, labour

The maintenance of a local skills base has always been a major challenge for agricultural development in northern Australia. Human skills, experience and farming practices cannot be simply transferred from southern Australia to northern Australia, and the body of people required to accumulate and interpret experience remains limited. 'Mistakes due to inexperience can be costly in the early years of new crop evaluation' (56), a time when costs can be absorbed least easily.

Farmers need a wide variety of skills. These range from business and production management through to agricultural and ecological sciences (25). In regional areas it is unlikely that appropriately skilled staff or technical expertise will be available for large scale agricultural expansion, particularly in the short term. It can be difficult to attract staff to work and live in remote areas, and this can escalate the cost of labour.

The development of the cotton industry in northern Australia, for example, would require the movement of a large amount of skill and labour to the region. 'The extensive system of production, harvesting and ginning provides countless ... jobs for mechanics, distributors of farm machinery, consultants, crop processors and other support services workers' (57), most of which are lacking at present.

10.3 Energy supply

Electricity and gas supply in northern Australia is largely reliant on local generators. Most of these generators have a small capacity and use locally available gas and liquid fuels. Gas is a vital source of electricity for commodity production and processing in northern Australia. The gas production and transmission industries in northern Australia are large and growing (58). In the ORIA power is generated from a 30 MW hydroelectric station built in the mid 1990s (16).

Many potential irrigated agriculture development sites in northern Australia are likely to be in rural locations. Lack of, or a limited, power supply has the potential to restrict the size of the operation.

11. SOCIAL AND ECONOMIC IMPACTS OF DEVELOPMENT

11.1 Economic benefits and costs

The economic costs and benefits arising from irrigated agricultural development are many and varied, and difficult to quantify with certainty. A brief qualitative summary is provided below.

Table 4 Economic benefits and costs of irrigated agricultural development

Potential benefits	**Potential costs**
Increased incomes for those obtaining employment created directly or indirectly by the growth of irrigated agriculture	Increased prices of many goods and services, property rents and prices where development occurs
Incomes for new businesses created directly or indirectly as a result of irrigated agricultural development	Costs associated with negative biophysical outcomes (e.g. changed river flows, salinisation, pollution from agrichemicals, soil erosion, etc.)
Reduced transport costs for residents and businesses using improved transport networks	Public and private infrastructure, plant and equipment costs
Better access to services	Costs of additional public services
Economies of scale associated with large development projects	Potential loss of amenity value at sites affected by agricultural development
Reduced risk through farm diversification	
Irrigated farmers benefit from increased research and development potentially resulting in productivity improvements	

Net economic benefit (benefits less costs) is a measure of economic efficiency. It is not the same as economic impact, which is about changes in the size of the regional economy or the structure of its sectors, or changes in employment. Impacts are addressed below, using data derived from input-output models.

11.1.1 Regional economic growth and job impacts

Development of irrigated agriculture would cause gross regional product (GRP) to grow through increased agricultural output and flow-on effects generated through the demand for local goods and services (as outlined below). Expenditure by the irrigated agricultural sector in northern Australia is concentrated in:

- services to agriculture
- wholesale trade
- road transport
- property and business services
- finance and insurance
- petrochemicals and other chemical products
- non-irrigated other agriculture.

The impacts of irrigated agricultural development in northern Australia on the northern population and economy were estimated using two development trajectories or scenarios (Table 5Table 5).

Table 5 Development trajectories or scenarios, irrigated agriculture, northern Australia

Trajectory	Description
Trajectory One: A two-fold increase in land under irrigation over 20 years	Total irrigated area would increase from its current level (34,000 ha) to 68,000 ha. Total water use for irrigation would increase from 223GL to 393GL.
Trajectory Two: A five-fold increase in land under irrigation over 20 years	Total irrigated area would increase from its current level (34,000 ha) to 171,000 ha. Total water use for irrigation would increase from 223GL to 983GL.

As outlined in section 8.2, trajectory one (the doubling of irrigated agricultural area) is much more likely than trajectory two (a five-fold increase in irrigated agricultural area) because of the severe water limitations that exist in northern Australia.

Estimates of economic and population impact were based on estimates of irrigated area, production and value of production under each scenario. Estimated value of irrigated agricultural output for each development trajectory is detailed in Figure 3.

Estimates of total (i.e. direct plus flow-on) regional economic impacts were calculated for a 20 year period. Gross regional product (GRP), employment and population impacts for each trajectory are summarised in Figure 4 to

Figure 6.

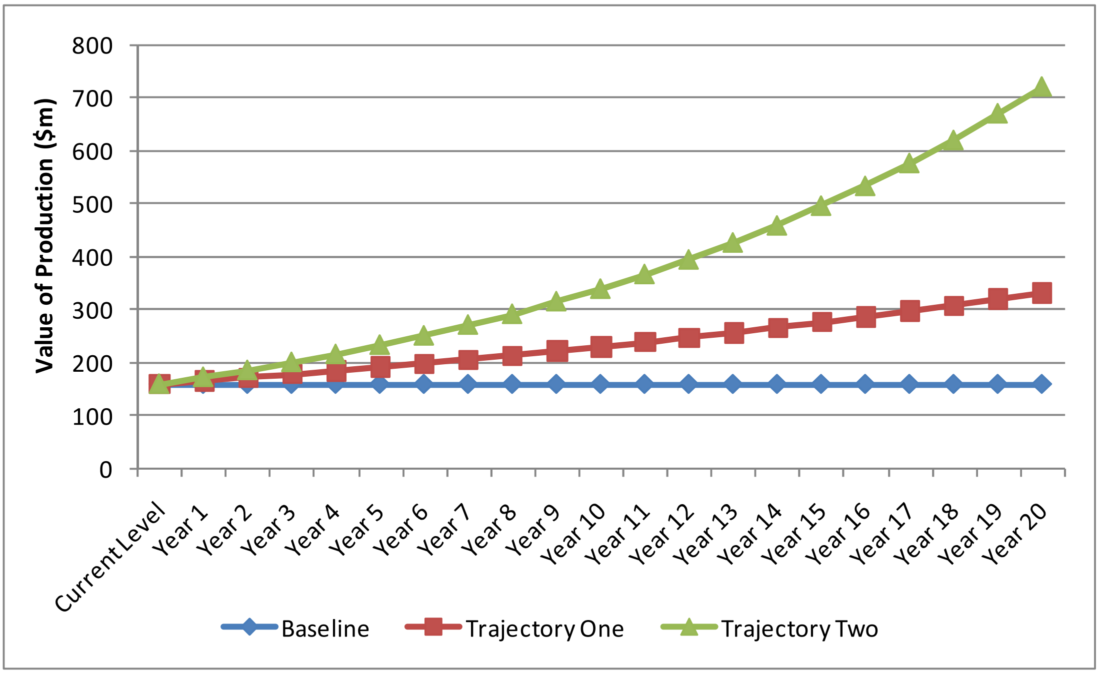
Value of Output

The baseline value of irrigated agricultural production assumes maintenance of the current irrigated area, quantity of production and value of production ($159.2 m; in real terms) over the next 20 years (Figure 3).

Trajectory one's two-fold increase in the area of land under irrigation over a 20 year period increases the value of irrigated agriculture production from its current level ($159.2 million) to $331.0 million, an increase of 108 per cent overall (Figure 3).

Trajectory two's five-fold increase in the area of land under irrigation over 20 years increases the value of irrigated agriculture production to $721.0 million by year 20, an increase of 353 per cent from the current level (Figure 3).

Figure 3 Value of irrigated agriculture production, northern Australia



In 2009 dollars.

Source: EconSearch analysis.

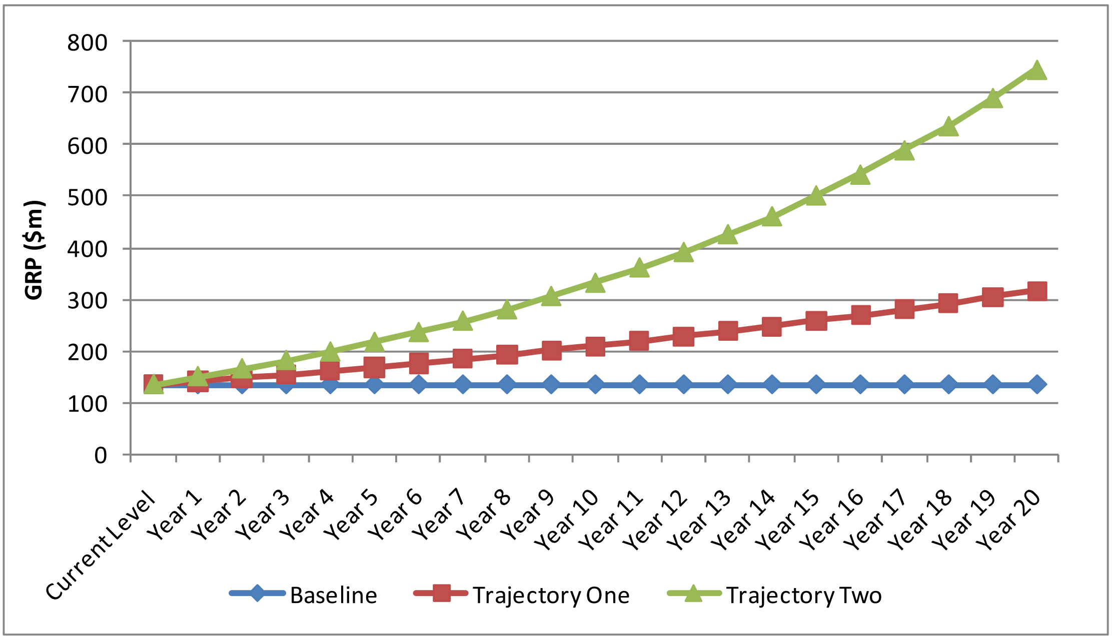
Gross Regional Product

The current contribution of irrigated agriculture to northern Australia is approximately $134.5 million in GRP ($44.5 million directly), which represents around 0.9 per cent of the regional total economic activity.

If irrigated agriculture production increases in line with trajectory one (a two-fold increase in irrigated area), total GRP attributable to irrigated agriculture will increase from *ca* $135 million to $317 million by year 20, an increase of approximately $185 million or 136 per cent (Figure 4).

If a five-fold increase in irrigated agricultural area were to occur over the next 20 years, total GRP in northern Australia attributable to that growth would increase by over $610 million after 20 years, an increase in irrigated agriculture related GRP of 455 per cent above current levels (Figure 4).

Figure 4 GRP impacts of northern Australia irrigated agriculture development trajectories [a]



[a] In 2009 dollars.

Source: EconSearch analysis.

Employment and Population

Employment currently generated by irrigated agriculture, directly and indirectly, is estimated to be approximately 1,800 full-time equivalents (ftes). This represents around 1.3 per cent of the region's total labour force.

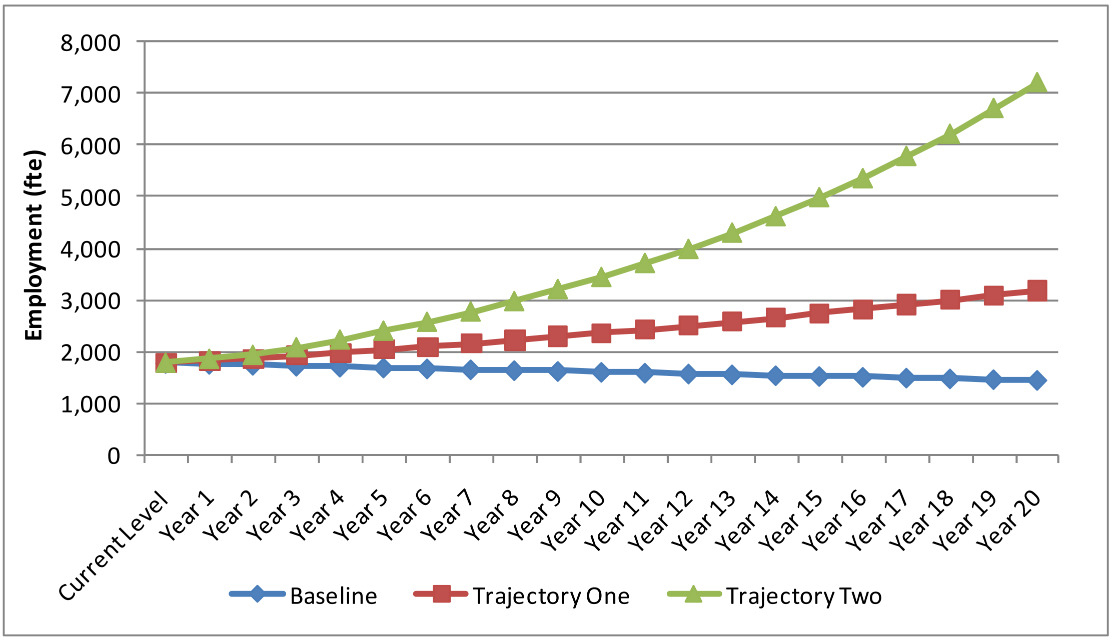
If irrigated agriculture in northern Australia were to stay at current levels, total irrigated agriculture related employment would be expected to decline over the next 20 years from the current 1,800 (ftes) to approximately 1,400 ftes because of productivity improvements across all sectors (Figure 5). Related to the decline in employment we assume a decline in the population of northern Australia as individuals leaving these jobs depart the region with their families (

Figure 6).

If irrigated agricultural area were to increase 2-fold over 20 years total employment would be *ca* 120% per cent higher than if the current level of production continued. Under this trajectory there would be a net increase in irrigated agriculture related employment of approximately 1,400 ftes by year 20 (Figure 5). Associated with this increase in employment would be an increase in regional population above the base case by just over 2,200 people by year 20 (

Figure 6).

Figure 5 Employment impacts of northern Australia irrigated agriculture development trajectories

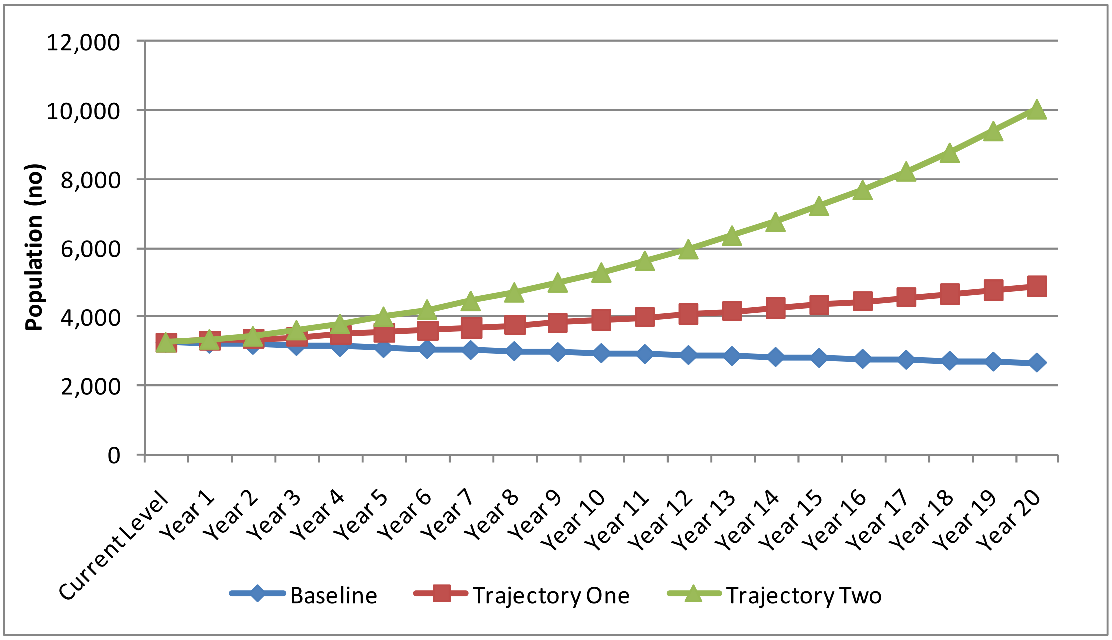


Source: EconSearch analysis.

If the area of irrigated land were to increase five-fold, net employment is estimated to increase by around 5,800 ftes after 20 years compared to the baseline. Total irrigated agriculture related employment would be almost 400 per cent higher under this trajectory than if irrigated agriculture production remained at its current level (Figure 5). Associated with the increase in employment would be an increase in the population above the base case of approximately 7,400 persons by year 20 (

Figure 6).

Figure 6 Population impacts of northern Australia irrigated agriculture development trajectories



Source: EconSearch analysis.

11.1.2 Social impacts

The advantages and disadvantages arising from irrigated agriculture will differ between large scale and mosaic developments. The social impacts of large scale projects can be more easily assessed. The social impacts from dispersed mosaic irrigation are difficult to measure. Because the net social impact of each small scale development is small, it does not mean that the aggregate net regional benefit differs from that derived from a comparable investment in a large scheme. Performance measures of diffuse impacts are needed.

Community viability and cohesion

A social and economic assessment for water resource planning in the upper Mitchell catchment, containing the Mareeba-Dimbulah Irrigation Area (59), found different sectoral interests and perceptions on future water related development. Positive outcomes from local governments' perspective were: i) the protection of small rural communities and benefit of development to those communities; and ii) a maintenance of community identity as 'irrigation towns'. Primary producers saw the benefits of: i) maintaining and improving enterprise viability – and community stability - through expansion and diversification of cropping; ii) improved knowledge of the capacity of the ground and surface water resource arising from the development planning process; and iii) survival of local towns and businesses.

Irrigation can impact negatively on social resilience and long-term economic sustainability (47) through, for example, salinisation, or excessive dependence on what may prove to be an unreliable foundation for household and regional economies. Social impacts may result from perceived as well as actual causes.

A water allocation planning process for the La Grange (WA) groundwater resource (60) found local stakeholders, including pastoralists, tourism operators and the public, were concerned with: health risks to people and stock from agricultural chemicals; constraints on future water use options caused by reduced availability and quality of groundwater; and fears over the inability of government to regulate economically important industries once established.

Social impacts arise from the failure of an irrigation project, for example sugar production in the Ord (61). These may include damage to community pride and local identity, and the opportunity cost associated with unrealised development options. Such consequences have been reported in the East Kimberley (62) where dissatisfaction and the generation of a victim mentality amongst farmers in the Ord followed the failure of cotton crops in earlier decades. Farmers at that time viewed themselves as “victims of bad government planning, failed agricultural research” and “political expediency”. Farmers came to resent ‘experts’ and the lack of long term commitment to the region by government officers. Poor town planning, where farmers were required to reside in Kununurra rather than on-farm also resulted in negative and unintended social impacts by exaggerating the division of “domestic lives of women in the town from working lives of men on the farm” (62). This highlights the need to consider the spatial design of irrigation areas and settlements and its effect on social cohesion.

The social assessment for the Upper Mitchell catchment (59) incorporating the Mareeba-Dimbulah Irrigation Area and surrounds lists issues raised by different stakeholders:

- Conservation interests held concerns over which stakeholders will have priority during periods of water shortages; that smaller farmers would be disadvantaged in favour of large agribusiness; and that ‘political manoeuvring’ will influence the final decision.
- Local governments raised concerns that councils would have to wear the costs of damage to infrastructure (e.g. from overflows); and over the long duration of the planning process and the uncertainty this generated.
- Primary producers were concerned that costs to irrigators might rise; concerns over ‘non-landowner ownership’ of water and non-consumptive users having allocations, and again transparency of the planning process.
- ‘undue political influence’ was also a concern voiced by state government agency representatives who feared that the water resource planning process “will not provide a clear set of rules for operation”.

Communities in the Gulf are seeking water related development opportunities, such as expansion of existing small scale horticulture and introduction of peanuts, bananas and rice. Such development was seen to help mitigate negative impacts of Century Zinc mine closure over coming years, particularly the loss of current Indigenous employment at that mine. Irrigated agriculture is seen as a less ephemeral source of income providing a good standard of living underpinned by a skilled workforce in these remote communities, making them less vulnerable to booms and busts in mining. There was also a view that whilst mining persists it will continue to compete with irrigated cropping for skilled workers (63).

Socio-economic assessment conducted for the Gulf water resource plan (63) suggests that those enterprises likely to diversify into irrigation have already done so, and further intensification is likely to occur in those same locations with “much of the future demand … likely to be generated by the small number of established irrigators in the plan area”. It notes that “there remain relatively few farmers in the region who are prepared to make significant investments in irrigation infrastructure” given the availability of risk capital, project development expertise and farming technology. This implies a tendency for benefits accruing from development to concentrate amongst enterprises which are already more developed, a phenomenon identified elsewhere in this report.

Provision of services and facilities

Large irrigation projects, unlike mosaic developments, are likely to attract support from health, education and other public services, and have better electricity and water supplies and sewage facilities. They may attract banks and support pubs and sporting activities. The more fragmented nature of a truly dispersed mosaic development would be less likely to support these.

Flooding and relocation

Dams may have negative consequences associated with the relocation or dislocation of communities because of flooding, inundation of cultural sites or resources, and changes to aesthetic and other values, such as sense of place. Smaller mosaic-style developments are much less likely to cause these problems.

Impacts on Indigenous, conservation, tourism and recreational interests

Values associated with agricultural development compete with other values attached to northern rivers and water resources. Research into social values of tropical rivers in Australia highlights how some intensive agricultural practices may generate conflict with other values (64) – as when, for example, landholders erect fences that block access to rivers; or when water diversion or abstraction impacts on other values. On the other hand, farmers interviewed in Kununurra and the Ord River Irrigation Area (62) spoke of improved aesthetic and recreational benefits from increased vegetation along riverbanks and lakes due to impoundments and diversions for the irrigation area.

The values of the agricultural sector could conflict with those associated with fishing in northern rivers, as well as broader environmental and Indigenous values. Recent studies in northern catchments present evidence of emerging ‘conflict’ between commercial and recreational fishermen and agricultural land-holders caused by reduced access, reduced catch or catch quality and reduced amenity for fishers (64).

Straton and Zander (65) have captured conflicts and synergies in their valuation of the preferences of residents and city dwellers for alternative uses of the Fitzroy, Daly and Mitchell rivers. Using choice modelling, they showed that residents of the region and of major cities generally want tropical river systems to be in good condition for environmental, recreational and cultural values and uses, and they value medium rather than large scale expansion of irrigated agriculture.

The social and economic assessment conducted for the Mitchell Water Resource Plan (WRP) states:

> Mitchell Basin is a major fish habitat for fisheries in the Gulf of Carpentaria. There is strong and growing interest in nature-based tourism, including recreational fishing, camping and bird watching. In addition, the Indigenous communities retain very close social and cultural ties to the water and land resources of the area. Significant impacts on streamflows and water quality would have important implications for the balance between consumptive and non-consumptive use in the plan area. However, as indicated from an assessment of current and probable future water use, there is likely to be a very limited impact on non-consumptive use (63).

12. BENEFITS ACCRUING IN RESPONSE TO DEVELOPMENT OF IRRIGATED AGRICULTURE

Many of these benefits have been discussed throughout the text, and are summarised here for ease of access.

12.1 Biophysical

The biophysical benefits emanating from development of irrigated agriculture in northern Australia may include:

- Less reliance, and perhaps pressure, on southern irrigation areas
- An increased focus on irrigated agricultural production may lead to research and practical experience that develops improved management systems for tropical soils, pests and weeds, and methods for better managing the landscape and hydrological impacts of irrigated agriculture
- The development of agricultural, industrial and community infrastructure that is adaptable to the risks and uncertainties of developing northern Australia.

12.2 Economic

Successfully developed irrigation industries in the north may provide a range of economic benefits, such as:

- Increased incomes for those employed, and for existing and new businesses
- If development is accompanied by enhanced infrastructure and increased population, this is likely to reduce transport costs and improve the cost-effectiveness of a wide range of services
- Large scale projects provide broad public and private economies of scale
- Reduced risk through farm diversification may enhance farm productivity and, in turn, increase gross regional product.

A two-fold (100%) increase in the area of irrigated agriculture may, over 20 years, increase:

- value of agricultural production by *ca* 110% ($171m, or average $8.5m p.a.)
- gross regional product by *ca* 140% ($185m, or average $9.25m p.a.)
- regional employment by *ca* 120% (1,400 ftes, or average 70 ftes p.a.)
- regional population by *ca* 130% (2,200 people, or average 110 people p.a.).

12.3 Social

The social impacts of irrigation development vary with local circumstances, the establishment process, who wins, who loses and whose perspective is taken on the outcome. Experience suggests that:

- Community viability and cohesion can be enhanced
- Residents benefit from enhanced services and facilities.

12.4 Maximising the benefits

Actions that can help to improve the likelihood and extent of positive impacts are outlined below.

Table 6 Potential positive impacts of irrigated agriculture, and methods for enhancing them

Impact	Measure to enhance it
Less reliance on southern irrigation alone	Establish robust institutional arrangements for water allocation that take account of risks and uncertainties, and can be adapted to new circumstances
Crops and cropping systems compatible with tropical landscapes and hydrological systems	Invest in agricultural research that is founded on understanding of landscape and catchment function, beyond field-focused agronomic research Invest (public and private) in the development of plant varieties specifically for northern Australia Adapt weed control regulations to account for the risks from new crops and varieties
Potential to reduce greenhouse gas emissions per hectare	Invest in R&D for low emission crops and cropping systems Design incentives to enhance adoption of low emission crops and cropping systems
Infrastructure adaptable to the high risks and uncertainties of developing northern Australia	Invest in infrastructure that can be adapted or abandoned if climate of markets change or sea level rises
Increased incomes for those employed, and for existing and new businesses	Support agricultural development with education and training opportunities Provide services for new industries Explore commercial partnerships with Indigenous communities Change land tenure conditions where they currently constrain a commercial opportunity that has a sustainable net social benefit
Reduced transport costs for residents and business using new transport networks	Design roads and other transport infrastructure to suit both agricultural and residential needs
Economies of scale from large scale development	Place a lower bound on the scale of new agricultural development involving significant public investment
Increased Gross regional product from increased agricultural output	Promote new support services and industries
Reduced risk through farm diversification	Support R&D for crops suitable to tropical regions
Reduced farm costs through economies of agglomeration	Promote industries in the region that supply farms
Enhanced community viability and cohesion	Support agricultural development with education and training opportunities

Increase in private and public services	Governments will probably need to establish health and other public services to create a favourable environment for businesses, which may then encourage the private provision of services

13. NEGATIVE OUTCOMES ACCRUING IN RESPONSE TO DEVELOPMENT OF IRRIGATED AGRICULTURE

The development of irrigated agriculture in northern Australia could, like any perturbation, involve a range of negative and unintended outcomes.

13.1 Biophysical

The impacts of development vary widely with scale and design. Consequently we present this qualitative summary rather than a quantitative assessment. Impacts include:

- Dams transform flow regimes of waterways, with negative impacts on fish movements, nutrient transport and basic aquatic system function. Most aquatic systems are valued by residents, including Indigenous people, visitors, and the tourism and fishing industries
- Groundwater abstraction can also affect flow regimes, with consequent impacts on aquatic systems and their values
- Salinisation of soils and water
- Pollution from agricultural sediments and chemicals
- Clearing of savanna, in particular selective clearing on more fertile soils, with disproportionate consequences for species adapted to higher quality sites
- Enhanced soil erosion, especially directly after clearing
- Increased total greenhouse gas emissions from the increased area cropped, and from the infrastructure and energy use to support development.

13.2 Economic

The development of irrigated agriculture in northern Australia can have the following negative and unintended economic outcomes:

- Increased prices of many goods and services
- Costs from negative biophysical outcomes
- Costs of additional public services
- Potential loss of amenity value at sites affected by agricultural development.

13.3 Social

Depending on local circumstances, social processes, who wins, who loses and who pays, irrigation projects can have various negative social impacts:

- Benefits accruing increasingly to those already endowed with resources, and a widening wealth gap separating them from those less wealthy
- Increasing social conflict arising from a growing wealth gap
- Collapse of a community if markets fail, or salinity or pests make production financially unviable
- Perceived or actual impacts on health from agricultural chemicals
- Loss of options for other uses of water once it is committed to agriculture.

Although construction would appear to be unfavourable, and possibly unlikely, a large dam would impact on those displaced by it, and by the loss of cultural sites.

13.4 Minimising the disadvantages

Actions that can help to reduce the likelihood and extent of negative impacts arising from irrigated agricultural development are outlined below.

Table 7 Potential negative impacts of irrigated agriculture, and methods for reducing them

Impact	**Measures to reduce it**
Impact of dams on aquatic habitats and fish passage	Rigorous hydrological and ecological appraisals of potential sites, coupled with stringent economic and social impact analyses that account for option costs and impacts on other sectors. Dam construction proceeds only if it is likely to generate sustainable net benefits.
Groundwater abstraction impacts on flow regimes	Invest in groundwater research and flow modelling so that much better understanding is gained of the hydrological consequences of various volumes, locations and frequencies of abstraction from particular aquifers. Build this understanding into water institutions.
Soil and water salinisation	Invest in hydrological, soil and irrigation research so that much better understanding is gained of the salinisation risks for particular soils, management systems and water regimes. Build this understanding into water institutions And into drainage and other schemes that mitigate salinity risk.
Pollution from agricultural chemicals	Assess risks, monitor, train farmers and regulate. Share pollution and training costs with manufacturers.
Selective clearing of more fertile savanna lands	Develop incentives that increase the attractiveness to farmers of conserving fertile patches.
Increased total greenhouse gas emissions from the increased area cropped	R&D for low emission crops and cropping systems. Design incentives to promote adoption of these and to encourage switches to crops that earn carbon credits.
Increased greenhouse gas emissions from the infrastructure and energy use to support development	Invest in low emissions infrastructure, transport and energy systems. Design incentives to promote adoption of these.
Increased prices of goods and services	Education and training to enable residents to increase their incomes.
Potential loss of amenity value at sites affected by agricultural development	Invoke planning and conservation laws and regulations to protect prime sites.
Unequal distribution of	Education and training, and micro-credit schemes for those already disadvantaged.

benefits and costs, and increased social conflict	
Collapse of a community if markets fail, or salinity or pests make production financially unviable.	If a collapse is foreseen, and irrigation is not sustainable, create opportunities in other sectors through education, training and incentives. Do not invest public funds trying to sustain the unsustainable.
Loss of options for other uses of water once it is committed to agriculture	Establish robust institutional arrangements for water allocation that take account of risks and uncertainties, and can be adapted to new circumstances.

14. CRITICAL KNOWLEDGE GAPS FOR SUSTAINABLE IRRIGATION DEVELOPMENT

- Behaviours of specific aquifers, their influences on river flows, and the responses of both to abstraction.
- Salinity hazards on potentially irrigable soils.
- Design of institutions that take account of:
  - farmers' needs for reasonable levels of water security
  - groundwater and catchment hydrology
  - impacts of diversion and abstraction on aquatic systems and their users
  - the need to change rules and incentives when circumstances change – rules for changing the rules.
- Design and management of cropping systems compatible with tropical landscapes and hydrological systems.
- Design of adaptable infrastructure or with low sunk cost, for the uncertainties of northern development (transport systems, bridges, energy supply and other infrastructure).
- How to develop mutually beneficial commercial partnerships with Indigenous land owners.

15. SUMMARY AND CONCLUSIONS

Northern Australia's soils have been highly weathered by millennia of monsoonal rain. They are typically low in organic carbon, have low water holding capacity and are highly erodible. These traits unite to provide soils that are susceptible to surface sealing and have low infiltration rates which, combined with the north's high rates of solar radiation and evaporation, confer on crops a low water use efficiency. In the north's severely water-limited environment, this poses a strict limitation on the expansion of irrigated agricultural development.

While there is potentially *ca* 17 million ha of soil suitable for annual crops, and as much as *ca* 32 million ha suitable for forestry, there is probably only water sufficient to exploit *ca* 60,000 – 120,000 ha, or <1.0% of this potential via irrigation. Rainfall is not sufficient to support crops in large tracts of northern Australia. Water, rather than soil, is the resource that limits irrigated agricultural development in northern Australia.

The available water resource may be sufficient to enable a two- to four-fold increase of northern Australia's existing irrigated cropping industry. Within 20 years a doubling of its size could increase gross regional product by $185 m (136%), create an additional 1,400 full-time equivalent jobs and increase regional population by 2,200 people.

Groundwater appears to be the source of water most likely to sustain new development of irrigated agriculture. Whereas surface water favours development of a small number of centralised irrigation schemes (such as the Ord River Irrigation Area), groundwater is best suited to supporting a larger number of small scale and widely dispersed irrigation developments; often called 'mosaic' irrigation.

The application of mosaic irrigation is logically attractive but largely untested. Its advantages over larger schemes include the potential to reduce salinity, erosion and runoff. Its small scale makes it within reach of private investors, which may induce capital and operating cost efficiencies that can escape larger public schemes. Its small scale also makes it well suited to the adaptive management that may be required in the north: the costs of 'learning by doing' are probably more bearable than in larger schemes.

The potential disadvantages of mosaic style irrigation development include the possibility that it reduces water use efficiency through enhanced advective losses. Its distributed nature may mean that it less able to provide for industry 'hubs' around which the soft and hard infrastructure that support new industries can develop. On the other hand, its distributed nature may help the already well-established beef industry to increase productivity and capital efficiency, by improving the amount, quality and timeliness of feed supply.

It is not clear whether biodiversity and conservation values are enhanced or reduced by the use of a smaller number of larger irrigation schemes or a larger number of distributed activities.

Humans have practised irrigation for 5,000-7,000 years. It has rarely been sustainable, though it has been variously acceptable, desirable and necessary. The problems of irrigation – including salinisation, local-scale waterlogging, nutrient depletion and the degradation of surrounding landscapes through water depletion – usually take a long time to become evident and, though examples of it are rare, even longer to ameliorate.

It is possible that the 'problem' of irrigation is less that it is not sustainable, than that we persistently pretend that it is. Positing irrigation design and management on the assumption that it is sustainable may lead us to conceive and operate it in ways that do not maximise its many benefits or minimise its various disadvantages.

Whether or not irrigated development proceeds, and whether or not it occurs via large schemes or irrigation mosaics, it is critical that it does not repeat *all* of the errors of previous irrigation developments. *Some* of the impacts of irrigation are unavoidable, as they are inextricably linked with consumptive water use.

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