Water for coal

Coal mining and coal-fired power generation impacts on water availability and quality in New South Wales and Queensland

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Executive summary

Water is essential to coal mining and coal-fired power generation.

But water is a finite resource and people understand that water used by coal mining or coal-fired power generation is not available for communities, ecosystems or food production.

The public is also increasingly concerned about water shortages due to the impacts of climate change, such as drought and reduced rainfall. These impacts are highlighting the need to ensure scarce water resources are managed sustainable.

Sustainable water management involves monitoring how much water is used by various industries, but there is a lack of transparency about how much water is being used by coal activities in Australia.

There is also a lack of understanding of the true impact of coal activities on Australia's water resources and this has major implications on the sustainability of our climate and access to water.

This report used publicly accessible information to examine the impact of coal mining and coal-fired power generation on water in New South Wales (NSW) and Queensland (QLD).

The key finding is coal is a major water user in Australia and is competing for freshwater resources with other water activities, including water for people.

Summary of coal water use in NSW and QLD

Type in Australia	Approximate Amount	Source
Freshwater consumed by coal mining	224,640 ML	Based on coal mine annual reviews
Freshwater consumed by coal-fired power stations	158,300 ML	Based on Smart and Aspinall (2009)
Total freshwater consumed by coal	382,940 ML	Combined figures
Coal water consumed - domestic use equivalence	5.2 m people	Based on ABS (2019) water use
Cost of coal water consumed	$0.77 to $2.49 billion	Average supply costs for low to high security water in NSW
% of available water consumed by coal	4.3%	Based on ABS (2019)
Freshwater withdrawn by coal mining	224,640 ML	Based on average water consumption from references
Freshwater withdrawn by coal-fired power stations	2,128,743 ML	Based on average water consumption from references
Total freshwater withdrawn by coal	2,353,383 ML	Combined figures
% of available freshwater withdrawn by coal	7.2%	Based on ABS (2019)

Coal water use in NSW and QLD shows coal activities consume water equivalent to the domestic use of 5.2 million people (based on an average of 73,000 litres a year per person (ABS 2019). This is equal to the water needs of a city the size of Sydney.

An analysis of 39 coal reports in NSW found the average water use by coal mining was 653 litres per tonne (L/t) of coal in 2018, compared with a previous published figure of 250 L/t (Cote et al, 2010).

Black coal mining in NSW and QLD consumed 280,000 megalitres (ML) (1 megalitre = 1,000,000 litres) of water, which comprised approximately 80% freshwater and 20% recycled water.

The burning of coal to generate energy is also a large water user. Australian coal-fired power stations annually consume a total of 158,300 ML (Smart and Aspinall, 2009). A typical 1,000 megawatt (MW) coal-fired power station uses enough water in one year to meet the basic water needs of nearly 700,000 people.

Coal-fired power's dependence on water makes it vulnerable to water scarcity and the data shows coal-fired power generation uses significantly more water than other types of energy. Solar and wind power, for example, use approximately 10 litres of water per megawatt hour (L/MWh) compared to 1,254 L/MWh for average energy generation from black coal. This means that coal uses approximately 120 times the water to generate the same amount of electricity as solar or wind. If you include the water required for the coal fuel source for the coal-fired power stations that adds another approximately 306 L/MWh.

Coal activities consume significant amounts of water, even in comparison to other large water users such as agriculture and domestic water supply. The amount of water withdrawn by coal related activities in NSW and QLD is over double domestic water use and about 30% of the water withdrawn for agriculture. Considering coal water use is concentrated in regions such as the Hunter Valley and the Bowen Basin, the impact of water use is significant in these areas.

Research was based on available information and the evidence suggests the true impact of coal activities on Australia's water resources is not well known and is likely underestimated due to a lack of transparency and current regulatory frameworks.

The lack of data, in particular, is a significant challenge to understanding the true impact of coal mining and coal-fired power on Australia's water resources. In QLD, for example, there was no data on water use in coal mines freely available while in NSW, coal mines are only required to report on water they take under license from rivers or groundwater. Comprehensive water use reporting is not required, so there is no way of knowing the total amount of water used or impacted.

In both NSW and QLD, data on water use in coal activities is only available through written reports that use different formats, making it difficult to interpret. Despite the development of Australian and international water accounting frameworks, there is no reporting to these standards.

Given the inconsistency of water data and reporting, it is very difficult to benchmark water efficiency in coal mining or coal-fired power stations.

The opaqueness of impacts on water resources from coal activities is reinforced by complex regulatory frameworks which can allow gaps in water use reporting to occur.

In NSW, planning and operating a mine crosses many authorities and there is no consistent reporting or auditing to capture the range of water impacts. Different government agencies regulate water licenses, quality and discharge and other government agencies regulate coal mine planning and annual reviews of mine operations. In the annual review of mines, water reporting is not a requirement and the data provided is not audited.

Another issue in NSW is water licenses are based on one-off water models, but once the license is issued and the mine is operating, there is no mechanism to check how much water is being used and if it differs from the original model.

In QLD, coal mines are not required to publish annual reviews reporting water use. And the water license granted to the state's biggest and most controversial mine, the Adani Carmichael mine, puts no limit on the water it can take from the Great Artesian Basin. This is despite the fact water licenses for mines in QLD usually specify the amount of water that can be taken and require assessment and public scrutiny if access to more water is requested.

Given this the amount of water used and impacted by coal activities could be much greater than the 7.2% of Australia's freshwater that can be determined from published information. Other impacts on water resources include polluting waterways, diverting streams, reducing the quality of groundwater and the release of toxic mercury into the air from burning coal that then rains down into rivers and streams. Coal-fired power generation is responsible for one-third of carbon dioxide (CO_2) emissions, making coal a huge contributor to global warming which is intensifying water shortages in Australia.

This report highlights the need for greater transparency and a holistic approach to managing water that takes into account all the water used and affected by coal activities to ensure Australia's scarce water resources are managed sustainably for all water users.

Summary of recommendations

Title	Recommendation
Water Accounting	Mandatory monthly reporting of full water balance.
Water Modelling	Comprehensive water model, updated yearly and audited.
Data Storage	Single data storage for all water data with open access.
Mining Impacts	Standardised accounting for all mining impacts from water consumed, withdrawn and impacted.
Water Efficiency	Benchmarking water efficiency for mine and power station assessments and increasing recycled water use.
Mining Governance	Single authority to govern and audit water use at State or Federal level.
Value of Water	Adopting a 'value of water' framework, to identify mine and power station impacts on the water availability and the ethical and economic sharing of this finite resource.
Responsible Water Management	A sustainable approach to resource management considering the climate change impacts.

Contents

Table of figures

Units

Unit	Meaning	Use
L	Litre	Water volume
ML	Megalitre (1,000,000 litres) (Kilolitre or cubic metre is 1,000 litres, a Gigalitre is 1,000 ML)	Water volume
t	Tonne (1,000 kilograms)	Coal production
Mt	Megatonne (1,000,000 tonnes)	Coal production
L/t	Litres per tonne	Water use for coal production
MW	Megawatt (1,000,000 watts)	Energy capacity
MWh	Megawatt hour	Amount of energy supplied
L/MWh	Litres per megawatt hour	Water use for energy production
Kpi (kpsi)	kilo-pounds per-square-inch (1,000 psi)	Pressure
$	Australian dollars	Cost

1. Introduction

Before examining the relationship between coal and water, it is necessary to understand how coal is mined and used for energy. This section explains what coal is, how it is mined and how coal-fired power stations generate electricity.

Coal is a fossilised sedimentary rock that is highly combustible and produces heat when burnt. Water is used in many parts of the coal production process and in power generation derived from burning coal. The amount of water consumed in coal mining and power generation, and the amount of water impacted (displaced or polluted) can be thought of as its water footprint.

The coal water footprint needs to be considered in comparison to the water footprint of other power generation processes, such as generation from renewable energy sources, as water is a finite, and in many locations, highly contested resource. The use of water in energy production is only part of the water-energy-food nexus that needs to be considered for a sustainable land and resource management future.

1.1 Coal

Coal is a combustible sedimentary rock formed by coalification which is a process whereby ancient vegetation (including peat) is consolidated between other rock strata and transformed by the combined effects of microbial action, pressure and heat over millions of years. Coal is usually deposited in layers between other strata, called coal beds or coal seams. Coal deposits can also contain gas (methane) called coal seam gas which is an onshore 'unconventional' source of natural gas. To help the release of gas the coal seam can be subjected to hydraulic fracturing (fracking).

The quality of the coal is dependent on how it is formed, with greater heat and pressure, the carbon content of coal is increased. High carbon content provides greater energy and less emissions. Coal is composed of mainly carbon with variable quantities of other elements including hydrogen, sulphur, oxygen and nitrogen (GA, 2019a). Coal is identified depending on its carbon content with low carbon content (60-70%) coal called brown coal or lignite, 70-76% carbon content called black coal (sub-bituminous or brown coal in Europe), 76-86% called black coal (bituminous or thermal coal) and over 86% called black coal, anthracite or metallurgical coal (Figure 1).

Figure 1. Types of coal - brown coal (GA, 2019a), black coal (thermal or coking) (Indiamart, 2019) and anthracite (Eisco, 2019).

Lignite (brown coal) is used for thermal power generation and is the most common form of coal in Victoria (VIC) and South Australia (SA). It produces less energy than black coal when burnt and emits greater amounts of emissions. It contains approximately 30-70% water. Thermal coal (black coal) is used for thermal power generation and is the most common form of coal found in QLD and NSW. It contains approximately 10% water. Metallurgical coal (anthracite) is used to produce coke, used in blast furnaces for iron and steel production. It contains approximately 1.5-7% water.

Coal can also be used to make carbon fibre, but the more common method is to use polymers. Coal is also used in making: plastics, explosives, cement and bricks, paper, aluminium, glass, cosmetics and toiletries, disinfectants and detergents, dyes, ammonia, medicines, nylons, synthetic rubber, fertilisers, filters for water and air purification and in kidney dialysis machines (GA, 2019a). The amount of coal used in products is very small compared to thermal coal for power generation and coking coal for steel making (approximately 10%, World Coal Association, 2019).

1.2 Open-cut coal mining

The most common form of coal mining in Australia is the open-cut or open pit mine. Open-cut mining occurs where mineral deposits are close to the surface. It involves blasting and removing surface layers of soil and rock to reach the mineral deposit. When the mineral seam becomes exposed, it is drilled, fractured and the mineral recovered for processing. Open-cut mining can be more effective than underground methods, generally recovering 90% of a mineral deposit, and accounts for about 65% of raw coal production in NSW (NSW Mining, 2019) (Figure 2). Figure 3 shows a typical open-cut coal mine with the open pit and coal processing facilities and sludge ponds. Open-cut coal mines tend to be larger than underground mines with an average production of 7.23 Mt (Annual Reviews).

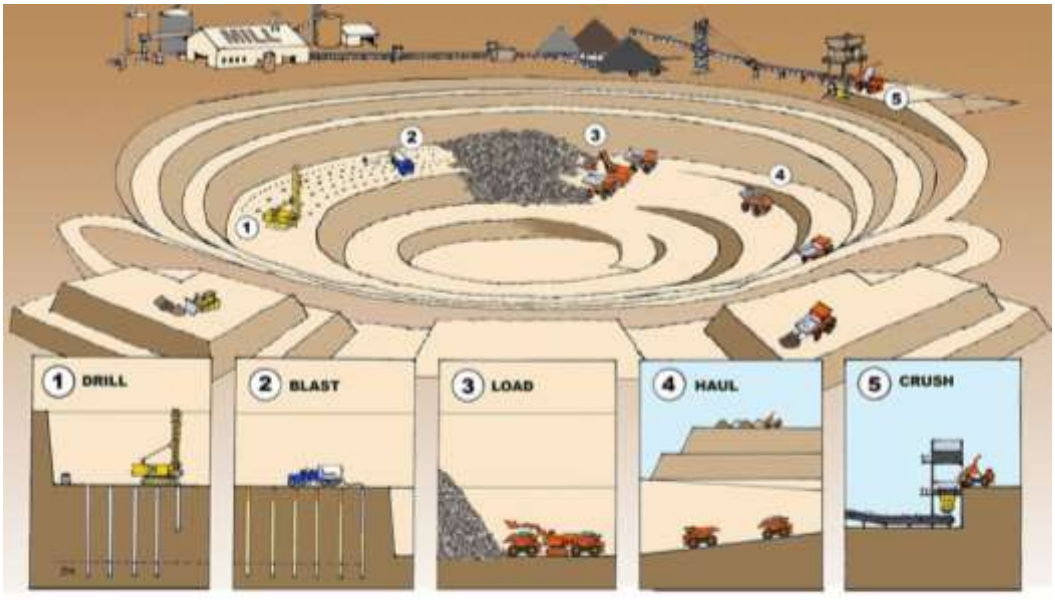

Figure 2. Open cut coal mining (Source: 4570book.info).

Figure 3. Typical open-cut coal mine (Source: unknown).

1.3 Underground coal mining

Underground mining involves tunnelling under the surface into the mineral seam, which can be hundreds of metres below the surface (Figure 4). The tunnels transport machinery that extracts the coal. Underground mining accounts for 60% of world coal production, but is less common in NSW, making up around 35% (NSW Mining, 2019). The two main types of underground mining in NSW are bord-and-pillar and longwall mining (Figure 5).

- ***Bord-and-pillar*** Bord-and-pillar is the oldest underground mining technique and was the most common method before longwall mining began in the 1960s. Bord-and-pillar uses a grid of tunnels and involves progressively cutting panels into the coal seam while leaving behind pillars of coal to support the mine. It is less efficient than longwall mining and is only used in a small number of mines today (NSW Mining, 2019).
- ***Longwall mining*** Longwall mining is safer, more cost effective and more efficient than bord-and-pillar mining. Longwall mining uses mechanical shearers to cut coal away while hydraulic-powered supports hold up the roof of the mine. As coal is removed, the supports are moved forward and the roof is collapsed behind them. A downside of longwall mining is that it produces subsidence as the roof collapses. It is more efficient as it does not have to leave pillars (NSW Mining, 2019)

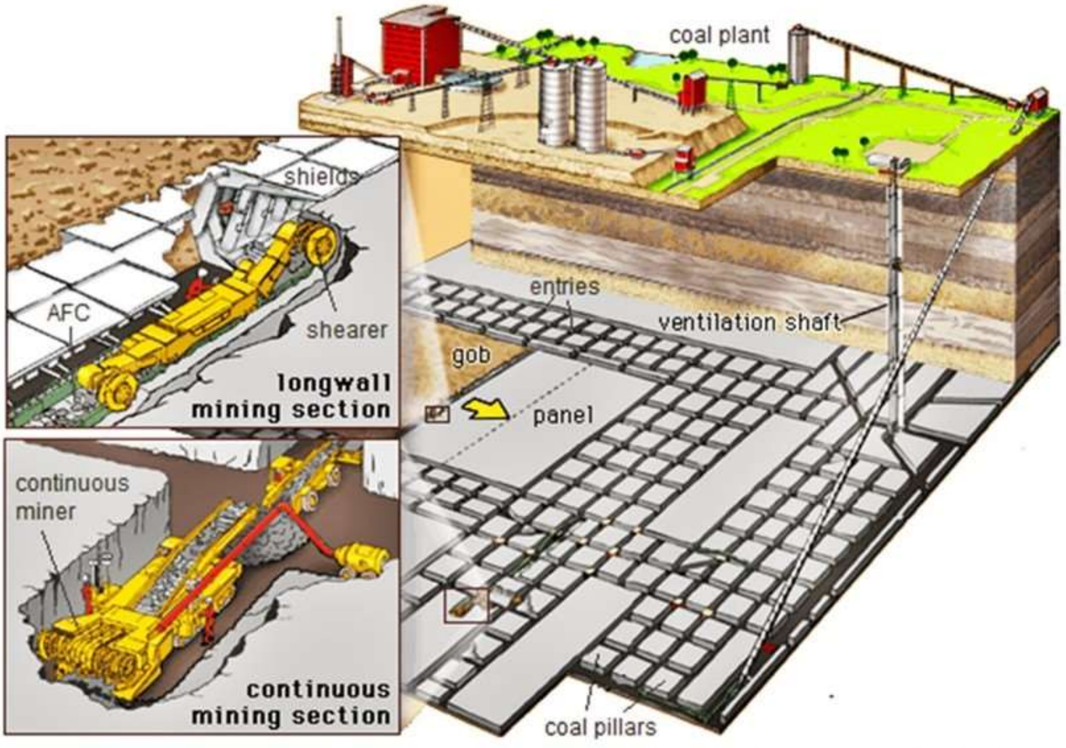

Figure 4. Underground coal mining. (Source: Britannica, 2017).

Figure 5. Typical underground longwall coal mining (Source: unknown).

1.4 Coal-fired power generation

A coal-fired power station burns coal to generate electricity. Coal is used to produce furnace heat that is used to convert boiler water to steam, which is then used to spin turbines to turn generators. The coal is usually pulverised into a fine powder and then burned in a furnace with a boiler to heat water into high-pressure steam. The chemical energy stored in coal is converted into thermal energy, then mechanical energy and finally, electrical energy (megawatt hour).

Coal-fired power stations generate over one-third of the world's electricity but the global trend is to move away from coal and other fossil fuels and generate electricity from renewable sources such as wind and solar.

In Australia in 2018, black coal accounted for 120,600,000 megawatt hours of energy production which was 46% of Australia's energy needs (CEC, 2019), 33% came from natural gas and brown coal, and 21% came from renewable energy sources including hydropower, wind and small scale solar.

There are 13 coal-fired power stations currently operating in NSW and QLD. The four main types of coal-fired power stations in increasing order of efficiency are: subcritical, supercritical, ultra-supercritical and Circulating Fluidised Bed (CFB) (Sourcewatch, 2019). The difference between subcritical, supercritical, and ultra-supercritical is the steam pressure within the boiler (Sourcewatch, 2019).

Figure 6 shows a schematic diagram of a typical coal-fired power station. Bayswater is a typical coal-fired power generation station (Figure 7). In NSW and QLD eight stations are subcritical, four supercritical and one is ultra-supercritical.

- In a subcritical station steam pressure is below 22,000 kpi and temperature is below 550 degrees Celsius. Subcritical units have efficiencies of between 33% and 37% as the energy in the coal is converted into electricity;
- In supercritical units, there is a higher pressure in the boiler to about 24,000 kpi and temperatures are 565 degrees Celsius. At this higher pressure and temperature, water can be maintained as a fluid despite being above the atmospheric boiling point, allowing greater efficiency. Efficiency ratings for supercritical coal stations range from 37% to 40%.
- In ultra-supercritical units, pressures are at 32,000 kpi and temperatures are 600-610 degrees Celsius, efficiency is greater than 40% with further refinements targeting 44-46%.

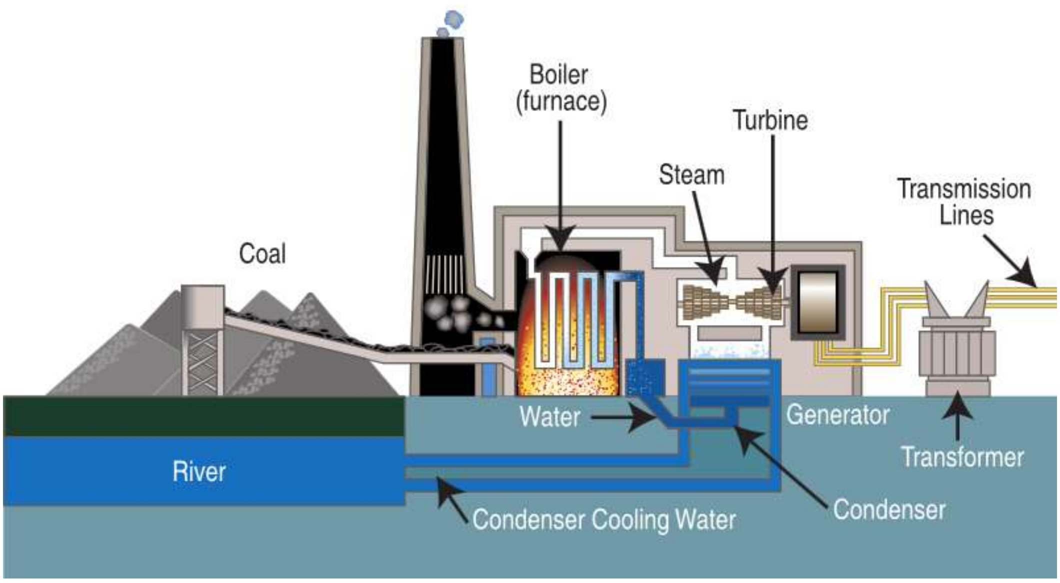

Figure 6. Typical coal-fired power generation station that uses coal to heat water for the steam to turn a turbine that generates electricity (Wikimedia Commons, 2019).

Figure 7. Bayswater coal-fired power generation station (Source: unknown).

Even though all thermoelectric stations use water to generate steam for electricity generation, not all station cooling systems use the same amount of water. There are three main methods of cooling (Union of Concerned Scientists, 2014):

- Once-through systems take water from nearby sources (e.g., rivers, lakes, aquifers, or the ocean), circulate it through pipes to absorb heat from the steam in condensers, and discharge the now warmer water to the local source. Once-through systems were initially the most common due to their simple process and lower cost. Very few new power stations now use a once-through cooling system. Large disruptions to local water supplies and ecosystems from the significant water withdrawals, discharges involved and the increased difficulty in siting power stations near available water sources have made other methods more popular.
- Wet-recirculating or closed-loop systems reuse cooling water in a second cycle rather than immediately discharging it back to the original water source. Most commonly, wet-recirculating systems use cooling towers to expose water to ambient air and some use cooling ponds. Some of the water evaporates, the rest is then sent back to the condenser in the power station. These systems have much lower water withdrawals than once-through systems but tend to have appreciably higher water consumption.
- Dry-cooling systems use air instead of water to cool the steam exiting a turbine. Dry-cooled systems have 90% less water consumption than once through systems but still require water. The trade-offs to these water savings are higher costs and lower efficiencies. In power stations, lower efficiencies mean more fuel is needed per unit of electricity, which can in turn lead to higher air pollution and environmental impacts from mining, processing, and transporting the fuel.

Four of the power stations in NSW and QLD are once-through cooling systems, seven are wet-recirculating and two are dry-cooled. Using data from Kogan Creek and Bayswater power stations, approximately 20% of the electricity produced by a coal-fired power station is used to operate the station itself. This means that water use figures can be multiplied by 1.25 as the amount of electricity generated is approximately 80% of the power stations capacity.

1.5 Coal Mining in NSW and QLD

Australia has large brown and black coal deposits, including thermal and metallurgical coal, and a long history of coal mining for export and for power generation and iron and steel production since 1790. The major black coal deposits are located in QLD and NSW with some deposits found in Tasmania (TAS) and Western Australia (WA). The major brown coal deposits are located in VIC, SA and WA (Figure 8). Mining occurs by both surface open-cut mines and underground mines.

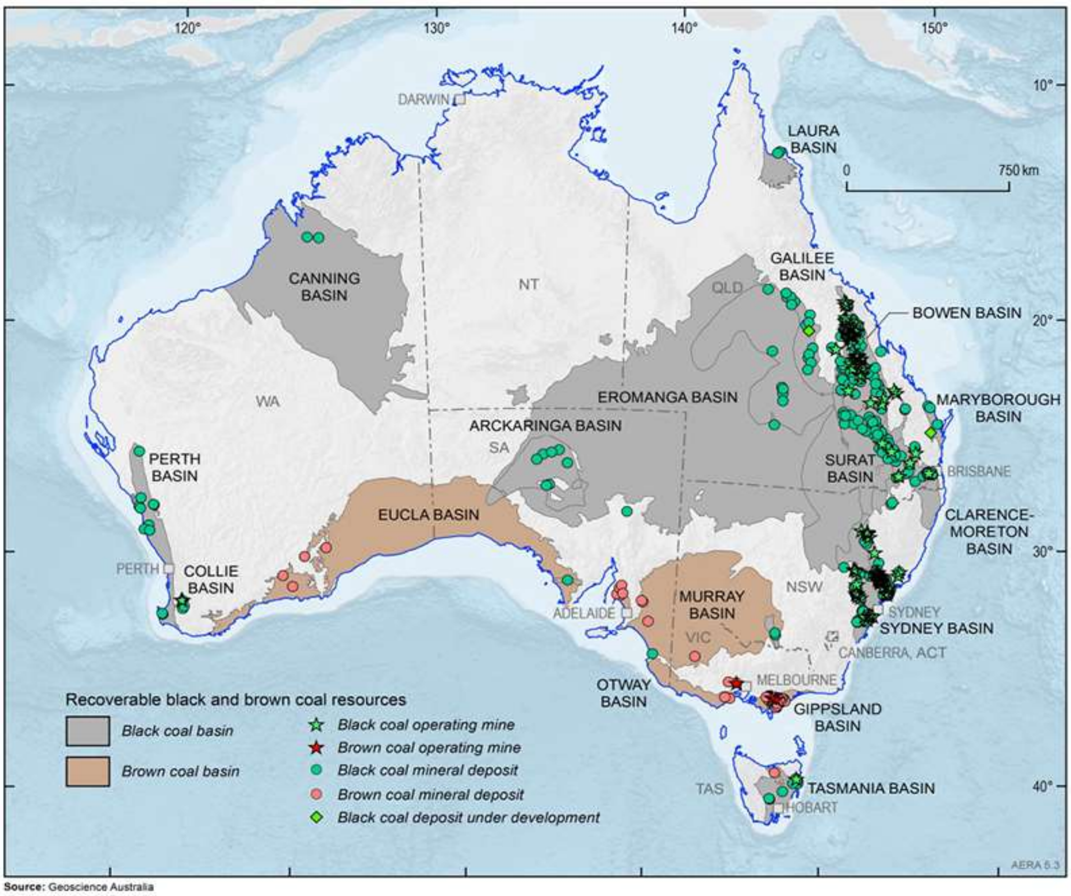

Figure 8. Coal deposits in Australia (Source: Geoscience Australia, 2019b)

The first coal mines in Australia where in Newcastle in the 1790s, with the first coal shipment leaving Newcastle in 1799, being Australia's first commodity export (NSW Mining, 2019). In 2018, Australia exported 203 Mt of thermal coal worth $22.6 billion and 179 Mt of metallurgical coal worth $37.8 billion. This was from the 89 black coal mines currently operating in Australia, 86 of which are in NSW and QLD and three in WA and TAS (MCA, 2019 and GA, 2019a). There are a further four brown coal mines operating in VIC.

In NSW there are 41 operating black coal mines with approximately half underground and half open-cut, and a further 39 identified coal deposits (GA, 2019b). Production was 246 Mt in 2017

(Coalservices, 2018) and 232 Mt reported in 2018 (Table 1). Appendix A lists the black coal mines currently in operation in NSW.

Table 1. Production by coal mines in NSW (Source: Annual Reviews, 2018)

Type	Production (Mt)	Number	Average	Smallest	Largest
All mines	231.7	39	5.9	0.03	40.9
Open cut mines	119.6	19	6.3	0.03	23.7
Underground mines	28.9	14	2.1	0.20	5.2
Thermal coal	189.7	30	6.3	0.03	40.9
Coking coal	8.2	6	1.4	0.20	2.7

Note: Production data for two mines (Musswelbrook and Glendell) could not be sourced. Open cut, underground, thermal and coking categories contain mines that are only of that type and do not include open and underground mines or thermal and coking mines.

The size increase of the coal mines is shown in Figure 9. Figure 10 shows the location of the mines operating in NSW and Figure 11 shows the location of the different coal basins.

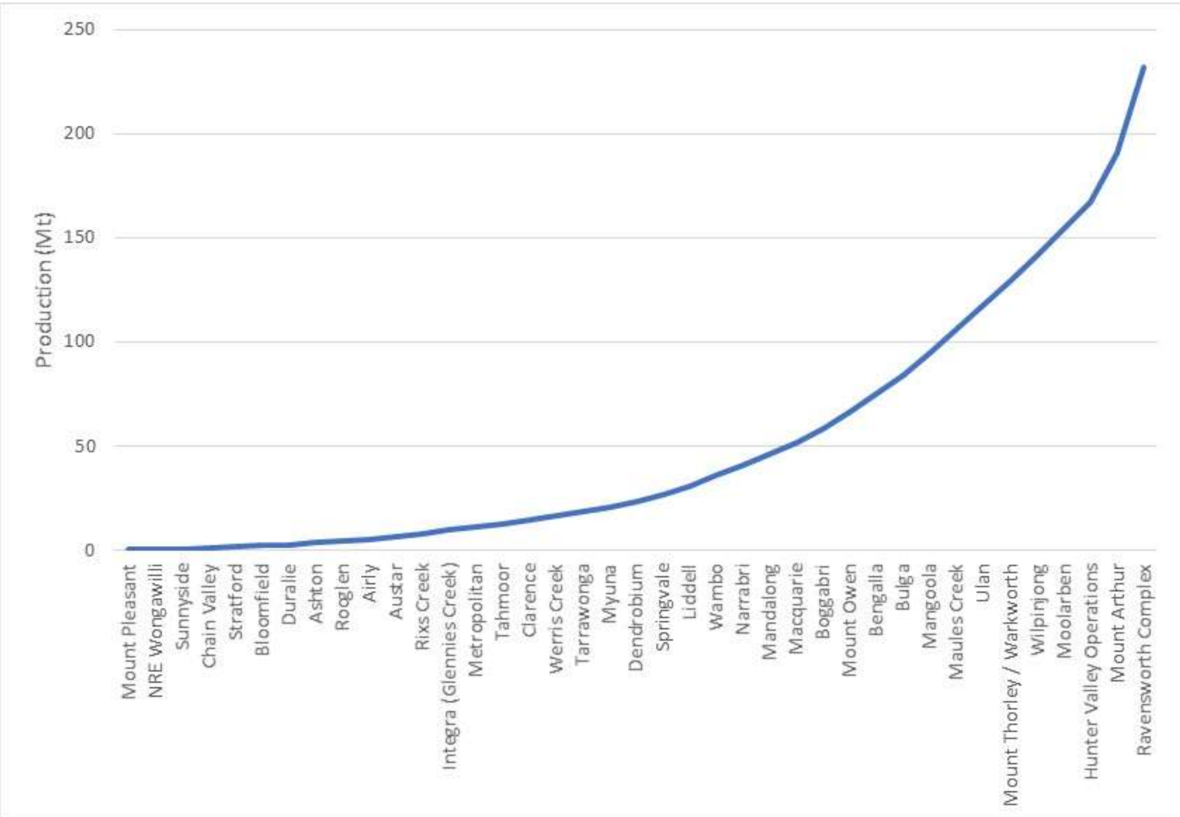

Figure 9. Coal production in NSW (Source: Annual Reviews, 2018)

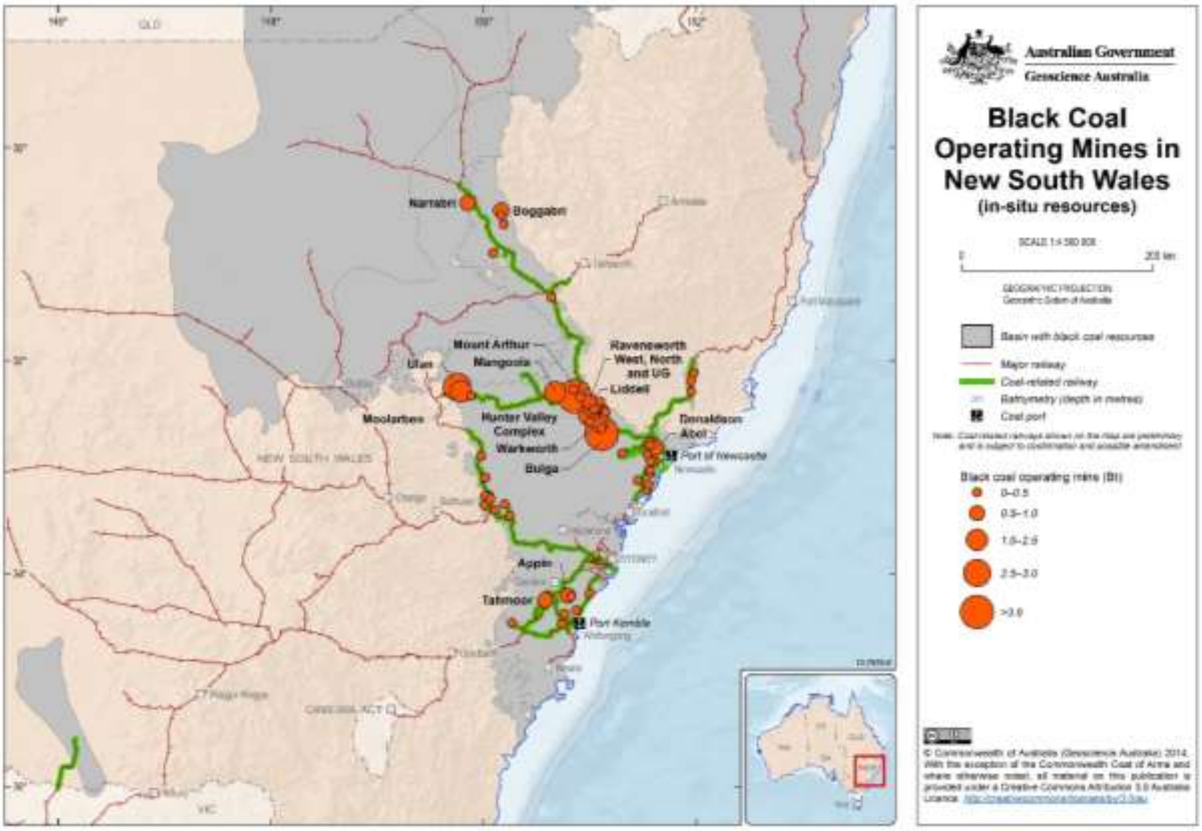

Figure 10. Operating black coal mines in NSW (MCA, 2019)

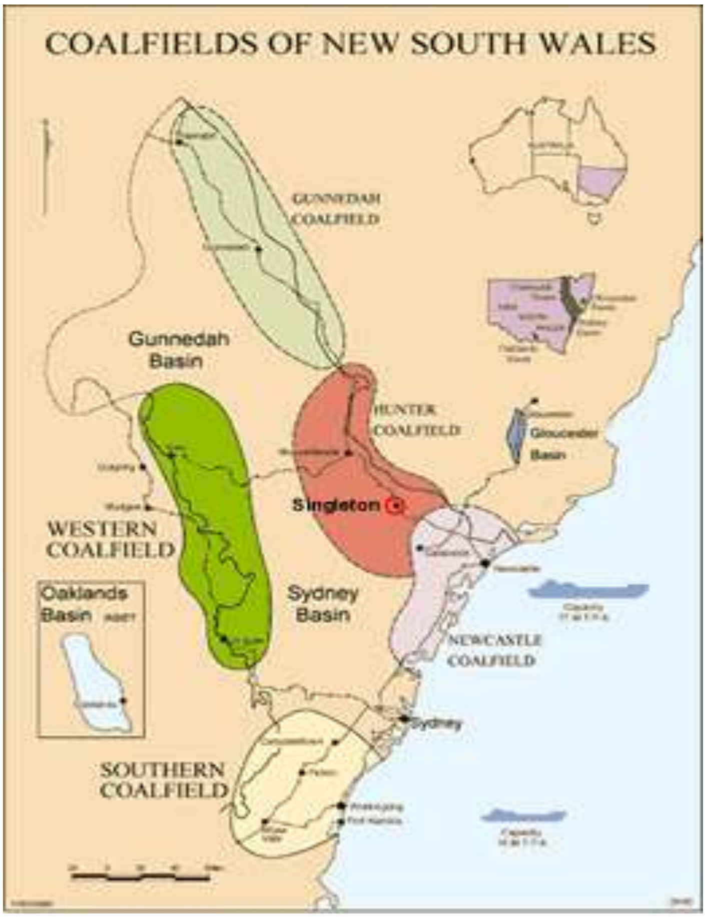

Figure 11. NSW coal field basins (NSW Department of Mineral Resources)

In QLD there are 45 operating black coal mines and a further 179 identified coal deposits (GA, 2019b). Appendix B lists the black coal mines currently in operation in QLD and the production is shown in Table 2 and Figure 12.

Figure 13 shows the location of the coal mines and Figure 14 shows the location of the coal basins.

Table 2. Production by coal mines in QLD (Source: Annual Reviews, 2018)

	Production (Mt)	Number	Average	Smallest	Largest
All mines	274.15	45	6.1	0.5	15.9
Open cut mines	198.8	35	5.7	0.5	13.9
Underground mines	40.5	7	5.8	1.8	15.9
Thermal	64.0	11	5.8	0.5	13.9
Coking	152.5	26	5.9	1.8	15.9

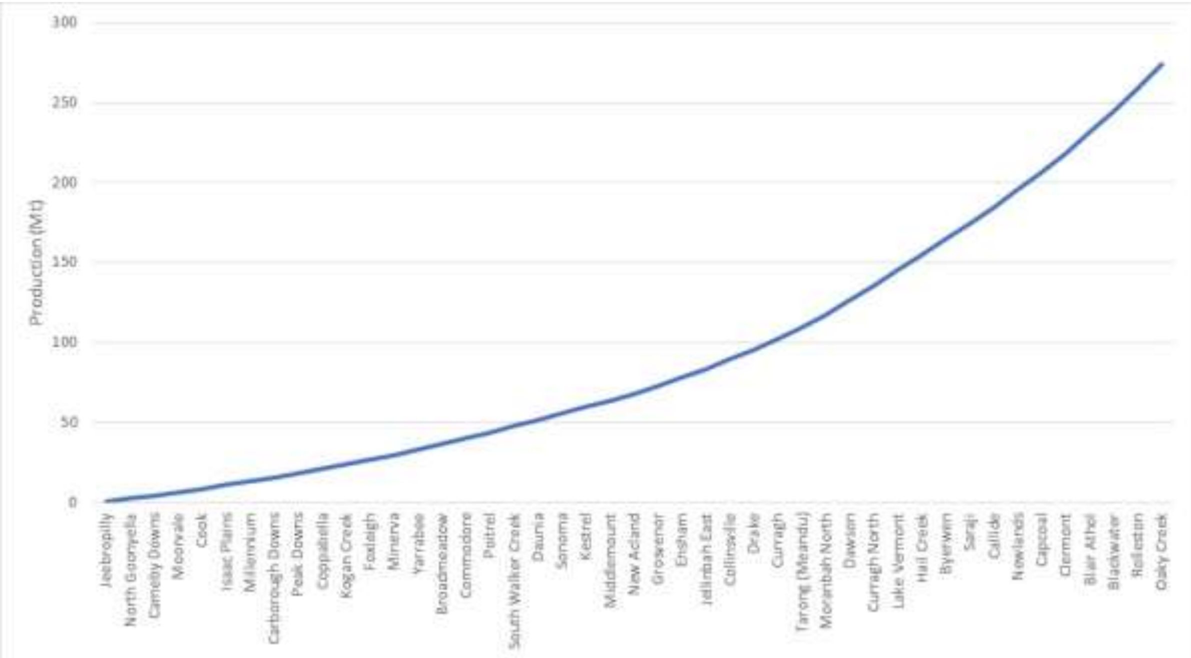

Figure 12. Coal production in QLD (Source: web searches)

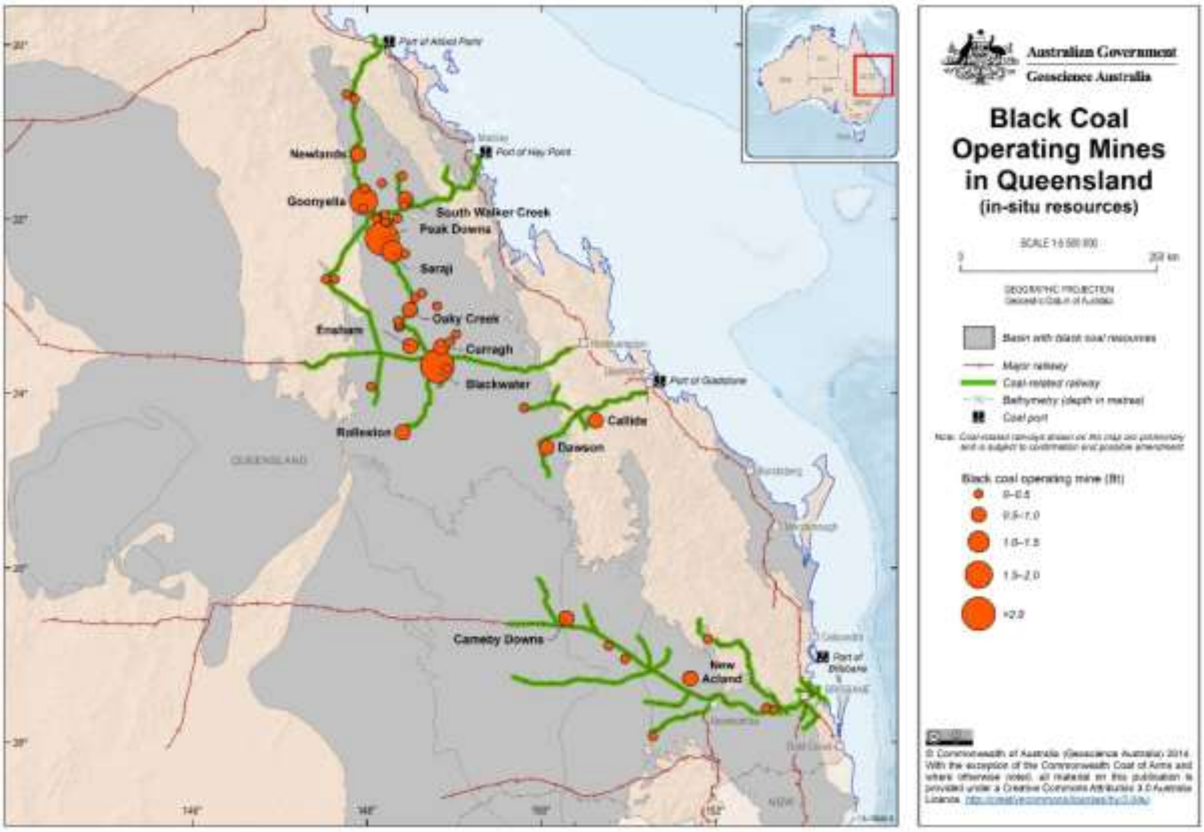

Figure 13. Operating black coal mines in QLD (MCA, 2019)

Figure 14. QLD coalfield basins (Queensland Government, 2007)

1.6 Coal-fired power generation in NSW and QLD

Coal burning is the main source of electricity in Australia (46% in 2019 (CEC, 2019). NSW, QLD, VIC and WA are the only States and Territories that have coal-fired power stations. Thirteen power stations operate in NSW (Table 3) and QLD (Table 4). In Australia, 75% of coal-fired power stations are operating beyond their original design life.

Approximately 80% of the electricity produced in NSW is sourced from coal (NSW Resources and Geoscience, 2019). Coal-fired power generation produces higher Co2 emissions than other generation options and accounts for about 35% of NSW's total greenhouse gas (GHG) emissions. Together with fugitive emissions from mining coal, 48% of the state's total GHG emissions come from coal production and utilisation (NSW Resources and Geoscience, 2019).

Table 3. ***NSW's five operating coal-fired power stations which all use black coal*** *(Source: McConnell, 2016)*

Power Station	Owner	Type	Year Started	Mine Type	Region	Cooling Water	Cooling Method	Capacity (MW)
Eraring	Origin Energy	Subcritical	1982	Underground	Coast	Salt	Once-through	2,880
Bayswater	AGL Energy	Subcritical	1982	Open-cut	Hunter	Fresh	Recirculating	2,640
Liddell	AGL Energy	Subcritical	1971	Open-cut	Hunter	Fresh	Once-through	1,680
Mt Piper	EnergyAustralia	Ultra-supercritical	1993	Underground	Western	Fresh	Recirculating	1,400
Vales Point B	Sunset Power International	Subcritical	1978	Underground	Coast	Salt	Once-through	1,320
Total								9,920

Liddell power station is the third largest in NSW (Figure 15).

Figure 15. Liddell Power Station, NSW (www.esdnews.com.au)

Table 4. ***QLD's eight major operating coal-fired power stations which all use black coal*** *(Source: McConnell, 2016)*

Power Station	Owner	Type	Year Started	Mine Type	Region	Cooling Water	Cooling Method	Capacity (MW)
Gladstone	Rio Tinto, NRG Energy, others	Subcritical	1976	Open-cut	Coast (Central)	Salt	Once-through	1,680
Stanwell	Stanwell Corporation	Subcritical	1993	Open-cut	North	Fresh	Recirculating	1,460
Tarong	Stanwell Corporation	Subcritical	1984	Open-cut	Central	Fresh	Recirculating	1,400
Callide C	CS Energy	Supercritical	2001	Open-cut	North	Fresh	Recirculating	810
Millmerran	InterGen Services	Supercritical	2002	Open-cut	South	Dry-cooled	Dry-cooled	851
Kogan Creek	CS Energy	Supercritical	2007	Open-cut	South	Dry-cooled	Dry-cooled	750
Callide B	CS Energy	Subcritical	1989	Open-cut	Central	Fresh	Recirculating	700
Tarong North	Stanwell Corporation	Supercritical	2002	Open-cut	Central	Fresh	Recirculating	443
Total								8,094

Stanwell is the second largest coal-fired power station in QLD (Figure 16).

Figure 16. Stanwell power station, QLD (www.southburnetttimes.com.au)

2. Water use and licensing in NSW and QLD

The lack of open data and the complexity of the licensing and regulatory environments means it is not clear exactly how much water coal activities are using in NSW and QLD. The State Governments has several Departments and Agencies that cover certain aspects of the licensing and regulation of coal mining and water use but there is no universal reporting format to ensure that all aspects of water use can be assessed together.

2.1 Water use in coal activities in NSW

All coal mining development in NSW is classified as state significant development under the Environmental Planning and Assessment Act 1979 and requires development consent. This consent and its conditions establish the framework for other licences and approvals that are required, including environment protection licences for air and water pollution under the Protection of the Environment Operations Act 1997, and mining leases under the NSW Mining Act 1992.

To achieve development consent the mine must go through the Environmental Impact Statement process. During this stage mining companies are required to undertake modelling that estimates water usage and the volume of water the mine will take from surface and groundwater sources, as well as a total water balance. This assessment process informs the conditions of consent, which for each mine requires water access licences to be held for water take, prior to the take occurring.

The NSW Mining Act 1992 provides the mechanism for government to regulate exploration and mining by granting authorities. All exploration and mining activity in NSW must be conducted in accordance with an authority issued under this Act. There are Conditions of Authorities set out in the NSW Mining Act 1992 and in the NSW Mining Regulation 2016 which lists the Mining Lease Conditions for Coal mines. There is a condition that the lease holder must comply with an approved Mining Operations Plan (MOP). Holders of coal authorities are required to lodge annual reviews on operations that include expenditure, along with maps, plans and data that are necessary to satisfactorily interpret the reports.

Compliance with the conditions of mining leases is enforced by the NSW Government. Mining development consents require the submission of Annual Reviews reporting against the conditions of the consent. Guidelines for these Annual Reviews requires reporting of water management, with a suggested format that matches water take against Water Access Licences under the Water Management Act 2000. The Water Management Act 2000 stipulates that such licences must be held for water taken in the course of mining. Rainfall and runoff are not licensed as they are usually simply diverted and released, however some mines capture and use this unlicensed water. There is no requirement for water reporting to use the Water Accounting Framework.

The Digital Imaging of Geological System (DIGS) is a public, online archive that provides access to non-confidential reports and other material held by the NSW Government. This includes exploration, geological and mining information with 140,000 reports dating back to 1875. However, the database does not contain information on water.

Water use by coal-fired power stations in NSW is not publicly available. Water is self-extracted for cooling and requires a license if it is from a freshwater body.

2.2 Water use in coal activities in QLD

All coal mining activities in QLD require approval and licensing by the QLD Government. Water reporting requirements depend on whether the water that is taken is 'associated' or 'non-associated'.

- Associated water is any underground water that you take or interfere with while (or as a result of) carrying out an authorised activity on your resource authority (e.g. mine dewatering activities).
- Non-associated water is any other underground water that is taken (e.g. taken from a water bore for use in mine operations).

Associated water

Amendments to the Mineral Resources Act 1989 that allow resource authority holders to take associated water as a statutory right came into effect in 2016 and requires reporting the volume of associated water taken. Holders of a mining lease or a mineral development licence must report the total volume of associated water to the QLD Government (even if water take is zero), and report the exercise of underground water rights to another Government Department when it begins.

There are additional reporting requirements under the Water Act 2000. However, these do not apply if you are taking the associated water under an existing water licence or if you would have been authorised to take the underground water before the Mineral Resources Act was amended in December 2016.

Non-associated water

A mineral development license or mining lease holder must have the required water permit or licence to take or interfere with surface water or groundwater when undertaking authorised activities. This applies to Coal authority holders who hold water licences or water permits under the Water Act 2000 or entities acting on behalf of these holders. This includes taking or interfering with water for:

- consumptive uses
- diversion of a watercourse
- impoundment of a watercourse
- water taken from a bore.

Groundwater:

- licence to take underground water (annual or quarterly monitoring report, performance review report, mine closure report, report of volumes taken, water levels and water quality)
- permit to take underground water (report of volumes taken, water levels and water quality).

Surface water:

- licence to interfere with flow (as built engineering plan diversion of a watercourse, monitoring report)
- licence to take surface water (Report of volumes taken)
- permit to take surface water (Report of volumes taken).

The Queensland Water Reform and Other Legislation Amendment Act (2014) expanded the underground water management framework in the Water Act to the mining sector. A cumulative management area (CMA) may be declared in an area that is likely to experience an impact on underground water, due to the exercise of underground water rights by two or more resource tenure holders. When a CMA has been declared, the QLD Government prepares an underground water impact report (UWIR) for the CMA. The UWIR for the CMA will assign the following responsibilities to relevant resource tenure holders:

- Ownership, access to and use of land (tenure), and payments to the State Government for extraction of minerals (royalties) are regulated under the Mineral Resources Act 1989 (QLD) (Mineral Resources Act); and
- Environmental protection associated with mining regulated under the Environmental Protection Act 1994 (QLD) (Environmental Protection Act).

Declaring a CMA enables the assessment of future impacts using a regional modelling approach and the development of management responses that are relevant to the potential cumulative impacts.

The regulatory environment for water use in coal mining in QLD will not protect water resources in the Great Artesian Basin unless the cumulative impacts of mining are taken into account.

Water use by coal-fired power stations in QLD is also not publicly available. How water is licensed and regulated for coal-fired power stations in QLD was also not publicly available.

2.3 Coal mining of Commonwealth interest

During the decision to issue a mining license there are triggers that may mean that the license application needs Commonwealth approval as identified in the EPBC Act 2013 amendments, which protects water resources from coal seam gas and large coal mining developments as a matter of national environmental significance. The matters of national environmental significance include world heritage area, national heritage places, ecological values of a Ramsar wetland, nationally listed threatened species and ecological communities, listed migratory species, nuclear activities (including uranium mines), Commonwealth marine areas, the Great Barrier Reef Marine Park, and water resources, in relation to coal seam gas development and large coal mining development.

If an activity is likely to have a significant impact on one of these triggers, it must be referred to the Commonwealth Government for assessment. The decision to approve or refuse the project is made by the Minister for the Environment and Energy. Many of these triggers are relevant to coal developments, but the water trigger is particularly relevant. Under the water trigger, if a coal mine will have a significant impact on a water resource, such as an aquifer, it will trigger the need for referral to the Minister and approval before it can proceed (EDO, 2017). The NSW Environmental Defenders Office have produced a guide to mining and the law in NSW (EDO, 2017).

Coal mining is subject at Commonwealth level to adaptive management principles to manage uncertainty and reduce it over time to achieve ecologically sustainable development, which is fundamental to decision-making under the EPBC Act. The principles of ecologically sustainable development include (DEE, 2019b):

- That decision making processes should effectively integrate both long term and short term economic, environmental, social and equitable considerations.
- The precautionary principle – that if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

"The assessment process draws on independent expert scientific advice to identify the potential environmental impacts of a coal development project, as well as the effectiveness of proposed management strategies. However, some uncertainties can remain, and further work may be required after the approval is granted to address the environmental risks associated with the project. An adaptive management approach set out in the conditions of approval is often used to manage uncertainties about environmental impacts. Adaptive management means that impacts are monitored, and changes are made if impacts cross a specified threshold. This approach is critical to managing risks for major projects" (DEE, 2019b).

Adaptive management is underpinned by (DEE, 2019b):

- A robust monitoring system to establish site specific baseline information about the current state of water (such as the water table, pressure of aquifers, salinity, etc).
- Precautionary triggers which are based on the baseline monitoring data and often require companies to conduct investigations and/or take action at an early stage to avoid an unacceptable impact from occurring triggers that, if reached, require the company to stop the activity.

2.4 Issues and recommendations

The licensing, reporting and regulation environment in NSW and QLD have the following issues:

- **Water Accounting**

  Issue

  Detailed water use and water balance reporting is not mandatory. Reporting on water use is mandatory in NSW but only on the surface water take (license) and groundwater pumping (license). In some cases, mine leases state other reporting requirements such as water accumulation. In general reporting is not required on total volumes of water that may be displaced or used as a result of rainfall/runoff, water stored, etc. The Water Accounting Framework (Minerals Council of Australia) is recommended but not required. There is no required or standard reporting format for water withdrawal/consumption.

  Recommendation

  The Water Accounting Framework should be mandatory and water use reports should be public. Coal mines may be using more water than the current reporting requirements show as there is no mandatory water consumption reporting across all mining activities. It should be mandatory for complete water reporting. In the case of water quality, Ali *et al.* (2017) stated that it is evident that the current regulatory approach may need to consider inclusion of appropriate tools and measures for achieving a more sustainable environment and called for a more comprehensive Environmental Water Quality index to be routinely monitored.

- **Governance**

  Issue

  Depending on the current Government structure there can be up to five NSW Government Departments or Agencies and four QLD Government Departments that oversee licenses for water volumes, regulation of water quality and discharge volumes, regulation of planning legislation, regulation of annual reviews and water management, and the regulation of illegal water take – this can lead to discrepancies and things 'falling between the cracks'. There is little evidence of adaptive management practices.

Recommendation
Water should be elevated to a single reporting framework and be under the regulation of one Department or Agency, or at least one framework that can be accessed by all Departments. Water use should be managed using adaptive management practices.

- **Modelling**
  Issue
  Licenses are issued based on water use models, but the reality can be quite different once the mine is operating. In some cases, coal mines will review their water models annually, but this does not occur in all cases. There is no later recourse if water balance models are wrong and different volumes of water are used or impacted.

  Recommendation
  Water balance modelling should be mandatory and water models independently audited and updated annually. The accuracy of these models is hard to determine as complex groundwater and surface water models are not transparent or easily accessed by government staff and the public and rarely do these models report on uncertainties and indicative accuracy. The communication of these models should be improved to convey volumes and uncertainty.

- **Data**
  Issue
  Data on water levels, flows and quality are typically collected for coal management operations and compliance. There is not a central database that allows access by all Government Departments and the public to this data. Previous attempts at a universal database have failed (for example the SEEK database and the 'Water Miner').

  Recommendation
  Make water data freely available to provide a much higher level of scrutiny on mine operations by NSW and QLD Government Departments and the public.

3. Water use in coal mining

When looking at how much water is used by coal, it is important to look at more than just the water used directly in coal mining or coal-fired power generation and look at all types of water used and impacted by coal activities. This chapter documents the water balance and Water Accounting Framework (WAF) and explains water inputs, use and outputs in coal mining.

3.1 Water balance and the Water Accounting Framework

Water use is a common term but requires further explanation and division into:

- Water consumption – the water that is taken out of the water resource (rainfall, surface water, groundwater, etc) and used in a way that it is no longer available for other users. This can include conversion to steam, drinking, etc.
- Water withdrawal – the water that is taken out of the water resource, used and then returned to the same or another water source. This can include water used to cool a power station and returned to a river, etc.
- Water impacted – this is not usually considered as water use but includes water that is impacted either through diversion of surface water or groundwater flow due to earthworks, polluted water from spills or modified local climate such as rainfall patterns due to the drying of the air by the cooling towers. It includes the impact on the water resource such as the depth of groundwater or river flow that is not accounted for by direct pumping.

Water can be considered as:

- Potable or clean water – fit for human consumption but also required to be used in tasks that have human exposure such as sprays.
- Dirty water – that has sediments or other contaminants that can be used for dust suppression etc.
- Saline water – that has high salinity that cannot be used for certain equipment maintenance. Water that has come into contact with coal is considered saline water.

When considering water use by coal it is important to consider all types of water use and types of water. Different water uses impact on the total water balance. The Minerals Council of Australia (MCA) have promoted the use of the Water Accounting Framework (Côte *et al.*, 2009) to provide a definition and structure for water classification and reporting. Figure 17 shows the basic structure of the Water Accounting Framework. The framework provides a classification for water use as water stores, treatments and tasks. A water balance model for the Glencore Ulan mine shows the different amounts of water moving between water stores, treatments and tasks at the mine site (Figure 18).

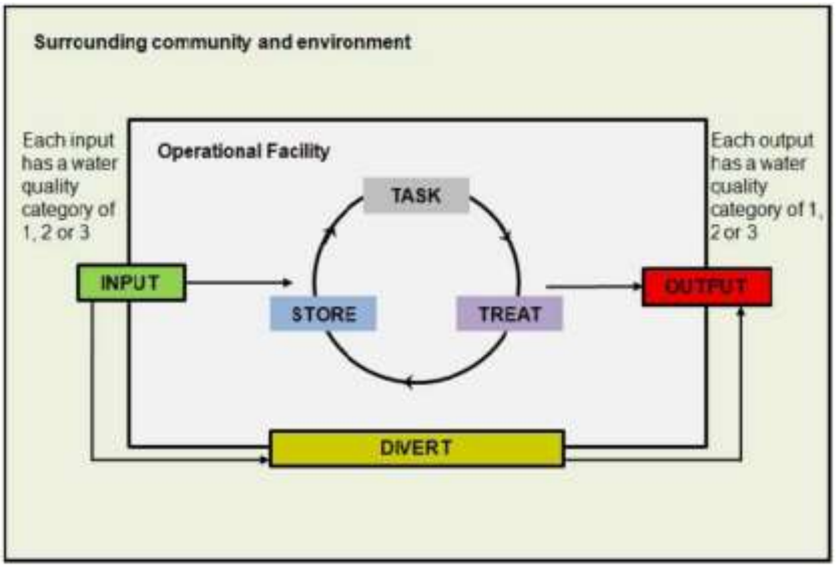

Figure 17. Water system concept model for accounting purposes (MCA, 2014)

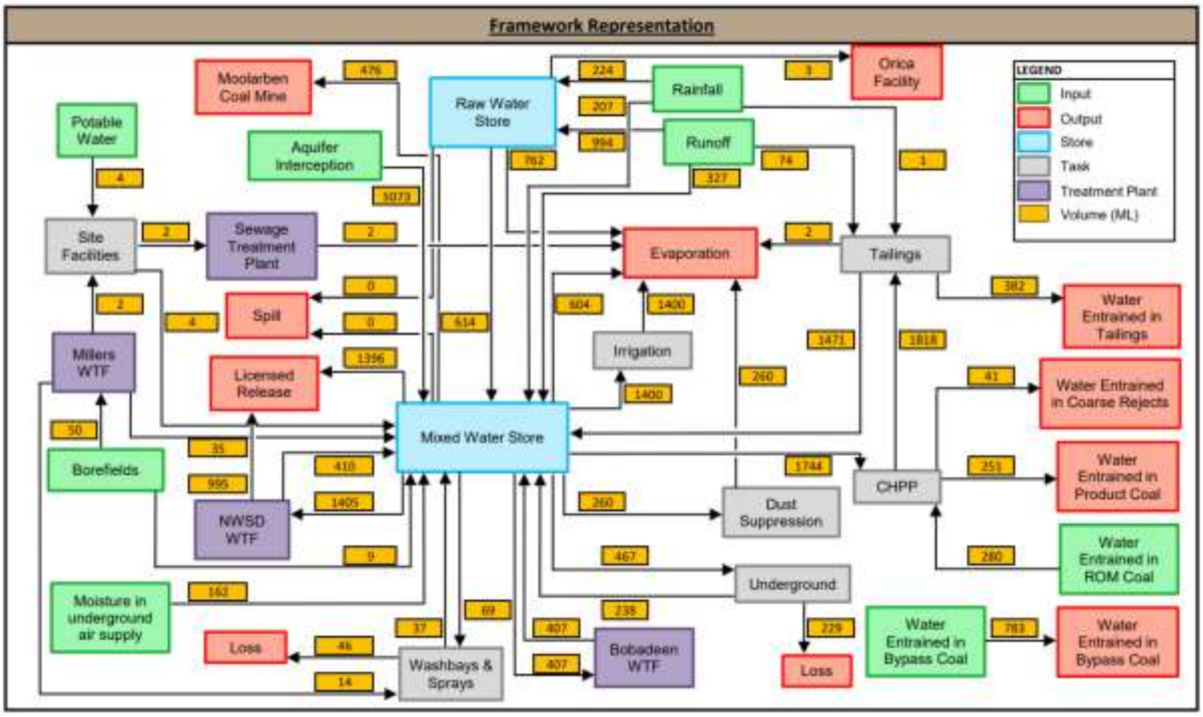

Figure 18. Water balance model using the Water Accounting Framework for the Ulan Coal Mine (Glencore, 2017)

These water balance models and subsequent summary tables are reported in the Annual Reviews for NSW mines. However, the reporting is not a requirement and different mines report to different levels of detail. There is also a major difference in the way water is balanced with some mines reporting total water inputs (rainfall, extractions, groundwater pumping, etc) equal to the mine's total water outputs (evaporation, discharges, losses, etc) in a comprehensive water balance account, while other mines do not record all components and can combine water tasks with water outputs which confuses the water balance. There is no such framework adopted by QLD mines.

The Water Accounting Framework provides an excellent way for mines to report total water usage and the water balance of the mine (Danoucaras and Woodley, 2013). However, water impacted is not considered in the framework explicitly and is therefore not considered in annual review of water balances.

The mine Annual Reviews contain data ranging from no records to comprehensive water balance data. However, the data is not audited and comes from a range of data source, from complex water balance modelling to simple mine site recordings of some volumes in the Water Accounting Framework.

This report recommends more comprehensive water balance reporting and the requirement for this reporting to be audited by the state government department in charge of mine regulation.

Given the lack of comprehensive accounting it is difficult to accept that the reported water use is the total water use for the mine. For example, not all mines report rainfall and yet all would receive some. Not all mines record the water entrained in the coal and yet all coal has water in it. The data recorded is incomplete in most cases.

The International Council on Mining and Metals uses the same water accounting components as Figure 17. In their guidelines they list the components that should be part of water reporting (Figure 19) including a simple, consistent and transparent report on water interactions.

Appendix C provides a breakdown of water use in 39 NSW coal mines as reported in their annual reviews. QLD coal mines are not required to publish annual reviews reporting water use.

The data was only available in report format and had to be manually entered for analysis. An open access database would allow better scrutiny of coal mining operations and provide data for regional assessments.

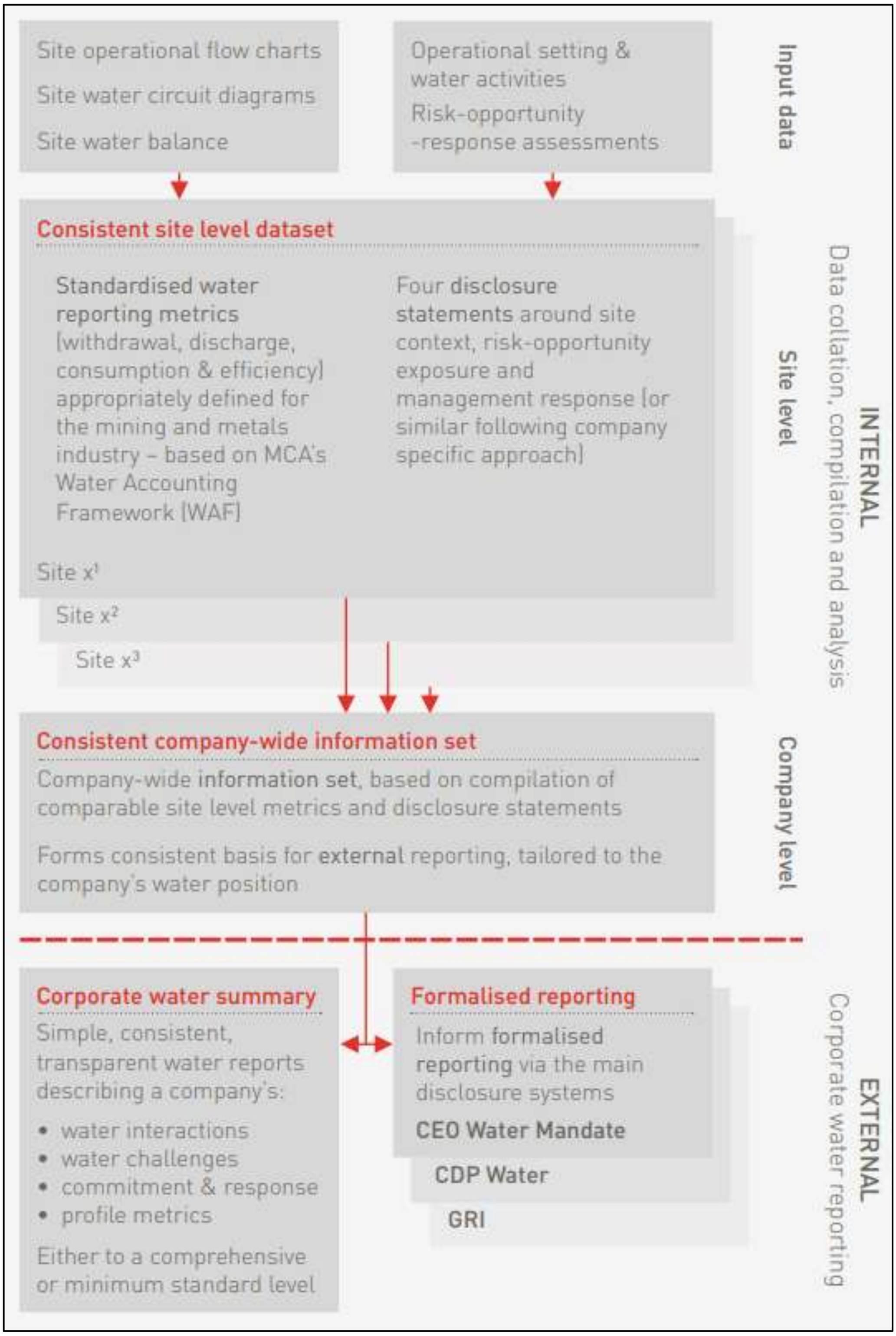

Figure 19. Consistent water reporting for the mining industry from the International Council on Mining and Metals (ICMM, 2017)

3.2 Coal mine water use

Coal mining uses approximately 653 L/t (191-3,286 L/t) based on 29 coal mine Annual Reviews in NSW. Mekonnen *et al.* (2015) reported a range of 180-4,200 L/t for all types of coal mining and Côte *et al.* (2010) reported data with an average of 1,061 L/t (501-2,932 L/t) for all types.

Table 5 provides data on coal mine water use from other studies. The range in water use per tonne is due to differences in the types of mining operation, the amount of impurities in the coal that need washing and dust suppression differences due to landscape and climate.

Almost all of the water inputs to a coal mine are consumed water so estimates of water withdrawals are the same as water consumption.

The amount of 653 L/t from 2018 Annual Reviews was used to estimate water use for all coal mines in Australia giving a total water use of 292,500 ML for the 448 Mt of production. Approximately 80% of the source water is freshwater from rainfall and runoff, extracted from rivers and water bodies, groundwater inflows and transfers from other mines. The remaining 20% of water comes from water already entrained in the tailings, recycled water supplies and seepage from the mine. This equates to 234,000 ML of freshwater used in one year by coal mines in Australia.

Open-cut coal mining uses approximately 649 L/t (365-3,284 L/t) based on annual reports from 18 coal mine Annual Reviews in NSW. The main water sources are rainfall and runoff (32.5%), extractions from rivers and water bodies (23.8%) and interception of groundwater aquifers (14.1%).

Underground coal mining uses approximately 1,001 L/t (191-3,286 L/t) based on annual reports from nine coal mines in NSW. The main water sources are groundwater pumped (66.3%), groundwater inflows (10%) and rainfall and runoff (4.6%).

The majority of water used in coal mining is used in the coal handling and preparation plant (CHPP) (47%), dust suppression (42.2%) and onsite facilities, irrigation, vehicle washing, etc. Major water outputs from coal mines include evaporation (21.1%), discharges to rivers (14%) and the water entrained in the product coal (13.1%)

Table 5. Coal mine annual water withdrawal and consumption

	Withdrawal (L/t)	Consumption (L/t)
All mine types	220 (2) 2,037 (2)	653 (1) 61 (2) 704 (2) 180-4,200 (4)
Open-cut mine	23-227 (3)	649 (1) 23-220 (3)
Underground mine	64-871 (3)	1,001 (1) 64-871 (3)
Coal handling and preparation		168 (1)
Dust suppression		151 (1)
Transport (slurry pipeline)	1,790 (2)	644 (2)
Plant construction	26 (2)	
Amount used for water calculations	**653** (given that the majority of water inputs are consumed)	**653** (actual data for Australian mines)

(1) Coal mine Annual Reviews for 2018
(2) Wilson *et al*. (2012)
(3) Meldrum *et al*. (2013)
(4) Mekonnen *et al.* (2015)

Coal mines can be separated based on the type of mining undertaken into open-cut and underground mining. There are different water use rates for a mine size depending on the type of mining. Figure 20 plots the coal mines in NSW for their production of coal and their annual water use. There is no significant pattern to the underground mines, but they generally have higher water usage for their production size than open-cut mines.

For the open-cut mines there is a statistically significant relationship between the size of the mine and the amount of water it uses. This provides evidence that using a multiplier of production is a useful estimate of water use, at least for the open-cut mines. Due to a lack of water data for mining, an estimate was made using a multiplier for each mine type.

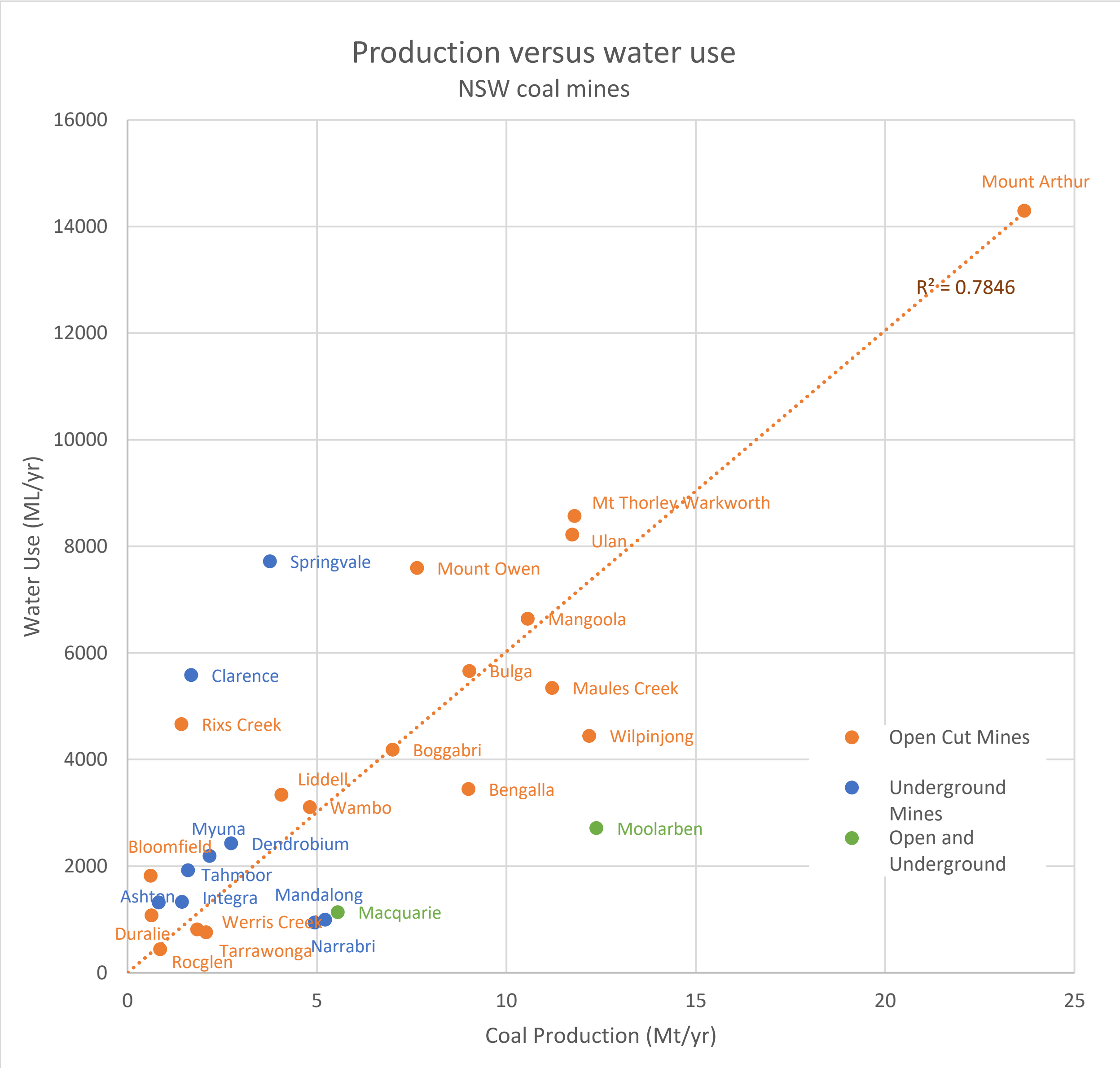

Figure 20. Water use for NSW coal mines against coal production (Annual Reviews, 2018)

3.3 Major types of water inputs

3.3.1 Rainfall and runoff

Rainfall and runoff accounts for about 32.5% of the mines' water input and depends largely on the climate, land area and topography. Open-cut mines have a much higher input of direct rainfall and run-off. Underground mines can have large amounts of rainfall seepage from areas outside of the surface area of the mine lease which enters the mine through seepage and aquifer recharge. Rainfall and runoff are difficult to measure and even harder to model given changes in rainfall over different years and localised rainfall and runoff patterns. As a result, the largest water input cannot be measured accurately and therefore makes water balance reporting difficult.

3.3.2 Surface water

Extractions from surface water bodies (usually rivers) accounts for about 23.8% of water sources for coal mines. Water extraction is usually licensed and is usually low priority, meaning critical human needs, industry and agriculture have first rights to water when rivers are low. High security water licenses, those that have greater rights to water and whose licenses are fulfilled first, are used by mines and power stations for critical operations.

Water extracted from rivers is a major concern for the public in highly contested water catchments and is a major factor in the coal industry's social license to operate. Surface water extractions can reduce the water available for environmental flows for floodplains and rivers. In extreme cases it can reduce the availability of refuge ponds in drought conditions.

3.3.3 Groundwater inflow (aquifer interception or seepage)

The interception of aquifer water into the mine is the third major water source for coal mines accounting for approximately 14.1%. This is of major concern for underground mining but can also be an issue for deep pit open-cut mining. Water seepage needs to be removed to allow safe mining operations. The groundwater provides a water source for the mine but in many cases is water that exceeds requirements and needs to be removed.

Groundwater lowering can be a major impact from this type of water source and can lower agricultural and domestic water bores. It can also lower groundwater levels that supply groundwater-dependent ecosystems such a mound springs and gaining river systems from groundwater baseflow.

3.3.4 Transfers

Approximately 8% of water sourced for coal mines comes from transfers from other coal mines via piping or in extreme cases trucking or rail. This is often due to water being more available at one mine than another or the use of recycled water facilities at the source mine.

3.3.5 Water entrained in the raw coal

Approximately 7% of coal water is sourced from water entrained in the raw coal. This depends largely on the moisture content of the coal in situ. It is also dependent on the grade of coal. Many mines do not report or include the water content in their water balance reporting.

3.3.6 Mine water – tailings and dams

Approximately 6% of water comes from seepage from tailings and from tailings dams. This is dependent on how much water is stored on the mine site.

3.3.7 Effluent supply / recycled water

Some mines have water recycling facilities that can supplement their natural water supplies. These facilities can produce potable water but are more likely used to improve the water quality for other uses. Approximately 4% of coal mine water is sourced from recycled water from wastewater treatment plants either inside or outside the mine.

3.3.8 Spoil seepage and industrial return

This is a minor water source but can still be an issue that has to be managed by the mine. This type of water is dirty water and has to be moved to a water storage or managed for potential pollution impacts.

3.3.9 Groundwater pumping

Although a minor source on average it is the main water source for some mines. Where surface water resources are scarce and groundwater aquifers are available, the mine can source water from groundwater bores. This is also a major concern for the public where groundwater levels can be lowered reducing access to agricultural bores and domestic water supplies.

3.3.10 Moisture in the underground air

Moisture in the air in underground mines can contribute a noticeable input into the water balance. This moisture can be useful to reduce dust but has to be pumped out if concentrations are high.

3.3.11 Potable water supply

Mines are usually connected to a potable water supply from water supply organisations. This is for human needs and for some mine uses that require good quality water such as wash down bays when groundwater supplies are saline. It is a secure water source in times of drought but is very expensive water.

3.4 Major types of water tasks

3.4.1 Coal processing

The biggest water user at the mine is the coal handling and preparation plant (CHPP) which users approximately 47% of the task water. This includes coal handling, coal washing station, crushing, screening, separation and dewatering. Water is used to help transport the coal, wash the coal and to manage the dust produced during the processing stages (Figure 21).

Figure 21. Dust suppression on a coal conveyer belt (www.miningreview.com)

Coal washing is undertaken to reduce the impurities in the coal and sort it into different grades. Washing improves the quality of the coal, reducing emissions, increasing its efficiency and reducing transport volumes. Coal washing is used to remove 50-80% of ash, 30-40% of total sulphur and other rocks and soil which reduces the ash and sulphur dioxide emissions when the coal is burnt. The lighter coal particles rise to the top and are removed. Froth flotation or hydrophobic flocculation flotation are processes that selectively separate materials based on whether they are water repelling (hydrophobic), e.g. coal, or have an affinity for water (hydrophilic), e.g. other mineral inclusions (Figure 22).

Figure 22. Coal cleaning using froth washing (Wikimedia Commons)

3.4.2 Dust suppression

Water is applied to areas of coal dust, overburden, tailings and soil to reduce the amount of dust that is released to the air. It is the second highest task for water at approximately 42.2%. Mine haul roads are the largest contributor of dust at mine sites (40% Latimer, 2014). This is to prevent build-up of dust on equipment that can reduce productivity and increase tyre wear on roads. It is also to improve the atmosphere for workers and reduce health and safety concerns such as Coal Workers Pneumoconiosis (CWP), a fatal lung disease caused by inhalation and deposition of mineral dusts in the lungs. It is also to reduce dust being released offsite as Environment Protection Authorities have regulations on dust emissions.

Dust suppression is usually undertaken using large spray jets or a truck that sprays water behind it (Figure 23). Chemical surfactants can be used to increase the water efficiency in dust suppression by decreasing the surface tension to allow available moisture to wet more particles per unit volume. Hydroscopic compounds such as calcium and magnesium chloride increase roadway surface moisture by extracting moisture from the atmosphere. Negative pressure secondary dust removal (NPSDR) and ultrasonic dust suppression systems are technology improvements to traditional water application that reduce water usage. Dust suppression with water and chemicals invariably contaminates the water runoff and leads to water pollution issues.

Figure 23. Dust suppression in coal mining using aerial sprays (www.indiamart.com) and trucks (www.rstsolutions.com.au)

3.4.3 Cooling equipment

Water is used to cool cutting surfaces of mining equipment to prevent coal dust from catching fire and causing explosions in underground mining (Figure 24).

Figure 24. Spraying in underground coal mining to reduce dust and cool equipment (www.wattelectricalnews.com)

3.4.4 Slurry transport

Coal is transported short distances by trucks and by trains for longer distances. In some cases, crushed or ground coal can be carried through pipelines as a water-based slurry for further processing (Figure 25). The coal-water slurry is mixed in approximately a 1:1 ratio. Slurry transport is more economical and has less impact than rail (Kania, 1984).

Figure 25. Coal slurry transported by pipe (University of Western Australia)

3.4.5 Potable water

Mines need water for vehicle maintenance and for drinking and cleaning by the mine workers (Figure 26).

Figure 26. Mine site potable water supply and wastewater treatment (www.makwater.com.au).

3.4.6 Vehicle and site maintenance

Vehicles and other mining equipment need to be constantly cleaned given the dusty environment in which they work (Figure 27).

Figure 27. Cleaning down mining vehicles (http://www.tammermatic.com/)

3.4.7 Other tasks

Irrigation can be a minor water use in mine sites (approximately 4% for the NSW mines reported). It depends on the amount of rehabilitated area to maintain and the general site conditions.

3.5 Major types of water outputs

3.5.1 Evaporation, surface spills and seepage

Evaporation can add up to a significant amount when open storages are used for input and/or output water, particularly for mines that rely on ponds for water supply. Approximately 21.1% of water outputs reported are evaporation. Evaporation is a particularly concerning water output as it is water consumption by the mine. In many cases this is water that is sourced from underground aquifers and then evaporated. Evaporation for the NSW coal mines ranged from 14 to 3,030 ML/yr with some mines not recording evaporation losses.

Surface spills can occur through dam wall failure or during extreme weather conditions when floods cause overspills from the storages into adjacent watercourses (Figure 28). As this water is likely to be contaminated it is a major concern for mine operations and for ecosystems and communities near the spill.

Seepage into groundwater can also account for large amounts of water loss.

Figure 28. Adani Abbot Point coal spill in 2017 (www.theguardian.com)

3.5.2 Discharges to rivers

At 14%, planned and licensed discharges to rivers and water bodies accounts for the second highest losses in the mine water balance. In NSW the Environmental Protection Authority monitors mine discharges for volume and water quality. Impacts can include temperature increases, sediment and heavy metal pollution.

3.5.3 Entrainment in product coal

For those mines that included moisture content in their water balance reporting, this was the third highest water output at about 13.1%. The moisture content of coal is dependent on the type of coal. Black thermal coal has around 10% water content. The higher the water content the less heat is produced which is why brown coal (30-70% water content) is less efficient. Pre-combustion methods can be used to reduce the moisture content in the coal before leaving the coal mine to reduce transport costs and make the coal more efficient.

3.5.4 Other outputs

Transfers to other mines can be a large water output in some cases. Water entrained in the tailings dams is often reported in the water balance. Discharges to rivers is also a common but small water output that does not occur every year.

4. Water use in coal-fired power stations

The burning of coal to generate energy is a large water user. Almost all of the water used by coal-fired power stations is used for cooling systems. A typical 1000 MW coal-fired power station uses enough water in one year to meet the basic water needs of nearly 700,000 people. Globally, coal stations consume about 8% of our total water demand (CoalSwarm, 2019).

Most power stations use freshwater for cooling, using either rivers or stored water (ponds), although recycled wastewater and salt water are other possibilities with advantages and disadvantages. Salt water is an obvious and abundant option for coastal power stations but can have impacts on salt water ecosystems. Inland power stations using freshwater sources also have potential impacts on ecosystems from excessive withdrawals and thermal pollution.

Implementing carbon capture technologies to reduce greenhouse gas emissions increases the amount of water required from 30% for wet cooled to 700% for dry cooled systems (Smart and Aspinall, 2009).

It is important to distinguish between the consumption and withdrawal of water for power stations. A typical 500 MW coal station withdraws an Olympic-sized swimming pool amount of water every 3.5 minutes (CoalSwarm, 2019). Water withdrawals for once-through cooling systems are discharged back into the original water source but at higher temperatures. Water consumed by coal stations is not returned to the original source and is no longer available for ecosystems, drinking water, aquaculture or food production by downstream communities. The water may be contaminated by pollutants during the combustion process and stored in ash ponds or have evaporated during cooling processes (CoalSwarm, 2019).

The amount of water withdrawn and consumed by coal stations varies significantly depending on the type of cooling system used and their location (CoalSwarm, 2019). Different cooling systems use different amounts of water for consumption and withdrawal:

- **Once-through (open-loop) systems** – use a continuous flow of water to cool the turbines. This water can come from rivers, ponds or the ocean.
- **Wet-recirculating (closed-loop) systems** – recycle the water to be used again. They withdraw less but consume more.
- **Dry cooling systems** - approximately 6% of coal stations worldwide, and two of the 13 power stations in NSW and QLD, have dry cooling systems, using air instead of water for cooling. These power stations use 75% less water than stations with recirculating cooling systems but are expensive and energy intensive. Power stations with dry cooling must burn more coal for operation due to reduced efficiency and therefore have greater impacts.

While most of the water withdrawn in all cooling wet systems is discharged back into the original water sources, it is usually discharged at temperatures 5.6-11°C hotter than when it was withdrawn (CoalSwarm, 2019). This “thermal water” can impact aquatic ecosystems, which can be extremely sensitive to small variations in temperature change. The cooling of the steam after boiling for turbine activation uses approximately 90% of the total water use (Martin, 2012). Subcritical systems use 10-50% more water than supercritical systems (Wilson *et al.*, 2012). A conventional wet cooled coal-fired power station consumes around 2.2 L of water per MWh (Smart and Aspinall, 2009). Water is used by the boiler for steam raising (0.01-0.03 L/MWh), the cooling system including evaporation (1.6-1.8 L/MWh) and water for cooling tower blowdown (0.2-0.2 L/MWh), managing and disposing of ash (0.1 L/MWh) and site services (Smart and Aspinall, 2009). Water withdrawals for a once-through cooling system are between 130,000 – 200,000 L/MWh) (Smart and Aspinall, 2009). Table 6 shows a range of water use values from previous studies.

Data was available for the currently operating coal-fired power stations from 2009 (Smart and Aspinall, 2009). This was the only data available and as water use is unlikely to have changed much since then, it was used in this analysis. Water use rates vary significantly from previous studies so actual data was preferred for estimating water use in Australia (Table 7).

Table 6.Water used in typical coal-fired power stations

	Freshwater Withdrawal L/MWh	Freshwater Consumption L/MWh
Once-through (open-loop)	76,000 - 190,000 (1; 2) 133,000 (3) 130,000 – 200,000 (5)	1,254 (5) 380 - 1,200 (1; 2) 1,140 (3) 2,548 (5)
Wet Recirculating (closed-loop) - Tower	1,900 - 4,540 (1; 2) 2,840 (3)	1,820 - 4,160 (1; 2) 2,650 (3) 106-327 (4)
Wet Recirculating - Cooling Pond	42,230 (3)	1,570 (3) 1,466 – 3,465 (5)
Salt Water Cooling	-	74 – 216 (5)
Dry Cooling	-	134 – 288 (5)
Average	Once through - **165,000** (average of 1,2,3,5) Recirculating – **3,000** (average of 1,2,3)	**1,254** (actual Australian data for stations currently operating)

(1) Union of Concerned Scientists (2014)
(2) Macknick *et al.* (2012)
(3) Wilson *et al.* (2012)
(4) Martin (2012)
(5) Smart and Aspinall (2009)

Table 7. Water consumption and withdrawal by coal-fired power stations in Australia

Power Station	Type	Cooling Water	Cooling Method	Capacity (MW)	Production (Mwh)	Water Consump (ML/yr)	Water Cons Rate (L/MWh)	Fresh water Withd (L/MWh)	Freshwater Withdraw (ML) modelled
Gladstone	Subcritical	Salt	Once-through	1,680	11,773,440	1,600	136	0	0
Eraring	Subcritical	Salt	Once-through	2,880	20,183,040	1,500	74	0	0
Vales Point B	Subcritical	Salt	Once-through	1,320	9,250,560	2,000	216	0	0
Millmerran	Supercritical	Dry-cooled	Dry-cooled	851	5,963,808	800	134	0	0
Kogan Creek	Supercritical	Dry-cooled	Dry-cooled	750	5,256,000	1,200	228	0	0
Stanwell	Subcritical	Fresh	Recirculating	1,460	10,231,680	15,000	1,466	3,000	30,695
Tarong	Subcritical	Fresh	Recirculating	1,400	9,811,200	20,000	2,038	3,000	29,434
Callide C	Supercritical	Fresh	Recirculating	810	5,676,480	12,600	2,220	3,000	17,029
Callide B	Subcritical	Fresh	Recirculating	700	4,905,600	17,000	3,465	3,000	14,717
Tarong North	Supercritical	Fresh	Recirculating	443	3,104,544	9,000	2,899	3,000	9,314
Bayswater	Subcritical	Fresh	Recirculating	2,640	18,501,120	32,000	1,730	3,000	55,503
Liddell	Subcritical	Fresh	Once-through	1,680	11,773,440	30,000	2,548	165,000	1,942,618
Mt Piper	Ultra-supercritical	Fresh	Recirculating	1,400	9,811,200	15,600	1,590	3,000	29,434
Total				18,014	126,242,112	158,300	1,254		2,128,743

Water consumption data from Smart and Aspinall (2009) and water withdrawal data modelled from average withdrawal rates from references

There is a strong correlation between power station capacity and water consumption for power stations using once-through and wet-recirculating cooling methods, with Liddell being the only once-through station that uses freshwater (Figure 29).

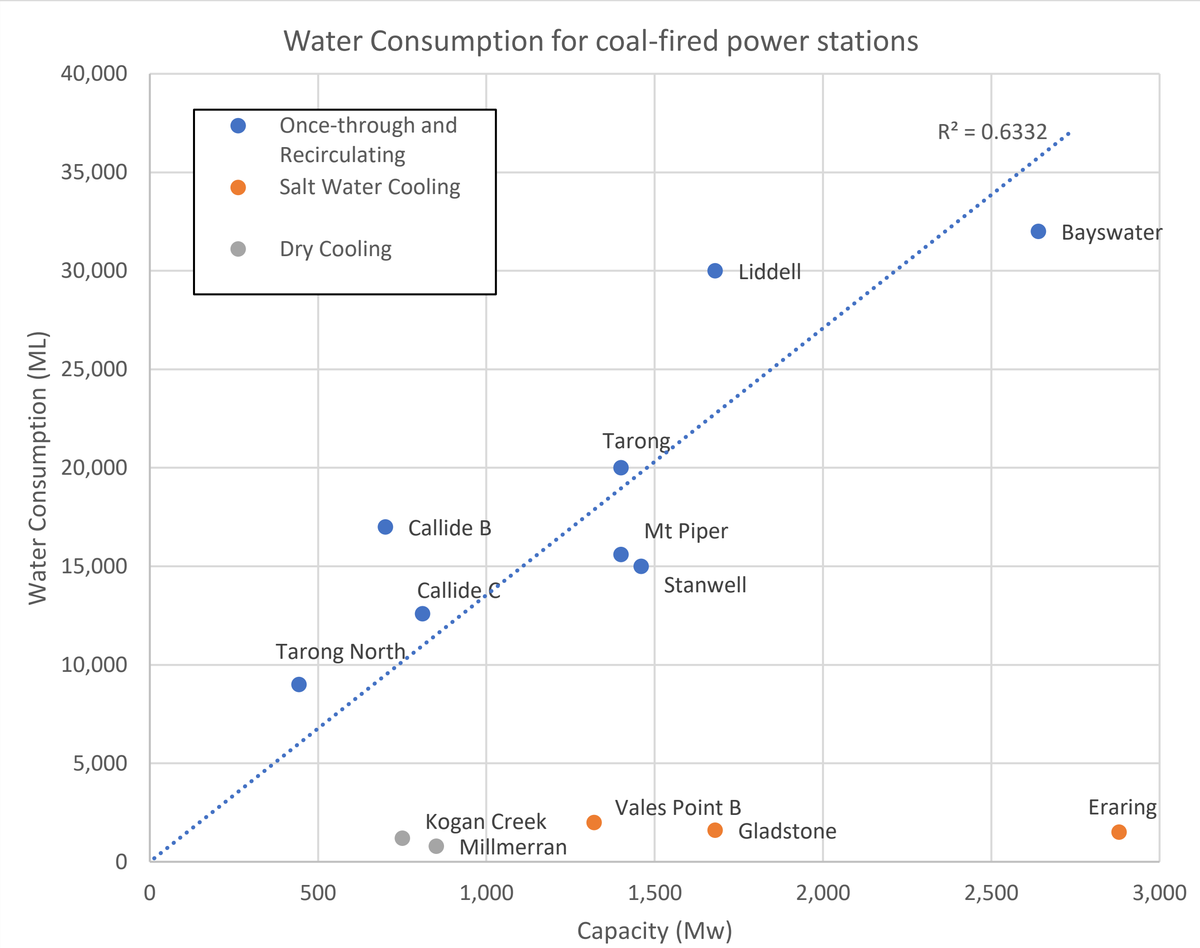

Figure 29. Water consumption of coal-fired power stations currently operating in 2019 in Australia (2009 water data) (Smart and Aspinall, 2009)

Adding carbon capture technology to the power station to reduce carbon emissions increases the water withdrawal and consumption by approximately 10 times on conventional power stations. Retrofitting the carbon capture increases water withdrawal by 50 times and consumption doubles (Table 8).

Table 8. Water use by wet-recirculated coal-fired power stations without and with carbon capture (Wilson et al., 2012)

Wet-Recirculating	Withdrawal L/Mwh	Consumption L/Mwh
No Carbon Capture	2,840	2,650
Carbon Capture	19,840	17,750
Retrofitted Carbon Capture	136,270	4,920

5. Water use in power generation

Water used in coal-fired power stations is only part of the water required when you consider the fuel source for the power station. It is important to add the water use of the coal mining to the power station water use to compare coal generated power with other power sources.

Water consumption from the coal-fired powers stations in NSW and QLD was 1,254 L/MWh (Smart and Aspinall, 2009). To operate these would have required approximately 9,000 t of coal per day per 1,000 MW capacity power station (Hinrichs and Kleinbach, 2006). This means a total of approximately 59 Mt per year for the power stations in NSW and QLD. At 653 L/t for the coal production estimated from coal water use reported in NSW annual reviews, that equates to 38,642 ML per year for the water used in the coal production. This is equivalent to 306 L/MWh for the fuel source for the coal-fired power stations.

Table 9 shows a range of values from previous studies on the water withdrawal and consumption of different energy sources. These figures were averaged and plotted in Figure 30. Once-through (open) and wet-recirculating (closed) coal power stations are large water users compared to other closed systems that consume less water. Dry cooled systems withdraw and consume less water but are less efficient. Solar photovoltaic and wind have the least water consumption and withdrawal.

Table 9. Water use in energy production systems

Fuel Type	Cooling System	Freshwater Withdrawal (L/MWh)	Freshwater Consumption (L/MWh)
Coal Thermal	Once-Through	130,000 – 200,000 (6) 76,000 – 189,000 (5) 133,000 (7) 60,760 (7) 56,780 – 215,768 (9) 142,500 (10)	1,254 (6) + 306 (Coal) 1,000 (2) 284 – 7,550(3) 400 – 2,000 (1) 380 - 1,200 (5) 1,140 (7) 2,620 (7) 2,548 (6) 269 – 1,325 (9) 380 (10)
	Wet-Recirculated (Cooling Tower)	1,900 – 4,540 (5) 2,840 (7) 1,742 – 4,542 (9) 4,500 (10)	1,600 (2) 106-327 (4) 1,820 - 4,160 (5) 2,650 (7) 757 – 4,921 (9) 4,200 (10)
	Wet-Recirculated (Cooling Pond)	42,230 (7) 1,136 – 98,420 (9)	1,570 (7) 1,136 – 3,785 (9)
	Salt Water Once-Through		74 – 216 (6)
	Dry-Cooled	310 – 590 (1)	134 – 288 (6) 0.00059 (1)
	Once-Through with Carbon Capture	4,543 – 5,300 (9)	1,800 (2) 3,407 – 3,558 (9)
	Wet-Recirculated with Carbon Capture	19,840 – 136,270 (7)	2,900 (2) 4,920 - 17,750 (7)
Nuclear Thermal	Once-Through	94,600 – 227,100 (5) 56,066 (7) 174,600 (10)	1,600 – 2,800 (2) 65 – 5,220 (3) 380 – 1,510 (5) 2,165 (7) 380 (10)
	Recirculated	3,030 – 9,840 (5)	2,270 – 3,030 (5)
Natural Gas	Once-Through	28,400 – 75,700 (5) 24,545 (7)	700 (2) 273 – 4,460 (3) 380 – 1,510 (5)

			651 (7)
	Recirculated	570 – 1,140 (5) 5,700 (10)	490 – 1,140 (5) 5,700 (10)
	Dry-Cooled	0 – 380 (1) 0 – 15 (5)	0 – 380 (1) 0 – 15 (5)
	Once-Through with Carbon Capture		1,300 (2)
Shale Gas			291 – 4,570 (3)
Conventional Oil			770 – 4,281 (3)
Solar	Photovoltaic	874 (7)	10 (2) 8 (7)
Wind		3 (7)	10 (2) 1 – 43 (3) 0 – 1 (5) 3 (7)

(1) Pan *et al*. (2018)
(2) Hightower (2014)
(3) Meknonnen *et al.* (2015)
(4) Martin (2012)
(5) Macknick (2012)
(6) Smart and Aspinall (2009)
(7) Wilson *et al.* (2012)
(8) ABS (2005)
(9) Meldrum *et al*. (2013)
(10) WEC (2010)

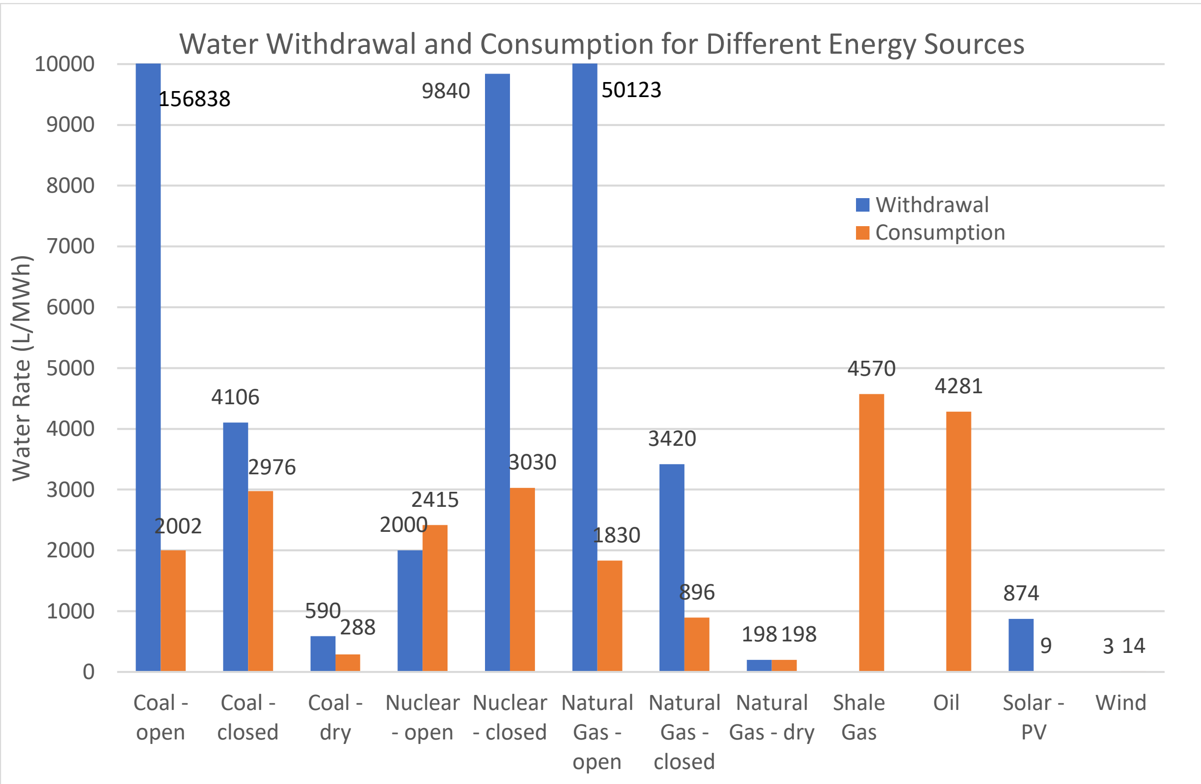

Figure 30. Water withdrawal and consumption for different energy sources.

6. Case Studies

6.1 Hunter Valley coal mines NSW

The Hunter Valley coalfield is the largest coal producing area of NSW with 31 operating mines (NSW Mining, 2019), containing significant reserves of export quality low-ash, high energy thermal coals. Coal is mined within 60 seams in the Greta Coal Measures, Wittingham Coal Measures and the Newcastle Coal Measures. Many mines are large-scale, multi-seam, open-cut mining operations, with lesser numbers of underground operations (NSW Gov, 2019). There is approximately 18,000 Mt of coal resources in the valley. The NSW Department of Industry (2018) developed a water strategy for the Greater Hunter Region in 2018.

Figure 31. The Hunter Valley with coal mine (www.lockthegate.org.au)

During the 2019 drought a coal mine near Lithgow, south of the Hunter Valley, had extreme water shortage and relied on water delivery by train. Figure 32 shows the train that supplied 725,000L per day between Centennial Coal’s Charbon and Airlie coal mines near Lithgow.

Figure 32. A train carrying water to Lithgow coal mines in 2019 (www.abc.net.au)

The Australian government's Bioregional Assessment Program assessed impacts on the Hunter subregion as part of the Northern Sydney Basin Bioregion. This bioregional assessment considered the potential cumulative impacts on water and water-dependent assets due to 22 additional coal resource developments in the Hunter subregion in NSW that were under consideration. The subregion covers the Hunter, Newcastle and Western coal fields.

The assessment is a regional overview of potential impacts on, and risks to, water-dependent ecological, economic and sociocultural assets, identifying where potential changes in water resources and ecosystems may occur, and ruling out areas where impacts are very unlikely. Governments, industry and the community can then focus on the areas that are potentially impacted and apply local-scale modelling when making regulatory, water management and planning decisions (BA, 2019a).

For the Hunter subregion, regional-scale modelling indicates potential risks to Wyong River, Loders Creek, Saddlers Creek and Wollars Creek. Using more detailed local information significantly reduced modelled risk to the Wyong River. Other streams were not modelled using local data.

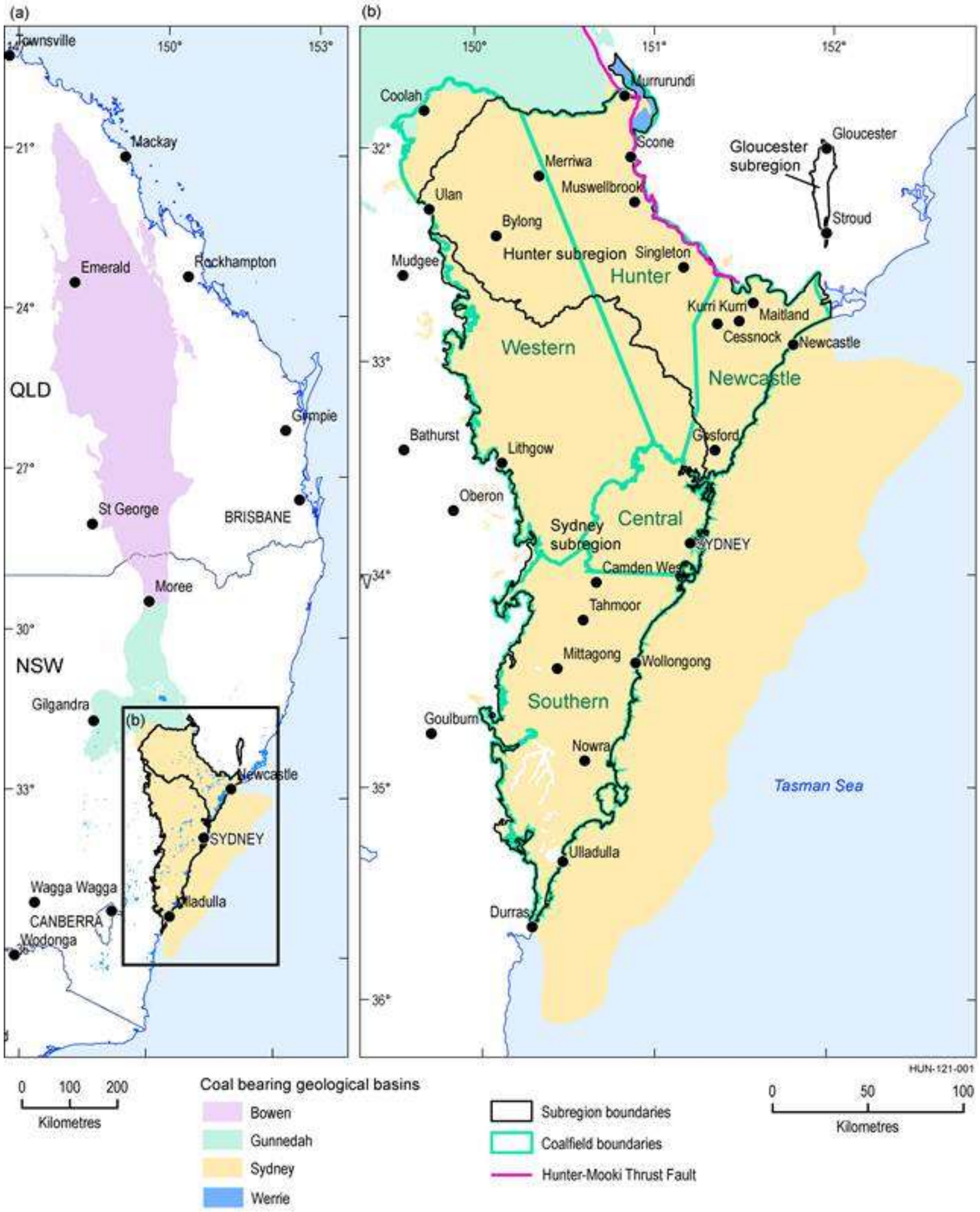

Figure 33. Hunter coalfield location in comparison to the Hunter sub-region in the Sydney Basin (Source: Bioregional Assessments, 2019c)

The main impacts include:

Groundwater: An area of 1,879 km2 potentially experiences cumulative groundwater impacts due to baseline and additional coal resource developments of greater than 0.2 metre drawdown.

Surface water: Regional-scale modelling indicates potentially large changes in flow regime in Wyong River, Loders Creek, Saddlers Creek and Wollars Creek.

Ecosystem impacts: The zone of potential hydrological change includes 102 km2 of groundwater-dependent ecosystems, predominantly rainforests, forested wetlands, and wet and dry sclerophyll forests.

Asset impacts: Reductions in water availability in the Hunter River at Greta are very likely to exceed 5 GL per year, but are very unlikely to exceed 12 GL per year, over the period from 2013 to 2042.

Figure 34. The zone of potential hydrological change in the Hunter subregion (BA, 2019a)

The zone of potential hydrological change (Figure 34. The zone of potential hydrological change was developed to show where efforts to identify potential impacts should be focused. Impacts are ruled out in areas outside this zone, which combines (i) the area with at least a 5% chance of exceeding 0.2 m drawdown due to additional coal resource development, and (ii) the area with at least a 5% chance of exceeding changes in specified surface water characteristics that arise due to additional coal resource development.

6.2 Galilee Basin QLD

The Galilee Basin lies adjacent to the Great Artesian Basin (GAB) and has significant coal deposits. Given its resources and proximity to the GAB it has attracted great interest. The Adani Carmichael mine, located in the Galilee Basin, has received considerable press and opposition as a consequence of its size.

The Adani Carmichael mine’s 12,000ML forecasted use (equivalent to 4% of the water extracted from the Great Artesian Basin in QLD in 2016) would place it equal to the biggest annual user of GAB water, the Olympic Dam copper and uranium mine in SA, which currently draws 10,000ML each year.

According to Adani’s own modelling, the Carmichael mine’s annual freshwater use is projected to peak at just over 12,000ML. The water licence granted to Adani puts no limit on the water it can take from the GAB but requires regular monitoring of water levels, water quality and flow in each aquifer that is used.

“Unlike other controversial Queensland mining projects, such as the New Acland coal mine, Adani’s water licence application was exempted from public scrutiny, courtesy of a November 2016 amendment to the existing laws. Water licences usually specify the total amount, and/or the daily rate, of groundwater that can be taken. Changes to a water licence to increase the amount of water must be assessed like a new application and pass public scrutiny. But with an unlimited licence, there is no need for Adani to apply for a new licence if they need more water than originally predicted." (Moon, 2017).

The Australian government's Bioregional Assessment program assessed impacts on the Galilee subregion as part of the Lake Eyre Basin Bioregion (BA, 2019b). The geological Galilee Basin contains extensive resources of black coal. Although no commercial coal mines or coal seam gas production facilities are currently established in the subregion, six new large coal mines are scheduled to start production by 2020. Five of these coal mines will involve both open-cut and underground operations. Most of these proposed coal mines are well advanced in securing all necessary development approvals.

Seven of the 17 additional coal resource developments identified had sufficient available information to be modelled. This assessment is a regional overview of potential impacts on, and risks to, water-dependent ecological, economic and sociocultural assets, identifying where potential changes in water resources and ecosystems may occur due to the seven modelled coal mines, and ruling out areas where impacts are very unlikely (less than 5% chance). Governments, industry and the community can then focus on the areas that are potentially impacted and apply local-scale data and modelling when making regulatory, water management and planning decisions.

For the Galilee Basin cumulative hydrological changes in the Belyando river basin are very likely (greater than 95% chance) and extend farther than previously predicted from impact assessments of individual mines. The major findings are:

> **Groundwater** Drawdown in the near-surface aquifer due to modelled additional coal resource development occurs in two areas near clusters of coal mines in the east, with an area of 2820 km2 very likely to experience greater than 0.2 m drawdown. Major aquifers of the geological Eromanga Basin (part of the Great Artesian Basin) are not expected to be impacted.
>
> **Surface water** Modelled additional coal resource development could impact 6285 km of streams (with at least a 5% chance). Of these, most are temporary streams.
>
> **Ecosystem impacts** In the zone of potential hydrological change in the Galilee Basin, Figure 35 shows 8% of groundwater-dependent streams are at some level of risk of ecological and hydrological changes, and 188 springs have a source aquifer with at least a 5% chance of greater than 0.2 m drawdown due to modelled additional coal resource development.
>
> **Asset impacts:** Of 241 potentially impacted ecological assets, 148 are relatively 'more at risk of hydrological changes'. In addition, one surface water right, five groundwater economic assets, and four heritage or Indigenous sites are potentially impacted.

The zone defines the area in the Galilee subregion outside of which impacts are ruled out under the same conditions as Figure 34.

HEC (2013) reported on the impacts of groundwater changes from coal mining in the Galilee basin. Gippel (2017) undertook a preliminary review of potential impacts of the Adani mine from the proposed surface water take. Winn (2018) further described the impacts on the Great Artesian Basin from the proposed coal mines in the Galilee Basin shown in Figure 36.

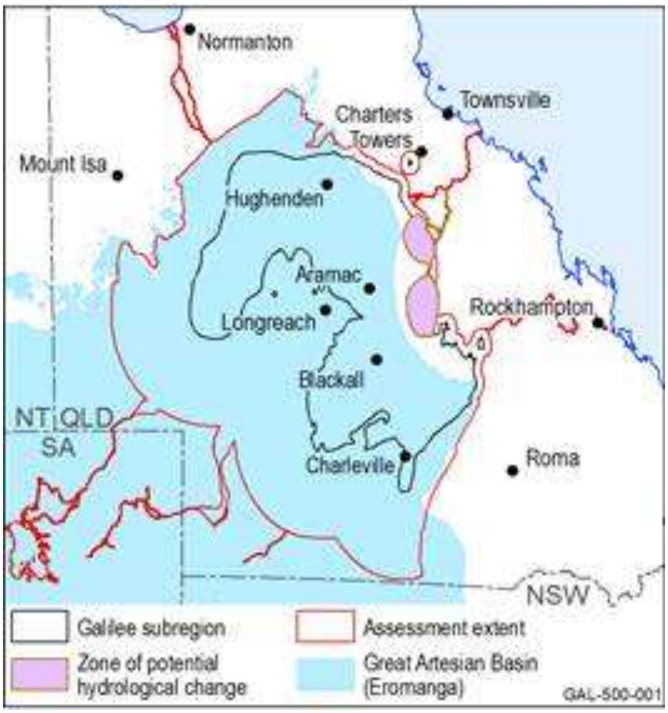

Figure 35. The zone of potential hydrological change in the Galilee Basin (BA, 2019b)

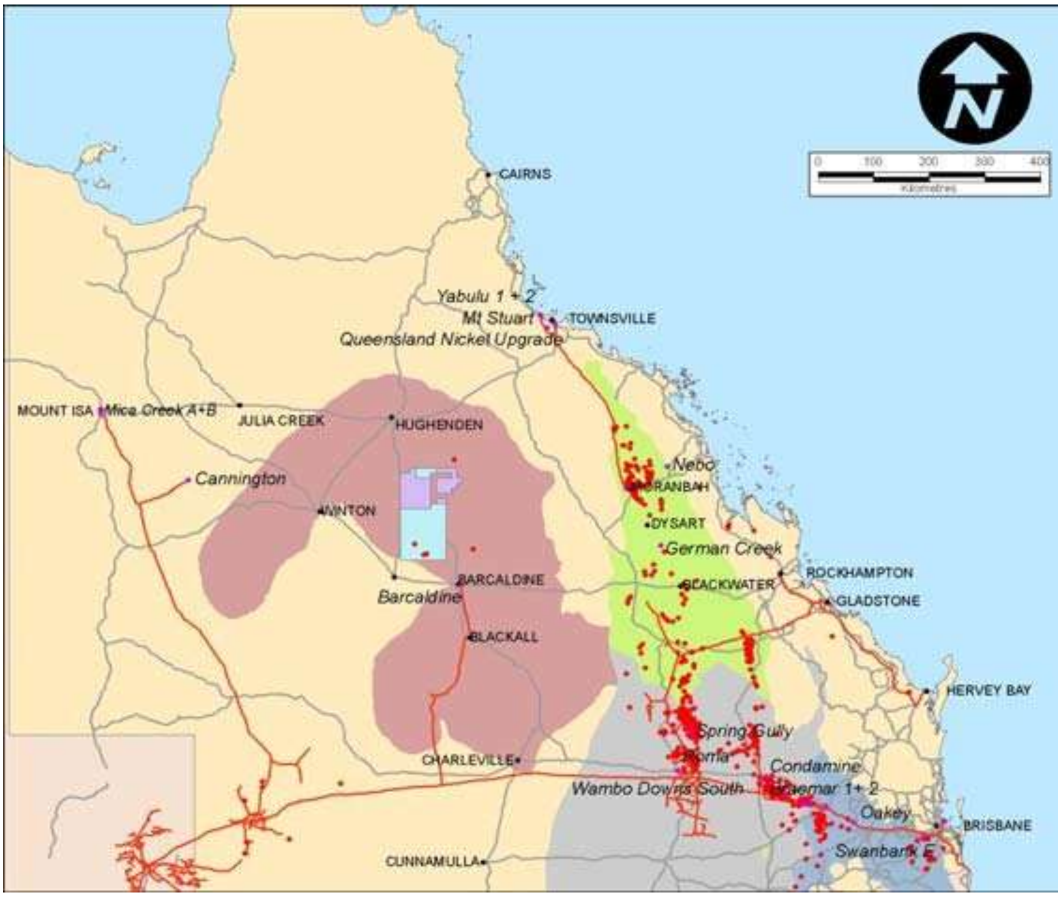

Figure 36. The Galilee Basin in QLD (Source: Holland, Applegate and Bocking, 2008)

7. Water use in comparison

Data shows that coal activities consume significant amounts of water in comparison to other water users.

7.1 Water use in other industries

Thermal energy production is a large water user in comparison to other water uses. Coal-fired power generation includes the production of the coal material and the conversion to electrical energy. Table 10 shows the water consumed and withdrawn for different water users in NSW and QLD in 2019. The water volumes for coal mining and coal-fired power were obtained from analysing the data collected in this study and the amount of water consumed for coal is higher than that for all energy in that year as the coal data was from 2009.

Table 10. Water use, consumed and withdrawn, compared for users in NSW and QLD (ABS, 2019) for major users and this report for coal mining and coal power (note values from this report are higher than ABS values)

	Consumed (ML)	Percentage	Withdrawn (ML)	Percentage
Agriculture	7,208,440	69	7,209,264	21.3
Mining	235,170	2.3	301,708	0.9
Coal Mining	280,800	2.7	280,800	0.8
Energy	118,847	1.1	15,645,095	46.2
Coal Power	158,300	1.5	2,128,743	6.3
Manufacturing	286,492	2.7	290,625	0.9
Water Supply and Waste	972,777	9.3	8,790,359	26
Other Industry	669,141	6.4	670,817	2
Household	956,401	9.2	956,401	2.8
TOTAL	10,447,267		33,864,682	

The data shows that coal water consumption is a significant amount in comparison to other water users such as agriculture and domestic water supply. Figure 37 shows the proportion of water consumed and the portion of this that is related to coal mining and coal-fired power generation. It accounted for one third of the domestic water for both states.

Figure 38 shows the proportion of water withdrawn. Coal related activities accounted for over double domestic water use and were about 30% of total agriculture.

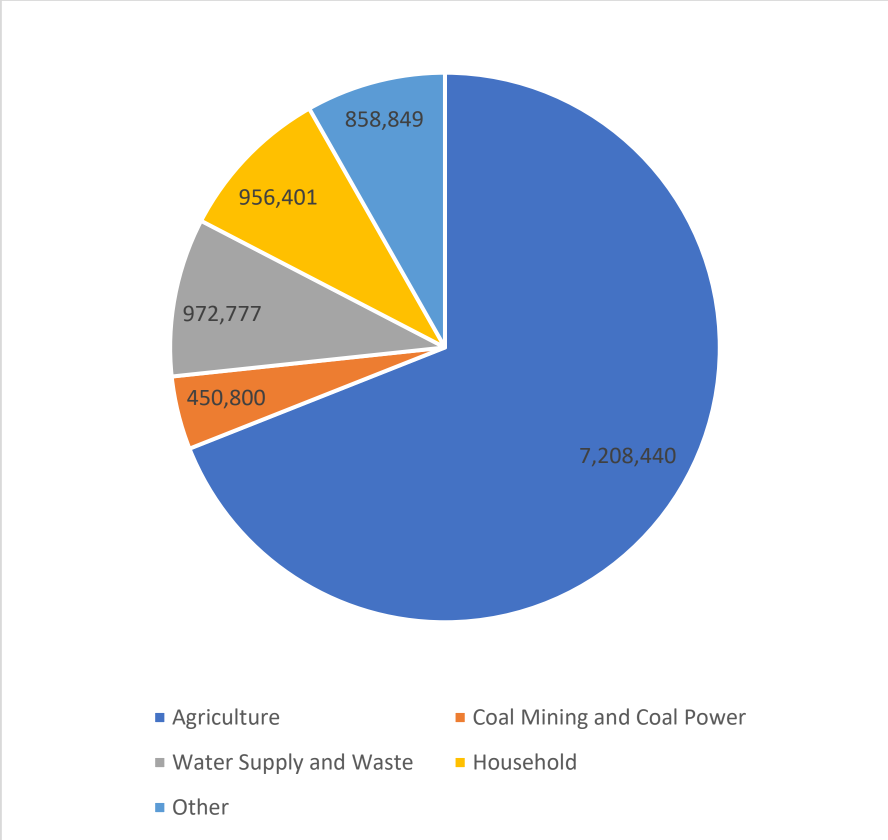

Figure 37. Water consumed in NSW and QLD by type (ABS, 2019 and this report)

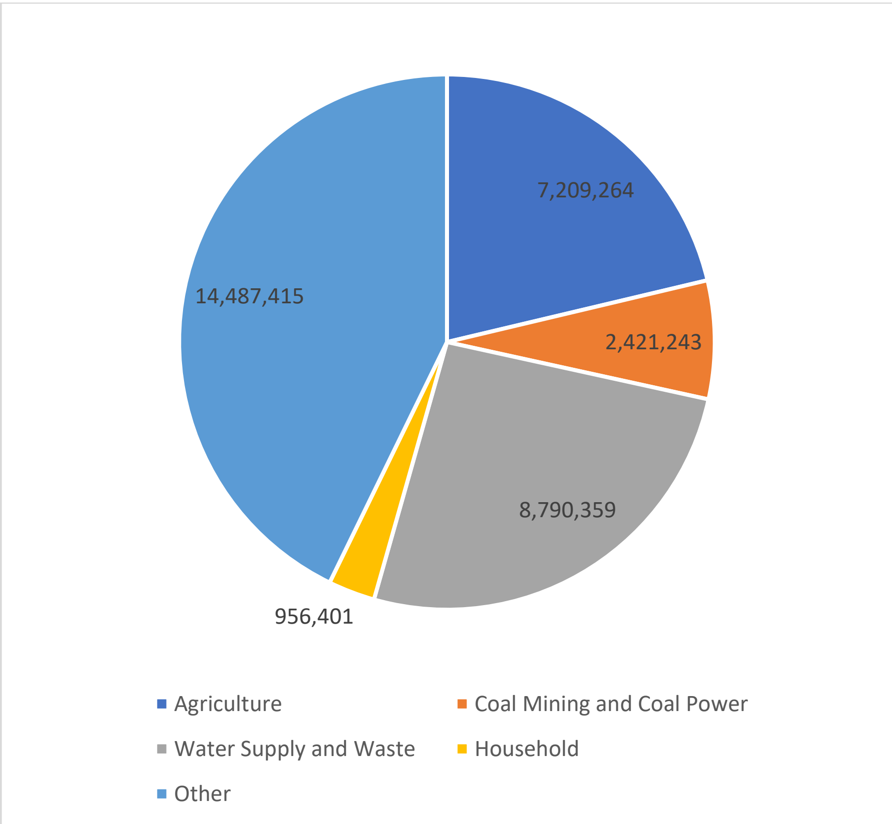

Figure 38. Water withdrawn in NSW and QLD by type (ABS, 2019 and this report)

7.2 The water footprint of coal

A Water Footprint is a way of describing the amount of water used or impacted from the production of goods and services. The Water Footprint for coal includes the water used in fuel supply, construction and operation. This can be described as the consumptive water footprint (Mekonnen *et al*., 2015).

A water footprint concept is important as water needs to be managed from a systems perspective - water used in one area is not available for use in another area. For example, the water entrained in the product coal is exported to other countries and reduces the water available to Australians. Figure 39 shows the global water balance as virtual water moves between countries in products. Australia is a very high net virtual water exporter.

Energy production requires significant volumes of fresh water and therefore has a large water footprint which has significant impacts on water resources through thermal and chemical pollution. Energy's dependence on water availability makes it vulnerable to water scarcity.

The Water Footprint Calculator (Water Footprint Calculator, 2017) can be used to generate water footprints.

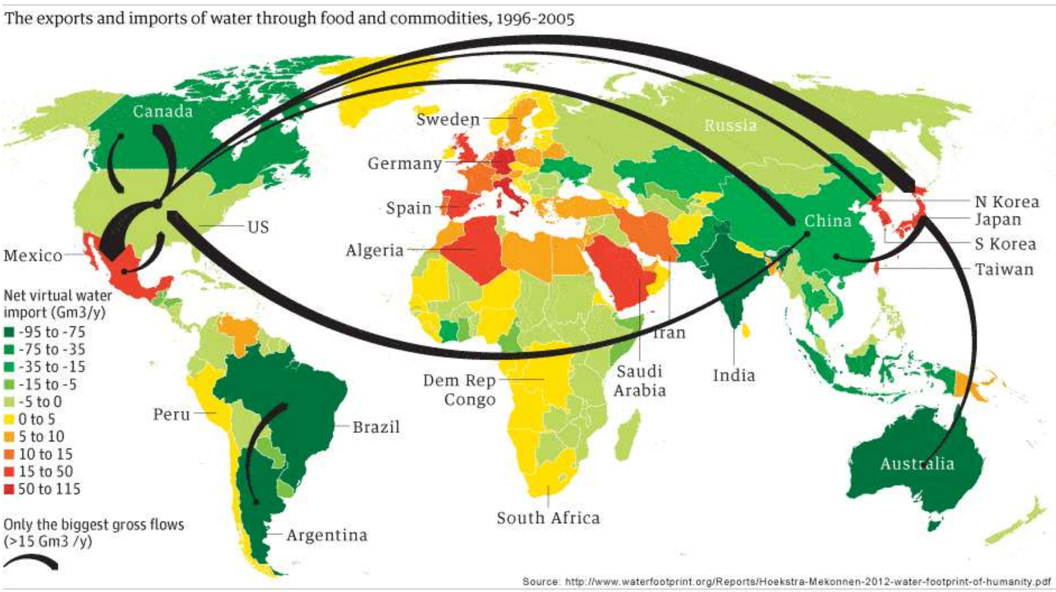

Figure 39. Virtual water balance showing Australia as a net exporter of water (Source: The Guardian, 2012).

7.3 The water-energy nexus

There is a close interlink between energy and water, which requires a nexus approach to ensure a sustainable supply of both (Mekonnen *et al.*, 2015). The Water-Energy Nexus is the interaction of aspects of water and energy that can be complimentary or oppositional. Water is used to generate energy and energy is used to 'generate' water by pumping and moving water supplies. Averyt (2016) discusses the water-energy nexus. Figure 40 shows the interaction with water, energy and also food as water and energy are required to produce food, etc.

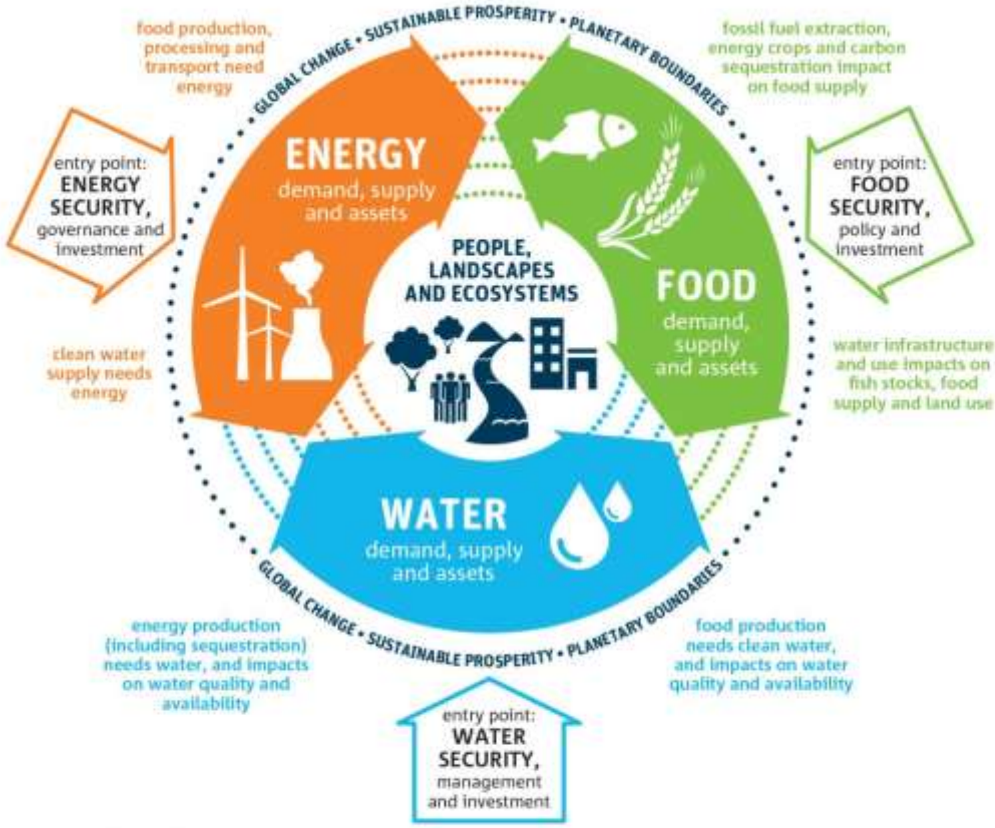

Figure 40. Water-food-energy nexus (Source: IWA, 2019)

Larsen and Drews (2019) undertook a water-energy nexus assessment for Europe's use of water for electricity generation. The concept is important when taking a system view of natural resources. The other aspect of this approach is the concept of limits. Natural resources must be managed within environmental limits. When resources get highly contested there is a reduction in the supply of that resource to certain sectors. If water is taken for use in mining, then it is not available to other areas such as food and domestic water supply. The implications can go beyond the direct impact of water scarcity and effect ecosystem services and other production services that water underpins.

Resource management must take this systems perspective and identify sustainable uses of water to service all needs. Not to mention the pollution, GHG emissions and wealth distribution issues that are raised with increasing mining activity.

8. Water impacts from coal mining and coal-fired power generation

Water impacts include both direct impacts such as water quantity and quality in locations associated with the mining, processing, transportation, burning and outflow of coal mining and coal-fired power generation, and indirect impacts that are offsite, downstream, impacting aquifer flows or as a consequence of earthworks. Figure 41 shows a range of water impacts from coal mining and coal-fired power stations.

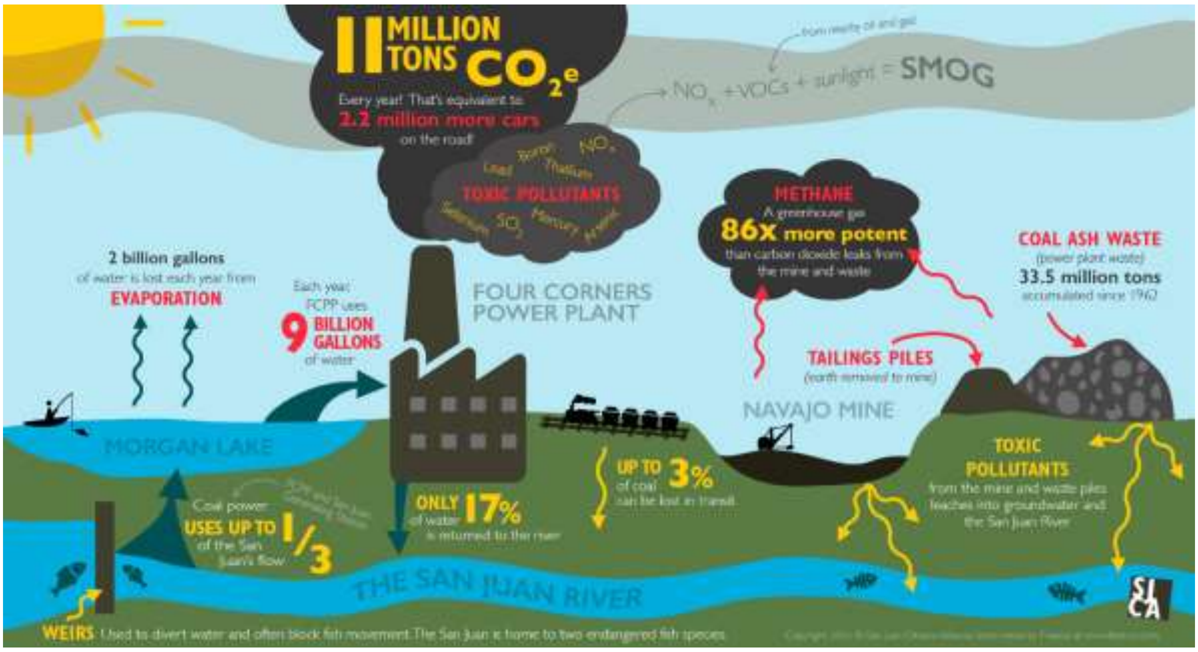

Figure 41. Four Corners Power Station, USA (San Juan Citizens Alliance, 2019)

8.1 Water impacts of coal mining

Coal mining negatively impacts water, ecosystems and people in a wide range of ways.

Major water impacts of coal mining include (CoalSwarm, 2019):

- Direct water extraction from surface water causing a reduction in river flows, a reduction in surface-groundwater interactions and a reduction in groundwater recharge.
- Direct water extraction from groundwater causing a reduction in river flows, a reduction of groundwater inflows (baseflows), a reduction in surface-groundwater interactions and a reduction in groundwater levels.
- In-direct through excavation of earth works causing water diversion of surface flows, loss of surface flows to infiltration, reduction in groundwater levels, diversion of groundwater flows.
- Water pollution due to temperature increases, contaminants and salinity.
- Impacts of subsidence in large coal mining, reviewed by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC, 2014) include:
  - Diversion of surface water
  - Infiltration of surface water through new cracks – rivers and drainage of standing pools
  - Diversion of groundwater

  - Changes in groundwater levels
  - Contamination of water bodies
  - Deposition of iron oxide mats.
- Acid mine drainage of acidic water from coal mines where coal mining activities have exposed rocks containing the sulphur-bearing mineral pyrite. Pyrite reacts with air and water to form sulphuric acid and dissolved iron, and as water washes through mines, this compound forms a dilute acid, which can wash into nearby rivers and streams.
- Coal dust stirred up during the mining process, as well as released during coal transport, can cause severe and potentially deadly respiratory problems.
- Coal fires occur in both abandoned coal mines and coal waste piles. Internationally, thousands of underground coal fires are burning. Global coal fire emissions are estimated to include 40 tonnes of mercury going into the atmosphere annually, and three percent of the world's annual carbon dioxide emissions.
- Coal combustion waste is the second largest waste stream after municipal solid waste. It is disposed of in landfills or "surface impoundments," which are lined with compacted clay soil, a plastic sheet, or both. As rain filters through the toxic ash pits year after year, the toxic metals are leached out into the local environment.
- Coal sludge is the liquid coal waste generated by washing coal. It is typically disposed of at impoundments located near coal mines, but in some cases, it is directly injected into abandoned underground mines. Since coal sludge contains toxins, leaks or spills can endanger underground and surface waters.
- Floods can have large impacts on failures of coal mine impoundments and lead to spillage downstream.
- Loss or degradation of groundwater - Since coal seams are often serve as underground aquifers, removal of coal beds may result in drastic changes in hydrology after mining has been completed.
- Radical disturbance of farmland, rangeland, and forests, most of which has not been reclaimed. This impacts groundwater recharge and leads to surface run-off taking sediments into streams.
- Heavy metals and coal - Coal contains carbon and many heavy metals, as it is created through compressed organic matter containing virtually every element in the periodic table. The heavy metal content of coal varies by coal seam and geographic region. Small amounts of heavy metals can be necessary for health, but too much may cause acute or chronic toxicity (poisoning). Many of the heavy metals released in the mining and burning of coal are environmentally and biologically toxic elements, such as lead, mercury, nickel, tin, cadmium, antimony, and arsenic, as well as radio isotopes of thorium and strontium.
- Methane released by coal mining accounts for about 10 percent of releases of methane (CH_4), a potent global warming gas.
- Mountaintop removal mining and other forms of surface mining can lead to the drastic alteration of landscapes, destruction of habitat, damages to water supplies and air pollution. Not all of these effects can be adequately addressed through coal mine reclamation.
- Particulates and coal - Particulate matter (PM) includes the tiny particles of fly ash and dust that are expelled from coal-burning power stations. Studies have shown that exposure to particulate matter is related to an increase of respiratory and cardiac mortality.
- Radioactivity and coal - Coal contains minor amounts of the radioactive elements, uranium and thorium. When coal is burned, the fly ash contains uranium and thorium "at up to 10 times their original levels".

- Waste coal, also known as "culm," "gob," or "boney," is made up of unused coal mixed with soil and rock from previous mining operations. Runoff from waste coal sites can pollute local water supplies.
- After it is mined, coal is typically washed with water or other chemicals to remove impurities such as sulphur, ash and rock. The resulting wastewater is stored in slurry ponds.
- Environmental impacts of increased pollutants from both past and present mining activities in the Sydney Basin were found to be associated with a reduction of water quality and resource depletion (Ali *et al.*, 2017).
- Transportation - Coal is often transported via trucks, railroads, and large cargo ships, which release air pollution such as soot and can lead to disasters that ruin the environment, such as the Shen Neng 1 coal carrier collision with the Great Barrier Reef, Australia that occurred in April 2010.
- Indirect impacts on water include the reduction of water available for other industries including agriculture and domestic water supply. Energy production uses water and the access and purification of water needs energy. This Water-Energy Nexus plays out at many scales from the mine site to the region and globally.

8.2 Water impacts of coal-fired power generation

While coal-fired power's contribution to GHG is well documented, there are other impacts from coal-fired power that are less well known.

Major water impacts of coal-fired power generation include (CoalSwarm, 2019):

- Pollutants such as heavy metals leaching into groundwater from unlined coal ash storage pollute water (Figure 42).
- Water discharged from a once-through power station is between 5.6 and 11 degrees hotter than when it was withdrawn. Thermal pollution contributes to the degradation of water quality by power stations and industrial manufacturers. When water used as a coolant is returned to the natural environment at a higher temperature, the change in temperature impacts organisms by decreasing oxygen supply and affecting ecosystem composition.
- Large amounts of water evaporation from storage ponds.
- Air pollution from coal-fired power stations includes sulphur dioxide, nitrogen oxides, particulate matter (PM), and heavy metals, leading to smog, acid rain, toxins in the environment, and numerous respiratory, cardiovascular, and cerebrovascular effects. Air pollution from coal mines is mainly due to emissions of particulate matter and gases including methane (CH4), sulphur dioxide (SO2), and nitrogen oxides (NOx), as well as carbon monoxide (CO).
- Climate impacts of coal stations - Coal-fired power stations are responsible for one-third of carbon dioxide (CO2) emissions, making coal a huge contributor to global warming. Black carbon resulting from incomplete combustion is an additional contributor to climate change.
- Coal-fired power stations have been shown to impact the local rainfall patterns by drying out the atmosphere.
- Mercury and coal - Emissions from coal-fired power stations are the largest source of mercury in the United States, accounting for about 41 percent (48 tons in 1999) of industrial release.

- Sulphur dioxide and coal - Coal-fired power stations are the largest human-caused source of sulphur dioxide, a pollutant gas that contributes to the production of acid rain and causes significant health problems. Coal naturally contains sulphur, and when coal is burned, the sulphur combines with oxygen to form sulphur oxides.
- Toxins - According to a July 2011 NRDC report, "How Power Stations Contaminate Our Air and States" electricity generation in the U.S. releases 381,740,601 lbs. of toxic air pollution annually, or 49% of total national emissions, based on data from the EPA's Toxic Release Inventory (2009 data, accessed June 2011). Power stations are the leading sources of toxic air pollution in all but four of the top 20 states by electric sector emission.
- Coal ash pollution from power stations can enter surface and groundwater systems. Coal combustion waste has caused an estimated US$2.32 billion in damages to fish and wildlife in the US. Highly toxic selenium is largely responsible for the damages (End Coal, 2014).
- Burning coal releases toxic mercury into the air that then rains down into rivers and streams. Mercury is a powerful neurotoxin that can damage the brain and nervous system.
- Indirect impacts also include the contribution of coal mining and coal-fired power generation on greenhouse gas emissions leading to climate change. For example, the Adani Carmichael Mine is estimated to produce 4.7 billion tonnes of greenhouse gas emissions from the mining and burning of the coal (Moon, 2017).

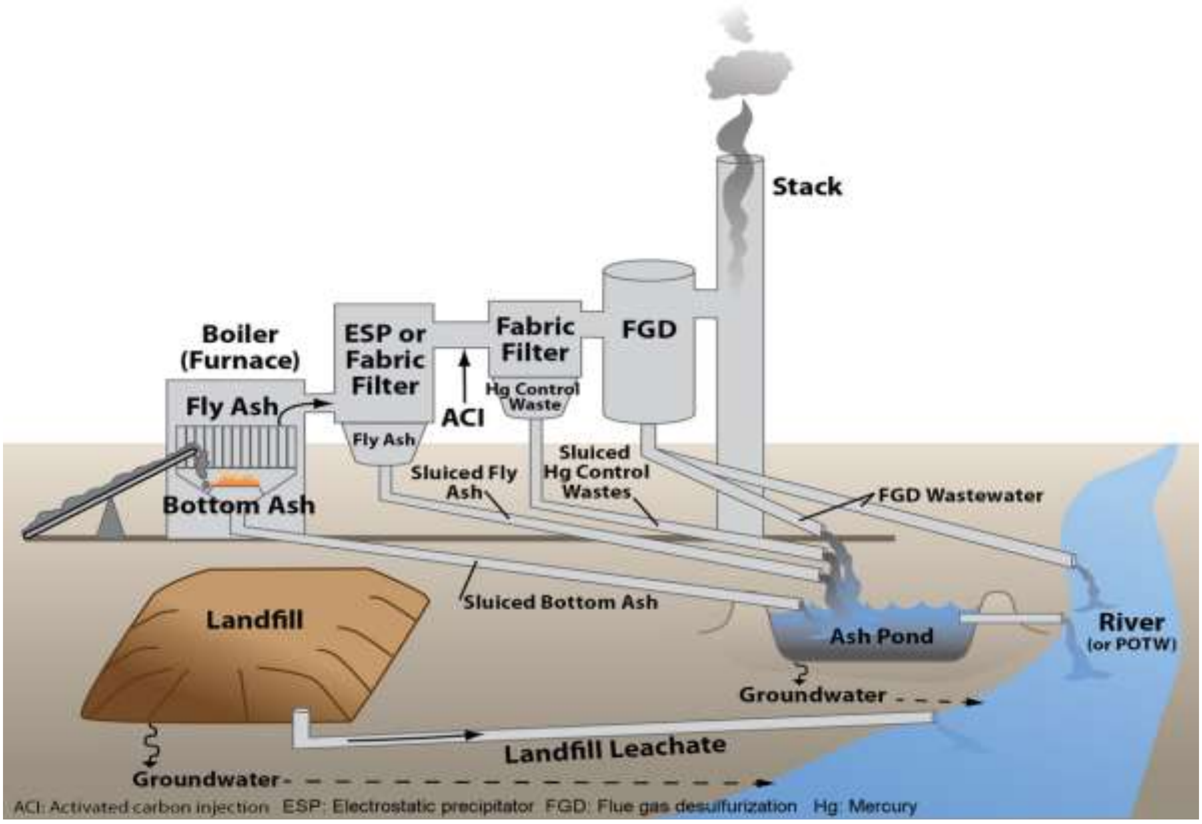

Figure 42. Coal power station waste streams (USEPA, 2015).

9. Conclusion

This report identifies the impacts on water availability and water quality from coal mining and coal-fired power generation in NSW and QLD. The report outlines the water used and impacted by typical coal mines and coal-fired power stations and compares this water use with other main electricity production methods.

Coal mining and the burning of coal for electricity generation has played a significant role in the development of Australia since 1790. Total black coal production in 2018 was approximately 448 Mt with 82% from open-cut mines and 18% from underground mines (OCE, 2018). The majority of coal being mined in NSW and QLD (96%). Black coal in Australia produced 126,000,000 MWh which counted for 46% of Australia's energy needs (CEC, 2019). The remaining coming from natural gas, brown coal, hydro, wind and solar. Coal mining exports in 2018 were worth $67 billion.

Water is essential to coal mining and coal-fired power stations. Water use can be categorised into: water consumption, the water that is taken out of the water resource (rainfall, surface water, groundwater, etc) and used in a way that it is no longer available for other users; water withdrawal, the water that is taken out of the water resource, used and then returned to the same or another water source; and water impacted, this is not usually considered as water use but includes water that is impacted either through diversion of surface water or groundwater flow due to earth works, polluted water or modified local climate such as rainfall patterns.

An analysis of 39 coal mine reports in NSW found that the average water use by coal mining was 653 L/t in 2018, with 522 L/t of freshwater, compared to a previous published figure for Australia of 250 L/t (Cote et al., 2010). Black coal mining in Australia accounted for approximately 292,500 ML of water used (consumed or withdrawn) in 2018, 280,800 ML in NSW and QLD. This was approximately 234,000 ML of freshwater with the remaining 20% recycled water at the mine site (coal mine annual reviews), 224,640 ML in NSW and QLD.

Energy generation from black coal in Australia was approximately 126,000,000 MWh in 2019 (DEE, 2019a). Australian coal power stations use on average 1,245 L/MWh and consumed a total of 158,300 ML (Smart and Aspinall, 2009). 73,815,000 MWh was produced from freshwater cooled power stations with an estimated water withdrawal of 1,740,000 ML. This water was then discharged with a potential range of temperature and chemical pollution issues.

Coal-fired power stations with open cooling systems were identified as the second highest water withdrawing sector at approximately 157,000 L/MWh from a range of energy generation systems.

In total coal and coal-fired power accounted for approximately 382,940 ML of water consumed in NSW and QLD (4.3% of all water consumed). The water consumption amount is approximately equivalent to the household water needs of 5.2 million people in Australia (based on an average of 73,600 L/yr per person (ABS, 2019)), approximately 21% of Australia's domestic water needs. The cost of 382,940 ML of water is approximately $0.77 to $2.49 billion (based on a range from low security water at $2,000 to high security water at $6,500 per L (NSW prices June 2019 (DA, 2019)). The amount of water consumed to generate this much electricity through wind generation or solar photovoltaic would be approximately 1,260 ML (based on 10 L/MWh (Hightower, 2014)) at a cost of approximately $2.5 to $8.2 million.

Coal mining and coal-fired power generation withdrew 2,353,383 ML in NSW and Queensland QLD with agriculture withdrawing 7,209,264 ML (ABS, 2019). This places coal activities at 7.2% of water withdrawn in NSW/QLD and equivalent to 33% of the amount withdrawn by agriculture. Considering that coal water use is concentrated in a few regions such as the Hunter Valley and the Bowen Basin, the impact of water use is significant in these areas.

To this extent coal is considered a major water user and is competing for freshwater resources in Australia with other water using activities, including critical human needs. Coal technologies are reducing the water consumption of coal mining and coal-fired power generation. However, advances in carbon reduction and improved environmental outcomes are often at the cost of increased water use. Alternative energy sources have been shown to have a much smaller water footprint and should be considered the future for a sustainable water management.

9.1 Challenges in understanding water use

Major challenges in understanding the water use of coal mining and coal-fired power stations are the availability, consistency and transparency of water data.

Water data that is available is in report format and not easily analysed or compared. Data is also limited to mine site inputs and outputs and does not indicate the impacts of water use on the regional water balance. Australian (MCA, 2014) and International (ICMM, 2017) water accounting frameworks and guidelines have been developed but reporting to these standards is not undertaken. Planning and operating a coal mine involves many government authorities and no consistent reporting or auditing occurs to cover the range of water impacts. The true impact of coal mining and coal-fired power generation on Australia's water resources is not well known and this has major implications on the sustainability of our climate and our access to a finite and critical water source.

Many claims are made about coal mining and coal power being high water users. The lack of detailed reporting suggests that the water footprint of coal, being the water consumed, withdrawn and impacted on could be much higher than 7.1% of our freshwater reserves. Coal has an even greater impact on water resources if you include the impacts of coal mining on surface water and groundwater diversions, changes in local climatic patterns and impacts on global warming that has reduced rainfall in most of the coal mining regions of Australia.

The Bengalla mine (Table 11) is a good example of a more comprehensive reporting in the NSW Annual Reviews. Most of the reports have data gaps and there is no water reporting for QLD mines freely available.

Table 11. Water use figures for Bengalla Coal Mine

Bengalla Coal Mine Data	Water Management Plan 2019 (Yr4)	Annual Review 2018
Inflows		
Groundwater inflow (Aquifer interception)	14	99
Rainfall and runoff	1400	619
Extracted from rivers	1323	1571
Water in CHPP feed (Entrained)		1013
Total Inflows	2736	3302
Task		
CHPP supply	1164	0
Dust suppression	608	574
Vehicle wash bay	132	115

Outflows		
Evaporation	93	873
In product coal (Entrainment)	0	1673
Discharge to rivers	779	0
Other losses	88	213
Total Tasks and Outflows	2864	3448

Northery *et al.* (2019) note that advances over the last two decades of corporate sustainability reporting and water accounting standards has resulted in increased disclosure of water use by mining companies. They also note that opportunities still exist to improve reporting practices, such as by ensuring that all relevant water flows are reported and to explicitly state non-existent flows (e.g. discharges).

The second major challenge is the consistency and transparency of the data that is available. Despite the recommendations of the Australian Water Accounting Standards, the Minerals Council Water Accounting Framework and the International Council on Mining and Metals (ICMM, 2017), data that is available is difficult to interpret and only available through written reports that use various reporting formats. In 2017, the International Council on Mining and Metals (ICMM (2017) called for the public reporting of water performance using consistent industry metrics, reporting of a water balance and information and understanding of how it relates to the cumulative impact of other water users.

The ICMM (2017) guideline lists the components that should be part of water reporting (Figure 19) including a simple, consistent and transparent report on water interactions. This is a call for mining companies to not only report standard volumes of inflow and outflow but also on the impact of the regional water bodies.

The following issues were identified while preparing this report:

- Modelled water use that is reported in water license applications and environmental impact assessments may be different to actual water used. In most cases this is likely caused by unforeseen changes in the coal operations and hydrology but in others it is due to the quality of the water models. In documents received by Freedom of Information on the Adani Carmichael mine water licence application, the amount of water reported for peak production was 10,900 ML for a production of 60 Mt. The annual review for 2018 of the BHP Mt Arthur mine reported 13,619 ML total with 4,697 extracted from rivers for a production of 23.679 Mt (BHP, 2018a). The amount of 10,900 ML for 60 Mt is comparable if this was the river extraction amount and a further 23,000 ML was obtained from groundwater, rainfall/runoff and other sources.
- Multiple reports on water use that have unclear origins.
- Multiple terms for water use – water consumption etc.
- Lack of clarity on the different sources of water used, including fresh, saline, dirty, worked, sea and recycled water through water treatment plants and wastewater treatment plants on-site.
- No reporting of water use for coal-fired power stations.

Different estimates of water use from different sources also compound the uncertainty. For example in the case of coal seam gas in 2012 reported by the ABC (Figure 43), mining company estimates were approximately 61 GL/y for the three major mines, government estimated the industry would use 300 GL/yr, scientists suggested approximately 1,000 GL/yr and extrapolated water data indicated anything from 666 to 5,400 GL/yr. Ignoring outliers, there was still a 20-fold difference between the company reported figure of 61,000 ML and an estimate from the QLD Government Mining Journal of 1,153,000 ML.

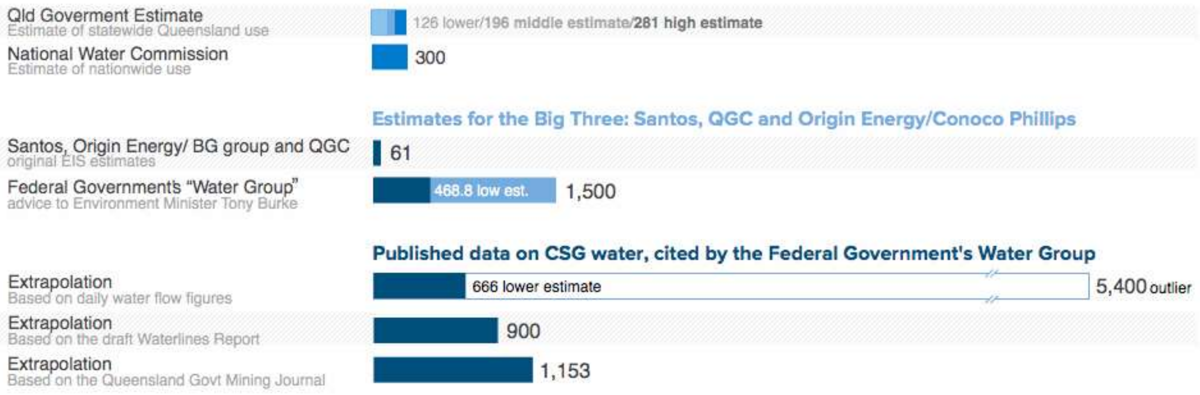

Figure 43. Various estimates of annual water use (Gl/yr) in Coal Seam Gas (ABC, 2012)

There is a need for a state or national independent body to oversee data collection and auditing. This body needs to have the power to invoke legislation to mandate water accounting reporting. The Upper Hunter Mining Dialogue has greatly improved the availability and transparency of water data, but it is affiliated with the NSW Minerals Council and is therefore not independent. The National Resource Access Regulator in NSW is a possible model for an independent body to oversee mining water use.

The 'Water Miner' online data system for QLD mining data provided a possible framework for a new system to be implemented. The 'Water Miner' system was closed in 2012.

Without consistent and trustworthy data, it is impossible to know what a reasonable amount of water use is for a coal mine or a coal-fired power station. There is a need to be able to benchmark mines and power stations to assess performance and drive water efficiencies. This needs to be monthly water data, not yearly, so that seasonal trends can be understood, and problems identified in a timely manner. The data should comply with the Bureau of Meteorology Australia Water Accounting Standards and follow the Water Accounting Framework. Currently there is no requirement to report on any water use other than licensed water. Corporate sustainability initiatives from some mines see more water reporting as part of their strategic management and social license to operate.

Given this inconsistency of water data reporting and the variability of water use it is very difficult to benchmark water efficiency in coal mining or coal-fired power stations (Northey *et al*, 2019).

9.2 Social license to operate and corporate social responsibility

Social license to operate is the public goodwill that allows a company to continue its operations. The problem with the social license to operate is that there are no quantifiable thresholds of concern that the mine can operate within so that the community can feel more secure when operations are below threshold.

Corporate social responsibility and coal mining's social license to operate have to operate in increasing pressure to share the water resources in the catchment along with human water needs, food production and healthy ecosystems.

Coal mining and coal-fired power stations need to reduce their freshwater use. One option is to increase their use of recycled water along with increased use of saline water.

However, it is not just the water share going to coal activities that is the issue. There are cumulative impacts from coal activities and the reduced water availability and feedback loops such as GHG emissions on reducing rainfall. The 'water trigger' of the EPBC Act is one of the only legislative tools for the protection of water in the catchment. Underground mines do not have surface water licenses and yet manage rainfall and runoff into the mine site and through groundwater recharge. The current planning approval process leads to bespoke water reporting requirements.

Water use is becoming much more of a concern to the general public that face water shortages and droughts in Australia. The coal industry's large water use is particularly concerning given that some of the largest coal producing and consuming countries, including India, China, Australia and South Africa, already face water stress and are currently planning enormous expansion of their coal industries. Australia has large coal reserves and government policies that are currently supporting coal mining. Figure 44 shows the location of new coal projects. However global movement away from coal power is making new coal mines unattractive financially.

Cheng and Lammi (2016) outline the growing threat to coal mining and coal-fired power stations from the expanding global water crisis. Collins and Woodley (2013) discuss a social water assessment protocol to improve the planning process and the social license to operate. IFC ICMM (2019) also addressed the shared responsibility of water in the environment between mining companies and the public. Kemp *et al.* (2010) identified water as a human right and discussed the interactions of mining and the community. Rickards and Alexandra (2017) describe the increasingly clear choice of water or coal.

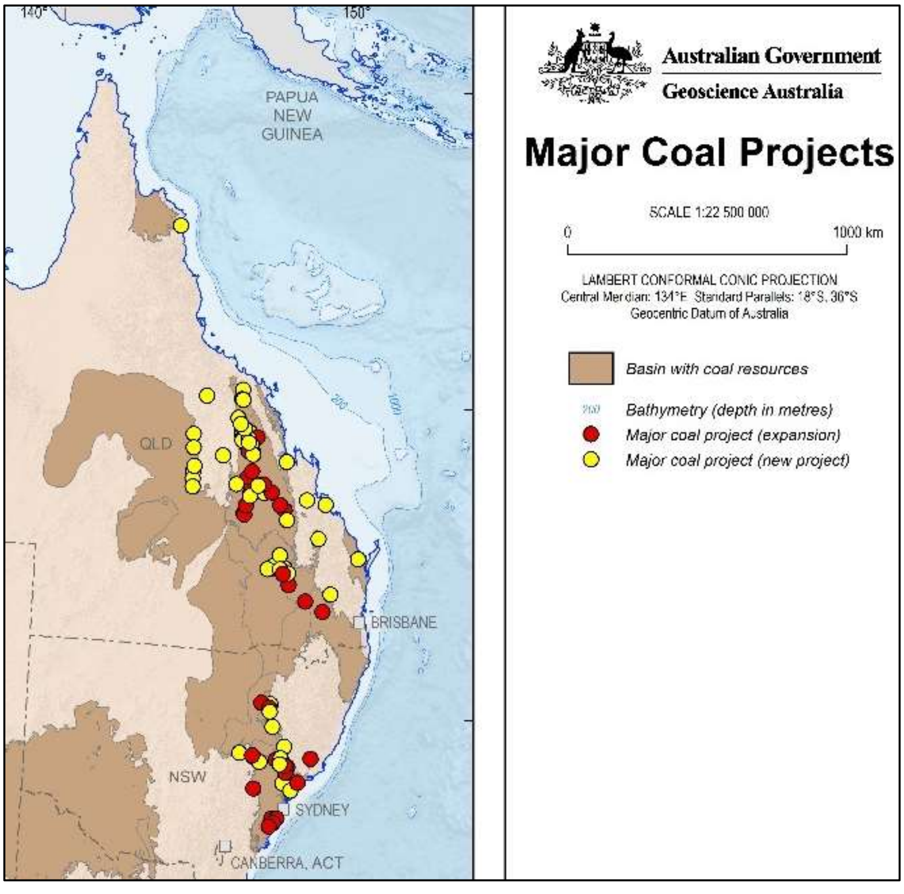

Figure 44. Major coal projects in NSW and QLD (Geoscience Australia, 2019a)

9.3 Limitations of this study

This study was a high-level assessment to provide a picture of water use in coal mining and coal-fired power stations. It relied on publicly accessible information as no 'Freedom of Information' requests were made and is therefore reflective of the information that is readily available to researchers and the general public. The report recommends that more detailed reporting is made publicly available.

No mine water data was available for QLD coal mines and water use was calculated by using water use rates obtained from analysing the NSW mine Annual Reviews. Coal-fired power station data was not easily available for either NSW or QLD. A report from 2009 (Smart and Aspinall, 2009) provided actual power station data for water consumed but water withdrawn was estimated from published rates.

9.4 Recommendations

Title	Recommendation
Water Accounting	**Mandatory monthly reporting of full water balance.** Current water reporting is inconsistent and lacks integrity in terms of all aspects of the water balance. There needs to be improved water accounting methods and understanding of the components of a water balance so that reporting can be accessible and comprehensive with mandatory monthly reporting. Monthly data provides insights into seasonal variations and can identify issues in a timely manner. This will require education in the use of the Water Accounting Framework to provide useful data that can be compared across coal mines and be used to contribute to regional water balance studies. This includes basic water use reporting for QLD coal mines in line with the Annual Reviews in NSW. There is currently no requirement to report on any water use other than licensed water.
Water Modelling	**Comprehensive water model, updated yearly and audited.** Water models are complex but are not audited and are not updated from an initial development pre-mining. Models should be updated yearly and include a full water balance and both surface water and groundwater components. These water models should be accessible both psychically and in a form that can be easily understood.
Data Storage	**Single data storage for all water data with open access.** Single data storage with open access to provide transparent and trusted data on all aspects of the water balance. This needs to be compliant with the Australian Water Accounting Standards and the Water Accounting Framework. This would provide a single point of truth for all government departments to interrogate water use.
Mining Impacts	**Standardised accounting for all mining impacts from water consumed, withdrawn and impacted.** There needs to be a better approach to understanding the full range of potential offsite impacts from water use in mining and

	power generation, particularly to the environment from direct and indirect impacts. This includes from water consumed, withdrawn and the water impacted through activities using a full water footprint approach.
Water Efficiency	**Benchmarking water efficiency for mine and power station assessments and increasing recycled water use.** Benchmarking mine and power generation water use to provide governance and consumer knowledge of water use and drive water efficiency, for example through the increased use of recycled water. Coal mines and power stations should be required to advertise their water efficiency. This should be reported along with GHG emissions. In the case of coal-fired power stations it should include coal usage.
Mining Governance	**Single authority to govern and audit water use at State or Federal level.** A single authority to govern and audit water use in mining and coal-fired power generation. Currently there is multiple agencies looking at individual components of the water balance. Water should be elevated to a single reporting framework to avoid gaps occurring in the water balance.
Value of Water	**Adopting a value of water framework, to identify mine and power station impacts on the water availability and the ethical and economic sharing of this finite resource.** Australia needs a much better handle on the value of its water and how the use of water for one activity impacts on others through a loss of access or a change in water quality. The cost of water is inconsistent and does not reflect the loss of value that the water would provide to other activities.
Responsible Water Management	**A sustainable approach to resource management considering the climate change impacts.** There needs to be a systems view of water and how it impacts the water-food-energy-environment nexus. Resource allocation needs to be managed in a sustainable manner to address the climate crisis.

References

ABC (2012) Coal Seam Gas and Water. Updated 4 April 2012. https://www.abc.net.au/news/2011-11-24/coal-seam-gas-and-water/3668284. Accessed August 2019.

ABS (2005) Water Supply and Use by Type. 4610.0 Water Account, Australia, 2003-04. Australian Bureau of Statistics, released 2005.

ABS (2019) Water Supply and Use by Type. 4610.0 Water Account, Australia, 2016-17. Australian Bureau of Statistics, released February 2019.

DA (2019) Water Entitlement Market Prices – Summary Report, June 2019. Department of Agriculture. https://www.agriculture.gov.au/water/markets/market-price-information#2019. Accessed November 2019.

Ali A, Strezov V, Davies P and Wright I (2017) Environmental Impact of Coal Mining and Coal Seam Gas Production on Surface Water Quality in the Sydney Basin, Australia. *Environmental Monitoring and Assessment* 189:408 DOI 10.1007/s10661-017-6110-4

Averyt K (2016) Energy-Water Nexus: Head-On Collision or Near Miss? *American* Scientist 104 (3): 158. DOI: 10.1511/2016.120.158

BA (2019a) Coal Resource Development and Water Resources in the Hunter Subregion. Australian Government Bioregional Assessments. https://www.bioregionalassessments.gov.au/factsheets/coal-resource-development-and-water-resources-hunter-subregion Accessed September 2019.

BA (2019b). Coal Resource Development and Water Resources in the Galilee Subregion. Australian Government Bioregional Assessments. https://www.bioregionalassessments.gov.au/factsheets/coal-resource-development-and-water-resources-galilee-subregion. Accessed July 2019.

BA (2019c) Bioregional Assessment Explorer. Australian Government Bioregional Assessments. https://www.bioregionalassessments.gov.au/ba-explorer Accessed September 2019.

Britannica (2017) Coal Mining. https://www.britannica.com/technology/coal-mining. Accessed July 2019.

Cheng I and Lammi H (2016) The Great Water Grab: How the Coal Industry is Deepening the Global Water Crisis. Greenpeace.

CEC (2019) Clean Energy Australia Report 2019. Clean Energy Council. cleanenergycouncil.org.au.

Coalservices (2018) April 2018 – NSW cola industry statistics. https://www.coalservices.com.au/mining/news-and-events/media-releases/april-2018-nsw-coal-industry-statistics/. Accessed August 2019.

CoalSwarm (2019) Environmental Impacts of Coal. https://www.sourcewatch.org/index.php/Environmental_impacts_of_coal. Accessed September 2019.

Collins N and Woodley A (2013) Social Water Assessment Protocol: A Step Towards Connecting Mining, Water and Human Rights. *Impact Assessment and Project Appraisal*. DOI: 10.1080/14615517.2013.774717.

Côte CM, Moran C, Cummings J and Ringwood K (2009) Developing a Water Accounting Framework for the Australian Minerals Industry. Water in Mining 2009, Perth, 15 - 17 September 2009.Carlton, Victoria: Australasian Institute of Mining and Metallurgy.

Côte CM, Moran CJ, Hedeman CJ and Koch C (2010) Systems Modelling for Effective Mine Water Management. *Environmental Modelling and Software* 25 (2010) 1664-1671.

Danoucaras AN and Woodley AP (2013) Water Reporting Using the Water Accounting Framework. AusIMM Bulletin (5) 47-49.

DEE (2018) What are the Ecological Impacts of Groundwater Drawdown? Australian Government Department of the Environment and Energy.

DEE (2019a) Australian Energy Statistics: Table O Australian Electricity Generation by Fuel Type Physical Units. Australian Government Department of the Environment and Energy.

DEE (2019b) Coal and Coal Seam Gas – Regulation. http://www.environment.gov.au/water/coal-and-coal-seam-gas/regulation. Accessed October 2019.

DES (2019) Water. https://environment.des.qld.gov.au/management/activities/non-mining/water/groundwater. Queensland Department of Environment and Science. Accessed October 2019.

EDO (2017) Mining Law in New South Wales: A Guide for the Community. Environmental Defenders Office, New South Wales.

Eisco (2019) https://www.eiscolabs.com/products/esng0053pk12. Accessed July 2019.

End Coal (2014) Insatiable Thirst: How Coal Consumes and Contaminates Our Water. End Coal Factsheet #3. https://endcoal.org/resources/insatiable-thirst-how-coal-consumes-and-contaminates-our-thirst/?ref=water. Accessed September 2019.

Gippel C (2017) Preliminary Review of Potential Impact of Surface Water Proposed to be taken by Adani Infrastructure Pty Ltd (Adani) for its Carmichael Coal Mine in the Galilee Basin. Report Prepared by Fluvial Systems.

Geoscience Australia (2019a) Coal. https://www.ga.gov.au/education/classroom-resources/minerals-energy/australian-energy-facts/coal. Accessed July 2019.

Geoscience Australia (2019b) Australian Atlas of Minerals Resources, Mines and Processing Centres. http://www.australianminesatlas.gov.au/?site=atlas&tool=search. Accessed August 2019.

HEC (2013) Draining the Life-Blood: Groundwater Impacts of Coal Mining in the Galilee Basin. Report prepared by Hydrocology Environmental Consulting in consultation with Tom Crothers – Stellar Advisory Services.

Hinrichs RA and Kleinbach M (2006) Electricity: Circuits and Superconductors. In Energy: Its Use and the Environment, 4th ed. Toronto, Ont. Canada: Thomson Brooks/Cole Ch.10, Sec.A, pp.320.

Hightower M (2014) Reducing Energy's Water Footprint. Cornerstone: The Official Journal of the World Coal Industry, 2 (1) 4-8.

Holland J, Applegate J and Bocking M (2008) Recent Coalbed Methane Exploration in the Galilee Basin, Queensland, Australia. 2008 International Coal Bed and Shale Symposium.

IFC ICMM (2019) Shared Water, Shared Responsibility, Shared Approach: Water in the Mining Sector. International Finance Corporation Infrastructure and Natural Resources Advisory Team and the International Council on Mining and Metals.

IESC (2014) Subsidence from Coal Mining Activities: Background Review. Australian Government Department of Environment. June 2014.

ICMM (2017) A Practical Guide to Consistent Water Reporting. International Council on Mining & Metals (ICMM). Accessed November 2019.

IWA (2019) International Water Association. http://www.iwa-network.org/wp-content/uploads/2018/05/sfs.jpg. Accessed on 02/07/2019. Accessed July 2019.

Kemp D, Bond CJ, Franks DM and Cote C (2010) Mining, Water and Human Rights: Making the Connection. *Journal of Cleaner Production* 18 (15) 1553-1562. https://doi.org/10.1016/j.jclepro.2010.06.008

Larsen MAD and Drews M (2019) Water Use in Electricity Generation for Water-Energy Nexus Analyses: The European Case. *Science of the Total Environment* 651 (2019) 2044-2058.

Macknick J, Newmark R, Heath G and Hallet KC (2012) A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies: A Review of Existing Literature. *Environmental Research Letters* 7. DOI:10.1088/1748-9326/7/4/045802.

Martin AD (2012) Water Footprint of Electric Power Generation: Modelling its use and analysing Options for a Water-Scarce Future. Massachusetts Institute of Technology, Cambridge.

MCA (2014) Water Accounting Framework for the Minerals Industry: User Guide. Version 1.3 January 2014. Minerals Council of Australia.

MCA (2019) Minerals Council of Australia. https://minerals.org.au/minerals/coal. Accessed August 2019.

McConnell D (2016) Submission to: Commonwealth of Australia, Senate Environment and Communications References Committee Inquiry on: Retirement of Coal Fired Power Stations.

Mekonnen MM, Gerbens-Leenes PW and Hoekstra AY (2015) The Consumptive Water Footprint of Electricity and Heat: A Global Assessment. *Environmental Science: Water Research and Technology* 2015 (1) 285-297. DOI: 10.1039/c5ew00026b.

Meldrum J, Nettles-Anderson S, Heath G and Macknick J (2013) Life Cycle Water Use for Electricity Generation: A Review and Harmonization of Literature Estimates. *Environmental Research Letters* 8 (1) 015031.

Moon E (2017) Why Does the Carmichael Coal Mine Need to Use so Much Water? The Conversation April 13 2017. https://theconversation.com/why-does-the-carmichael-coal-mine-need-to-use-so-much-water-75923. Accessed August 2019.

Northey SA, Muddb GM, Werner TT, Haquec N and Yellishetty M (2019) Sustainable Water Management and Improved Corporate Reporting in Mining. *Water Resources and Industry* (21).

NSW Department of Industry (2018) Greater Hunter Regional Water Strategy: Securing the Future Water Needs of the Hunter, Central Coast and Mid-Coast Areas.

NSW Government (2019) Thermal Coal: Opportunities in New South Wales, Australia. November 2017.

NSW Mining (2019) NSW Mining History. http://www.nswmining.com.au/industry/nsw-mining-history. Accessed July 2019.

NSW Resources and Geoscience (2019). https://www.resourcesandgeoscience.nsw.gov.au/investors/coal-innovation-nsw/future-of-nsw-coal-fired-power-generation. Accessed October 2019.

OCE (2018) Resources and Energy Quarter December 2018. Office of the Chief Economist. Department of Industry Innovation and Science.

Ossa-Moreno JS, *et al.* (2018) The Hydro-Economics of Mining. *Ecological Economics*, March 2018. DOI: 10.1016/j.ecolecon.2017.11.010

Pan S, Snyder SW, Packman AI, Lin YJ and Chiang P (2018) Cooling Water Use in Thermoelectric Power Generation and its Associated Challenges for Addressing Water-Energy Nexus. *Water-Energy Nexus* 1 (2018) 26-41.

Rickards L and Alexandra J (2017) Water or Coal? The Increasingly Clear Choice. http://www.globalwaterforum.org/2017/10/30/guest-op-ed-water-or-coal-the-increasingly-clear-choice/. Accessed September 2019.

San Juan Citizens Alliance (2019) Four Corners Power Plant. https://www.sanjuancitizens.org/four-corners-power-plant-navajo-mine. Accessed July 2019.

Sourcewatch (2019) Coal Power Technologies. https://www.sourcewatch.org/index.php/Coal_power_technologies. Accessed August 2019.

Smart A and Aspinall A (2009) Water and the Electricity Generation Industry. National Water Commission. Waterlines Report Series No. 18, August 2009.

The Guardian (2012) Water Footprint World Map. https://www.theguardian.com/environment/graphic/2012/feb/14/water-footprint-world-map. Accessed July 2019.

Union of Concerned Scientists (2014) Energy and Water Use. https://www.ucsusa.org/clean-energy/energy-water-use?_ga=2.147795575.1566765193.1568256164-846559718.1568256164. Accessed September 2019.

USEPA (2015) Steam Electric Power Generating Effluent Guidelines – 2015 Final Rule. United States Environmental Protection Agency.

Water Footprint Calculator (2017) The Water Footprint of Energy. https://www.watercalculator.org/water-use/the-water-footprint-of-energy/. Accessed September 2019.

Wikimedia Commons (2019) Coal Fired Power Plant Diagram. https://commons.wikimedia.org/wiki/File:Coal_fired_power_plant_diagram.svg. Accessed July 2019.

Wilson W, Leipzig T and Griffiths-Sattenspiel B (2012) Burning Our Rivers: The Water Footprint of Electricity. River Network Report.

Winn P (2018) Describing Impacts on the Great Artesian Basin from the Proposed Galilee Basin Thermal Coal Mines.

WEC (2010) Water for Energy. World Energy Council.

World Coal Association (2019) Uses of Coal. https://www.worldcoal.org/coal/uses-coal#:~:targetText=The%20most%20significant%20uses%20of,mainly%20used%20in%20power%20generation. Accessed November 2019.

Appendix A: Black coal mines in NSW

Mine Name	Owner	Basin	Type	Product (Black Coal)	Production (Mt) (2018/2019)	Report Available
Airly	Centennial	Western	Underground	Thermal	0.906	Yes
Ashton	Yancoal Australia Pty Ltd	Hunter	Underground	Coking	0.825	Yes
Austar	Yancoal Australia Pty Ltd	Hunter	Underground	Coking	1.413	Yes
Bengalla	New Hope Coal	Hunter	Open	Thermal	9	Yes
Bloomfield	Bloomfield Group	Newcastle	Open	Thermal	0.609	Yes
Boggabri	Idemitsu Kosan Co Ltd	Gunnedah	Open	Thermal	7	Yes
Bulga	Glencore	Hunter	Open and Underground	Thermal & Coking	9.023	Yes
Chain Valley	LD Operations (Delta Coal)	Newcastle	Underground	Thermal	0.4	Yes
Clarence	Centennial	Western	Underground	Thermal	1.68	Yes
Dendrobium	South32	Southern	Underground	Coking	2.735	Yes
Duralie	Yancoal Australia Pty Ltd	Gloucester	Open	Thermal	0.632	Yes
Stratford	Yancoal Australia Pty Ltd	Gloucester	Open	Thermal	0.456	Yes
Glendell	Glencore	Hunter	Open	N/A	N/A	No
Hunter Valley Operations	Yancoal / Glencore	Hunter	Open	Thermal & Coking	13	Yes
Integra (Glennies Creek)	Glencore	Hunter	Underground	Coking	1.44	Yes
Liddell	Glencore	Hunter	Open	Thermal	4.065	Yes
Macquarie	Glencore	Newcastle	Open and Underground	Thermal	5.55	Yes
Mandalong	Centennial	Newcastle	Underground	Thermal	5.217	Yes
Mangoola	Glencore	Hunter	Open and Underground	Thermal	10.562	Yes
Maules Creek	Whitehaven Coal Ltd	Hunter	Open	Thermal	11.21	Yes
Metropolitan	Peabody Energy	Southern	Underground	Thermal	1.585	Yes
Moolarben	Yancoal Australia Pty Ltd	Western	Open and Underground	Thermal	12.38	Yes
Mount Arthur	BHP Billiton	Hunter	Open	Thermal	23.679	Yes
Mount Owen	Glencore	Hunter	Open	Thermal	7.64	Yes
Mount Pleasant	Rio Tinto Coal Australia	Hunter	Open	Thermal	0.03	Yes
Mount Thorley / Warkworth	Yancoal Australia Pty Ltd	Hunter	Open	Thermal & Coking	11.8	Yes
Muswellbrook/Beltana	Idemitsu Kosan Co Ltd	Hunter	Open	Thermal	N/A	No
Myuna	Centennial	Newcastle	Underground	Thermal	2.167	Yes
Narrabri	Whitehaven Coal Ltd	Hunter	Underground	Thermal	4.94	Yes
NRE Wongawilli	Gujarat NRE (Illawarra Coal)	Southern	Underground	Coking	0.2	Yes
Ravensworth Complex	Glencore Plc	Hunter	Open and Underground	Thermal	40.9	Yes
Rixs Creek	Bloomfield Group	Hunter	Open	Thermal	1.42	Yes
Rocglen	Whitehaven Coal Ltd	Hunter	Open	Thermal	0.857	Yes
Springvale	Centennial	Western	Underground	Thermal	3.76	Yes
Sunnyside	Whitehaven Coal Ltd	Gunnedah	Open	Thermal	0.364	Yes
Tahmoor	Glencore Plc	Southern	Underground	Coking	1.599	Yes
Tarrawonga	Whitehaven Coal Ltd	Gunnedah	Open	Thermal	2.075	Yes
Ulan	Glencore Plc	Western	Open	Thermal	11.738	Yes
Wambo	Peabody Energy	Hunter	Open and Underground	Thermal	4.81	Yes
Werris Creek	Whitehaven Coal Ltd	Hunter	Open	Thermal	1.839	Yes
Wilpinjong	Peabody Energy	Hunter	Open	Thermal	12.19	Yes
			TOTAL (Mt)		231.7	39

Appendix B: Black coal mines in QLD

Mine Name	Owner	Basin	Type	Product (Black Coal)	Produ (Mt)
New Acland	New Hope Coal	Clarence-Moreton	Open	Thermal	4.2
Blackwater	BHP Billiton	Bowen	Open	Coking	13
Callide	Anglo American Plc	Callide	Open	Thermal	10
Clermont	Glencore Plc	Bowen	Open	Thermal	12
Collinsville	Glencore Plc	Bowen	Open	Coking	6
Cook	Caledon Resources plc	Bowen	Underground	Coking	2.2
Ensham	Idemitsu	Bowen	Open	Thermal	5.2
North Goonyella	Peabody	Bowen	Underground	Coking	1.8
Hail Creek	Rio Tinto Coal Australia	Bowen	Open	Thermal and Coking	9.4
Jellinbah East	Jellinbah Group	Bowen	Open	Coking	5.3
Kogan Creek	CS Energy	Surat	Open	Thermal	2.8
Lake Vermont	Jellinbah Group	Bowen	Open	Coking	9.4
Moranbah North	Anglo American Plc	Bowen	Underground	Coking	8
Dawson	Anglo American Plc	Bowen	Open	Thermal & Coking	9
Oaky Creek	Glencore Plc	Bowen	Underground	Coking	15.9
Peak Downs	BHP Billiton	Bowen	Open	Coking	2.5
Millennium	Peabody Energy	Bowen	Open	Coking	2.4
Carborough Downs	Vale S.A.	Bowen	Open	Coking	2.4
Byerwen	QCoal Pty Ltd	Bowen	Open	Coking	10
Blair Athol	Rio Tinto	Bowen	Open and Underground	Coking	12.9
Newlands	Glencore Plc	Bowen	Open and Underground	Thermal and Coking	11
Poitrel	BHP Billiton	Bowen	Open	Coking	3.72
Middlemount	Yancoal Australia Pty Ltd	Bowen	Open	Coking	4.1
Minerva	Yancoal Australia Pty Ltd	Bowen	Open	Thermal	3
Curragh North	Wesfarmers	Bowen	Open	Coking	9.3
Daunia	BHP Billiton	Bowen	Open	Coking	4
Moorvale	Peabody Energy	Bowen	Open	Coking	2.1
Sonoma	QCoal Pty Ltd	Bowen	Open	Thermal and Coking	4
Cameby Downs	Yanzhou Coal Mining	Surat	Open	Thermal	1.8
Yarrabee	Yancoal Australia Pty Ltd	Bowen	Open	Thermal and Coking	3.2
Foxleigh	Anglo American Plc	Bowen	Open	Coking	3
Curragh	Wesfarmers	Bowen	Open	Coking	7
Jeebropilly	New Hope Coal	Clarence-Moreton	Open	Thermal	0.5
Rolleston	Glencore Plc	Bowen	Open	Thermal	13.94
Saraji	BHP Billiton	Bowen	Open	Coking	10
Commodore	Huaneng Power	Clarence-Moreton	Open	Thermal	3.6
Grosvenor	Anglo American Plc	Bowen	Underground	Coking	5
Kestrel	Rio Tinto Coal Australia	Bowen	Underground	Thermal and Coking	4
Broadmeadow	BHP Billiton	Bowen	Underground	Coking	3.6
Drake	QCoal Pty Ltd	Bowen	Open	Thermal and Coking	6
Orion Downs	Endocoal	Bowen	Open	N/A	N/A
Isaac Plains	Stanmore Coal	Bowen	Open	Coking	2.39
Capcoal	Anglo American Plc	Bowen	Open and Underground	Thermal and Coking	11
South Walker Creek	BHP Billiton	Bowen	Open	Coking	3.8
Coppabella	Peabody Energy	Bowen	Open	Coking	2.7
Tarong (Meandu)	Stanwell Corporation Ltd	South Burnett	Open	Thermal	7
		TOTAL (Mt)			274.2

Appendix C: Water use in coal mining

Black Coal and Water Numbers for Australia							
		NSW		QLD		NSW+QLD	%
Open-Cut Mines							
	Number of Open-Cut	22	56%	35	78%	57	68%
	Total Production Open (Saleable) (ML)	119.61	52%	198.75	80%	318.36	66%
	Average Production per Mine (ML)	5.44		5.68		6	
	Average Water Use per Mt (ML)	649		649		649	
	Average Freshwater Use per Mt (ML)	519		519		519	
	Total Water Use (ML)	77,627	44%	88,738	56%	166,365	50%
	Total Freshwater Use (ML)	62,078	44%	14,582	21%	76,660	36%
Underground Mines							
	Number of Underground	14	36%	7	16%	21	25%
	Total Production (Saleable) (Mt)	28.87	12%	40.50	16%	69.37	14%
	Average Production per Mine (Mt)	2.06		5.79		3	
	Average Water Use per Mt (ML)	1,001		1,001		1,001	
	Average Freshwater Use per Mt (ML)	801		801		801	
	Total Water Use (ML)	28,899	16%	40,541	26%	69,439	21%
	Total Freshwater Use (ML)	23,125	17%	32,441	46%	55,565	26%
Open & Underground Mines							
	Number of Open and Underground	6	15%	3	7%	9	11%
	Total Production (Saleable) (Mt)	83	36%	34.90	14%	118.13	25%
	Average Production per Mine (Mt)	34		11.63		13	
	Average Water Use per Mt (ML)	4,950		825		825	
	Average Freshwater Use per Mt (ML)	3,960		660		660	
	Total Water Use (ML)	68,665	39%	28,793	18%	97,457	29%
	Total Freshwater Use (ML)	54,932		23,034	33%	77,966	37%
All Coal Mines							
	Number of Mines	39	46%	45	54%	84	
	Total Production (Saleable) (Mt)	231.69	100%	248.47		480.16	
	Total Production Thermal (Mt)	223.48	96%	121.64		345	
	Total Production Metallurgical (Mt)	8.21	4%	121.64		130	
	Average Production per Mine (Mt)	5.94		5.52		6	
	Average Water Use per Mt (ML)	653.00		653.00		653	
	Total Water Use by Type (ML)	175,191		158,071		333,262	
	Total Freshwater Use (ML)	140,134		70,057		210,191	

Appendix D: Water use in coal-fired power stations

Black Coal and Water Numbers for Australia			
	NSW	QLD	NSW+QLD
Number	5	8	13
Total Capacity (MWh)	9,920	8,094	18,014
Total Production (MW)	69,519,360	56,722,752	126,242,112
Average Production per Station (MW)	13,903,872	7,090,344	20,994,216
Total Water Withdrawn (ML)	2,027,555	101,189	2,128,743
Total Water Consumed (ML)	81,100	77,200	158,300
Amount of Coal Used (Mt)*	33	27	59
Amount of Water Used for the Coal (ML)**	21,279	17,362	38,642
Total Water Use (Coal + Power) (ML)	102,379	94,562	196,942

*1 MW power station uses 9 t of coal per day (Hinrichs and Kleinbach, 2016)
**653 L/t (Annual Reviews for 2018)

Appendix E: Water use by all water users

Black Coal and Water Numbers for Australia						
	NSW	Percentage	QLD	Percentage	NSW+QLD	%
Withdrawn (ML)						
Agriculture	4,673,683	17.6%	2,535,581	34.8%	7,209,264	21.3%
Coal Mining	204,791	0.8%	207,100	2.8%	292,500	0.9%
Total Mining	110,001	0.4%	191,707	2.6%	301,708	0.9%
Black Coal Power	2,027,555	7.6%	101,189	1.4%	2,128,743	6.3%
Total Energy	14,439,794	54.3%	1,205,301	16.5%	15,645,095	46.2%
Manufacturing	121,029	0.5%	169,596	2.3%	290,625	0.9%
Water supply and waste	6,267,801	23.6%	2,522,558	34.6%	8,790,359	26.0%
Other Industry	387,337	1.5%	283,480	3.9%	670,817	2.0%
Total industry	6,776,167	25.5%	2,975,634	40.8%	9,751,801	28.8%
Potable water use by households	569,009	2.1%	387,392	5.3%	956,401	2.8%
Total Withdrawn	26,569,068	100.0%	7,295,614	100.0%	33,864,682	100.0%
Consumption (ML)						
Agriculture	4,672,858	71.2%	2,535,582	65.4%	7,208,440	69.0%
Coal Mining	204,791	3.1%	207,100	5.3%	292,500	2.8%
Total Mining	97,460	1.5%	137,710	3.5%	235,170	2.3%
Black Coal Power	81,100	1.2%	77,200	2%	158,300	1.5%
Total Energy	62,278	0.9%	56,569	1.5%	118,847	1.1%
Manufacturing	120,992	1.8%	165,500	4.3%	286,492	2.7%
Water supply and waste	657,673	10.0%	315,104	8.1%	972,777	9.3%
Other Industry	387,181	5.9%	281,960	7.3%	669,141	6.4%
Total industry	1,325,584	20.2%	956,843	24.7%	2,282,427	21.8%
Potable water use by households	569,009	8.7%	387,392	10.0%	956,401	9.2%
Total Consumed	6,567,450	100.0%	3,879,817	100.0%	10,447,267	100.0%