An assessment of the historic Bradfield Scheme to divert water inland from north Queensland

Summary report

PREPARED BY CSIRO FOR THE NATIONAL WATER GRID AUTHORITY

Australian Government

National Water Grid Authority

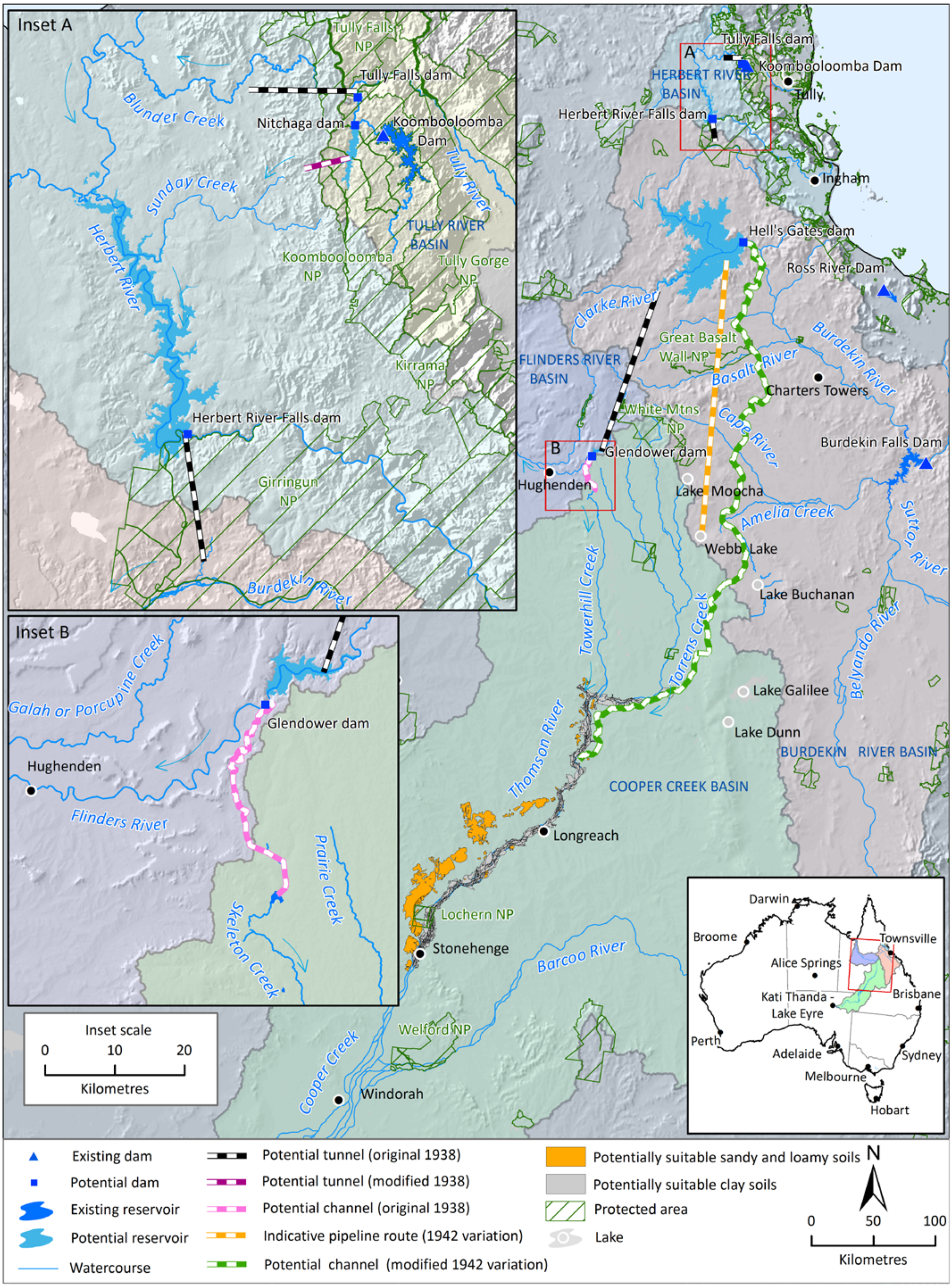
About this report

CSIRO completed a desktop assessment of the 1938 Bradfield Scheme and Bradfield's 1942 variation. The Assessment undertook a comprehensive re-analysis of the scheme, focusing on its hydrology and technical feasibility and using contemporary information and methods to verify key assertions and to assess contrasting claims.

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. In the event of unfavourable geological conditions being encountered in the process of further investigation or development, for which there is a high likelihood, the actual costs of construction would be significantly higher. Costs are provided in Australian dollars indexed to 2020. Numbers in this summary report have been rounded. Reported values are unconstrained by the current regulatory environment such as environmental flow objectives stipulated in current water plans, consideration of other uses of water in the catchments or other social, cultural and environmental considerations. 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.

The companion technical report, Petheram et al., (2020), details the analysis and assumptions that underpin the material presented in this summary report.

Herbert River Gorge, north Queensland. Looking downstream of the potential Herbert River Falls dam.



Map 1 The Bradfield Scheme

Bradfield's original scheme (1938) proposed diverting water from the 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 Tully, Herbert and Burdekin catchments to Webb Lake and then into Torrens Creek, a tributary of the Thomson River.

Executive summary

In 1938, 11 years before construction of the Snowy Mountains Scheme commenced, 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. The centrepiece of the scheme was a 122-m (400-foot) high dam at Hell's Gates on the upper Burdekin River, from which water would flow under gravity via a 144-km tunnel to the Flinders River. In 1942, one year before his death, Bradfield proposed a variation to his original scheme, whereby water would be diverted from a 152-m (500-foot) high dam at Hell's Gates via twin 25-foot pipelines to a low point on the Great Dividing Range at Lake Webb, and then into Torrens Creek, a tributary of the Thomson River.

Bradfield estimated that his scheme could divert 5360 GL/year into the Thomson River catchment, of which after evaporation and transmission losses, two-thirds would be available to irrigate *'... over 4000 sq. miles of the richest agricultural land in the State...'*. He estimated that the backbone water storage and diversion infrastructure of the scheme would cost a minimum of $2.8 billion (indexed to 2020).

Bradfield conceived his scheme with limited hydrological and topographic data. Although the topographic estimates were made with a barometer, Bradfield's gravity scheme is technically plausible. This Assessment found, however, that Bradfield overestimated the total streamflow in the upper Tully, upper Herbert and upper Burdekin rivers by about 125%, and although water was limiting in his original 1938 proposal, it is not likely to be the factor most limiting the scale of irrigation under his 1942 variation.

This Assessment found that Bradfield's original 1938 proposal has a unit capital cost ($35,500/ML per year) around three times that of other large dam options in the Flinders catchment, and that it would have a higher cost (~twice), lower yield (~a quarter), longer construction time (~twice), longer time to start generating revenue (11 to 36 years versus one year), and higher geological risk than a modified version of Bradfield's 1942 variation (Bradfield 1942) examined here.

For his 1942 variation, this Assessment estimated Bradfield's 152-m (500-foot) high dam would cost ~$12.5 billion. The Assessment also found that the reservoir would never fill as the net evaporation from the reservoir surface would exceed inflows. Rather, it was found that a modified version of Bradfield's 1942 variant that involves a $1.35 billion to $2.7 billion 98-m high dam at Hell's Gates and a $6.5 billion to $13 billion 680-km long channel (instead of more expensive twin pipelines) could deliver about 1880 GL in 75% of years to farms along the Thomson River, after losses. The mean annual volume of water that could potentially be taken from this dam, 2272 GL, in part the result of the identification of a gravity channel alignment with a ~45-m offtake above the base of the dam wall. This is lower than used by previous studies, resulting in a larger active storage capacity and less water lost to evaporation. The capital cost of the backbone water infrastructure of the modified version of Bradfield's 1942 variation was estimated at between $10 billion and $20 billion, assuming favourable geological conditions (excluding the costs of infrastructure for the farms and irrigation area).

> A desktop analysis of the original Bradfield Scheme (1938) and Bradfield's variation (1942) found that while technically feasible, the scheme is not commercially viable.
>
> The analysis found twice as much water could be diverted as previous reviews, but still only half that estimated by Bradfield. Diversion infrastructure costs alone would far exceed future net crop revenues. Diverting water inland was found to add cost without discernible benefit by expensively moving water to where it can be used less efficiently and at higher cost.

Under this modified version of Bradfield's 1942 variant, there is sufficient water to irrigate approximately 190,000 ha of dry season cotton (*Gossypium* spp.) along the Thomson River. However, it is likely that the '4000 sq. miles of the richest agricultural land in the State' to which Bradfield was referring was the extensive Mitchell grass downs landscape adjacent to the alluvial soils of the Thomson River. These soils have high levels of salt in their subsurface and would be highly susceptible to secondary salinisation if irrigated.

Although it is climatically plausible to grow a wide range of crops along the Thomson River it is estimated that there is only between 100,000 and 160,000 ha of alluvial soils moderately suitable for irrigated broadacre and industrial crops such as cotton, largely due to the dissected nature of the alluvial plains. A further limitation to large-scale riparian irrigation, which would require further investigation, is the capacity of the Thomson River to efficiently convey large volumes of channel water without disrupting farming logistics, incurring additional losses or causing erosion to the natural channels.

Irrigated agriculture and the town of Home Hill near the mouth of the Burdekin River.

These sandy-loam soils are potentially suitable for horticultural crops, which are much more profitable than cotton, but susceptible to oversupply and large price fluctuations. At Emerald (400 km east of Longreach and the Thomson river), there is currently around 3000 ha of high-value horticulture including citrus (*Citrus* spp.) and table grapes (*Vitis* spp.) along with extensive areas of irrigated cotton. The irrigation requirement for cotton (~10 ML/ha) and citrus (~12 to 13 ML/ha) at Longreach was modelled to be 40 and 25% higher than at Emerald due to lower in-crop rainfall and higher evaporative demand, meaning that less land can be irrigated for the same amount of water at Longreach.

Under a highly optimistic scenario of 30,000 ha of citrus for export, and 150,000 ha of cotton with a local cotton gin, and based on estimates from regional input-output analysis, the new farming enterprises could generate a regional benefit of up to $5.7 billion per year and create up to 14,000 ongoing direct and indirect (full time equivalent) jobs in the vicinity of Longreach, of which about 80% would be contract labour. Annual net farm revenue was estimated to be $470/ML. Based on a capital cost for the backbone water storage and diversion infrastructure of $14 billion (water cost of $920/ML), the farm revenue could only pay for at most 51% of the costs over the lifetime of the scheme, and the capital cost of the diversion infrastructure ($9.9 billion) alone would add a premium of $590 to the cost of each megalitre of water used to irrigate crops (64% of the water charge). However, this assessment is highly optimistic. Infrastructure that involves substantial subsurface excavation, such as dams and tunnels, are particularly susceptible to large cost overruns. International studies of mega-dam projects report a mean cost overrun of 100%. Also there is currently no export market for 30,000 ha of additional Australian horticulture, otherwise existing irrigation areas in Australia (e.g. lower Burdekin) would already be supplying these markets. Allowing for a modest combination of risks (Including a 20% infrastructure cost overrun) lowers the proportion of the revised scheme's costs that irrigators could pay for to 13%.

Although it is physically plausible that the revised scheme could divert large quantities of water inland, diverting large quantities of water would require trade-offs. These trade-offs become more contentious when water is transferred from one basin to another because the benefits accrued by one community occur at the expense of another. Adding water to the Thomson River and its headwater tributaries would result in major ecological change, where once ephemeral river systems become perennial. Since Bradfield first proposed his scheme, Indigenous people have secured legally-recognised native title rights and interests in land and waters, that would need to be considered in potential development, and there have been major legal and legislative changes in response to social demands. These have ramifications for schemes such as those proposed by Bradfield.

An overview of the Bradfield Scheme

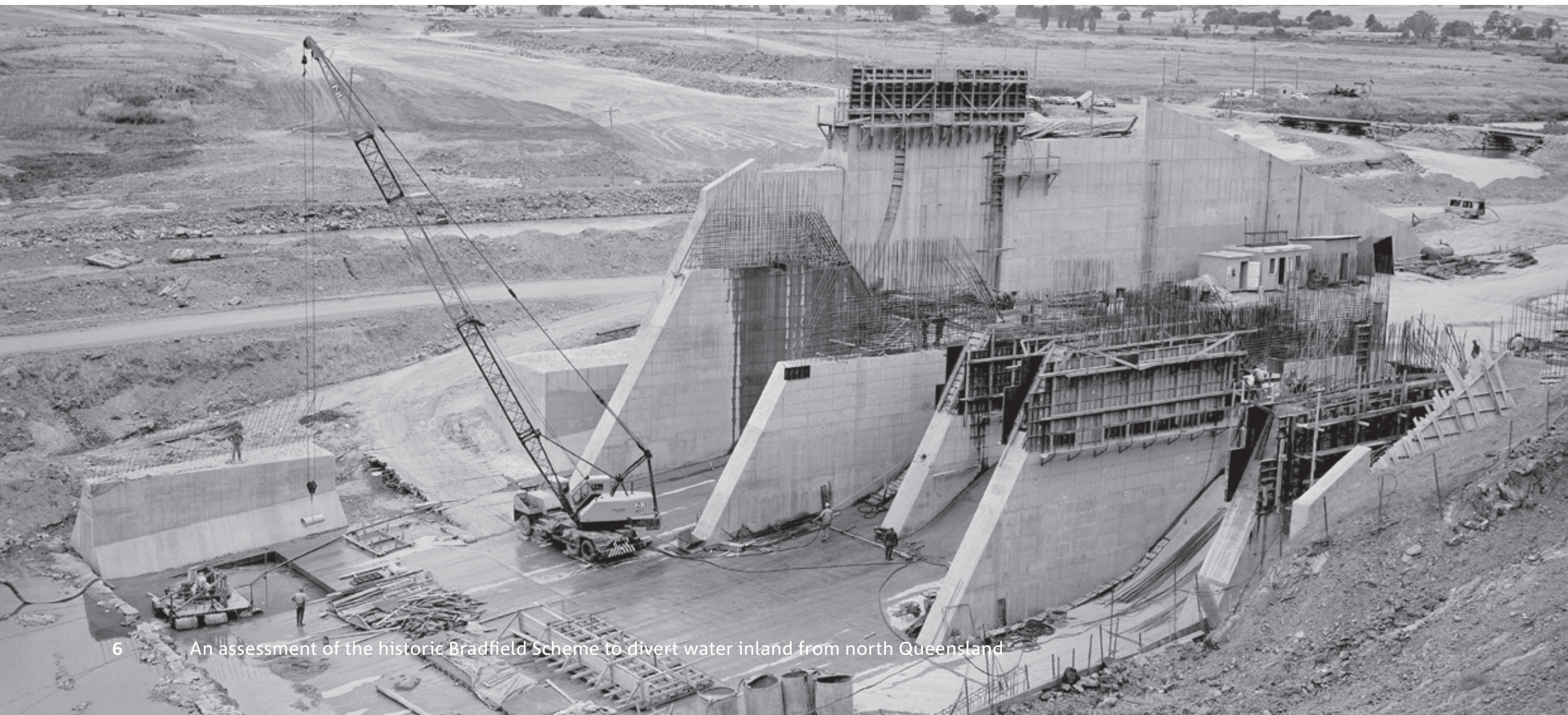
Water resource development schemes have been understood by successive governments and significant parts of the wider Australian community as key aspect of Australian 'nation-building'.

- Perhaps the most famous of these is the Snowy Mountains Scheme, which was constructed over a period of 25 years and completed in 1974. It comprises 16 major dams and hundreds of kilometres of tunnels, pipelines and aqueducts.
- In 1938, 11 years before the Snowy Mountains Scheme was started, Dr John Bradfield (1867–1943) put forward an ambitious scheme to divert water from east-draining rivers on the north-east Queensland coast to the rivers of the arid Queensland interior that drain into Kati Thanda-Lake Eyre. He estimated the cost at approximately £30 million, approximately $2.8 billion in 2020 terms.
- The Bradfield Scheme was a visionary idea. It was conceived with limited hydrological and topographic data, during a time when 'nation building' and the threat of invasion was prominent in the minds of Australians.

'In the development of Australia the wings of dawn are but beating at the break of day.'

'We can hold the Commonwealth only by effective occupation.'
Dr John Bradfield (1941)

Construction of Snowy Mountains Scheme – Khancoban Dam Spillway.



- Critics of the Bradfield Scheme highlight that calls for its implementation inevitably coincide with times of drought. Available evidence would suggest, however, that the Bradfield Scheme receives the most media attention when drought in the south-east of Australia and flooding in northern Queensland occur simultaneously, with advocates pointing to the perceived excess of water impacting upon one community and lack of water impacting on another.
- Past criticisms of Bradfield's scheme have been related to inaccurate perceptions of topographic levels and miscalculations in flow.

There is considerable confusion about what the Bradfield scheme is, and the last formal analysis of it was in 1985

- The original Bradfield Scheme (1938)[1] involved diverting water under gravity 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).
- Lamenting impacts of drought on the cattle and sheep industry in Australia, Bradfield's original scheme sought to provide water for stock in times of drought and for the irrigation of fodder crops, and to reduce the extraction of water from the Great Artesian Basin.
- Bradfield contended that hydro-electric power could be generated at various locations along the water supply line to provide power for northern towns and for pumping and irrigating the areas under reticulation.
- Bradfield recognised that the scheme would require considerable investment of public funds, and, in subsequent publications, highlighted broader potential benefits of the scheme: the ability of permanent bodies of water and irrigated agriculture to increase the moisture content of Australia's arid interior, thereby increasing rainfall and making the surrounding land more productive. Subsequent meteorological studies have concluded that this would not be the case.
- In 1941, three years after he presented his original Scheme, Bradfield expanded his vision of watering western Queensland[2] to include additional dams on other inland rivers of central Australia, including the Diamantina, Georgina and Finke. These were not examined in this Assessment, but past analyses indicate there are many larger yielding and more cost-effective potential dam sites in northern Australia than on these arid inland rivers.
- In 1942, Bradfield put forward a variation to his original scheme[3], whereby water would be piped from the proposed Hell's Gates dam south to Webb Lake and then into Torrens Creek, a tributary of the Thomson River (Map 1).
- The Bradfield Scheme has been the subject of a number of Committees of Inquiry commissioned by the Queensland Government. These studies have largely focused on hydrological aspects of the scheme, and highlighted differences to Bradfield's estimates of streamflow. The last formal analysis of the Bradfield Scheme was in 1985.

Bradfield undertook his study in the 1930s and had very limited data with which to work

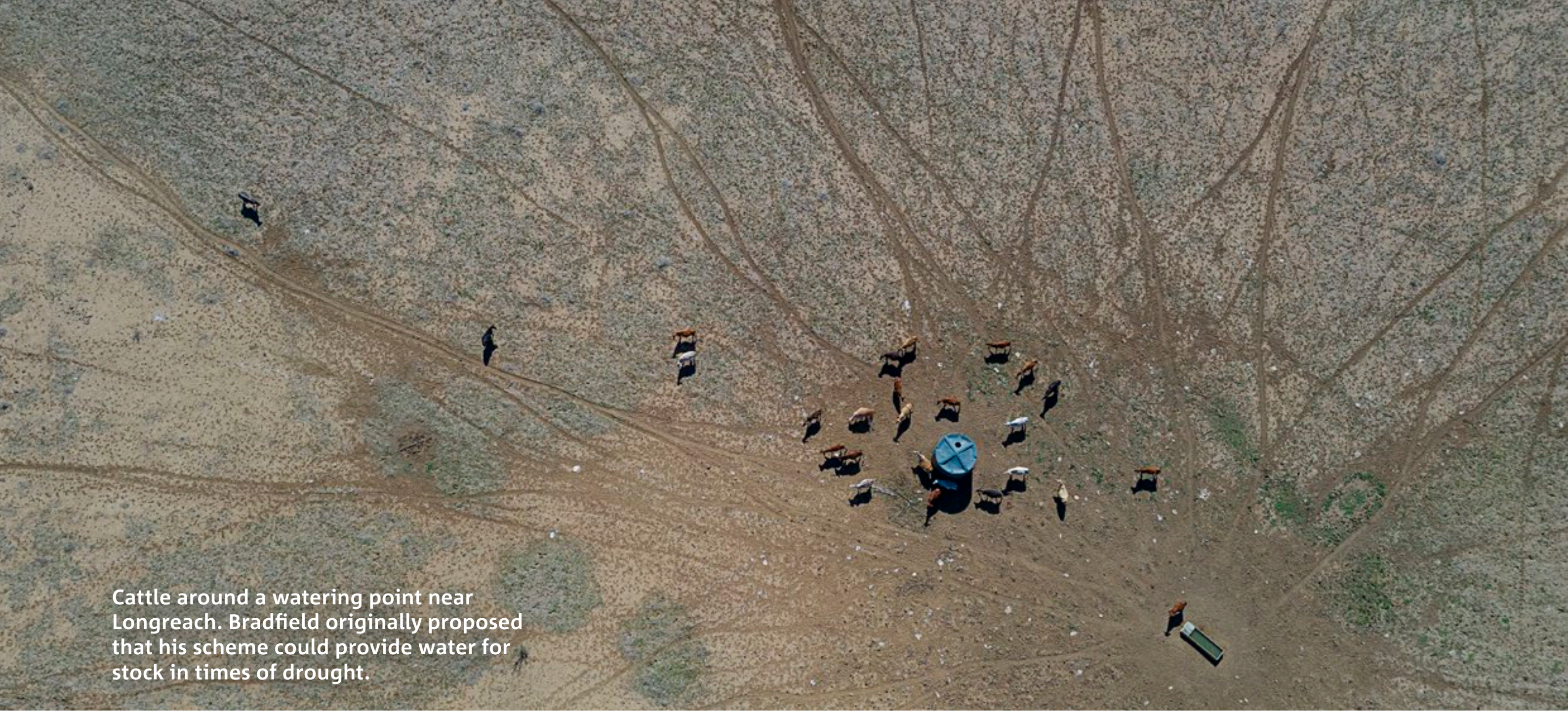
To understand how discrepancies could arise between the current analysis undertaken by CSIRO and Bradfield in his various iterations, it is worth noting that:

- For elevation data Bradfield relied on aneroid levels – measures of atmospheric pressure from a barometer – to determine elevation levels at key points in his schemes. Despite this limitation, Bradfield was remarkably accurate with most of his levels. The only location where elevation errors materially mattered was the diversion tunnel inlet of Hell's Gates reservoir and outlet to the Flinders River. The primary implication of using these data was that the tunnel inlet had to be so high in the reservoir that flow into the tunnel was greatly reduced. This is only relevant to Bradfield's 1938 scheme.
- For hydrological data Bradfield used rainfall-runoff relationships established in Germany. Using these relationships, Bradfield produced mean annual streamflow estimates for the upper Tully, Herbert, Burdekin and Flinders catchments (7190 GL). Bradfield's estimates were twice as large as those estimated in this Assessment (3306 GL), which used climate and hydrological information and tools that were unavailable to Bradfield in 1938.
- Since Bradfield proposed his schemes there has been considerable water resource development in the Tully, Herbert and Burdekin catchments.

[1] Bradfield JJC (1938) Queensland: the conservation and utilisation of her water resources. s.n., [Brisbane]

[2] Bradfield JJC (1941) Rejuvenating Inland Australia. Walkabout: Australia's Geographic Magazine July 1st, 1941, 7-15.

[3] Bradfield JJC (1942) Restoring Australia's parched Lands. The Australian Quarterly 14, 27-39.


Cattle around a watering point near Longreach. Bradfield originally proposed that his scheme could provide water for stock in times of drought.

Dorothea Mackellar's poem *My country*, where she describes 'a land … of droughts and flooding rains', is especially applicable to northern Australia

- Bradfield did not know, nor did he take into consideration in his calculations, that the rivers of northern Australia have some of the most variable annual flows of any rivers in the world. For this reason, in northern Australia, use of *median* annual flow values is often more instructive and useful than *mean* annual flow values.
- The high variability of streamflow to dams in northern Australia (and in Australia more generally) means that, to provide a reliable supply of water to meet a given demand, Australia's dams have to be considerably larger than most other places in the world and will, consequently, cost more to construct.

Since Bradfield first proposed his scheme there have been major legal and legislative changes in response to changing public perception of social and environmental concerns. These have major ramifications for schemes such as those proposed by Bradfield

- In 1994, the Council of Australian Governments released a communiqué setting out a framework for water reform in Australia. These directions were reinforced in 2004 when the Intergovernmental Agreement on a National Water Initiative (NWI) was released. One of the central tenets of the reforms was a 'user pays' principle, where the cost of providing and supplying water was to be recovered by the sale of water. Two other overarching principles of the NWI are: (i) provision of water for environmental flows and other public benefits, and (ii) provision of water to meet the needs of Indigenous people.
- Under the NWI reforms government is still able to provide subsidies for water storage and conveyance structures, as they currently do for roads, rail, port and even desalinisation, provided the subsidies are transparent.
- Investors seek certainty and many agricultural and water enterprises require long time frames to pay off their capital costs of development, which in turn requires long-term security of water. Investors in agriculture take many forms; they are not just farmers, but are also owners of agricultural supply businesses, post-processing infrastructure such as sugar mills and value-adding enterprises.
- State and territory governments are responsible for planning, allocating and managing water resources, and making decisions regarding new infrastructure to ensure communities have access to secure and affordable water.
- The Australian Government has previously assisted state and territory governments in these processes by supporting efforts that inform the underpinning of these plans, and support their ongoing revision, including providing grants to subsidise feasibility, design and construction costs.
- Since Bradfield's work, native title and other forms of Indigenous land rights have been formally recognised across significant areas of northern Australia, including in the catchments impacted by Bradfield's proposals. These changes are complemented by wider range of land tenure, environmental, and heritage legislation that directly influence how development occurs.

Key elements of the Bradfield Scheme

This section examines the veracity of key elements of the original Bradfield Scheme (1938) and Bradfield's variant (1942) that sought to divert water via gravity to inland Australia. These elements are shown on Map 1.

In providing this information it is hoped that it can also be used to broadly inform potential subsequent variations to Bradfield's proposals.

Outline of the original Bradfield Scheme

In the original words of Dr John Bradfield (1938):

> *'From a study of the information gathered, it appears feasible to divert a proportion of the normal flow of the Upper Tully River (1 and 2) and most of the floodwaters on this catchment into the Upper Herbert (3), and the combined waters then diverted near the Herbert Falls into the Upper Burdekin River (4). A dam constructed on the Burdekin at Hell's Gates would store up the flows of the Upper Tully, Upper Herbert, and the Upper Burdekin and its tributaries, backing the water up the Clarke River (5), here the principal Burdekin Tributary, towards the Great Dividing Range through which, by means of aqueducts and tunnels, the water may be discharged into the head of the Flinders River (6). The water would be stored in the Flinders by damming up a "corridor" through which the river passes (7) and the regulated outflow would be led into the head of the Thompson River through a short open out (8), thereby augmenting the water supply of the drier inland areas of Queensland by the floodwaters of the Tully, Herbert, Burdekin, Clarke and Flinders Rivers.'*

In the quote, the numbers in parentheses refer to the sections in the next few pages of this report where each of these individual components is addressed.

Bradfield's variant to the original scheme

In an essay in 1942, Bradfield proposed a variation to his scheme below Hell's Gates:

> *'The waters impounded by the Hell's Gates dam can be taken by twin pipes 25 feet in diameter to Webb's Lake at the head of Amelia Creek, where there is a gorge in the Dividing Range about 1200 feet above sea-level. Here the water could probably be passed through the Dividing Range without tunnelling into Torrens Creek and thence the Thomson River.'*

Koombooloomba Dam on the Tully River releases water for hydro-electric power production, white-water rafting, agricultural and domestic use and to meet downstream environmental flow objectives.

Components of Bradfield's schemes

1. Storage of water in the upper Tully catchment

Bradfield overestimated the amount of water at Tully Falls by about 10%.

> *'The diversion of the water of the Coastal rivers would be commenced near the Tully Falls by impounding the Tully River'* Bradfield (1938)

- The mean and median annual streamflow at Tully Falls on the Tully River is 506 and 483 GL, respectively. Bradfield's mean annual streamflow estimate at Tully Falls was 562 GL, which is about 11% higher than that calculated in this Assessment.
- Bradfield proposed constructing a 37-m high dam wall at Tully Falls, which being in a steep narrow gorge, would create a reservoir of modest capacity (<20 GL).
- Since the scheme's proposal, Koombooloomba Dam (1960) has been constructed on the Tully River 11.5 km on the escarpment upstream of Tully Falls, and is used for hydro-electric power production. The reservoir impounded by the dam, which at the time of this analysis still had a water filled inflatable rubber dam along the spillway, has a capacity of 205 GL. Using the existing Koombooloomba Dam is the cheapest option for diverting water to the Herbert catchment. However, this would considerably reduce the capacity to generate hydro-electric power from the Koombooloomba and Kareeya Hydro Power Stations.
- In this Assessment water was diverted from Koombooloomba Dam through a 3.7 km × 3-m diameter tunnel to a new dam on Nitchaga Creek. The tunnel and a new dam on Nitchaga Creek (reservoir capacity of 65 GL) would cost $135 million and $155 million respectively and could divert 335 GL/year of water on average into the Herbert catchment. By contrast, Bradfield stated that a dam at Tully Falls could have a mean annual diversion of 450 GL.

Tully Falls Weir on the Tully River. It is at Tully Falls that Bradfield proposed diverting water from the Tully River into a tunnel to the upper Herbert catchment.

2. Diversion tunnel to Sunday Creek in the Herbert catchment

A diversion tunnel from Nitchaga Creek to Sunday Creek in the Herbert catchment is physically feasible, and cheaper than Bradfield's proposal.

> *'...a short tunnel or cut would be made connecting with Blunder Creek, a tributary of the Herbert River.'* Bradfield (1938)

- It is topographically plausible that a 16.1-km diversion tunnel from a potential dam at Tully Falls to Blunder Creek in the Herbert catchment could operate under gravity flow, and cost approximately $395 million. However, at $195 million a 6.7 km × 3-m diameter gravity flow tunnel from the potential Nitchaga Creek dam to Sunday Creek is a considerably cheaper option.
- With a cumulative cost of approximately $570 million to the point of discharge in the Herbert River, and a mean annual diversion of 335 GL through the tunnel to Sunday Creek, this equates to a unit capital cost of $1700/ML per year.

3. Dam on the Herbert River near Herbert River Falls

Bradfield over estimated the amount of water that could be diverted from a dam upstream of Herbert River Falls to the Burdekin River by more than 66%.

> *'The next impounding site would be on the Herbert River above the Herbert Falls...'* Bradfield (1938)

- The mean and median annual streamflow at Herbert River Falls on the Herbert River is 1090 and 869 GL, respectively. This is 60% lower than the streamflow estimated by Bradfield. Bradfield's mean annual streamflow estimate at Herbert River Falls was 2675 GL, which is about 145% higher than that calculated in this Assessment.
- 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.
- Assuming only inflows from the upper Herbert catchment (i.e. not including diversions from the Tully River), a 62-m high dam wall above the Herbert River Falls could release on average 650 GL/year to meet year-round agricultural, urban and industrial demands in the lower Herbert catchment, and would have considerably hydro-electric power generation potential. This equates to a unit capital cost of about $1925/ML per year released from the dam wall.
- Including diversions from the Tully River, a 62-m high dam wall at this location could potentially result in a mean annual diversion of 1235 GL through a 6.5-m diameter tunnel to the upper Burdekin River. Comparatively, Bradfield estimated the mean annual diversion to be 2055 GL in addition to diversions from the Tully River.

4. Diversion tunnel to the Burdekin River

A diversion tunnel from Herbert River Falls to the Burdekin River is topographically feasible. It would entail considerable cost.

> *'...water would be diverted through a tunnel and open cut to the Upper Burdekin River.'* Bradfield (1938)

- Based on the most recent topographic information, water could flow under gravity though a 16.1 km × 6.5-m diameter tunnel from the dam at Herbert River Falls to Wairuna, and then through a 6-km long 4-m diameter pipeline to the Burdekin River.
- The cost of the tunnel and pipeline are estimated to be $725 million and $110 million respectively.
- With a cumulative cost of approximately $2.7 billion to this point in the scheme, and a mean annual diversion of 1235 GL through the tunnel to the Burdekin River, this equates to a unit capital cost of $2170/ML per year.

5. Dam on the Burdekin River at Hell's Gates

Bradfield (1938) over estimated the volume of water that could be diverted from a 122-m high dam wall at Hell's Gates to the Flinders River by over 1400%.

> *'The site chosen for the final impounding of water on the eastern side of the Divide is at Hell's Gates, a gorge on the Burdekin River, and consequent backing up of water along the Clarke River, a west-east flowing tributary of the Burdekin.'* Bradfield (1938)

- The gorge at Hell's Gates is a topographically favourable location for a dam to a height of about 82-m, above which saddle dams are required. Hell's Gates is the centrepiece of the Bradfield Scheme as well as a number of subsequent proposals for the inter-catchment transfer of water, which have drawn their inspiration from Bradfield, and in several recent major studies for increasing regulated water supply along the Burdekin River.


Upper Burdekin River during the dry season.

- Together with neighbouring alternative dam sites at Mount Fullstop and Mount Foxton, Hell's Gates commands a strategic elevated position in the landscape.
- Bradfield (1938) originally proposed a 400-foot or 122-m high dam wall, but in his 1942 variant scheme he proposed a 500-foot or 152-m high dam wall. Bradfield nominated the former dam wall height so water could be conveyed from the Hell's Gates reservoir to the Flinders River (122-m high dam wall option) via gravity. Bradfield did not explain the rationale for the 152-m high dam wall in his variant scheme.
- The storage capacities of 122-m and 152-m high dams at Hell's Gates would potentially be 54,950 and 142,350 GL, respectively, if there were sufficient inflows to fill them. These values are 4.4 and 11.5 times larger than the capacity of the largest reservoir in Australia, Lake Gordon (12,359 GL). If full, 122-m and 152-m high dams would have reservoir surface areas of 1900 and 3450 km^2, respectively.
- The costs of 122-m and 152-m high dams at Hell's Gates are estimated to be in excess of $4.5 billion and $12.5 billion, respectively, assuming favourable geological conditions.
- The mean and median annual streamflow at Hell's Gates on the Burdekin River is 1603 and 1004 GL. Bradfield's mean annual streamflow estimate at Hell's Gates was 3680 GL, which is about 130% higher than that calculated in this Assessment. With the addition of diversions from the Tully and Herbert catchments this study calculated the mean annual inflows to the Hell's Gates reservoir to be 2839 GL.
- For water to flow via gravity from Hell's Gates reservoir to a point on the Flinders River before Skeleton Creek (i.e. Glendower) as proposed by Bradfield the offtake level would have to be at least 108 m above the Hell's Gates dam river bed resulting in an effective 'dead storage' of 42,650 GL (3.5 times larger than the capacity of Lake Gordon). However, at this height the Hell's Gates reservoir is so large that, taking inflows and net evaporation (difference between evaporation and rainfall from/onto the reservoir surface) into account, it is estimated that it would take between 11 and 36 years for water to start spilling into the diversion tunnel to the Flinders River (this includes diversions from the Tully and Herbert rivers). So even once constructed (which would most likely take a minimum of ten years to construct, excluding approvals) there is a 50% chance that it would take longer than 19 years before any revenue could be generated from water diverted from the Tully, Herbert or Burdekin rivers into the Flinders River.
- Mean annual diversions from Bradfield's 122-m high dam and 11-m diameter tunnel were calculated to be about 350 GL. By contrast, Bradfield estimated about 5362 GL/year of water could be diverted from a 122-m high dam wall at Hell's Gates and through an 11-m diameter tunnel to the Flinders River.
- Increasing the height of the dam wall at Hell's Gates to a 128.5-m high dam increased the 'active storage' by 14,340 GL, and with a 10-m diameter tunnel could result in a mean annual diversion of 600 GL to the Flinders River. Further increasing the height of the dam wall would not increase the mean annual diversion to

the Flinders River. Further increasing the diameter of the tunnel would marginally increase diversions but substantially increase the cost of the tunnel.

- Assuming only inflows from the upper Burdekin catchment (i.e. not including diversions from the Tully and Herbert rivers), a dam at Hell's Gates with a FSL of 378 mEMG96 (~78-m high dam wall) could potentially release downstream a mean of 820 GL/year. At a cost of $825 million this equals a unit capital cost of $875/ML per year released from the dam wall.

6. Tunnel under the Great Dividing Range to a dam at Glendower on the Flinders River

Using modern elevation data it was found that a longer tunnel was required than envisaged by Bradfield, increasing the cost significantly.

Allowing the reservoir created by Hell's Gates dam to back up the Clarke River:

> *'…would permit the access of Tully, Herbert, and Burdekin waters to within a short distance of the Main Dividing Range through which they can be taken by tunnel. Once through the Divide the waters would be discharged into the headwater of the Flinders River or one of its tributaries and a suitable corridor (gorge) dammed, in order to create a large artificial water basin.'* Bradfield (1938)

- It was at this location that errors in Bradfield's elevation levels were found to make a significant difference to the length of tunnel required. It is not possible to divert water by gravity from a Hell's Gates reservoir into the headwaters of the Flinders River catchment higher than about Glendower, which is a location much lower along the Flinders River than proposed by Bradfield.
- This would require a 144-km long diversion tunnel, through variable geology. It is estimated that a 10-m diameter tunnel of this length would cost about $13.3 billion (–25% to +50% accuracy) or considerably more if unfavourable geological conditions were encountered, which is considered likely given the length of the tunnel. This tunnel is particularly expensive because the tunnel overburden is very thick, up to 300 m in places, requiring very deep intermediate access shafts for machinery and labour. The logistics associated with constructing this tunnel would be considerable.
- With seven tunnel boring machines operating simultaneously it may be possible to complete the tunnel in ten years. If constructed this would be the longest tunnel in the world.
- With a cumulative cost of approximately $21.6 billion to this point in the scheme, and a mean annual diversion of 600 GL through the tunnel to the Flinders River, this equates to a unit capital cost of $36,190/ML per year. This is considerably higher than the unit capital cost of water for large engineered dams in the Flinders catchment, which range between about $7000/ML/year and $25,000/ML/year.

7. Dam at Glendower on the Flinders River

Bradfield over estimated the streamflow in the Flinders River near Glendower by 160%.

> *'Once through the Divide the water would be discharged into the headwaters of the Flinders River or one of its tributaries and a suitable corridor (gorge) dammed, in order to create a large artificial water basin – a coolamon – from which…'* Bradfield (1938)

- A dam with a FSL of 430 mEMG96 (~42-m high dam wall at Glendower) has a storage capacity of 404 GL and is estimated to cost about $825 million. The dam would enable water to be diverted through a 34-km open-cut channel into Skeleton Creek.
- The mean and median annual streamflow in the Flinders River at Glendower is 105 and 70 GL, respectively (not including diversions from Hell's Gates reservoir). Bradfield's mean annual streamflow estimate for a similar location on the Flinders River was 275 GL, which is about 160% higher than that calculated in this Assessment.
- Past analyses have reported the Glendower dam site as being geologically unfavourable due to unstable slopes on the left abutment and permeable rock foundations of the dam site.
- Assuming only inflows from the Flinders River catchment (i.e. not including diversions from the Hell's Gates reservoir), a 42-m high dam wall at Glendower could potentially release downstream a mean of 55 GL/year to meet a potential demand for cotton with a December planting between Hughenden and Richmond. This equates to a unit capital cost of $12,800/ML per year released from the dam wall.

8. Diversion to the Thomson River from a dam at Glendower

Bradfield over estimated the volume of water that could potentially be diverted through an open-cut channel into Skeleton Creek by about 700%.

'...from which a constant stream of pure water 6000 cu.f/second would be led through a short open cut into Skeleton Creek, a tributary of the Thomson River.' Bradfield (1938)

- Mean annual diversion into Skeleton Creek from the Glendower dam was estimated in this Assessment to be about 656 GL. These diversions are a combination of water diverted from Hell's Gates reservoir in the Burdekin catchment and inflows from the Flinders catchment upstream of Glendower dam.
- By comparison, Bradfield estimated 6000 cubic feet per second, which is equivalent to a mean annual diversion of 5360 GL/year.
- With a total capital cost of approximately $22.5 billion including a potential Glendower dam, and a mean annual release of about 656 GL, this equates to a unit capital cost of $35,500/ML per year.
- This is more than three times as expensive as the unit capital cost of water released from a standalone dam at Glendower or Bradfield's 1942 variant.
- The water yield would, however, be sufficient to irrigate about 85,000 ha of cotton planted in December on the alluvial soils along the upper Flinders River. There are between 100,000 and 150,000 ha of cracking clay soils on alluvium moderately suitable for irrigated agriculture between Hughenden and 90 km downstream of Richmond.

The Flinders River near the Glendower dam site.

Bradfield variation from Hell's Gates dam to Webb Lake (1942)

Bradfield's proposed 152-m high dam wall at Hell's Gates under his 1942 variant would never fill.

> *'The site chosen for the final impounding of water on the eastern side of the Divide is at Hell's Gates, a gorge on the Burdekin River, where a dam, maybe 500 feet high… The waters impounded by the Hell's Gates dam can be taken by twin pipes 25 feet in diameter to Webb's Lake at the head of Amelia Creek…'* Bradfield (1942)

- Under Bradfield's variant scheme, the 152-m high dam wall (FSL 147-m high or elevation of 467 mEMG96) at Hell's Gates would never fill/spill, even with diversions from the Tully and Herbert rivers. This is because at this capacity the reservoir surface area is so large the net evaporation from the reservoir exceeds the inflows.
- Bradfield proposed twin 25-foot diameter pipes to convey water to Webb Lake. However, channels are considerably more cost-effective than pipes over gradual slopes (i.e. slopes less than 1 in 1000). A gravity pipeline between Hell's Gates and Lake Buchanan would be more than 20 times as expensive as a channel of equivalent capacity, or more than 17 times as expensive per ML of water delivered after accounting for losses from the channel. The capital cost of a pumping pipeline system would be more than 5 times that of a channel of equivalent capacity and the annual cost of electricity for pumping would exceed $300 million.

A modified version of Bradfield's variation from Hell's Gates dam to Webb Lake (1942) is half as expensive, can divert four times as much water and is lower risk than the original Bradfield 1938 scheme

By varying Bradfield's proposal using a 98-m dam height at Hell's Gates, approximately 2270 GL could be released on average into a 680-km long channel running south to Lake Buchanan and then south-west of the junction of Aramac Creek and the Thomson River.

- A 430-km open channel with an offtake ~45 m above the riverbed at Hell's Gates dam could convey water under gravity to Lake Buchanan, ~30 km south of Webb Lake and on the catchment divide. From Lake Buchanan water could flow under gravity along 238 km of channel and 9-km of pipeline to the junction of Aramac Creek and the Thomson River. Aramac Creek has insufficient capacity to convey water from the channel.
- With a channel offtake 45 m above the riverbed, the 'effective' dead storage capacity of the Hell's Gates reservoir would be 635 GL (though releases could still be made downstream at a cost to the reservoir yield). Dead storage is a one-off loss of water, but does increase the surface area of the reservoir.
- Varying Bradfield's proposal by adopting a more cost-effective 98-m dam height at Hell's Gates (15,130 GL capacity) enables an active storage capacity of 14,500 GL and a mean annual diversion from Hell's Gates dam of approximately 2270 GL (including diversions from the Tully and Herbert rivers). At this height a dam at Hell's Gates is estimated to cost between $1.35 and $2.7 billion. The average time taken for water in the reservoir of this dam to start spilling into the diversion channel would be less than one year.
- The channel is estimated to cost about $8.7 billion. Between the potential Hell's Gates dam and Lake Buchanan the channel has a depth and width of flow of 4.4 and 67-m respectively. Major components include 4.9-km of siphons and a 10-km long 10-m diameter tunnel crossing the Great Basalt Wall National Park.
- It is estimated that the channels peak flow efficiency and annual flow efficiency are 93.7 and 82.7% respectively.
- With a cumulative capital cost of approximately $13.2 billion to the outfall into the Thomson River, and a potential mean annual extraction or release from the channel of 1880 GL, this equates to a unit capital cost of $7460/ML per year. Note this cumulative capital cost does not include those components of the original Bradfield Scheme that are redundant in Bradfield's variation (i.e. capital costs outlined in components 6, 7 and 8).
- It is plausible that Bradfield's 1942 variant could be constructed in five years (excluding approvals).
- Of the water delivered into the Thomson River and Cornish Creek a further 10% was calculated to be lost during conveyance. Allowing for seepage and evaporation during transmission, Bradfield estimated that 3575 GL (4000 cubic feet per second) would be available for irrigation. This is approximately twice that calculated in this Assessment.
- Without inter-catchment diversions the mean and median annual streamflow in the Thomson River immediately upstream of the junction with the Barcoo River is 2583 and 765 GL, respectively.

Potential water uses

- The primary land use adjacent to the Thomson River and Cooper Creek is extensive grazing. Through here, and especially further south in the channel country, the grazing industry has a clean and green reputation and accredited organic production systems in places.
- It was calculated that it is physically possible to extract and store on-farm about 100 GL of water in 90% of years upstream of Stonehenge on the Thomson River.
- The mean annual rainfall at Longreach and Windorah is about 450 and 286 mm respectively. The low and seasonally variable rainfall of these regions relative to the high evaporative demands means cropping would require irrigation.

More water can be diverted from the potential Hell's Gate reservoir than there are soils suitable for irrigated agriculture along the Thomson River and Cooper Creek

- Between 110,000 and 180,000 ha of land moderately suitable for irrigated agriculture exists within 10-km of the Thomson River and Cornish Creek to just south of Stonehenge. The primary limitation is a network of extensive anabranches, which limits the areas that could be developed and the quantity of channel water that can be released into the Thomson River. Flood irrigation would need to be well designed and engineered, on the back of detailed on-ground investigations.

  'By means of this main waterway, over 4000 sq. miles of the richest agricultural land in the State could be irrigated, whilst dryland for many miles on either side of the main and subsidiary canals could be supplied with water, thus providing the facilities for raising and maintaining stock.' Bradfield (1938)

- The '4000 square miles of the richest agricultural land in the state' to which Bradfield was referring is most likely to have been the extensive Mitchell grass downs landscape adjacent to the alluvial soils of the Thomson River. While highly valued and productive cattle country, the soils of these landscapes tend to have high levels of salt in their subsurface and consequently are highly susceptible to secondary salinisation if irrigated.
- The younger alluvial plains of the Thomson River with structured or self-mulching surfaces have potential for irrigated agriculture. These areas are susceptible to irregular flooding.

A turkey nest dam in channel country. The dam fills during overbank events.

Mitchell grass plains support productive pastures but tend to have high levels of salt in their subsurface.

- Within 10 km of the Thomson River between 90,000 and 150,000 ha of cracking clay soils on alluvium moderately suitable for a wide range of irrigated broadacre and industrial crops (e.g. cotton and sugarcane (*Saccharum officinarum*)) and between 20,000 and 30,000 ha of elevated sandy and loamy soils moderately suitable for irrigated horticulture are within 10 km of the Thomson River, and a further 130,000 ha are further than 10 km from the river.
- Issues requiring field investigation include complex braided stream channels on the floodplains, soil complexity, secondary salinisation, flooding, erosion and contiguous areas for production units.
- The capacity of the Thomson River to efficiently convey water discharged from the channel without causing major limitations to irrigation operations and logistics and erosion to the river channels would need investigation. This is likely to limit the area that can be irrigated.
- Alternatively, the bulk water supply channel could be extended, outside of the flood zone, at additional cost, to service the left bank of the Thomson River, allowing the right bank to be serviced by riparian pumping of channel water discharged into the Thomson River.

It is climatically plausible to grow a wide range of crops at Longreach and along the Thomson River

- Large export markets and low perishability mean that broadacre and industrial crops are buffered from the large within-season price fluctuations that can affect horticultural produce. Cotton is the highest value broadacre crop suited to irrigated production in the region.
- Low rainfall and high year-round temperatures at Longreach result in large crop water requirements. However, these inland regions can also experience frosts, which could reduce the yields of some crops.
- August-sown surface-irrigated cotton along the Thomson River was modelled to use about 10 ML/ha of irrigation water per year at a realistic industry best practice of 70% whole-farm efficiency. This is about 40% higher than the irrigation requirement at Emerald, 400 km directly east.
- Modelled August-sown cotton yields at Longreach and Muttaburra were similar to those at Emerald at approximately 11 bales per hectare. This means each bale produced at Longreach and Muttaburra requires 40% more irrigation water than Emerald.

There is about 3000 ha of horticulture produced near Emerald with Murcott mandarins being the most profitable.

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.
- Horticultural crops currently grown at Emerald are those most likely to be suited to production along the Thomson river, with citrus (Murcott mandarins) currently the most profitable with a small but growing export market. Currently there is about 3000 ha of horticulture produced near Emerald, which could double over the next decade if current expansion rates continue.
- Citrus requires year-round irrigation, but the use of expensive highly efficient irrigation systems in high-value orchards means the modelled whole-farm irrigation requirement (i.e. including minimal on-farm losses) along the Thomson River would be about 12 to 13 ML/ha, about 25% higher than citrus at Emerald.
- Under the assumption that each location would achieve a similar yield per hectare, irrigation requirement per box of fruit is estimated to be 25% higher at the more inland locations.
- High-value export citrus was estimated to have a partial gross margin (before paying for water) of $38,000/ha per year compared with $3100/ha per year for cotton. However, a citrus enterprise is about 10 times more expensive per hectare to establish than a broadacre cotton farm. The farm-scale costs to establish 30,000 ha of citrus farms is estimated to be about $2.5 billion.

There are limited opportunities for the original Bradfield Scheme development to supply water to high-value non-agricultural users

- Very limited industrial and urban demand exists along the Thomson River and Cooper Creek. The largest town, Longreach, has a population of about 3000.
- There is limited potential for the Bradfield Scheme to recoup costs via in-line hydro-electric power generation along the water supply line. Modest elevation differences and water releases timed to meet agriculture demands not energy market price fluctuations reduce the feasibility of electricity generation. Overall it was calculated that there would be an average net loss in revenue from hydro-electric power generation of more than $18 million per year. This is because the loss in hydro-electric power generation from the existing 88 MW capacity Kareeya Hydro Power Station and 7 MW power station at Koombooloomba Dam would exceed the hydro-electric power generation potential along the water supply line.

Commercial viability

Bradfield's original scheme (1938)

- The Bradfield 1938 scheme was less commerically viable and would have to charge 13 times more for water than the 1942 variant. There were three reasons for this: (i) the higher cost of the infrastructure, (ii) the lower water yield, and (iii) the large lag time (median of 19 years) for the Hell's Gates to Flinders River tunnel to start spilling after construction.
- The dam filling time is an issue financially because it means that over $22 billion is expended on infrastructure that does not start to generate a return for 19 years.

Bradfield's variant (1942)

- Under optimistic assumptions (ignoring risks) the 1948 variant of the scheme could support 30,000 ha of horticulture (e.g. mandarins) for export and 150,000 ha of cotton, which based on estimates from regional input-output analysis, the new farming could generate a regional benefit of up to $5.7 billion per year and create up to 14,000 direct and indirect jobs in the vicinity of Longreach, of which about 80% would be contract labour. However, the scheme would not be financially viable.
- Capital costs for developing the backbone water infrastructure for the revised scheme were estimated at between $10 billion and $20 billion (excluding the costs of infrastructure for the farms and irrigation area).
- Based on a capital cost of $14 billion for the backbone water infrastructure, water would need to be charged at $920/ML, which is more than irrigators collectively would be able to afford.
- The diversion infrastructure required to transfer water between basins was estimated to have a capital cost of between $7 billion and $15 billion or about three-quarters of the total capital cost of the backbone infrastructure. Based on a capital cost of $9.9 billion, the diversion infrastructure alone would add a premium of $590 to the cost of each megalitre of water used to irrigate crops, without any discernible economic benefit to justify this extra cost.
- Under optimistic assumptions (before accounting for risks) revenue from 30,000 ha of exported mandarins and 150,000 ha of cotton would be able to pay for at most 51% of the costs over the lifetime of the revised scheme. This optimistic assessment is the reference point for the financial impacts of risks discussed below.

Longreach on the Thomson River after rain. Longreach has a population of about 3000 people and is the largest town along the Thomson River.

Risks associated with greenfield irrigation are usually poorly articulated

- Reductions in market price of only 10% can be sufficient for the variable costs of producing a horticultural crop to exceed the revenue from growing the crop.
- If produce prices dropped by 25% (such as losing premium export markets for citrus), irrigators would only be able to pay for 3% of the costs of the revised scheme.
- Mean annual diversion from Hell's Gates under the baseline climate was found to be 2270 GL/year but it was found that mean annual diversions could vary between 1700 GL (–25%) and 2500 GL (+10%) depending upon the timing and magnitude of wet and dry cycles.
- Global climate models (GCM) are in strong agreement that global temperatures are increasing. The majority of GCMs (two-thirds) project that mean rainfall over the 'Tully, Herbert and Burdekin catchments will decrease in the future. The yield at Hell's Gates under Bradfield's variant and a median future climate projection (assuming similar modes of variability to the baseline climate) decreased by 10%. If the water yield from the scheme was 10% lower, and the area of farmland developed was reduced to match, the price of water would be 11% higher and irrigators would be able to pay for 46% of the costs of the revised scheme.

Dam and tunnel infrastructure are particularly susceptible to cost overruns

- The propensity for cost overruns to occur in infrastructure projects, especially those involving substantial subsurface excavation such as tunnels and dams, means that geotechnical assessments should be undertaken at all stages of their investigation, construction and operation. Based on a 100% cost overrun, as reported by international studies for mega-dam projects, the price of water would be 82% higher and irrigators could pay for 28% of the costs of the revised scheme.
- At the feasibility stage, it is important that funding for geotechnical investigations is 'front-loaded'. Failure to invest adequately in geotechnical investigations before detailed planning or construction commences can be very costly.

'Build and they will come' is a high-risk strategy for bulk water infrastructure supply projects in greenfield areas

- A key consideration in bulk water infrastructure investment assessment processes is the confirmation of customer demand and their willingness to pay. If farms in the revised scheme were established gradually over a 10-year period, instead of immediately when the scheme was completed, the price of water would be 35% higher and irrigators could pay for 38% of the costs of the revised scheme.
- Greenfield agriculture, irrespective of where it is in the world, always involves a learning period before yields are maximised and input costs minimised. If there were an initial period of gradual improvement in farm performance before reaching long-term potential, then the proportion of scheme costs that irrigators could pay could drop to 38%.
- Another important consideration during the feasibility phase of a project is how implementation of the project should proceed, including institutional arrangements for construction and ongoing operation and maintenance of the scheme, for its entire operational life. This is likely to be particularly complex if one element of a project (e.g. pumped hydro-electric power generation) is effectively subsidising another element of the same project (e.g. irrigated agriculture).
- The only large irrigation schemes in operation in northern Australia – the Ord, Mareeba-Dimbulah Water Supply Scheme and the Lower Burdekin – have had significant government support and investment over a long period of time.

There is a systematic tendency of proponents of large infrastructure projects to substantially underestimate development costs and risks and/or over estimate benefits

- Planning for a combination of moderate risks provides a more realistic indication of real-world financial performance than optimistic assessments that ignore risks entirely. Allowing for cost overruns of 20% for water infrastructure, 10% lower water yields, and 15% lower farm gross revenue increases the break-even price of water by about 50% and lowers the proportion of the revised scheme's costs that irrigators could pay for to 13%. Ignoring such risks in initial planning would greatly undermine the prospects of the scheme's success.
- For a development to succeed, each component of the scheme would have to make commercial sense to their individual investors. This is a particularly important consideration, especially if getting a scheme to balance financially depends on investors acting altruistically by accepting suboptimal business arrangements to subsidise the rest of a scheme that would otherwise be unprofitable.
- High-value horticulture, such as exported citrus, could likely afford some of the water from the scheme at the high prices that would have to be charged. If it were possible to scale export mandarins to use half of the water supply (i.e. 75,000 ha of horticulture), agricultural revenue could cover up to 86% costs of the scheme (before accounting for risks), although this drops to 20% after allowing for moderate risks.
- There are, however, several major constraints to scaling horticulture to use and pay for most of the water in all years over the life of the scheme: (i) the inter-catchment diversion infrastructure imposes a substantial premium on the pricing of water that would be unattractive for a greenfield developer; (ii) it is difficult to rapidly expand markets for horticulture produce without negatively affecting prices; and (iii) prices for horticultural produce tend to fluctuate substantially.

Sugar cane in the Lower Burdekin. Sugar cane was first grown in the Burdekin Delta in 1879, with irrigation commencing in 1885. Today there is about 90,000 ha of irrigated agriculture in the Lower Burdekin.

Further considerations

With the exception of the Kareeya Hydro Power Station below Tully Falls, the potential impacts of the Bradfield Scheme on the existing water usage reliability in the Tully, Herbert and Burdekin catchments is relatively small. Impacts to Water Plan environmental flow metrics are higher.

- Since 1938, there has been considerable water resource related development in the Tully, Herbert and Burdekin catchments. For example, 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.
- On the Tully River the Koombooloomba Dam, constructed in 1960, releases water through its 7 MW power station to the 88 MW Kareeya Hydro Power Station below Tully Falls. The diversion of water from the Tully River above Herbert River Falls would reduce the mean annual flow at Tully Falls by 79%, which would severely impact the viability of the power station. It would also severely impact the existing Tully River white-water rafting industry.
- In the Herbert River system the largest impacts of Bradfield water storage and diversion infrastructure are to unallocated water harvesting entitlements. Impacts to the water usage reliabilities are small (1%) and the impacts to these users could potentially be mitigated by negotiating with stakeholders and purchasing some existing unallocated entitlements or releasing modest quantities of water from the Herbert River Falls dam.
- Downstream of Burdekin Falls Dam, regulated irrigation entitlements were modelled to be impacted by 2% by the Bradfield water storage and diversion infrastructure. It may be possible to mitigate this impact by negotiating with stakeholders and moving unallocated volumes of water from the Burdekin Haughton Water Supply Scheme to the proposed point of diversion upstream.
- Bradfield water storage and diversion infrastructure would impact the environmental flow metrics calculated for the Burdekin River immediately upstream of Burdekin Falls Dam and to a lesser extent at the end-of-system.

The diversion of water from above Tully Falls Weir would severely reduce flow through the Kareeya hydro-electric power station on the Tully River.

- It is likely that mitigating the impacts of Bradfield water storage and diversion infrastructure on environmental flow assessments upstream of Burdekin Falls Dam would require relatively large releases from the proposed Hell's Gates dam, at a cost to the yield of the dam. Alternatively, it would require changes to the water plan that would need to be negotiated with existing stakeholders.
- No assessment was undertaken of the impact of the Bradfield Scheme to cultural flow.

Since the Bradfield Scheme was first envisaged, Indigenous people have secured an important range of legally recognised native title rights and interests in land and waters that would need to be considered in potential development in the Assessment area

- Indigenous people comprise a large proportion of the population in northern Australia, particularly in regional and remote areas.
- Indigenous people in many parts of northern and central Australia have strong expectations for ongoing involvement in water, catchment and development planning. There is increasing recognition of Indigenous rights and interest in land and water resources.
- In many parts of northern Australia, Indigenous people have business development objectives designed to create opportunities for existing residential populations and to aid the resettlement and return of people currently living elsewhere.
- In general, Indigenous people in past studies have regarded large-scale water development as incompatible with contemporary Indigenous values and development objectives.
- Indigenous views regarding major inter-catchment transfer for purposes such as irrigated agriculture require further investigation. However, such development is unlikely to align with inter-group cultural relationships based on existing water regimes and with consequent Indigenous obligations regarding the protection of river flows and associated landscapes.
- Based on studies elsewhere, where development does occur, smaller scale developments that are perceived as being sustainable over the longest term and provide important opportunities for Indigenous ownership and employment are likely to be prioritised.

Water resource development requires trade-offs. These trade-offs become more contentious when water is transferred from one basin to another because the benefits accrued by one community occur at the expense of another

- Local community support for new water and agricultural developments will be influenced by who is likely to benefit from a development.
- It is likely that the benefits of major water resource development would need to be distributed to broaden stakeholder support beyond a single target area or community.

Establishing and maintaining a social licence to operate is a precondition for substantial irrigation development

- A proposed irrigated cotton development based on diversions from Cooper Creek in the 1990s raised strong local concerns that the clean and green reputation of the grazing industry in the channel country would be damaged.
- If a large greenfield irrigation or inter-catchment water transfer development in central or northern Australia, such as the Bradfield Scheme, resulted in adverse impacts to the environment and/or local communities, this would have major ramifications for the ability of future developments to acquire or retain a social licence to operate.

The Burdekin Falls Dam is downstream of the potential Hell's Gates dam. It was completed in 1987 and supplies up to 100 GL/year of water to meet mining and urban demands and up to 980 GL/year to meet irrigation demands.

The Wet Tropics World Heritage Area in north Queensland is the oldest and is one of the largest tropical rainforest areas left on earth.

The assessment and approval processes for large, complex projects in Queensland tend to take multiple years, and sometimes up to a decade

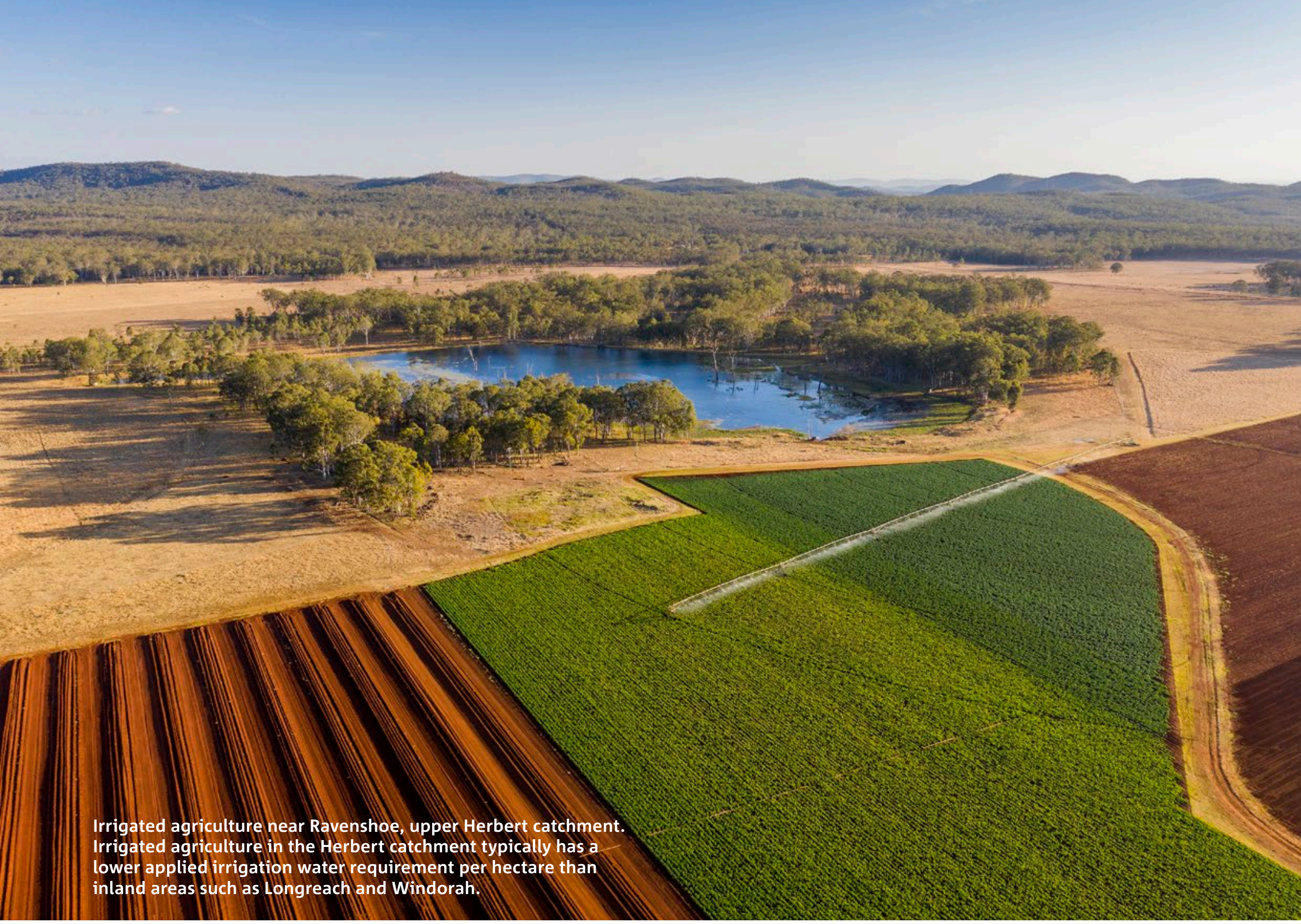
- The majority of this time tends to be associated with the assessment process, over which the proponent has considerable influence.
- Good prior research, evaluation and project design can significantly reduce assessment and approval times. Another important variable in the length of assessment and approvals is government support.
- With strong government (and preferably bipartisan) support at the state and federal levels, it is possible the Bradfield Scheme, or at least its main infrastructure components, could be assessed and approved within seven to ten years.
- Due to constitutional limitations of the Commonwealth it would be extremely difficult legally to establish a major water infrastructure development in Queensland such as the Bradfield Scheme without the full cooperation of the Queensland Government.

Past experience with large-scale water and agricultural developments indicates it is unlikely that all probable changes will be able to be predicted or anticipated

- The catchments of the Bradfield Scheme include highly diverse habitats ranging from tropical rainforest streams to parched arid floodplains. Many of the catchments are recognised as biodiversity hotspots for a range of biota, with high levels of endemism and are generally poorly understood in comparison to many other regions of Australia.
- The diversions proposed by Bradfield would result in reductions to flow downstream in the Tully, Herbert and Burdekin catchments, which would be likely to result in changes to water-dependent species and habitats with impacts to flora and fauna that will likely extend considerable distances from the source of impact.

- Changes in freshwater flows from rivers have been found to have a profound influence on coastal ecosystems with impoundments and changes in flow likely to impact geomorphological processes, such as erosion and deposition. The Tully, Herbert and Burdekin catchments discharge into the Great Barrier Reef Lagoon. Major water infrastructure developments and their end users will be particularly scrutinised in catchments adjacent to the Great Barrier Reef.
- Loss of terrestrial, riparian and stream habitat associated with the creation of impoundments as well as the conversion of land to irrigated agriculture in the Bradford Scheme includes habitat for listed and rare species and Endangered and Of Concern Regional Ecosystems.
- The inter-catchment transfer of water provides a pathway for the movement of accidental and deliberately released exotic and introduced flora (e.g. Mimosa) and fauna (e.g. Tilapia) as well as native species beyond their natural range. The lake-like environments of impoundments are often used by sports anglers to augment natural fish populations, through artificial stocking, including releases of exotic flora and fauna.
- The addition of water to the Thomson River and its headwater tributaries would result in significant ecological change, where once ephemeral river systems become perennial. The modified conditions likely favouring habitat generalists, a group which often includes invasive species. The environmental conditions associated with important wetlands in these catchments include values associated with the ephemerality of the system.
- Even minor instream barriers and their impoundment can disrupt migration and movement pathways, resulting in fragmentation of populations and loss of essential habitat for species that need passage along the river but may no longer be able to do so. This may be of particular concern in the Thomson River where levies and weirs if constructed could impede ecological connectivity thereby disrupting dispersal of individuals disrupting the important processes of recolonisation in some locations.
- In many, but not all cases, modest scales of developments, and brownfield developments and/or developments that do not create barriers within the main river channel are more likely to obtain local support and approval from regulators. They are also less costly and can be initially integrated into the existing broadacre grazing enterprises at lower risk.

Eastern great egret, commonly found in wetlands throughout the area of the proposed Bradfield Scheme.



Irrigated agriculture near Ravenshoe, upper Herbert catchment. Irrigated agriculture in the Herbert catchment typically has a lower applied irrigation water requirement per hectare than inland areas such as Longreach and Windorah.

The Bradfield Scheme adds cost without discernible benefit by expensively moving water to where it can be used less efficiently and at higher cost

- This Assessment highlights that moving water between basins is extremely expensive, and is only likely to be viable when the end users are prepared to pay a high price for the water (e.g. mining, industrial, water security of towns and cities).
- High transport costs to and from inland Australia put new irrigation developments at a competitive disadvantage to existing farming areas. The Bradfield Scheme moves water from locations where the transport and input costs are lower to locations where the transport and input costs are higher.
- It is difficult to envisage how, by moving water such large distances, to locations where it can less efficiently be used, it would be possible to generate a benefit greater than that derived from simply using the water in irrigation or other developments at its source.
- The challenges of identifying financially viable opportunities for dam-based irrigation developments are already considerable; they are increased where proposals include the requirement for long-distance water diversion infrastructure.

Australia’s challenge remains that there is a geographic disparity between where the population resides and where the water resources are located. There are opportunities, however, to think about providing water security differently

- With irrigation using 70% of water consumed in Australia’s, and northern Australia generating over 60% of Australia’s runoff, there are opportunities to reconfigure some of Australia’s water use without expensive water diversion schemes by using water locally in northern Australia, provided new regional development opportunities in which a social licence to operate can be established.

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Important disclaimer

Cover: Hell's Gates dam site on the Burdekin River is the centrepiece of the Bradfield Scheme.

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