An assessment of contemporary variations of the Bradfield Scheme

Summary report

PREPARED BY THE CSIRO FOR THE NATIONAL WATER GRID AUTHORITY

Australian Government

National Water Grid Authority

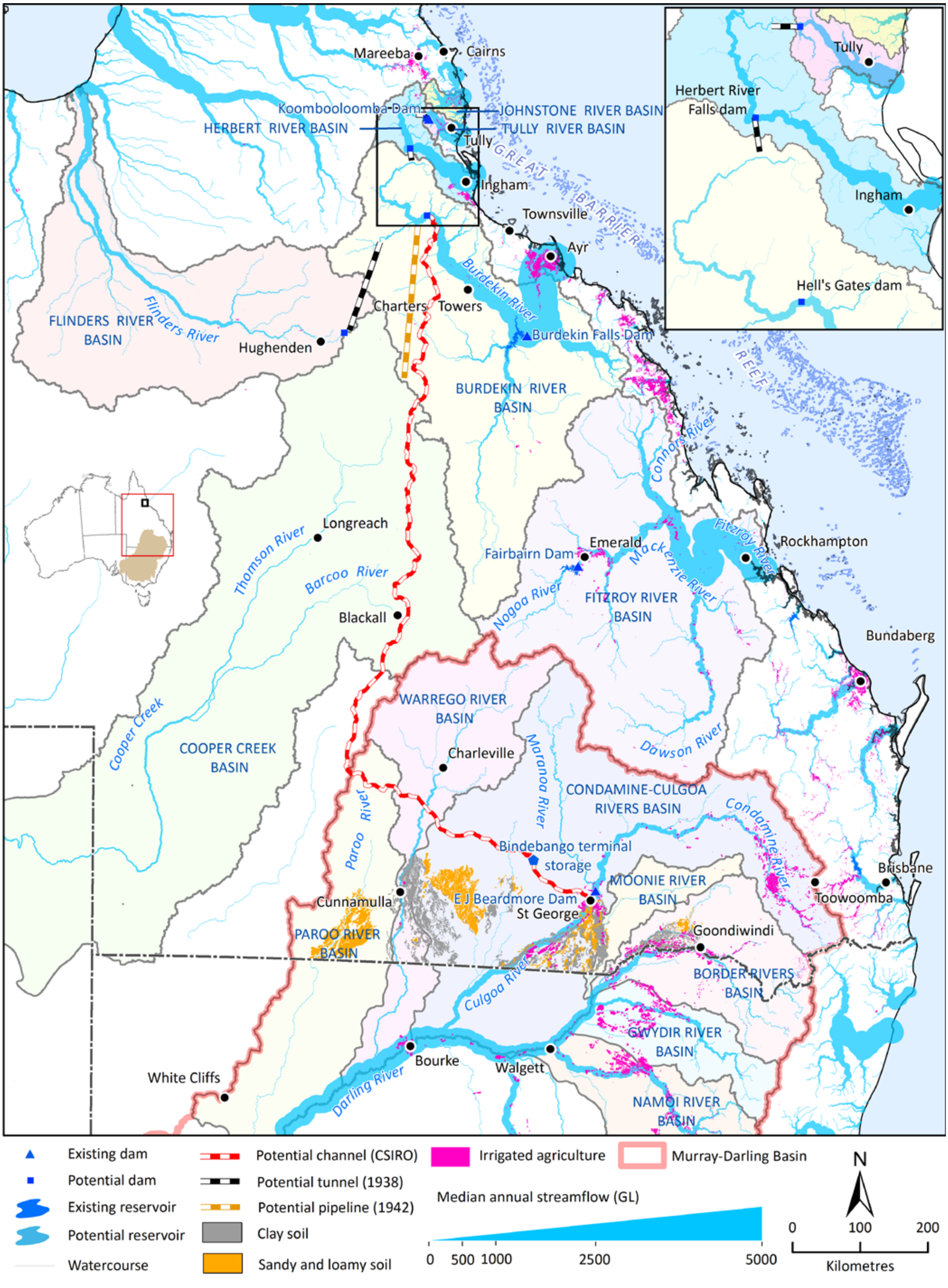
About this report

CSIRO completed a desktop assessment of contemporary proposals of the Bradfield Scheme to divert water to the Murray–Darling Basin (MDB) to verify key assertions and to assess contrasting claims (Map 1). The study complements an earlier analysis of the historic Bradfield Scheme undertaken by CSIRO.

Costs provided in this report are considered consistent with a ‘scoping-level study’, with a likely accuracy of –25 to +50% of the actual value. No field geological assessment was undertaken. Should unfavourable geological conditions be encountered in the process of further investigation or development, which would be highly likely, the actual costs of construction would be significantly higher. Costs are provided in Australian dollars indexed to 2020. Backbone water infrastructure is defined as that infrastructure used to capture, store and divert water. It does not include reticulation or farm-scale infrastructure within an irrigation scheme. Numbers in this summary report have been rounded. Reported reservoir yields and mean annual diversions should be considered as those physically possible, rather than those probable. While the diversion values stated in this report take into consideration existing users of water in the catchments they are unconstrained by the current regulatory environment, or other social, cultural and environmental considerations. For the purposes of this report, dam height is defined as the height from the river bed to the dam crest. All elevations are referenced to the EMG96 geoid.

The companion technical report details the analysis and assumptions that underpin the material presented in this summary report.

The Warrego River at Wyandra. The Warrego River is the most northerly river in the Murray-Darling Basin and is often proposed as a natural channel in Bradfield Scheme variants.



Map 1 The Bradfield Scheme and modelled pre-development streamflow

Bradfield's original scheme (1938) proposed diverting water from the upper Tully, Herbert and Burdekin catchments to the Flinders River and then Skeleton Creek, a tributary of the Thomson River. Bradfield's variant (1942) proposed piping water from the upper Tully, Herbert and Burdekin catchments to Webb Lake and then into Torrens Creek, a tributary of the Thomson River. Contemporary commentators have advocated diverting water from the upper Tully, Herbert and Burdekin catchments to the northern Murray–Darling Basin. Only soils potentially suitable for irrigated agriculture in Queensland south of Bindebango terminal storage are shown.

Executive summary

In 1938 Dr John Bradfield, an eminent engineer at the time, proposed an ambitious scheme to divert water via a series of dams and tunnels from the east-draining Tully, Herbert and Burdekin rivers on the north-east Queensland coast to the westerly draining semi-arid Flinders River and then to the arid internally draining Thomson River, which flows into Kati Thanda-Lake Eyre.

Eighty-three years after first being proposed, the Bradfield Scheme and its variants still arise as part of the national discourse on drought and water security. Interest in 'Bradfield concepts' rise especially in times of drought and are generally promoted as means to stimulate 'nation building' through creating significant and enduring regional economic development opportunities in water supply and irrigation. Instead of diverting water to western Queensland, many contemporary variations of Bradfield's scheme propose diverting water to the Murray–Darling Basin (MDB) where there is already an established irrigation industry and supporting infrastructure and demand for water. The Australian Government through the National Water Grid Authority commissioned CSIRO to undertake an assessment of contemporary variations to Bradfield's scheme.

This assessment found that a partially solar photovoltaic (PV) powered pumped pipeline from the upper Tully catchment to the upper Herbert catchment and a ~62-m high dam and gravity diversion tunnel from the upper Herbert River to the upper Burdekin catchment, combined with runoff from the upper Burdekin catchment could generate a combined mean annual inflow of 2644 GL to a potential ~98-m high dam at Hell's Gates on the upper Burdekin River, while ensuring sufficient water was released down the Tully, Herbert and Burdekin rivers to meet the needs of existing downstream entitlement holders. A 152-m (500 foot) Hell's Gates dam, as proposed by Bradfield (1942) and some contemporary commentators, would never fill because the net evaporation from the reservoir surface would exceed the long-term inflows.

After releasing water to meet the needs of downstream entitlement holders a potential ~98-m high Hell's Gates dam could potentially release 2280 GL in 75% of years into a water supply channel with an offtake ~45 m above the base of the dam. This offtake height would enable a 1600-km gravity channel with a deep cutting or a slightly longer gravity channel with a 43-m re-lift station to convey water to St George on the Condamine-Balonne River in the northern MDB, the first major irrigation area along the potential channel alignment. Taking into consideration the 28% annual flow loss in the adopted channel configuration to St George, a pumped pipeline from the potential Hell's Gates dam to St George had a levelised cost (i.e. the annualised cost divided by the mean annual diversion) greater than three times that of the channel configuration.

A desktop analysis of contemporary variations of the Bradfield Scheme to divert water to the Murray–Darling Basin found while technically feasible, the cost of the water storage and diversion infrastructure alone would be at least four times the amount irrigators could afford to pay for the water.

There are alternative options for configuring water infrastructure to be able to meet the water supply and security objectives of Bradfield-style schemes with less risk lower, lower cost and better spatial and temporal matching of water infrastructure development to where opportunities are greatest.

There is little scope to enhance channel diversions between the potential Hell's Gates dam and the northern MDB by capturing additional water en route. Major drainage lines that intersect the potential channel alignment have unfavourable topography for potential off-line channel storages, and resulting dams would be low yielding and costly. There is also limited potential to generate hydro-electric power along the backbone infrastructure water supply line. Opportunities to supply water to other industries along the water supply channel are also limited. The potential channel alignment traverses the most resource poor parts of Queensland, largely due to the extensive sedimentary cover. Furthermore, relative to agriculture, mining requires relatively little water and does not typically require high-quality water. Mining companies usually have sufficient resources to be self-sufficient in terms of their water requirements. No regional centres with water security issues are located near the potential channel alignment, and therefore the contemporary Bradfield Scheme offers little benefit for improving the water security of regional centres in Queensland.

The optimal backbone infrastructure configuration (i.e. dams, pipes, tunnels and channels along the main water supply line) to St George is estimated to cost between $15 billion and $30 billion (assuming favourable geological conditions) with an annual cost of between $130 million and $255 million (including operation and maintenance, annual pumping costs and net revenue). After taking 7 to 10 years for approvals it is estimated that the backbone infrastructure would take a minimum of 12 years to construct. For a mix of 'high' priority (100% reliability) and 'medium' priority (75% annual time reliability) water, a mean of ~1270 GL of water could be diverted to St George after losses, which is equivalent to 25% of the average annual volume of water used for irrigation in the MDB between 2015 and 2019. It should be noted, however, in the Bradfield Scheme source catchments no releases were made to mitigate impacts to downstream water dependent ecosystems or meet environmental flow objectives stipulated in the state government water plans. Releasing water for this purpose is a requirement of the National Water Initiative and could substantially reduce the volume of water that could be diverted.

Adjacent and downstream of the existing Beardmore Dam (capacity 81.7 GL) near St George there is approximately 90,000 ha of land already developed for irrigated cotton, and other broadacre crops and 600 ha of land already developed for irrigated horticulture. However, collectively, irrigators along the Condamine-Balonne River currently only extract their full entitlement in about 40% of years, and this area of developed land is only fully irrigated in very wet years when 'flood harvesting' is possible. In drier years large extraction shortfalls occur because there are relatively few large dams and weirs to regulate the highly variable flows in the river, and the northern MDB more generally. Although high-value horticulture is two to nine times more profitable per unit of irrigation applied than cotton, which is the most profitable broadacre/industrial crop, large-scale expansion of horticulture in the northern MDB is limited by the reliability of water supply, and as discussed later, ultimately, markets. South of St George along the Condamine-Balonne River and the nearby Moonie River there is more than 780,000 ha of soil potentially suitable for irrigated agriculture, of which about 150,000 ha are sandy and loamy soils potentially suited for horticultural crops.

Looking upstream along the Burdekin River towards the potential Hell's Gates dam axis. Hell's Gates dam is synonymous with the Bradfield Scheme.

It was found that under the ‘optimal’ Bradfield Scheme backbone infrastructure configuration, which included a 43-m re-lift pump station and a large terminal storage, sufficient water could be delivered to increase the reliability of fully irrigating the existing 90,000 ha of cotton and broadacre cropping in 75% of years, as well as fully irrigating an additional 80,000 ha of new cotton in 75% of years and about 30,000 ha of new high-value horticulture in 100% of years. Thirty thousand hectares of citrus, the most profitable crop per megalitre of water consumed that could be grown in the St George region, was adopted for this analysis to represent an optimistic economic ceiling for horticultural production.

Assuming the total cost of backbone and reticulation infrastructure to be $21 billion, under a set of extremely optimistic assumptions used to estimate an unattainable upper bound of financial performance, a discounted cash flow analysis over the lifetime of the scheme (100 years) showed water would have to be charged at $2310 for each megalitre supplied to cover the costs of the scheme. Net farm revenue was sufficient to afford no more than $580 per megalitre of water supplied, which would only cover about a quarter of the scheme’s costs. The cost of diversion infrastructure alone would add a premium of $1920 to the cost of each megalitre of water used to irrigate crops, making water cost about six times what it would without the diversion infrastructure. The inclusion of renewable energy and pumped pipelines made a very small change to the overall economics of the scheme, mainly because the cost of the water storage and particularly the main water supply channel from potential Hell’s Gates dam to the northern MDB dwarf all other costs.

However, this analysis is highly optimistic. Infrastructure that involves substantial subsurface excavation, such as dams, tunnels and channels, and have long construction periods, are particularly susceptible to large cost overruns. Australian and international studies of large-dam and mega-dam projects report a mean cost overrun of 120% and 100% respectively. Further, market projections estimate horticultural growth in the St George region would be unlikely to exceed 13,000 ha by 2050, even if unconstrained by the availability of water. Allowing for a modest combination of risks (Including a 20% infrastructure cost overrun and slower more realistic expansion of horticulture) lowers the proportion of the revised scheme’s costs for which irrigators could pay to 8%.

The Bradfield Scheme storage and diversion infrastructure offers minor financial benefit in mitigating flooding in the lower Tully, Herbert and Burdekin catchments relative to the overall capital and annual operation and maintenance costs of the backbone infrastructure. If implemented it was calculated that the Bradfield Scheme could result in an overall reduction in anthropogenic load of total suspended solids and particulate nitrogen delivered to the Great Barrier Reef of 10 and 8 per cent, respectively.

Commissioned in 2000 Windy Hill wind farm near Ravenshoe in the upper Herbert catchment was the second wind farm constructed in Queensland.

Although there may be some potential for possible ecological benefits in diverting water from north Queensland and strategically releasing it to try and achieve better environmental outcomes for the northern MDB, it would need to be considered against the range of possible ecological impacts both within the northern MDB and within the Bradfield Scheme source catchments. These impacts are likely to be large.

The upper limit of the regional benefit from expanded farming would be less than $6.1 billion per year and create up to 11,000 jobs, but this would only occur if: (i) horticulture in the vicinity of St George were to expand by an amount equivalent to 30% of the gross value of all fruit, vegetable and nuts currently produced in all of Australia (which could take more than 100 years if this were technically possible); and (ii) farmers did not have to pay for water. Most of the new jobs would be for seasonal fruit picking and packing work, which historically has largely been undertaken by foreign and domestic migratory workers from outside the region (so much of the benefit would accrue outside the northern MDB, and partially outside Australia).

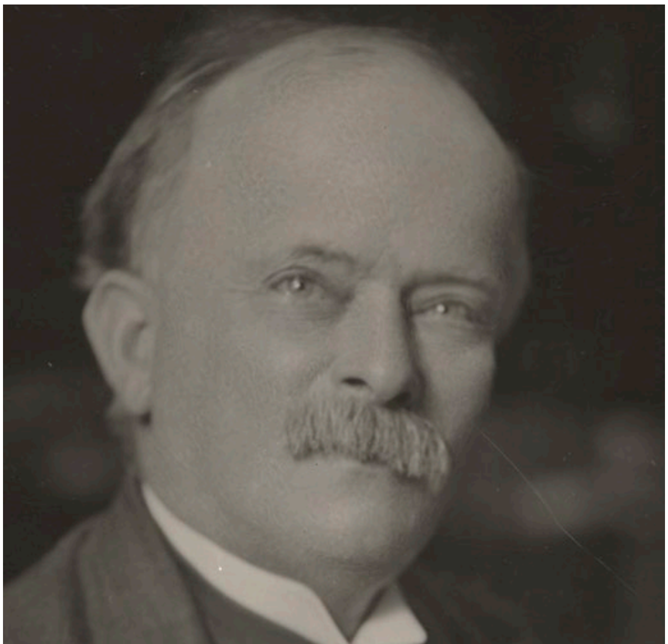
The fundamental weakness of Bradfield-style schemes are the high costs of diversion infrastructure without an offsetting locational benefit, and large volumes of expensive water in excess of what high value industries could expand to consume and pay for in the medium term. While it may be difficult to find new water development options that are financially viable in their own right, it would at least be possible to find more efficient alternatives that avoid high financial losses. Such alternatives could involve strategically planned regionally-distributed additional water storages that could be progressively staged to scale with the demand of high value water users. This could be done in two ways, depending on whether the priority was to cost-effectively expand local bulk water supply volumes or increase regional water security (or some combination of the two). If the priority were on increasing water volumes to allow local high value industries to expand, then augmenting regional water storage capacity to capture additional water supplies and meet local demands would likely achieve the highest benefit per million dollars of infrastructure spending. If the priority were on improving local water security and water supply reliability, then drought-related water shortfalls could be mitigated by gradually building additional water supply capacity and by linking relatively smaller pieces of new and existing infrastructure into a number of 'inter-connected regional grids'. However, this may come at the expense of inefficiencies from having infrastructure on standby in non-drought periods during which it would not be used to its full capacity. These alternative options for configuring water infrastructure would be able to meet the water supply and security objectives of Bradfield-style schemes with less risk, lower cost and better matching of water infrastructure development to where demands and opportunities (in terms of where natural resources and other existing infrastructure are located) are already greatest.

The Bradfield Scheme: Introduction

- Eighty-three years after first being proposed, the Bradfield Scheme and its variants still arise as part of the national discourse on drought and water security. The term Bradfield has become almost synonymous with ideas for 'solving drought' – by turning northern Queensland rivers inland and/or moving water from northern Australia south.

There is considerable confusion about what the Bradfield Scheme is.

- In 1938, Bradfield[1] proposed a gravity diversion scheme in north Queensland that involved diverting water from the upper Tully and Herbert catchments into a potential large storage area at Hell's Gates on the Burdekin River, where a tunnel could divert water to the Flinders River, which then could be linked to the upper Thomson River via an open-cut channel (Map 1).



Dr John Bradfield (1867–1943)

Bradfield conceived his scheme during a time when 'nation building' and the threat of invasion was prominent in the minds of Australians.

- In 1942, Bradfield[2] put forward a variation to his original scheme, whereby water would be piped from the potential Hell's Gates dam south to Webb Lake and then into Torrens Creek, a tributary of the Thomson River (Map 1).
- Together these designs constitute what is referred to here as the historic Bradfield Scheme.

Interest in 'Bradfield Scheme concepts' rise especially in times of drought and are generally promoted as means to stimulate 'nation building' through creating significant and enduring regional economic development opportunities in water supply and irrigation.

- Since Bradfield originally proposed his scheme more than 80 years ago, a variety of alternatives have been put forward by prominent Australians, media personalities, politicians and Bradfield advocates.
- In support of the scheme these contemporary proponents have made various assertions, including:
  - Water could be diverted under gravity to the Murray–Darling Basin (MDB) where it could be used to increase the reliability of irrigation and used to develop new areas of high-value horticulture for export.
  - Additional water could be diverted from the South Johnstone catchment.
  - Water could be supplied to meet the needs of other industry en route to the MDB.
  - There could be a reduction in runoff, sediment and nutrients to the Great Barrier Reef.
  - The scheme could reduce the incidence of flooding on the Tully, Herbert and Burdekin coastal floodplains.
  - Pumped pipelines, potentially utilising renewable energy as a source of power, could enable the scheme to be viable.
  - Additional water could be diverted into the channel from adjacent drainage lines en route to the MDB.

1 Bradfield JJC (1938) Queensland: the conservation and utilisation of her water resources. Brisbane.
2 Bradfield JJC (1942) Restoring Australia's parched lands. The Australian Quarterly 14, 27–39.


The iconic 566 km Goldfields pipeline running from Perth to Kalgoorlie is one of Australia's lesser known 'nation building' projects. Completed in 1903 it enabled the rapid development of the Western Australian Goldfields region and continues to supply water to over 100,000 people. At the time of its design and construction it faced widespread criticism.

The various contemporary claims and the counter-claims made by opponents to the scheme have not been subject to a formal technical analysis and remain unsubstantiated.

- The last formal technical review of aspects of the Bradfield Scheme was in 1985.
- While Bradfield proposed diverting water inland to enable greenfield irrigation and regional development of western Queensland, some contemporary proponents have instead advocated diverting water to the MDB, where there is already an established irrigation industry and supporting infrastructure and demand for water.

The Murray–Darling Basin covers over 1 million km^2 (one-seventh) of mainland Australia and is home to over two million people. In 2018–2019 1.1 million ha of land in the Murray–Darling Basin was irrigated, about 50% of the total area in Australia under irrigation. The Murray–Darling Basin is often referred to as Australia's 'food basket'.

- The Darling River, Australia's longest river (2740 km), and its tributaries extend into southern Queensland and northern NSW (Map 1). To the south the Murray River, Australia's second longest river (2530 km), dissects the Riverine Plain from east to west (Map 4).
- The southern MDB including irrigation areas around Griffith, Coleambally, Deniliquin and along the Murray River, are supplied water from the Snowy Mountains Scheme, Australia's largest inter-basin diversion scheme. The rivers of the southern MDB are heavily regulated, and account for about two-thirds of average annual consumption of surface water use across the MDB.
- In the northern MDB, the Darling River and its major tributaries are less regulated than the southern MDB and a larger proportion of irrigation water is sourced from harvesting flood waters and held in large on-farm storages. As a consequence of this and the variable nature of streamflow in the northern MDB, the area under irrigation fluctuates from one year to the next and mainly annual broadacre crops are grown.
- In 2008, CSIRO reported that the total modelled streamflow at the Murray River mouth had reduced by 61% and that the river ceased to flow through the river mouth 40% of the time compared to 1% of the time in the absence of water resource development.
- Sixteen MDB wetlands are listed as internationally important under the Ramsar Convention on Wetlands and about 220 are listed in the Directory of Important Wetlands in Australia. Many of the floodplain wetlands and forests have been degraded and some have suffered significant loss of area over recent decades due to changes in flooding and land use.
- A wide range of irrigated crops have been grown using irrigation in the MDB. In the northern MDB where the supply of irrigation water is less reliable, cotton is the most profitable irrigated broadacre crop, being best suited to the rapid expansion and contraction of production in response to the extreme variation in irrigation water availability. Smaller pockets of horticultural production (e.g. citrus, pecans, table grapes) also exist in the northern MDB but expansion is limited by a lack of high security irrigation water.
- Cotton production is also expanding in the southern MDB where water supply is more reliable and significant areas of citrus, table and wine grapes, almonds and grain crops (e.g. rice, wheat, maize) are also produced, with decreasing areas of irrigated pastures for dairy.
- As with other irrigation schemes around Australia, horticultural production has the highest gross margins per unit land area and also per unit irrigation water applied, and horticulture is expanding in districts where water supply is reliable.

The upper Tully, upper Herbert and upper Burdekin catchments are referred to as the Bradfield source catchments and have a combined area of 23,378 km^2.

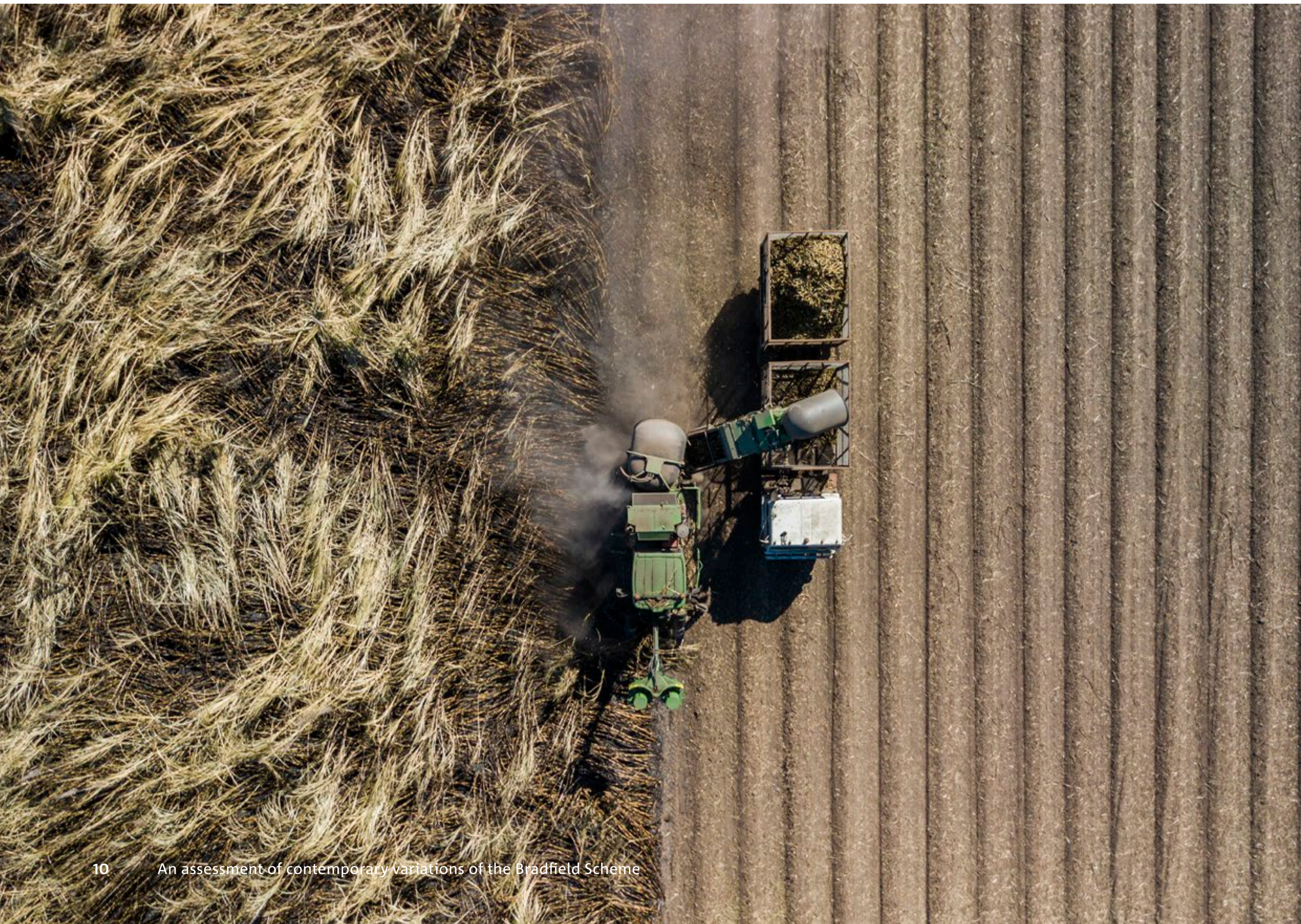
- The upper Tully catchment (275 km^2) is situated in the Wet Tropics, and is one of the wettest places in Australia. However, like other catchments within the narrow coastal strip between Ingham and Cairns that constitutes the Wet Tropics, its catchment area is small, so streamflow volumes are modest compared with other rivers in Queensland (Map 1). The same applies to the upper Herbert and upper Burdekin catchments, which while having larger catchment areas they have temperate and semi-arid climates and modest rainfall.

The companion technical analysis into the original Bradfield Scheme found that Bradfield overestimated streamflow by over a factor of two (Table 1).

Table 1 Estimates of mean annual streamflow at key diversions along the water supply line of the original Bradfield Scheme

LOCATION	BRADFIELD 1938 (GL/YEAR)	CSIRO 2020 (GL/YEAR)
Tully Falls on the Tully River	562	506
Herbert River Falls on the Herbert River	2677	1090
Hell's Gates on the Burdekin River	3678	1603
Flinders River at Glendower	275	107
Total	**7192**	**3306**

Harvesting sugarcane in the lower Burdekin. In 2019–20 the Burdekin produced nearly one quarter of Australia's sugarcane.



When the Murray–Darling Basin is experiencing a deficit in water, the Bradfield source catchments (i.e. upper Tully, Herbert and Burdekin) are no more or less likely to also be experiencing a water deficit.

- Correlations between rainfall and runoff in the MDB and the Bradfield source catchments are weakly positive. The correlation is not statistically significant.
- The modelled shortfall in water extracted by irrigators in the northern MDB was found to have no correlation with inflows to the Bradfield source catchments, meaning in order to supply water with the same reliability potential 'Bradfield Scheme' dams and reservoirs would not need to be as large as if there was a strong positive correlation. Conversely potential Bradfield Scheme dams and reservoirs would have to be larger than if there was a strong negative correlation.

Since Bradfield first proposed his scheme there has been considerable water resource development in the Tully, Herbert and Burdekin catchments.

- In the Burdekin catchment three large dams and seven weirs have been constructed and over 80,000 ha of land developed for irrigated agriculture in the lower Burdekin and Burdekin Haughton Water Supply Scheme.
- Koombooloomba Dam on the Tully River was constructed in 1960 and releases water for the generation of hydro-electric power at the Koombooloomba Hydro Power Station (7 MW) and the Kareeya Hydro Power Station (86.4 WM). The intake of the Kareeya Hydro Power Station is at Tully Falls weir.

Some contemporary proponents of the Bradfield Scheme have advocated for the inclusion of the South Johnstone River. However, the Assessment found that it is not technically possible to divert water under gravity from the South Johnstone into either the upper Tully or upper Herbert catchments.

- The upper Tully with its existing Koombooloomba Dam and upper Herbert catchments sit atop the steep coastal escarpments of the Wet Tropics and form the most southern extent of the Atherton and Evelyn tablelands. Their commanding position with a higher elevation than the southerly draining Burdekin catchment to the south is what gives rise to the potential for the gravity drainage diversion scheme proposed by Bradfield.
- The southerly orientated gently sloping upper Herbert catchment turns perpendicular to the steep gradient to the east at Herbert River Falls, below which lies the steep and deeply incised Herbert River Gorge.
- The upper Johnstone catchment lies to the north-east of the Herbert catchment with their shared catchment boundary demarking the edge of the southern tablelands and the coastal escarpment. As a consequence the Johnstone River and its tributaries occupy a different geomorphic setting, more similar to the Herbert River Gorge below Herbert River Falls, with steep gradients to the coast and potential dam and diversion sites considerably lower in elevation than the upper Herbert and Tully catchments.
- The inclusion of the upper reaches of the South Johnstone River into a Bradfield Scheme would require pumped pipelines of about 21 km in length and 215-m pumping head at the nearest point. At this point the mean annual flow of the South Johnstone River is estimated to be 78 GL, of which only a proportion could be diverted. A potential dam on the South Johnstone River would be situated within the Wet Tropics World Heritage Area.

The inclusion of the South Johnstone River in the Bradfield Scheme would add a small volume of water at considerable cost. It was not considered further.

- The levelised cost of a pumped pipeline from the South Johnstone and North Johnstone rivers is estimated to be $168/year per ML/year and $285/year per ML/year respectively. This is before factoring in the very steep, remote and heavily vegetated landscape along which the pumped pipeline would need to traverse or a dam on either river to impound the water. The levelised cost of the pumped pipeline from the South Johnstone River alone is about three to four times the levelised cost of diverting water from the upper Tully to Blunder Creek and the upper Herbert to the upper Burdekin respectively.

Key elements of a contemporary Bradfield Scheme

- In an earlier companion analysis on the original Bradfield Scheme[3], CSIRO found Bradfield's original gravity diversion scheme was technical feasible and with modifications could divert on average 2272 GL/year from a potential dam at Hell's Gates. This is more than twice that of past critical reviews of the Bradfield Scheme, but less than half of that estimated by Bradfield in 1938.
- The earlier companion analysis by CSIRO sought to calculate what diversion volumes were physical possible, and consequently did not take into consideration existing entitlement holders or environmental flow objectives stipulated in the Tully, Herbert and Burdekin water plans, and instead analysed the impact of the scheme on these users' reliabilities and environmental flow metrics.

This section considers the viability of a modified Bradfield Scheme, including pumping pipeline options, to divert water from north Queensland to the Murray–Darling Basin, after allowing for the needs of existing downstream entitlement holders in the Tully, Herbert and Burdekin catchments.

- The overall cost of diverting water to the northern MDB is estimated to be between $15 billion and $30 billion with an annual cost of between $130 million and $255 million (including operation and maintenance (O&M), annual pumping costs and net revenue from renewable energy generation along the backbone infrastructure water supply line). A breakdown of the costs of the adopted configuration is provided in Table 2.

The potential to use pumped pipelines and renewable energy rather than gravity diversion tunnels.

- With the decrease in costs of renewable technologies and battery storage there has been interest in whether renewable energy powered pumped pipelines offer a cheaper alternative to gravity diversion tunnels.

There are attractive renewable energy resources across the Bradfield Scheme Assessment area.

- The upper Tully and upper Herbert catchments have one of the highest wind resources in Australia and this region is attractive to wind developers in part because the wind resource is not correlated with those parts of southern Australia with high wind energy penetration. This region is also encompassed in the Australian Energy Market Operator's renewable energy zones.
- West and south along the potential channel alignment the solar resource is extremely high.

Projections of the levelised cost in 2040 of wind energy, which is a relatively mature technology, suggests a plateauing, while solar photovoltaic (PV) is projected to still be steadily decreasing such that by 2040 it would be 60% lower than wind.

- With approvals likely to take between 7 and 10 years and construction of the adopted configuration a minimum of 12 years, the earliest a potential Bradfield Scheme could be in operation is about 2040.

It was found that if a solar farm receives no revenue for exporting surplus renewable energy it is cheaper to purchase electricity from the grid to power the pumped pipelines.

- It is cheaper to purchase grid electricity than use a completely off-grid system even at the most remote location examined (i.e. 170 km from the nearest transmission connection point).
- Currently there is limited local demand for electricity in these renewable energy zones. With development of renewable resources in these zones the inclusion of significant loads, in the form of pumped pipelines for example, would increase grid strength.

3 CSIRO (2020) An assessment of the historic Bradfield Scheme to divert water inland from north Queensland. A summary report to the National Water Grid Authority from the CSIRO Bradfield Scheme Assessment. CSIRO, Australia.


Oakey Solar Farm is on agricultural land in the northern Murray-Darling Basin, 30 km north-east of Toowoomba. It provides local land owners an additional source of income through long-term leasing.

Table 2 Summary of backbone and reticulation infrastructure used in economic analysis

Costs have a likely accuracy of –25 to +50% of the actual value, assuming favourable geological conditions. Annual revenue is the revenue that could potentially be generated along the backbone infrastructure water supply line by hydro-electric power and solar photovoltaic (PV) power. Annual revenue is negative at Tully Falls Weir because water is diverted to the Herbert catchment before it is used by the existing Kareeya Hydro Power Station. FSL = full supply level; O&M = operation and maintenance.

INFRASTRUCTURE	CAPITAL COST ($ MILLION)	ANNUAL O&M ($ MILLION)	ANNUAL PUMPING ($ MILLION)	ANNUAL REVENUE ($ MILLION)	MEAN ANNUAL DIVERSION (GL)
Tully catchment					
Solar PV	5.2	0.1		~0	
Tully Falls Weir to Blunder Creek pumped pipeline	45	0.5	2.9	-10.8	180
Herbert catchment					
Herbert River Falls dam (FSL 597 mEMG96)	1,280	5.1			
Herbert River Falls dam to Wairuna diversion tunnel	726	7.4			1057
Burdekin catchment					
Wairuna to Burdekin River pipeline	110	1.1			
Hydro-electric power station at Hell’s Gates dam	54	1.6		5.6	
Hell’s Gates dam (FSL 405 mEMG96)	1,814	7.3			1881
Channel					
Hell’s Gates to Bindebango channel	11,654	90			
Solar PV	70	1.7		4.1	
Pump stations at Blackall (includes grid connection)	606	6.1	19.9		
Blackall pipeline	149	1.5			
Great Basalt Wall tunnel	1,091	10.9			
Bindebango terminal storage	1728	6.9			
Bindebango to Jack Taylor Weir channel	941	7.3			1365
St George					
Nominal reticulation scheme cost from Jack Taylor Weir to farm gate	735	7.4	6.7		1270
Total	**21,000**	**155**	**29**	**–1.1**	

There is limited potential to generate hydro-electric power along the Bradfield Scheme water supply line.

- The limited potential to generate hydro-electric power is due to modest elevation differences, water releases timed to meet agricultural demands not energy market fluctuations and the expense of larger diameter pipes in order to preserve head for hydro-electric power generation.
- It was calculated that the net revenue associated with hydro-electric power generation would be about –$5 million/year due to loss in revenue at Kareeya Hydro Power Station ($10.8 million/year) exceeding the revenue generated from releases from Hell's Gates into the water supply channel (~$5.6 million/year).
- Based on a general principle which states the capacity of a solar PV farm should be ~80% of the peak load, approximately $4.1 million/year of revenue could potentially be generated by solar PV installed at pumping locations along the water supply line.

Pumped pipeline from Tully Falls Weir to Blunder Creek

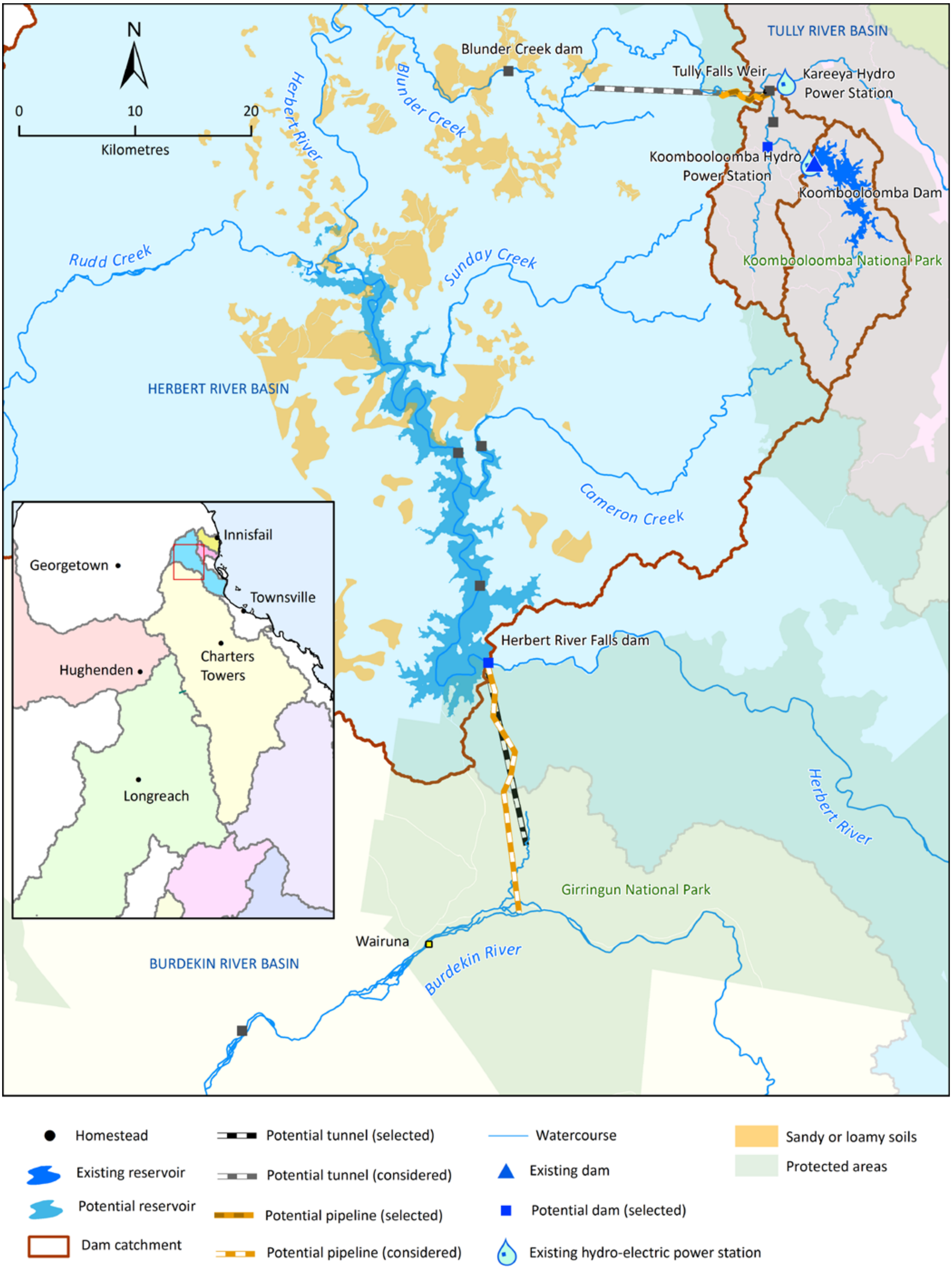
The most cost-effective configuration for diverting 180 GL/year of water from the upper Tully to the upper Herbert catchment was a 4-km pumped pipeline from Tully Falls Weir to Blunder Creek. The 180 GL/year diversion corresponds to the total high-flow strategic reserves in the Tully catchment.

- The existing Koombooloomba Dam (capacity 205 GL) releases water for the generation of hydro-electric power at Koombooloomba Hydro Power Station (7 MW) and the Kareeya Hydro Power Station (88 MW) (Map 2). The intake for the Kareeya Hydro Power Station is at Tully Falls Weir.
- It was estimated that this pumped pipeline configuration would cost about $45 million and an additional $5.2 million for a solar PV system, which could provide about 25% of the electricity to the pump, reducing annual pumping cost to about $2.9 million. Diverting 180 GL/year from Tully Falls Weir to Blunder Creek would result in the owners of the dam and Kareeya Hydro Power Station losing on average about $10.8 million in revenue per year. However, of the water diverted to Blunder Creek, approximately 33% could be captured from Nitchaga Creek and that part of the Tully River between Tully Falls and Koombooloomba Dam, leaving only 67% of water needing to be ordered from Koombooloomba Dam. Depending upon how the hydro power station is currently operated this could mean the loss in revenue is only about $7.2 million/year. For the purposes of this analysis the loss in revenue was assumed to be the full $10.8 million.
- The scheme as configured in this analysis would impact the environmental flow objectives stated in the Wet Tropics Water Plan and for the scheme to proceed the plan would need to be amended in consultation with stakeholders.

Potential dam upstream of Herbert River Falls and gravity diversion tunnel to the Burdekin River

Although not particularly topographically favourable, a dam 1.9 km upstream of Herbert River Falls, and 1.5 km upstream of Bradfield's proposed location, is the best location on the Herbert River to divert water to the upper Burdekin River.

- A dam with a full supply level (FSL) of 597 mEMG96 (~62-m high dam wall to crest) at this location has a storage capacity of 1485 GL. Assuming favourable geological conditions, it is estimated the dam would cost about $1.25 billion.
- Including diversions from the Tully River, a 62-m high dam wall at this location could potentially result in a mean annual diversion of 1057 GL through a 6.5-m diameter tunnel to the upper Burdekin River (Map 2). A gravity diversion tunnel was found to be more cost-effective than pumped pipeline configurations, including consideration of in-line hydro-electric power.
- The scheme as configured in this analysis would materially impact the environmental flow objectives stated in the Wet Tropics Water Plan and for the scheme to proceed the plan would need to be amended in consultation with stakeholders.
- Under the configuration adopted in this analysis, the Bradfield Scheme would result in an overall reduction in the mean annual streamflow at the mouth of the Tully and Herbert rivers of about 6% and 27% respectively.



Map 2 Upper Tully and upper Herbert catchments

Only those water storage and diversion options proposed by Bradfield (1938) and those adopted in this analysis are shown. FSL of potential Herbert River Falls dam at 597 mEMG96. Only shown are sandy and loamy soils potentially suitable for irrigated horticulture in Herbert catchment.

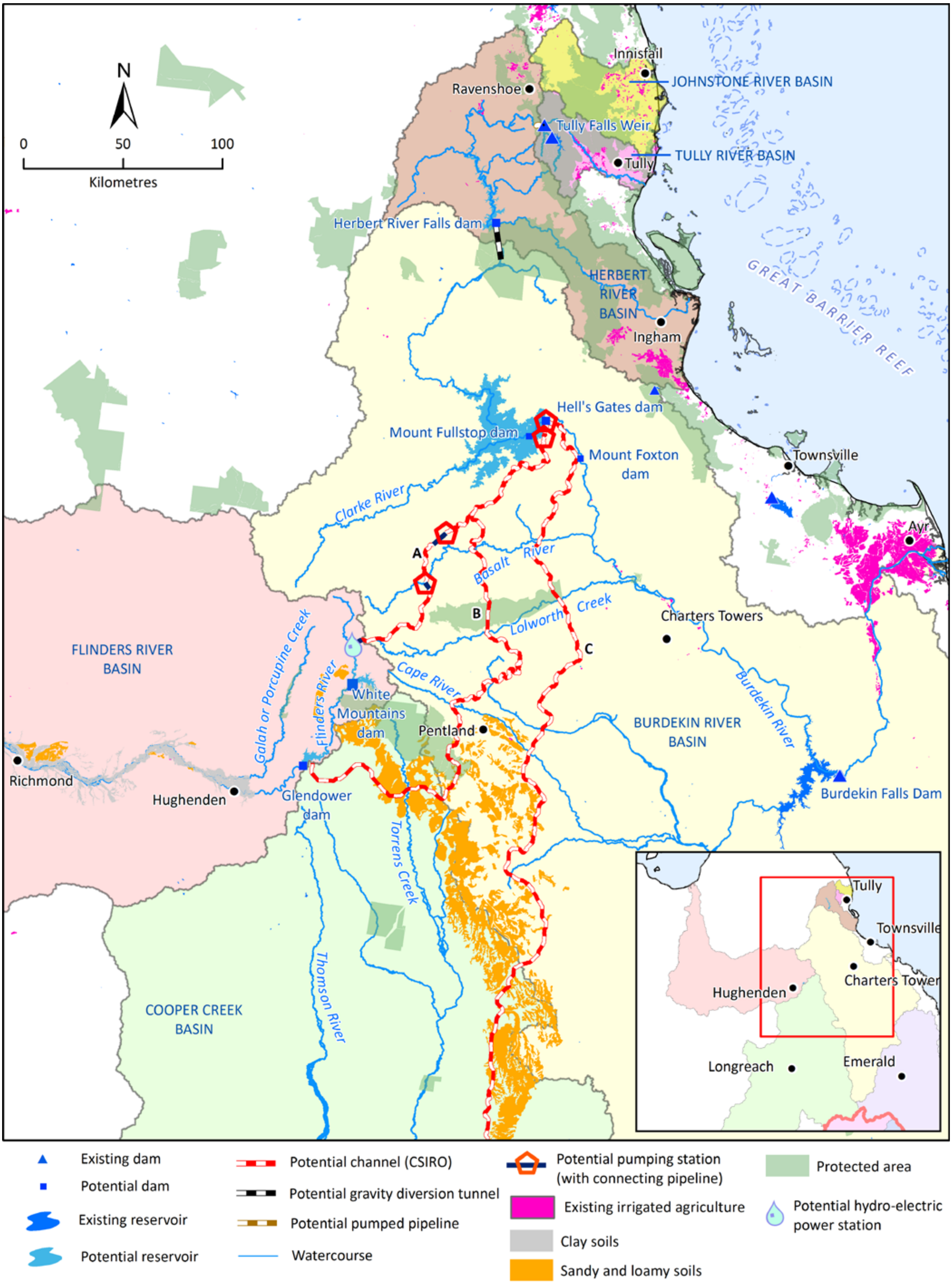
Herbert River Falls on the Herbert River is a popular local tourist attraction. It is situated about 2 km downstream of the inlet of the potential diversion tunnel from the Herbert River to the upper Burdekin River.

Potential Hell's Gates dam

- Bradfield's (1942) proposed 500-foot dam (152 m), for which some contemporary proponents also advocate, was found to never fill, even without releases to meet the water requirements of existing downstream users.
- The most cost-effective way of diverting water via gravity to the MDB was a 97.5-m dam at Hell's Gates with FSL at 405 mEMG96 and a channel outlet ~45 m above the riverbed at the dam (i.e. ~365 mEMG96). The cost of the dam was estimated to be about $1.8 billion (likely accuracy of -25% to +50% assuming favourable geological conditions).
- A channel outlet of 365 m was found to be the minimum elevation for water to flow in the channel under gravity to a low point in the Great Dividing Range at Lake Buchanan, from where the channel could flow into the Thomson catchment en route to the MDB (Map 3).
- Under this configuration a 97.5-m high dam at Hell's Gates dam could potentially yield 2280 GL in 75% of years, while also releasing water to meet the needs of downstream entitlement holders.
- A hydro-electric power station at the potential Hell's Gates dam could generate about 5.6 million/year in revenue from water released into the water supply channel.
- The environmental flow objectives for the Burdekin River above Burdekin Falls Dam as stipulated in the Burdekin Water Plan do not permit the pre-development mean or median annual flow to be reduced by greater than 3%. This makes water resource development along the upper Burdekin River challenging under the current water plan.
- The scheme as configured in this analysis would materially impact the environmental flow objectives stated in the Burdekin Water Plan and for the scheme to proceed the plan would need to be amended in consultation with stakeholders.
- Under the adopted configuration the Bradfield Scheme would result in an overall reduction in the mean annual streamflow at the Burdekin River mouth of ~18%.

Climate change is more likely to result in a reduction in water yield in the future than result in an increase.

- Of the 21 global climate models (GCM) examined, two-thirds projected a 'drier' future climate in the Bradfield source catchments as well as the northern MDB, suggesting extraction shortfalls between supply and demand in the northern MDB are likely to increase and that the quantity of water that could be reliably released from a potential Hell's Gates dam is more likely to be lower in the future.
- Based on the range of results from 21 GCMs, projected annual yields (at 75% annual time reliability) from Hell's Gates dam in 2060 were found to vary between 1150 GL (–50%) and 2950 GL (+30%).



Map 3 Contemporary variations of the Bradfield Scheme for the diversion of water to the MDB and Flinders River

Only soils potentially suitable for irrigated agriculture along the Flinders River and Desert Uplands shown.
(A) Potential pumped pipeline channel high alignment to Flinders River involving four pump stations and a hydro power station.
(B) Potential pumped pipeline channel low alignment option to Flinders River involving two pump stations.
(C) Potential channel alignment to the northern MDB. Potential hydro-electric power station at Hell's Gate dam not shown.
FSL of potential Herbert River Falls dam, Hell's Gates dam and Glendower dam shown at 597, 405 and 430 mEMG96 respectively.

Pumped pipeline and channel diversion infrastructure to the Flinders catchment

- In the companion technical report on the historic Bradfield Scheme, a 141 km gravity diversion tunnel from the potential Hell's Gates dam to the potential Glendower dam on the Flinders River was estimated to cost between $8.5 billion and $17 billion.
- Between Hughenden and 60 km downstream of Richmond there are about 100,000 to 150,000 ha of alluvial clay soils potentially suited to irrigated broadacre cropping and up to 10,000 ha of sandy and loamy soils potentially suitable for irrigated horticulture with 10 km of the Flinders River (Map 3).
- In this analysis it was found that high and low pumped pipeline channel alignments from the potential Hell's Gates dam to the Flinders River (Map 3) would be cheaper and could divert more water than the gravity diversion tunnel proposed by Bradfield in 1938.
- The pumped pipeline channel high alignment included four pump stations partially powered by solar PV, 20 km of pipeline, 190 km of open channel and two very large terminal storages. It would be possible to construct a small hydro-electric power station at the outlet to the Flinders River, which could potentially partially power the fourth pump station. This alignment was calculated to have a capital cost of between $4.5 billion and $9 billion and an annual cost of about $190 million (after factoring in hydro-electric power generation and revenue from solar PV generation).
- The pumped pipeline channel low alignment included two pump stations partially powered by solar PV, a 10 km gravity diversion tunnel, 1.3 km of pipeline and 420 km of open channel. There is no opportunity for hydro-electric power generation along the low alignment, however, the low alignment dissects more than 50,000 ha of sandy and loamy soils potentially suitable for irrigated horticulture near Torrens Creek (Map 3). The low alignment was calculated to have a capital cost of between $6 billion and $12 billion and an annual cost of about $100 million (after factoring in revenue from solar PV).
- Both alignment configurations could potentially divert a mean of 2100 GL from a 98-m high dam at Hell's Gates. This is considerably greater than the mean annual diversion calculated for Bradfield's diversion tunnel (598 GL), which is limited by the height of the tunnel inlet required for gravity flow.
- The lower alignment, with large areas of soil potentially suitable for irrigated horticulture was adopted for further analysis. After an overall water loss of about 20% it was calculated that it would be possible to irrigate 30,000 ha of mandarins at 100% reliability and 104,000 ha of dry season cotton in 75% of years.
- Assuming a total project cost of $12 billion and under an optimistic set of assumptions (used to indicate an unattainable upper bound of financial performance) the scheme could generate net farm revenue sufficient to pay up to $420 per megalitre of water. This would be sufficient to cover 43% of the cost of the scheme providing an IRR of 3.0%. Diversion infrastructure added $660/ML to the cost of supplying water, making up over two thirds of the total $970/ML that the supplier would have to charge to cover their costs.
- Under a moderate combination of risks the proportion of the scheme's costs that irrigators could afford to pay dropped to 8% and the cashflow of the scheme remained almost entirely negative throughout the life of the scheme.

Diversion infrastructure to take water to the Murray–Darling Basin

The potential Hell's Gates dam commands a strategic elevated position on the Great Dividing Range such that water could potentially flow via gravity in a 3300-km open channel to the Murray River near Deniliquin.

- It is estimated that a 3300-km gravity channel to Deniliquin (Map 4) with initial capacity of 91 cumecs (cubic metres per second) would involve moving about 1 billion cubic metres of soil and rock. It was modelled to cost between $20 billion and $40 billion, excluding cross drainage and siphons, and it is estimated that it would take about 25 years to construct using 36 full separate sets of earthmoving plant (which is likely to be equivalent to every plant currently available in Australia).
- This would be about twice as long as the world's oldest and longest constructed waterway the Beijing-Hangzhou Grand Canal, which connects five of the major rivers in China and passes through some of China's richest agricultural lands.
- Although a shorter channel alignment with several relift stations is plausible, the gravity channel alignment from Hell's Gates to Deniliquin passes through or near the majority of major irrigation districts in the MDB north of the Murray River (Map 4).
- In conveying water to Deniliquin it is calculated that about 50% would be lost in conveyance and consequently only about 1000 GL could potentially be available from the channel's terminal storage. This is equivalent to about 20% of the average annual volume of water used for irrigated agricultural production across the MDB between 2015 and 2019 (i.e. about 5000 GL).

If water from the Bradfield source catchments was to be diverted to the MDB, the most pragmatic option would be to limit the extent of the diversion channel to the northern MDB.

- St George on the Condamine-Balonne River is the first established irrigation district in the MDB through which the channel passes.

Goondiwindi on the Macintyre River in the northern Murray–Darling Basin. Studies in the southern Murray–Darling Basin have shown that irrigation production generates a level of economic and community activity that is three to five times higher than would be generated by rainfed (dryland) production.

Jack Taylor Weir and the city of St George on the Condamine-Balonne River. Jack Taylor Weir is operated conjunctively with Beardmore Dam to supply water for irrigation, urban and industrial water users in St George.

The most cost-effective channel alignment between Hell's Gates and St George was a gravity channel of about 1600 km in length with a 43-m relift station near Blackall and a large 1380-GL capacity terminal storage at Bindebango about 100 km from St George.

- Under this configuration a 97 cumecs capacity gravity channel, relift and terminal storage configuration is estimated to cost between $12 billion and $24 billion and would take at least 12 years to construct. It is estimated that it would require an annual O&M budget of ~$123 million and cost ~$20 million/year in pumping, assuming a solar farm operated as a separate entity provided 23% of the power to the pumped pipeline, which was 'situated behind the meter'.
- Incorporating a large terminal storage into the design meant the capacity of this channel could be designed to convey annual demands to the terminal storage rather than the larger peak evaporative demands, saving 37% on channel construction costs and reducing losses by about 24%. The capacity of the channel after the terminal storage to Jack Taylor Weir at St George was designed to meet peak evaporative demands.
- Based on the adopted channel configuration and taking into consideration annual variations in irrigation requirements in the St George region, including supplying water to irrigate 30,000 ha of horticulture at 100% annual time reliability, mean annual releases from the potential Hell's Gates dam would be 1881 GL/year.
- On average 1365 GL/year could be released from the Bindebango terminal storage, which equates to a loss of 28% of water during conveyance and net evaporation from the Bindebango terminal storage. Of that water released from Bindebango terminal storage 7% is lost in transmission between Bindebango and Jack Taylor Weir at St George.
- The cheapest entirely gravity channel alignment, which would involve a deep cutting rather than a relift over ranges south of Blackall, was estimated to cost between $14 billion and $28 billion.
- In order to increase the reliability of existing irrigators along the Macintyre River a 338-km gravity channel from Bindebango terminal storage to Goondiwindi Weir could be constructed at an additional cost of between $3 billion and $5 billion.

Taking into consideration channel losses and the cost of pumping, the levelised cost of a pumped pipeline from the potential Hell's Gates dam to Bindebango would be greater than three times that of an equivalent capacity open gravity channel.

- It is estimated that the cost of a 79 cumec capacity pumped pipeline to Bindebango terminal storage near St George would be more than $40 billion, before considering grid connections or complexities with pumped pipelines such as hydraulic transients, which can add considerable cost. Assuming a mean annual release of 1881 GL the annual cost of pumping is estimated to be about $670 million, with an additional annual O&M cost of $480 million.
- A gravity pipeline to the northern MDB would be considerably more costly than a pumped pipeline due to the very large number of large diameter pipes required to minimise head loss.

The potential to capture runoff from land adjacent to the channel could contribute up to an additional 15% of water but would significantly increase the cost of the system.

- In-line channel storage systems can be thought of as a section of the channel network where the upstream bank has been removed to allow runoff from the intercepting catchment to be directed into the channel in an uncontrolled manner.
- In-line channel storages are limited to capturing water from relatively small catchments and major issues include loss of head in order to provide operational storage to the in-line channel, increased evaporative and seepage loss arising from having a larger surface and wetted perimeter, sedimentation of the channel and challenges controlling flow along the channel.
- The Hell's Gates to MDB water supply channel is better suited to capturing runoff from adjacent catchments with off-line channel storages. Off-line channel storages are storages on an adjacent or intersecting catchment with the ability to release water along a branch channel or pipe to the main water supply channel.
- Seven potential off-line channel storages were identified along the water supply channel alignment. If these were designed to maximise water yield they could supply about 334 GL in 75% of years at a combined cost of $9.2 billion, which equals a unit capital cost of $27,639/ML per year. Alternatively, if the off-line channel storages were designed around cost-effectiveness then their collective yield would be about 230 GL in 75% of years at a combined cost of $5.4 billion, which equals a unit capital cost of 23,300/ML per year.

Natural drainage lines in the northern Murray–Darling Basin are not efficient at carrying water. Releasing water from the main water supply channel into the Darling River and its major tributaries would result in large volumes of water being lost in transmission.

- Utilising data from the CSIRO Northern Australia Sustainable Yields Project in 2008 it was found that average losses along the Condamine-Balonne River downstream of St George were 42%.
- Along the Barwon-Darling between Collarenebri and Wilcannia (~600 km in length), upstream of Menindee Lakes, it was calculated that on average a further 36% of water would be lost in transmission, resulting in a total loss in flow of about 63%. This is identical to the losses calculated between Collarenebri and Wilcannia during a recent 'protected' environmental flow release in 2018 to address cease-to-flow conditions along a 1000-km stretch of the Barwon-Darling River.
- Releasing channel water into the Warrego River system is likely to incur even higher losses en route to Menindee Lakes than the Condamine-Balonne River. Between 1993 and 2003 the mean annual flow at Wyandra was 539 GL, however, by Fords Bridge, ~200 km downstream, the mean annual flow over the same period was only 28 GL.

Potential to supply water to other industries en route to the northern Murray–Darling Basin

The potential for a channel from Hell's Gates dam to the northern Murray–Darling Basin to supply water to industries or regional centres along its alignment is limited.

- Relative to agriculture, mining requires relatively little water and does not typically require high-quality water. Mining companies usually have sufficient resources to be self-sufficient in terms of their water requirements.
- The northern section of the channel contains abundant, but now mostly historical, mineral resources sitting in an area of high rainfall, making demand low.

The gravity water supply channel from the potential Hell's Gates dam to the northern Murray–Darling Basin would traverse the most mineral resource poor parts of Queensland, due to extensive sedimentary cover.

- In many of these areas groundwater is readily available to mining industries from the Great Artesian Basin.
- What water could be provided by a Bradfield Scheme would be high quality, but high cost. It would exceed purity requirements of mining.

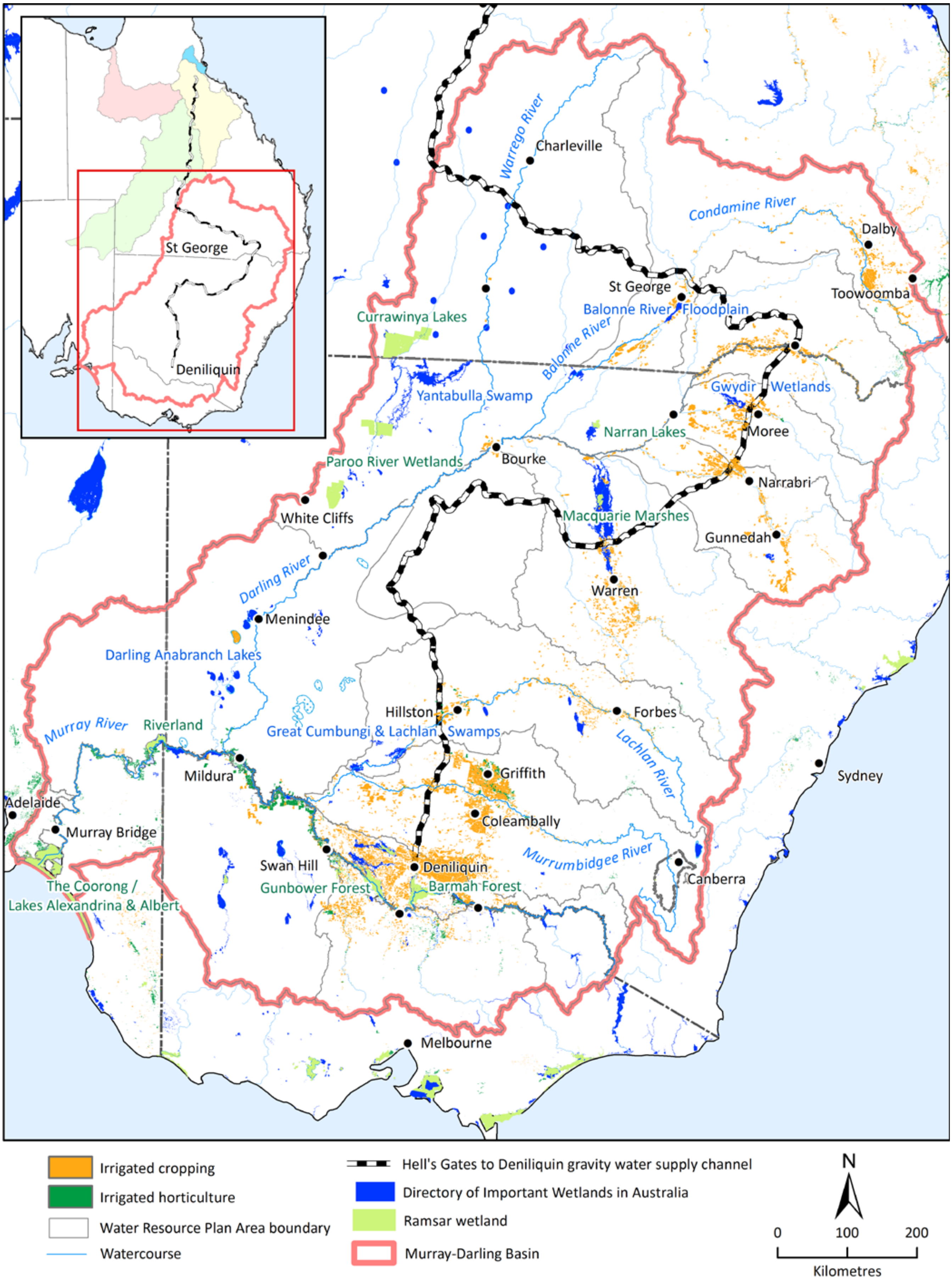
Cattle grazing for beef production is the most common land use along the length of the potential water supply channel. The livestock industry would benefit in multiple ways from better access to water.

Coal wash plant in the Bowen Basin (Queensland). Mining does not typically require high-quality water.

Incorporating irrigated agriculture into existing grazing enterprises has proven technically possible but financially challenging, even when using water of much lower cost. Experience has shown elsewhere in northern Australia that graziers who irrigate may find it more profitable to grow cash crops than to grow forages for their own livestock.

- Grazing properties along the route of the potential channels could make use of available water and sell hay to properties to their west and north. It could be used to provide water for livestock where on-farm supply is insufficient. It could also be used to irrigate forages and integrate the additional feed into the livestock enterprise.
- This could occur through mosaic-style development (i.e. small-scale patches of irrigation on existing pastoral properties), in contrast to large-scale scheme irrigation.
- While the idea of mosaic irrigation is attractive and has been demonstrated in parts of northern Australia there are very few examples where it has proven to be financially viable over time. This is largely due to the need to receive sufficient return on capital investment, including water infrastructure, land preparation and plant and equipment.

The Bradfield Scheme would not materially reduce the risk of regional centres in Queensland running out of water as no regional centres with water security issues are located along the potential channel alignment.



Map 4 Irrigated agriculture in the Murray-Darling Basin and a potential gravity channel from Hell's Gates to Deniliquin via St George

A shorter alignment by passing St George and with a pumped pipeline near Bourke may be technically feasible. This Assessment did not investigate channel and pumped pipeline alignments to the southern Murray-Darling Basin in detail.

Soils of the northern Murray–Darling Basin

The Murray–Darling Basin is a large depositional area and consequently has very large contiguous areas of soil potentially suited to irrigated agriculture, and climatically suited to a wide range of crops.

The northern Murray–Darling Basin has extensive areas of clay and sandy and loamy soils potentially suitable for irrigated agriculture. There are more soils suitable for irrigation than water to irrigate them.

- The clay soils are suitable for a range of spray- or furrow-irrigated grain, pulse and forage crops and cotton. Spray-irrigated crops and a diverse range of spray- and micro-irrigated horticultural crops are suitable for the light textured sandy and loamy plains.
- Between the Condamine-Balonne River and the Moonie River there is more than 780,000 ha of soil potentially suitable for irrigated agriculture:
  - clay soils (Vertosols) 390,000 to 450,000 ha
  - clay subsoils (Sodosols, Chromosols) 240,000 to 280,000 ha
  - sandy and loamy soils (Kandosols, Tenosols) 150,000 to 170,000 ha.
- Between Goondiwindi and the NSW border there is about 280,000 to 320,000 ha of soil potentially suitable for irrigated agriculture adjacent to the Macintyre River including:
  - clay soils (Vertosols) 165,000 to 180,000 ha
  - clay subsoils (Sodosols, Chromosols) 90,000 to 110,000 ha
  - sandy and loamy soils (Kandosols, Tenosols, Dermosols) 25,000 to 30,000 ha.

The Paroo and Warrego catchments in the western portion of the Queensland Murray–Darling Basin have large areas of sandy and loamy soils potentially suitable for irrigated horticulture. However, there are also large areas of sandy and loamy soils potentially suitable for irrigated horticulture at Pentlands and the Desert Uplands, less than one-third of the distance to the Murray–Darling Basin.

- The western section of the Queensland MDB includes the semi-arid Paroo and Warrego catchments and the Nebine Creek section of the Balonne catchment. It has over 1 million hectares of soil potentially suited to irrigated agriculture including:
  - 400,000 to 470,000 ha clay soils (Vertosols).
  - 600,000 to 680,000 ha sandy and loamy soils (Kandosols, Tenosols).
- In all areas, issues requiring further investigation include soil complexity, secondary salinisation, erosion, flooding and complex braided stream channels, in particular on the Warrego, Balonne-Balonne and Macintyre floodplains.

Irrigated agriculture in the northern Murray–Darling Basin

- Downstream of Beardmore Dam and St George along the Condamine-Balonne River there is approximately 90,000 ha of land already developed for irrigated cotton and other broadacre crops, and 600 ha of land already developed for irrigated horticultural production.
- Collectively irrigators along the Condamine-Balonne River can only extract their full entitlement in about 40% of years. Modelled mean annual extraction shortfall was calculated to be 485 GL but was highly variable between years.
- Extraction shortfalls arise because there are relatively few large dams and weirs to regulate the highly variable flows in the river, and the northern MDB more generally.
- When long-term commodity prices and production costs are considered, cotton is the most profitable broadacre crop in irrigated production regions of south-western Queensland and north-western NSW.
- Large-scale expansion of high-value horticulture in the St George region is currently limited by the reliability of irrigation water supply.
- Water diverted from the Bradfield source catchments could potentially meet the extraction shortfalls of existing irrigators downstream of Beardmore Dam on the Condamine-Balonne River with sufficient water to irrigate an additional 80,000 ha of new cotton in 75% of years and 30,000 ha of new citrus in 100% of years.
- Surface-irrigated cotton near St George was modelled to use on average 7.3 ML/ha of irrigation water per year assuming a realistic industry best practice of 70% whole-farm efficiency.
- Downstream of Goondiwindi along the Macintyre River the mean annual extraction shortfall was about 170 GL.
- Large areas of new surface water irrigation along the Condamine-Balonne River would increase the risk of groundwater induced secondary salinisation, which has already been observed to occur in some parts of the northern MDB.

An open earth constructed water supply channel in the St George channel scheme. The scheme comprises 112 km of pipelines and channels which supply water to about 10,000 ha of land.

Horticultural crops can command high prices but are at high risk of oversupply and large price fluctuations.

- Horticultural crops grown in Australia typically service the small domestic market, with some produce exported. The smaller markets and perishable nature of horticultural produce means that the industry is subject to large price fluctuations within each season that occur due to variable produce availability.
- High-value (export) horticulture is approximately two to nine times more profitable (per unit of irrigation water applied) than cotton, depending on crop and price assumptions.
- Citrus is considered the most likely crop suited to large-scale production for export and agronomically suited to the hot, dry environment. Maximum gross margins were forecast to be approximately $31,000/ha or $3250/ML of irrigation water for high-value (export) citrus assuming constant, favourable prices.
- Expansion of horticulture typically involves a mix of crops taking advantage of unique local opportunities, such as filling gaps in seasonal demand. While some specialised niche crops may perform better than export citrus, these would not be scalable, and the realities of intensive horticultural production mean that even the profitability of export citrus may not be achievable in the long term across tens of thousands of hectares of new farms.
- Consequently, export citrus was used to indicate the upper bound of what the mix of new horticulture in the St George district could achieve financially over the scale and lifespan of the scheme.
- Based on current market and production growth trajectories for Queensland, growth in all horticultural production in the St George district would be unlikely to exceed 13,000 ha by 2050, regardless of the availability of water for irrigation.
- This potential growth in horticultural production at St George assumes the full range of 20 potentially suitable horticultural crops are produced, many of which are substantially less profitable than export citrus. It also assumes that there is no growth in horticultural production in other districts that are more agronomically suited to many of the potential crop options, are closer to markets, and are more accessible to seasonal workers than the St George district.

Commercial viability and regional economic benefits of diverting water to the northern Murray–Darling Basin

- Extremely optimistic assumptions were used to estimate the unattainable upper bounds of financial performance for the northern MDB scheme. Under such a case, a new Bradfield-style diversion of water to the St George/Balonne area could support about 30,000 ha of high-value horticulture (developed over 30 years) and 80,000 ha of new cotton while supplying an additional 310,000 ML/year to offset shortfalls in water supplies for existing irrigators.
- Assuming total cost of water storage and delivery infrastructure of about $21 billion (assuming favourable geological conditions), discounted cash flow analysis over the lifetime (100 years) of the scheme showed water would have to be charged at $2310 for each megalitre supplied to cover the costs of the scheme. Net farm revenue was sufficient to afford no more than $580 per megalitre of water supplied, which would only cover about a quarter of the scheme's costs.
- The cost of diversion infrastructure alone would add a premium of $1920 to the cost of each megalitre of water used to irrigate crops, making water cost about six times what it would without the diversion infrastructure.
- The location-specific premium on the value of supplying water to meet shortfalls of existing irrigation in the northern MDB (versus the value of water for new greenfield farms) was less than $300 per megalitre, which is dwarfed by the cost of the infrastructure required to divert that water. There is therefore insufficient locational advantage in the northern MBD to justify the premiums associated with diverting water.
- Risks are often ignored in initial financial assessments of irrigation developments but doing so undermines the likelihood of the scheme's success and incurs wasted costs in pursuing options that have no prospect of being commercially viable. Financial analyses therefore considered four categories of risks: investors' borrowing costs and risk exposure; risks associated with the initial development staying on budget and on schedule; risks with the soil and water resources not being able to support the anticipated amount of farming; and risks associated with the productivity and performance of farms.
- Risk analyses showed the scheme would be particularly sensitive to farm yields and/or produce prices being lower than assumed, and any delays that disrupted farms achieving their full productive potential after construction of the scheme began.
- A modest combination of risks (20% greater construction costs, 15% lower crop revenue, 10% lower water use and 333 ha/year of horticultural expansion) was considered to provide a moderate indication of what real-world financial performance of a scheme might look like compared to the optimistic upper-bound assessment. These combined risks substantially impacted the performance of the scheme, increasing the cost of water to over $3000 per megalitre supplied, and reducing the proportion of the off-farm asset costs that irrigators would be able to cover to only 8%.
- While high-value horticulture would be able to contribute more towards the scheme's costs than broadacre farms, there are substantial constraints on the rate at which new horticulture can establish. For example, it is difficult to rapidly expand markets for horticultural produce without negatively affecting prices. This makes it challenging to sustain the consistent high returns over long periods and large areas required to both pay for the high capital costs of horticultural enterprises and contribute reliably to the costs of expensive, large-scale water infrastructure.
- Where the viability of a new irrigation scheme relies on rapid rates of expansion in horticulture (or other high-value water users) extra scrutiny of those assumptions is warranted to ensure that there is a realistic prospect of that development occurring, otherwise the scheme operator is likely to suffer losses from water revenue being insufficient to cover costs.
- The major financial weakness of this scheme lies in the high cost of the inter-basin diversion infrastructure, which exceeds the lifetime value of all gross revenue from crop sales and imposes a high premium on the cost of water. It would be unattractive for a greenfield developer to choose to pay this premium when water could be obtained more cheaply without it

Cotton has the highest returns per hectare and per megalitre of all broadacre/industrial crops. Cotton uses a similar amount of water to other broadacre crops sown at the same time and of comparable growing length. If farmers were not growing cotton they would use the same amount of water (i.e. their legislated water allocation) to grow the next most profitable crop.

(either through purchasing water from lower value water users in existing irrigation areas or from new developments where water infrastructure is configured more cost-effectively). This makes the notion of transferring large quantities of water between river basins for agricultural use, at the heart of Bradfield-type schemes, financially unattractive.

- The inclusion of rewnewable energy and pumped pipelines made a very small change to the overall economics of the scheme, mainly because the cost of the water storage and particularly the main water supply channel from potential Hell's Gates to the northern MDB dwarf all other costs.
- The unattainable upper-bound regional benefit from expanded farming would be less than $6.1 billion per year and create up to 11,000 jobs, but this would only occur if: (i) horticulture in the vicinity of St George were to expand by an amount equivalent to 30% of the gross value of all fruit, vegetable and nuts currently produced in all of Australia (which could take more than a century, if it were technically feasible); and (ii) farmers did not have to pay for water.
- Most of the new jobs would be for fruit picking and packing work done by foreign and domestic migratory workers from outside the region (so much of the benefit would accrue outside the northern MDB, and partially outside Australia) and may well need to be supplemented/replaced by automation for horticulture to eventually expand to this scale.
- The above summary of regional benefits of the agricultural phases of the scheme essentially treats the backbone infrastructure as a publicly funded contribution to farmers in the northern MDB (given that the lifetime revenue from crop production would be less than the costs of new infrastructure).

Nonetheless, if an investor was willing to accept that a financial loss on new water infrastructure development was highly likely, there are some options within the Bradfield Scheme source catchments where financial losses could be reduced by using water locally to avoid diversion costs and by reducing the scale of the scheme so that high-value water users could more rapidly expand production to consume and pay for all the water.

- Under a set of comparable highly optimistic assumptions for a 327-GL capacity dam on Blunder Creek (Map 2) in the upper Herbert catchment releasing water downstream for riparian pumping of 10,000 ha of irrigated citrus, the lifetime net farming benefits per million dollars of infrastructure spending was more than an order of magnitude greater than the benefits per million dollars of infrastructure spending from contemporary Bradfield Scheme concepts that divert water to the MDB.

Further considerations

The potential for the Bradfield Scheme to mitigate flooding in the Tully, Herbert and Burdekin catchments

- It has been widely suggested that the Bradfield Scheme could mitigate the impacts of flooding on communities on the coastal floodplains of the Tully, Herbert and Burdekin rivers.
- Potential dams on the Tully and Burdekin rivers are situated in headwater positions, occupying 19 and 14% of their respective catchment areas. Although a potential dam at Herbert River Falls would command 63% of the Herbert catchment area, the majority of runoff in the catchment is generated on the coastal floodplains.
- Based on local definitions of flood magnitude at flood gauges maintained by the Bureau of Meteorology it was found that the adopted configuration of the Bradfield Scheme could potentially reduce the occurrence of 'major' events in the Tully and Herbert rivers by 2 (4%) and 10 (22%) events per 100 years, respectively. The adopted Bradfield Scheme configuration could potentially reduce the total flood occurrence by 7 (3%), 15 (21%) and 4 (8%) events per 100 years for the Tully, Herbert and Burdekin rivers, respectively.

The adopted configuration of the Bradfield Scheme, which is optimised for water storage and diversion and not flood mitigation, would offer a negligible financial benefit in mitigating flooding in the lower Burdekin and a small financial benefit to mitigating flooding in the lower Tully and Herbert catchments.

- Flooding is a natural process that is essential to maintaining the health of existing instream, riparian and near-shore marine ecosystems as well as a key geomorphic function of rivers.
- The major land use on the lower Tully, Herbert and Burdekin coastal plains is sugarcane. Sugarcane can tolerate flooded conditions for up to two weeks.
- Valuing the damage and disruption caused by flood events in these catchments was difficult due to a lack of data and consequently the results are highly uncertain.
- Nonetheless, it was found that under the adopted Bradfield Scheme infrastructure configurations there could be approximately $2.9 million (42%) per year savings in commercial/industrial/residential damage in the Herbert, and a mean annual cost savings to public infrastructure of $1.5 million (9%), $9.1 million (46%) and $790,000 (17%) for the Tully, Herbert and Burdekin rivers respectively.

- Under the post-Bradfield Scheme scenario, about one less traffic disruption on the Bruce Highway is expected each year for the Herbert River.

Potential for the Bradfield Scheme to mitigate water-quality related impacts to the Great Barrier Reef

- Of the constituents in terrestrial runoff it is the fine (<16 µm) sediment that is considered problematic in terms of marine ecological impact.
- The current reef-wide 2025 water quality targets include a 25% reduction for anthropogenic end-of-catchment fine sediment loads, and a 20% reduction in anthropogenic end-of-catchment particulate nutrient loads.
- Under the adopted configuration of the Bradfield Scheme the overall reduction in load delivered to the Great Barrier Reef was modelled to be 0.60 million tonnes per year of total suspended solids (TSS) and 0.93 thousand tonnes per year of particulate nitrogen (PN).
- Collectively, the Bradfield Scheme could potentially contribute to load reduction targets by reducing the overall modelled TSS and PN anthropogenic load delivered to the Great Barrier Reef by 10 and 8 per cent, respectively.
- Noting that the adopted configuration of the Bradfield Scheme would take at least 20 years to construct, were it in operation today it would have accelerated progress towards the end-of-catchment water quality targets in the individual catchments, with long-term annual mean PN targets being met in the Herbert with the Bradfield infrastructure, but only modest progress towards the targets in the Burdekin and negligible impact in the Tully. Noting that of all the east coast catchments the Burdekin is the largest source of both fine sediment and particulate nutrients to the Great Barrier Reef.
- These modelled changes account for changes to flow due to the construction of the Bradfield Scheme, but they do not account for changes in TSS and PN concentrations that would result from agricultural expansion in the Tully, Herbert or Burdekin catchments, which under the scenarios adopted as part of this Assessment, agricultural expansion occurred in the northern MDB.

Flood plume from the Burdekin River extending out into the Great Barrier Reef. Anthropogenic landuse change has resulted in elevated sediment and particulate nutrient delivery to the coast driven by large flood events.

Photo: Matt Curnock (with funding by JCU, GBRMPA, Qld Gov., NQ Dry Tropics, CSIRO and NESP)

Since Bradfield first proposed his scheme Indigenous people have secured an important range of legally recognised native title and cultural heritage rights and interests in land and waters that must be considered in potential development in the Assessment area

- Indigenous values and lifeways are informed by millennia of ancestral use and occupation as well by more recent colonial circumstances.
- Past fieldwork on large-scale water development has demonstrated that, in general, Indigenous people regard such development as incompatible with contemporary Indigenous values and development objectives.
- Indigenous responses to inter-basin transfer have had limited consideration in the literature but are likely to be consistent with responses to large-scale intra-basin development.

Potential impacts and benefits of the Bradfield Scheme to the ecology of the Bradfield catchments and the Murray–Darling Basin

- Many species within the Bradfield catchments are dependent upon flow regimes including listed Endangered and Vulnerable species of fish, frogs and waterbirds. Changes in flow regimes, including changes in volumes and timing, can disrupt important ecological processes such as breeding and migration, or alter habitat availability, quality and productivity.
- Reductions in flow due to dams or extraction, as well as conversion of ephemeral streams into permanent channels, will result in changes to the natural ecology.
- Nationally and internationally significant wetlands including Directory of Important Wetlands in Australia and Ramsar-listed sites would be impacted by changes in flows across most catchments within the Bradfield Scheme.
- Loss of habitat due to dam site inundation and conversion of land for irrigation will result in loss of important habitat including Endangered and Of Concern Regional Ecosystems.
- Endemic species such as the cling gobbies (subfamily Sicydiinae), soft spined catfish (*Neosilurus mollespiculum*) and Koombooloomba prawns (*Macrobrachium koombooloomba*) occur within the scheme catchments and are at possible risk from development.
- Water transfer between catchments and creation of dam impoundments increases the risk of incidental or deliberate introduction of pest species into new regions. Pest species of concern include water hyacinth (*Eichhornia crassipes*), redclaw crayfish (*Cherax quadricarinatus*) and tilapia (*Oreochromis* spp.). Range or population expansion of common carp (*Cyprinus carpio*) is also a risk.

In recent years the Australian Government has undertaken investments in water recovery to protect and restore the rivers, wetlands and floodplains of the Murray–Darling Basin.

- The Australian Government has recovered water through a combination of investments in water-saving infrastructure, water purchases and other water recovery programs. However, the Australian Government is stopping the purchase of additional water holdings as it has been considered that they do not meet the ‘no social impact’ goal of the Basin Plan.
- In the northern MDB the Australian Government’s environmental water holdings total about 668 GL. This is about 50% of the water that could potentially be discharge by the water supply channel at St George.
- Potential benefits of new water in the MDB include providing water to support low-flow outcomes during periods of dry conditions as well as alleviating pressure on existing sources of water. Providing environmental water for in-channel connectivity to improve outcomes for water quality and fish is plausible.

Wallaman Falls on Stony Creek a tributary of the Herbert River is the highest permanent single drop waterfall in Australia. Wallaman Falls is part of the Wet Tropics World Heritage Area.

However, the financial cost of the Australian Government recovering water to achieve better environmental outcomes was less than one-tenth of the cost of the Bradfield Scheme backbone infrastructure.

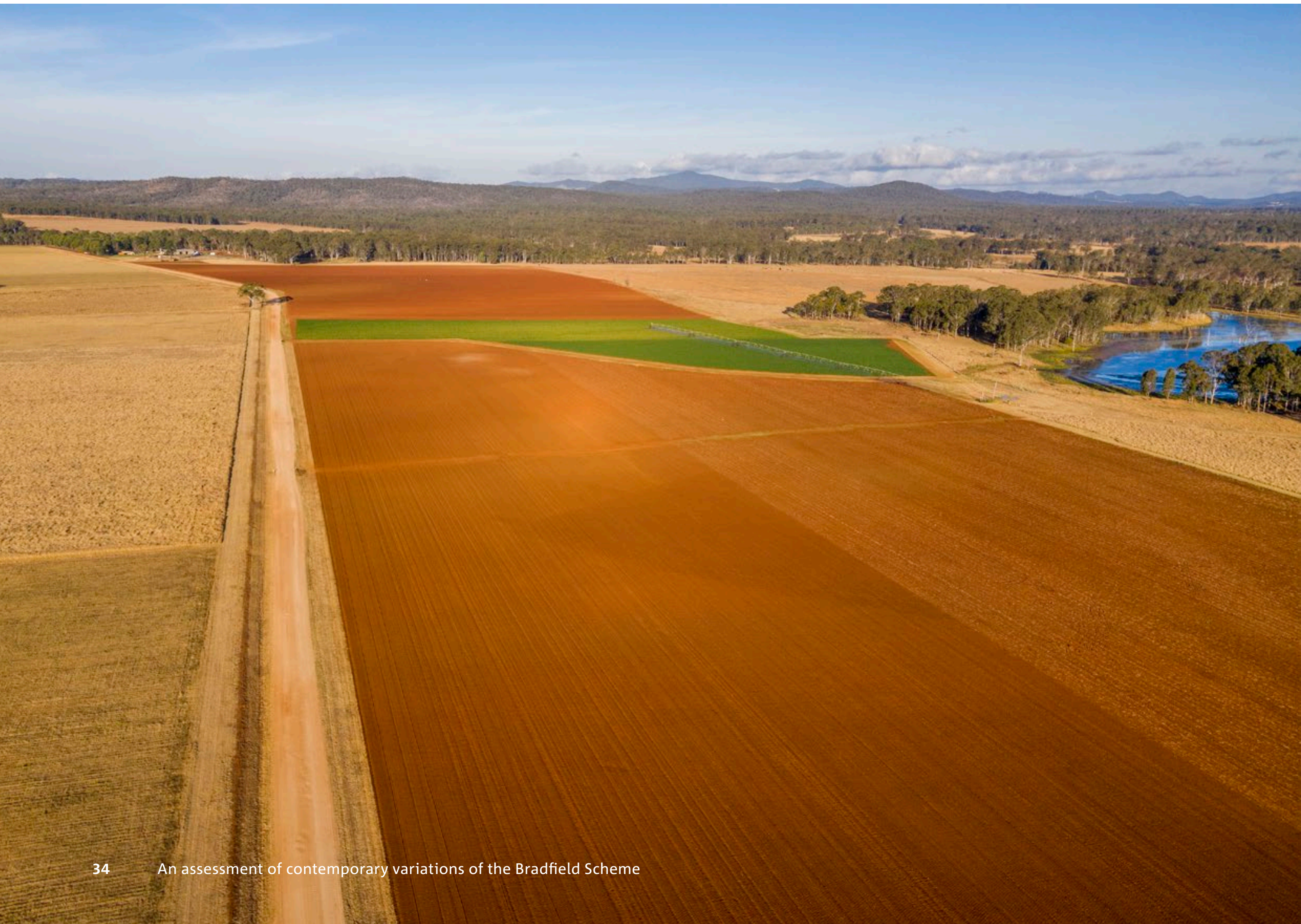
- Across the MDB the Australian Government environmental water holdings total about 2876 GL of registered entitlements with a long-term average yield of about 1989 GL. The states also have some holdings.
- Of these, 1670 GL of surface water was purchased from open tenders costing the Australian Government $2.6 billion. This equates to a unit capital cost of $1560 per ML/year.
- The potential of any possible benefits from releasing new water within the northern MDB needs to be considered against the range of possible impacts both within the northern MDB and elsewhere within the Bradfield Scheme source catchments. These impacts are likely to be large.

Opportunities beyond the Bradfield Scheme

The original Bradfield Scheme, which involved impounding water from the upper Tully, upper Herbert and upper Burdekin catchments in north Queensland and diverting the water inland to the Flinders and Thomson catchments is conceptually problematic.

- The original scheme involved capturing and then diverting water at great additional expense to a 'greenfield' location where the crop irrigation water requirements are generally higher and production occurs further from the ports where the produce could be exported, increasing input costs and thereby decreasing the profitability of the enterprise.
- While contemporary Bradfield Scheme proposals that involve diverting water to existing brownfield irrigation areas in the northern MDB overcome some of challenges associated with greenfield irrigation, and the remoteness and very high irrigation requirements of western Queensland, the challenge of covering the large premium added by long distance diversion infrastructure remains – the present value of the gross revenue of all crop sales over the life of the scheme would be less than the present value of the costs of just the backbone diversion infrastructure.

Irrigated agriculture near Ravenshoe in the upper Herbert catchment. There are about 25,000 ha of sandy and loamy soils in the upper Herbert catchment potentially suitable for irrigated horticulture.



There are two key reasons why it is extremely difficult to establish new irrigation areas that could compete and pay for themselves financially:

1. The best water resources near the best soils tend to be identified and developed first, so remaining options are less viable.
2. Public investment in previous schemes (predominantly in southern Australia) has reduced the cost users pay for water, compounding the challenge for irrigators in new schemes to compete effectively if they have to cover the full cost of water.

- The first point above highlights why northern Australia is now attracting attention, and with the largely undeveloped nature of water in northern Australia there would appear to be many opportunities. However, the large crop irrigation water requirements in most parts of the north relative to the southern MDB in particular means that irrigation infrastructure (e.g. reservoirs, pipes, channels, irrigation systems) in northern Australia generally needs to be larger and consequently is more costly. This further compounds the issue highlighted in the second key reason listed above.

There are high financial losses associated with Bradfield-style schemes that could be avoided by strategic development and staging of smaller water resource developments.

- The fundamental weakness of Bradfield-style schemes are the high costs of diversion infrastructure (without an offsetting locational benefit) and large volumes of expensive water (in excess of what high value industries could expand to consume and pay for in the medium term).
- Alternative approaches could avoid incurring such high losses by strategically planning regionally-distributed additional water storages that could be progressively staged to scale with the demand of high value water users. This could be done in two ways, depending on whether the priority was to cost-effectively expand local bulk water supply volumes or increase regional water security (or some combination of the two):

1. If the priority were on increasing water volumes to allow local high value industries to expand, then augmenting regional water storage capacity to capture additional water supplies and meet local demands would likely achieve the highest benefit per million dollars of infrastructure spending.
2. If the priority were on improving water security and water supply reliability, then drought-related water shortfalls could be mitigated by gradually building additional water supply capacity and by linking relatively smaller pieces of new and existing infrastructure into a number of 'inter-connected regional grids'. However, this may come at the expense of inefficiencies from having infrastructure on standby in non-drought periods during which it would not be used to its full capacity.

- These alternative options for configuring water infrastructure would be able to meet the water supply and security objectives of Bradfield-style schemes with less risk, lower cost and better matching of water infrastructure development to where demands and opportunities (in terms of where natural resources and other existing infrastructure are located) are already greatest.

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Cover: Beardmore Dam constructed in 1972 is the principal water storage on the Balonne River. It has a capacity of 81.7 GL and its primary purpose is to supply water to the St George channel scheme.

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