

# Australia's Interior Pathway of the Murray River: Need for a Comprehensive Plan for Sustainable Development of the Murray-Darling Basin to Mitigate the Environmental Impacts

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**Abstract:** The Murray-Darling Basin, is of immense economic significance, lying across the great wheat-sheep belt in its climatically most reliable section. The Murray-Darling Basin occupies about one-seventh of Australia's area. During the second half of the 19th century, river shipping was of great importance. With growing demand for irrigation water and competition from railways, navigation practically ceased. The basin has by far Australia's greatest area of irrigated pastures and crops, some 1.5 million hectares, more than 70 percent of the national total. It is the country's second largest wine-producing region; other major products include grains, cattle, fruit, and sheep. The River Murray Weirs were constructed 100 years ago for riverboat navigation and to supply water to inland communities. But the weirs have also degraded wetlands, salinized floodplains, and devastated fish populations. Historical lessons learned from other great rivers of North America can also be applied to the Murray River watershed in Australia which is experiencing lower water levels, salinization, and reduced navigation options. The primary objectives of this research are to document the history of the Murray River which became Australia's interior pathway for settlement, navigation, and trade and encourage the creation of a Comprehensive Plan for Sustainable Development of the Murray-Darling Basin to Mitigate the Environmental Impacts. Irrigation, however, led to serious salinity problems, and according to WHO (World Health Organization) criteria, was unfit for drinking. The problem of Murray salinity has been recognized as of national significance to Australia.

**Key words:** Murray River, Murray-Darling Basin, Murray Delta.

## 1. Introduction

Australia's river systems are varied and vast, weaving through diverse landscapes from alpine regions to arid outback (Fig. 1). They are an important part of the continent's ecology and human history, from supporting ancient Aboriginal cultures to fueling modern-day agriculture and tourism. Australia, known for its diverse landscapes (Fig. 2), is also home to an extensive network of rivers [1]. These rivers hold significant economic, environmental and cultural

importance, providing water for agriculture, industry, transport, and domestic use.

Australia's rivers are a critical component of the country's overall environmental health. Over-extraction of water, particularly for irrigation, coupled with climate change impacts, poses significant threats to the health of these waterways. These rivers are a habitat for a wide range of plant and animal species, many of which are endemic to Australia.

Water quality in Australia's rivers varies across the country and is influenced by factors such as land use,

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Fig. 1 Australia rivers. Photo Credit: Maps of the World.



Fig. 2 Elevation map of Australia. The green color is the lowlands, and the brown is the uplands. Photo Credit: worldmeters.info.

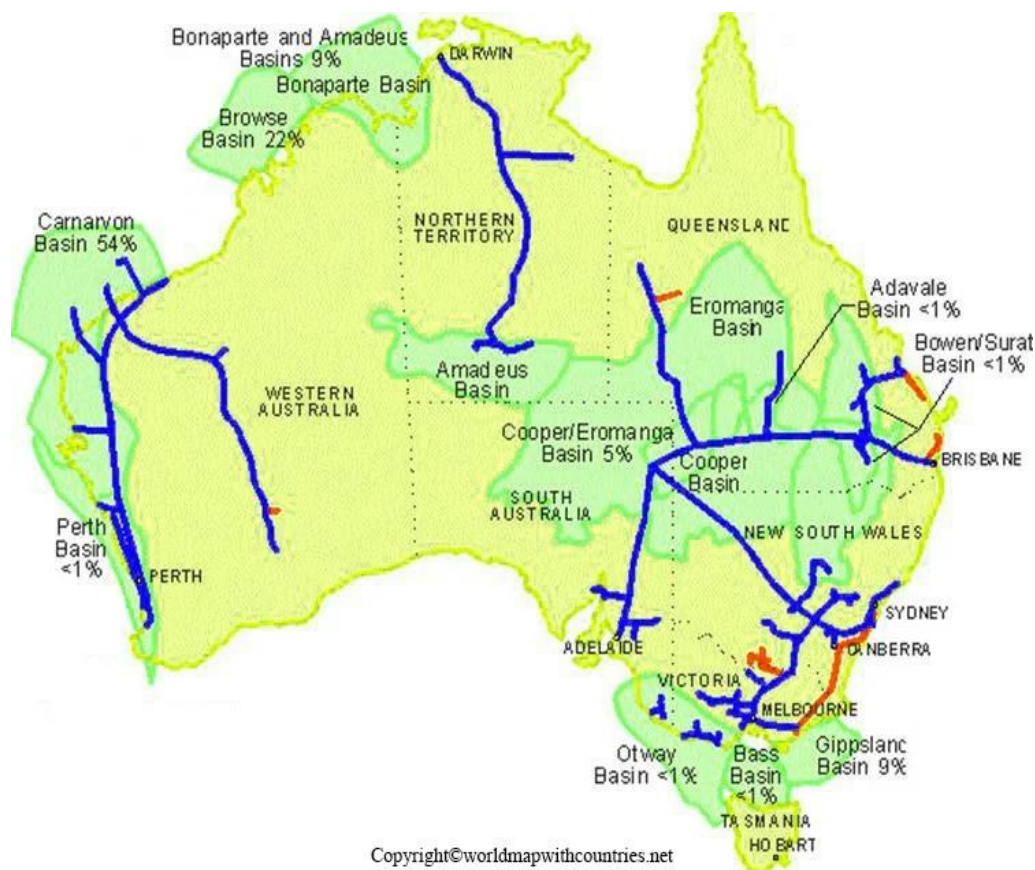
climate, and local geology. In some areas, water quality issues include excess nutrients, salinity, and pollutants. Rivers in Australia are significant for many reasons, including providing water supplies to cities, towns, and farming areas, maintaining biodiversity by supporting a wide range of ecosystems, and holding cultural value for Indigenous communities.

The Murray River is in south-eastern Australia, and is the longest river in Australia, at 2,508 km. Starting in the Australian Alps, it passes from the province of South Australia and then forms the border between Victoria and New South Wales. It is also generally considered the 19th longest river on earth (taken with Darling), just behind the Murat Su-Euphrates-Shatt al Arab river system. The river and its tributaries form the most important irrigation regions in the country. Known as the Murray-Darling basin (Fig. 3), the catchments from this river system cover roughly 15% of the area of Australia, and drains much of Victoria,

New South Wales and Queensland. The other tributary rivers—Murrumbidgee, Darling, Lachlan, Warrego, and Paroo Rivers, are five of the six next longest rivers, after Murray.

Though the river is large, its flow or output is much less than other rivers of similar size in other places in the world. The River Murray Weirs were constructed 100 years ago for riverboat navigation and to supply water to inland communities. But the weirs have also degraded wetlands, salinized floodplains and devastated fish populations. The water flow varies greatly depending on the season and year. Droughts have even caused the river to dry up completely.

One of the historical fundamental root causes of the growing crisis in management of the water and associated resources of the Murray Basin was articulated as early as the 1930s by Charles Fenner, a renowned Australian geographer [1]: “The human forces that control the Murray Basin do not reside within that basin, and it has



**Fig. 3** Australia rivers and basins. Photo Credit: worldmapwithcountries.net.



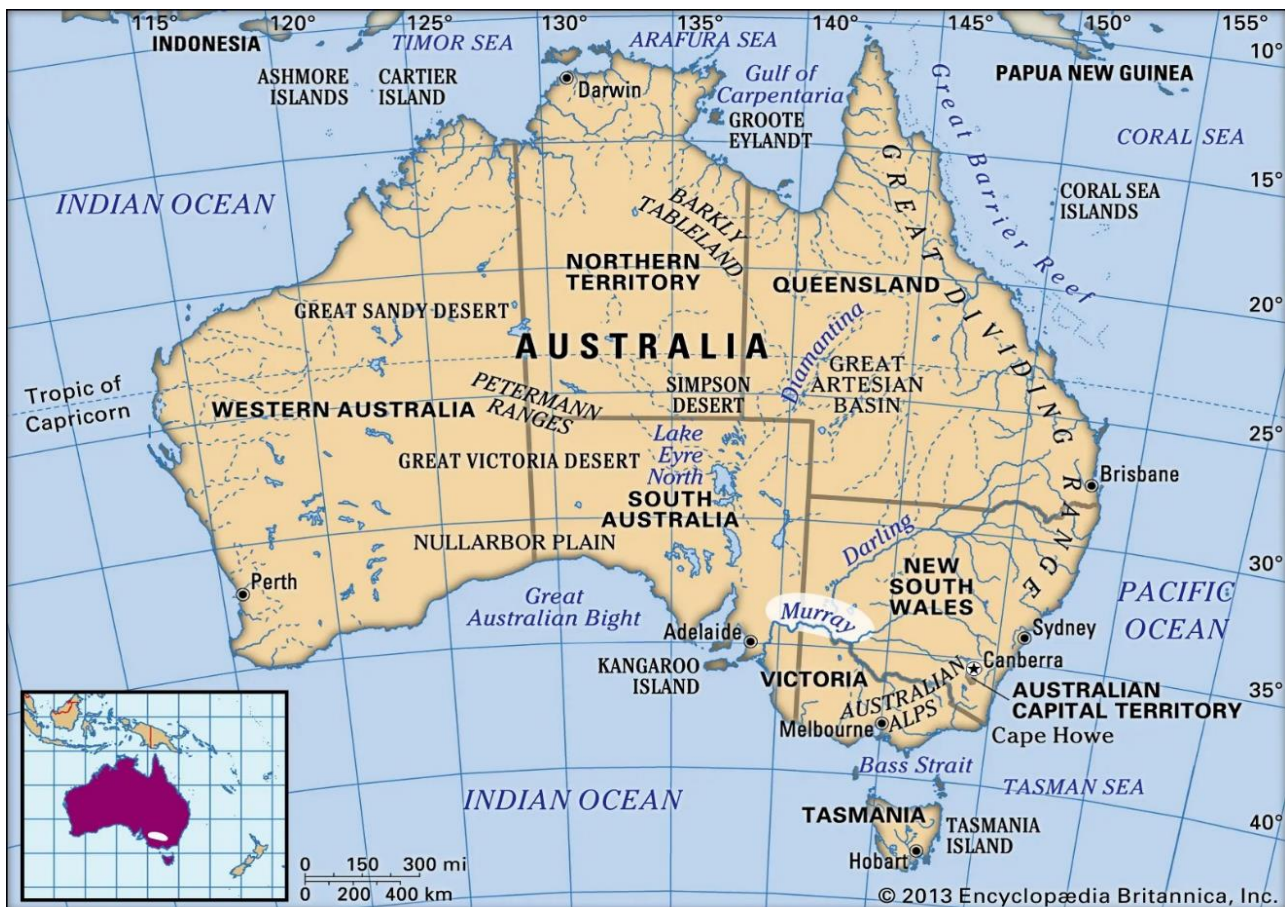
come about that in their tendencies they are to a large extent antagonistic to the chief natural geographical factors". Since then, the situation has changed dramatically, and modern Australia is an example of much more responsible management of natural resources, including the most critical part—fresh water and biodiversity, the main concentration of which on the “Green Continent” is the Murray Basin.

The primary objectives of this research are: (1) to document the history of the Murray River which is Australia's interior pathway for settlement, navigation, and trade and (2) to encourage the development of a Comprehensive Plan for Sustainable Development of the Murray-Darling Basin to mitigate the environmental impacts.

## 2. Study Site

Murray River (Fig. 4) is the main stream of the

Murray-Darling Basin and the principal river of Australia [2]. It flows some 2,530 km across southeastern Australia from the Snowy Mountains to the Indian Ocean. The main towns in the Murray River valley are Albury, Mildura, Renmark, Wodonga, Echuca, Swan Hill, and Murray Bridge. The river is named after Colonial Secretary Sir George Murray [3]. Although the Murray-Darling Basin has a total catchment area of some 1,061,469 km<sup>2</sup>, the Murray's average annual discharge is only 0.89 cubic meter per second, and it has dried up on at least three occasions in places. The river rises on a mountain, The Pilot, near Mount Kosciuszko in southeastern New South Wales. It flows north and northwest, passes through Hume Reservoir above Albury, and forms most of the boundary between Victoria and New South Wales. At Morgan, South Australia, it bends southward to flow through Lake Alexandrina to Encounter Bay on the Great Australian Bight.



**Fig. 4** Map of Australia. Photo Credit: Encyclopædia of Britannica.





**Fig. 5** Murray River River valley with agricultural lands in the background. Photo Credit: Encyclopedia of Britannica.



**Fig. 6** Murray River escarpment. Photo Credit: Tour council.

For most of its 400 km course through South Australia, the river is bordered by a narrow floodplain and flows between 30 m high cliffs (Fig. 5). Its upper 320 km cut through mountainous terrain (Fig. 6) [3]. The central section, however, lies on a wide mature

floodplain (Fig. 7), with the Riverine plains of northern Victoria to the south and the plains of New South Wales to the north. Its principal tributaries are the Darling, Murrumbidgee, Mitta Mitta, Campaspe, Ovens, Goulburn, and Loddon rivers [4].





**Fig. 7** Trees along the Murray River. Mallee eucalyptuses reflecting in calm water of Murray River at sunset. Riverland, South Australia. Photo Credit: World Atlas.

### **3. Natural Resources**

#### *3.1 Geologic History*

The geology of Australia includes virtually all known rock types, spanning a geological time period of over 3.8 billion years, including some of the oldest rocks on earth [5]. Australia is a continent situated on the Indo-Australian Plate. Australia's geology can be divided into several main sections: the Archaean cratonic shields, Proterozoic fold belts and sedimentary basins, Phanerozoic sedimentary basins, and Phanerozoic igneous and metamorphic rocks.

Australia as a separate continent began to form after the breakup of Gondwana during the Permian period, with the separation of the continental landmass from the African continent and Indian subcontinent. Australia rifted from Antarctica during the Cretaceous period [5]. Blewett et al. [6] suggested "The current Australian continental mass is composed of a thick subcontinental lithosphere, over 200 kilometers thick

in the western two-thirds and 100 kilometers thick in the younger eastern third. The Australian continental crust, excluding the thinned margins, has an average thickness of 38 kilometers, with a range in thickness from 24 to 59 kilometers."

"The Australian continent evolved in five broad but distinct time periods, namely: 3,800-2,100 Ma, 2,100-1,300 Ma, 1,300-600 Ma, 600-160 Ma and 160 Ma to the present. The first period saw the growth of nuclei about which cratonic elements grew, whereas the latter four periods involved the amalgamation and dispersal of Nuna, Rodinia and Pangea, respectively." [6].

Johnson [7] noted "The continental crust is composed primarily of Archaean, Proterozoic and some Palaeozoic granites and gneisses. A thin veneer of mainly Phanerozoic sedimentary basins cover much of the Australian landmass (these deposits are up to 7 km thick). These in turn are currently undergoing erosion by a combination of aeolian and fluvial processes, forming extensive sand dune systems, deep and prolonged

development of laterite and saprolite profiles, and development of playa lakes, salt lakes and ephemeral drainage.”

Jones et al. [8] found “The geologic history of the Australian continental mass is extremely prolonged and involved, continuing from the Archaean period to the recent. In a gross pattern, continental Australia grew from west to east, with Archean rocks mostly in the west, Proterozoic rocks in the center, and Phanerozoic rocks in the east. Recent geologic events are confined to intraplate earthquakes, as the continent of Australia sits distant from the plate boundary.”

### 3.2 Climate

Wikipedia [9] described “Australia’s climate is governed mostly by its size and by the hot, sinking air of the subtropical high pressure belt (subtropical ridge or Australian High). This moves northwest and

northeast with the seasons. The climate is variable, with frequent droughts lasting several seasons, thought to be caused in part by the El Niño-Southern Oscillation. Australia has a wide variety of climates due to its large geographical size. The largest part of Australia is desert or semi-arid. Only the south-east and south-west corners have a temperate climate and moderately fertile soil (Fig. 8). The northern part of the country has a tropical climate, varying between grasslands and desert. Australia holds many heat-related records (Fig. 9): the continent has the hottest extended region year-round, the areas with the hottest summer climate, and the highest sunshine duration.”

“Because Australia is a medium-sized continent, separated from the Antarctic by the Southern Ocean, it is not subject to movements of frigid polar air during winter, of the type that sweep over the continents in the northern hemisphere during their winter. Consequently,

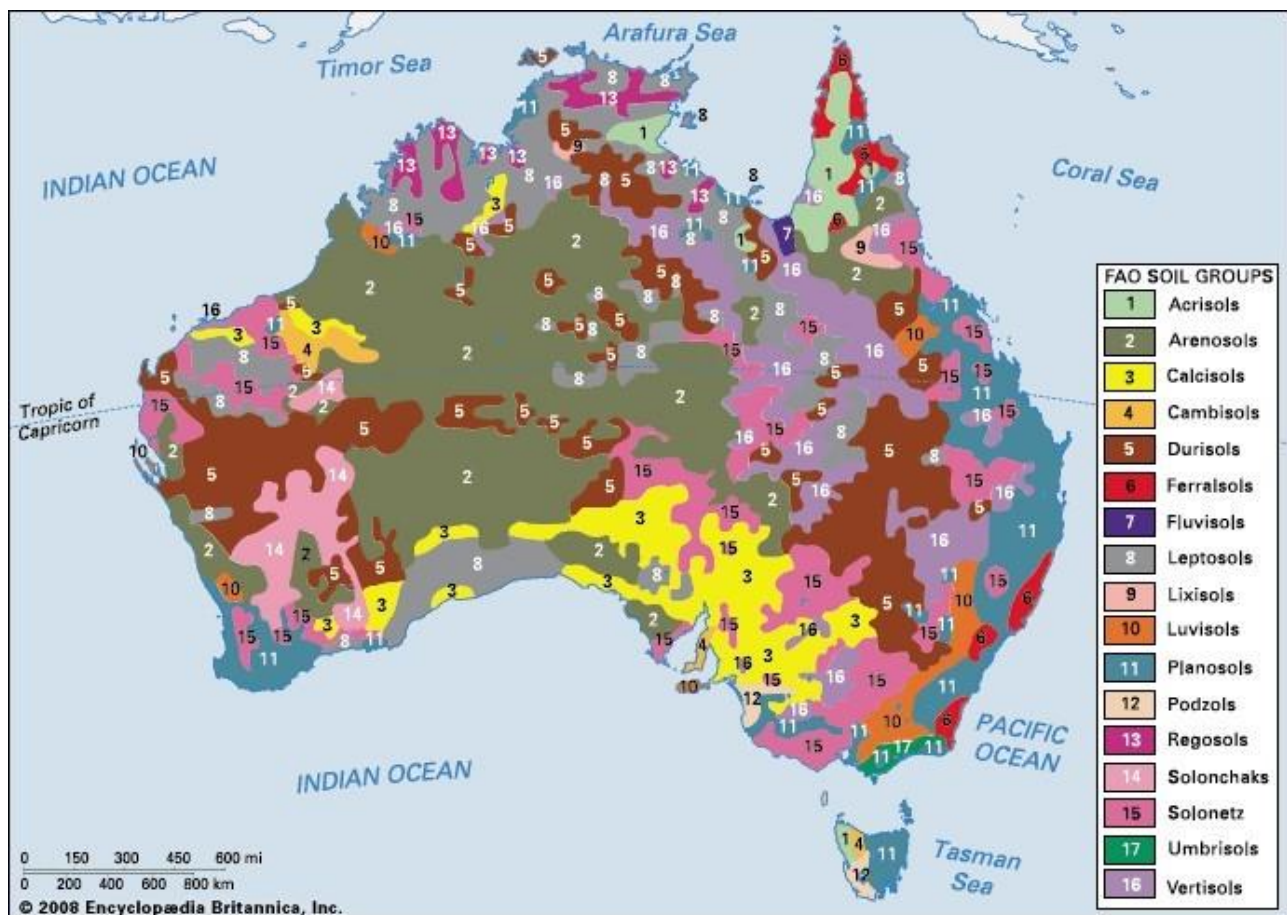
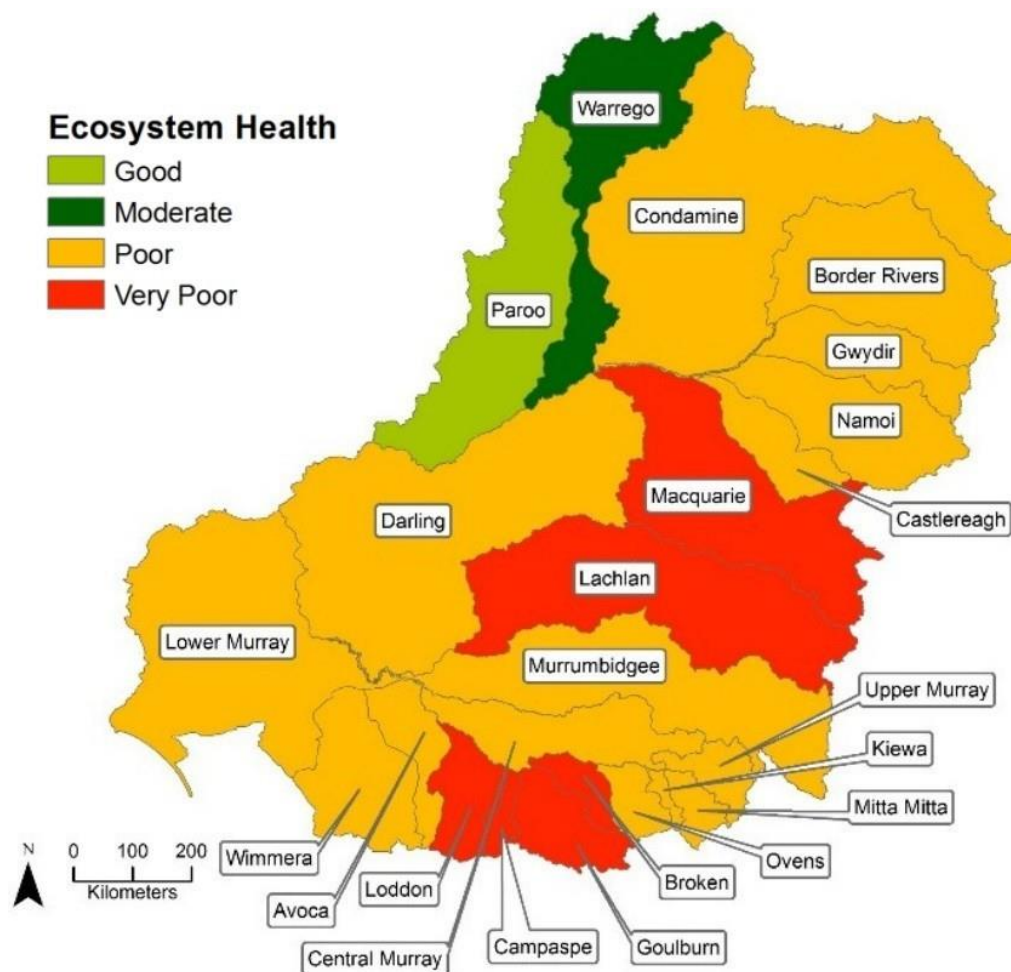


Fig. 8 Soils map of Australia. Photo Credit: Food and Agricultural Organization.





**Fig. 9 Ecosystem health. Photo Credit: Encyclopedia of Britannica.**

Australia's winter is relatively mild, with less contrast between summer and winter temperatures than in the northern continents—though the transition is more dramatically marked in alpine regions of Australia and places of substantial elevation. Seasonal highs and lows can still be considerable. Temperatures have ranged from above 50 °C (122 °F) to as low as -23.0 °C (-9.4 °F). Minimum temperatures are moderated.”

“The El Niño-Southern Oscillation is associated with seasonal abnormality in many areas in the world. Australia is one of the continents most affected and experiences extensive droughts alongside considerable wet periods (Fig. 10). Occasionally, a dust storm will blanket a region and there are reports of the occasional tornado. Tropical cyclones, heat waves, bushfires, and frosts in the country are also associated with the

Southern Oscillation. Rising levels of salinity and desertification in some areas is ravaging the landscape.” [9].

Climate change in Australia is a highly contentious political issue [10, 11]. Temperatures in the country rose by approximately 0.7 °C between 1910 and 2004, following an increasing trend of global warming [12]. Overnight minimum temperatures have warmed more rapidly than daytime maximum temperatures in recent years. The late-20th century warming has been largely attributed to the increased greenhouse effect [13]. According to the BOM (Bureau of Meteorology), 80% of the land receives less than 600 mm of rainfall annually and 50% has even less than 300 mm [14]. Australia has a very low annual average rainfall of 419 mm [15].





**Fig. 10** Dried up wetlands along the Murray River. Aerial Helicopter view of dried up and drought-stricken Murray River Wetlands, lagoon and back water in near Mildura, Australia. Photo Credit: World Atlas.

The climatic aridity of the main part of the Australian territory has led to extremely poor development of the continent's water network against which background the combined Murray and Darling valley is a truly unique water system for this huge island. The pronounced spatial irregularity of atmospheric moisture content of the Australian territory is also complemented by high inter-annual variability of the precipitation regime, including in the Murray Basin which experiences both floods and extreme drought.

### *3.3 Soils of the Murray Valley in South Australia*

The Murray catchment basin is the area with the

most favorable bioclimatic conditions in Australia which has also provided it with the greatest diversity of soils as well as the highest proportion of fertile soil variants for the entire continent. In the first soil maps of Australia<sup>1</sup>, the Murray and Darling Basin is dominated by soils with relatively high organic matter stocks, including gray and brown soils of heavy texture and solonized brown soils (Fig. 8). Subsequent more detailed surveys have also given considerable attention to soils of the Murray Basin as Australia's most important farming region which has historically acquired a reference value for continent-wide environmental management practices.

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<sup>1</sup> Their developer James Prescott was influenced, *inter alia*, by the principles of V.V. Dokuchaev soil science, so it is not surprising that in the legends of these maps some soils retained their Russian names.

Powell and Rickard [16] suggested “the continental pattern of soils (Fig. 8) is closely related to climatic factors. Mineral or skeletal soils exist over much of arid Australia that contain virtually no organic content and have developed little depth; they may consist merely of a rough mantle of weathered rock. Gypsum is present in many of the desert loams and arid red earths. The soils of the semiarid regions (where annual precipitation is 203 to 380 mm are also alkaline, with gypsum or lime a common feature. The organic content of the soils is again low in the solonized (salt-enriched) brown soils and the gray and brown soils of heavy texture that are common in those areas.”

“Both the arid and semiarid regions have developed swells and depressions (gilgai) patterns caused by the alternate swelling and contraction following wetting and drying of clay soils have developed. They are especially well represented in areas of seasonal rainfall. Areas with 380 to 635 mm of annual precipitation, black earths, brown soils, and red-brown earths are the most common soil types. In the wetter areas, where leaching out of minerals is a prominent feature of soils, Podzols are common. Podzol soils have a sandy texture, with much humus at the surface and acid throughout. In the alpine regions humus soils, surface peats over a mineral, are noteworthy.” [16].

The Murray Valley in South Australia is divided into 3 tracts [17]: (1) The swamps (once permanently flooded) which occupy the first 90 km of the narrow river valley that extends some 430 km upstream from the mouth, (2) The predominantly low terrace soils of the narrow river valley upstream from the swamps to Overland Corner, and (3) The high and low terrace soils of the wide river valley from Overland Corner to the Victorian border. The heavy clay soils of reclaimed swamps of Tract 1 are high in organic matter, and while the level of irrigation management is low, they have remained productive for 80 years of irrigation. The low terrace soils of Tract 2 are saline grey clays with poor physical properties and are subject to flooding; agricultural use is limited. In Tract 3, about

15% of the area is high terrace, which has clay soils with sand layers at depth and at the surface; the horticultural areas of Renmark, Cobdogla and part of Berri are established here. The remaining soils of this Tract, mainly low terrace or dissected areas, are generally used for dryland agricultural or recreational uses [17].

The River Murray in South Australia is some 700 km long. It includes Lake Alexandrina which extends about 60 km upstream from the mouth near Goolwa to Wellington. The river valley in South Australia is described in the following way: “The immediate floodplain of the River Murray passes through a series of gradual transitions from red gum and polygonum flats fringed with box trees ... to barer, low-lying flats subject to more frequent flooding, and finally to the permanent swamps of the lower reaches.” [17]. This description indicates the three distinct Tracts which reflect both the geological strata into which the river has incised, and the proximity to the mouth.

The river valley has been used for agriculture since settlement: the earliest use was for grazing and as a stock route [17]. Intensive use commenced with the irrigation scheme of the Chaffey brothers at Renmark in 1887, followed by village settlements at Waikerie, Lyrup, Pyap and elsewhere. In 1900, draining of the permanent swamps of River Tract 1 commenced, and extensive development for irrigation occurred all along the river valley for the soil types of land units. Much of the river valley has been described, if not mapped, in this way in recent years.

High-magnesium waters and soils are emerging examples of water quality deterioration and land degradation leading to environmental and food security constraints in several irrigation schemes [18]. A ratio of magnesium-to-calcium  $> 1$  in irrigation waters and an exchangeable magnesium percentage  $> 25\%$  in soils are considered high enough to result in soil degradation and impact crop yields negatively. These soil and water resources occur in the Murray-Darling Basin in Australia.



### *3.4 Flora*

The Murray-Darling Basin is composed of several different types of ecosystems which hold a variety of plant life [4]. The three major types, or areas include aquatic species that are permanently in water, floodplain species that prefer wet conditions but can live through a drought or dry season, and desert plants that survive extremely low amounts of water. The plants in and around major waterways are especially important, as they can help filter water, reduce salt levels in the area, stabilize river banks to reduce erosion, cycle nutrients into the ecosystem, and provide habitats or food for animals. Riverine forests are plentiful along the Murray River. These water-loving forests are full of species like river oaks, river red gum trees, and floodplain shrubs, grasses and herbs.

### *3.5 Fauna*

Many different animals can also be found around and in the Murray River [2]. Most notably, there is a wide variety of fish species that reside here, including Macquarie, silver, Murray cod (Fig. 11), trout cod,

(both endangered species, and golden perch (threatened species), Murray-Darling rainbowfish, bony herring, freshwater catfish, Australian smelt, and western carp gudgeon [3]. Recreational fishing (Fig. 12) is very popular in this area, and many of these species can be eaten as well. Aside from fish there are other aquatic creatures such as the Murray short-necked turtle (Fig. 13), yabbies, shrimp, Murray crayfish (Fig. 14), and platypus. Additionally, several mammal species live in the Murray-Darling basin along the riverbanks. These include species such as eastern grey and red kangaroos (Fig. 15), koalas (Fig. 16), swamp wallabies, wombats, ringtail possums, porcupines (Fig. 17), birds (Fig. 18), ducks (Fig. 19), echidnas, and sugar gliders [4].

Unfortunately, the Murray River (Fig. 20) has faced adversity throughout the years and has seen declines in its healthy and species populations. Changes in the river flow have caused issues with some of the aquatic life and extreme droughts have become a huge problem. These droughts put stress on the river and are highly detrimental to the red gum forests, along the riverbanks, that rely on large quantities of water to survive. Other



**Fig. 11 Cod.** Photo Credit: Dex Fisho, Phys.org.



**Fig. 12** Dying fish as a result of high water temperature. Photo Credit: National Geographic.

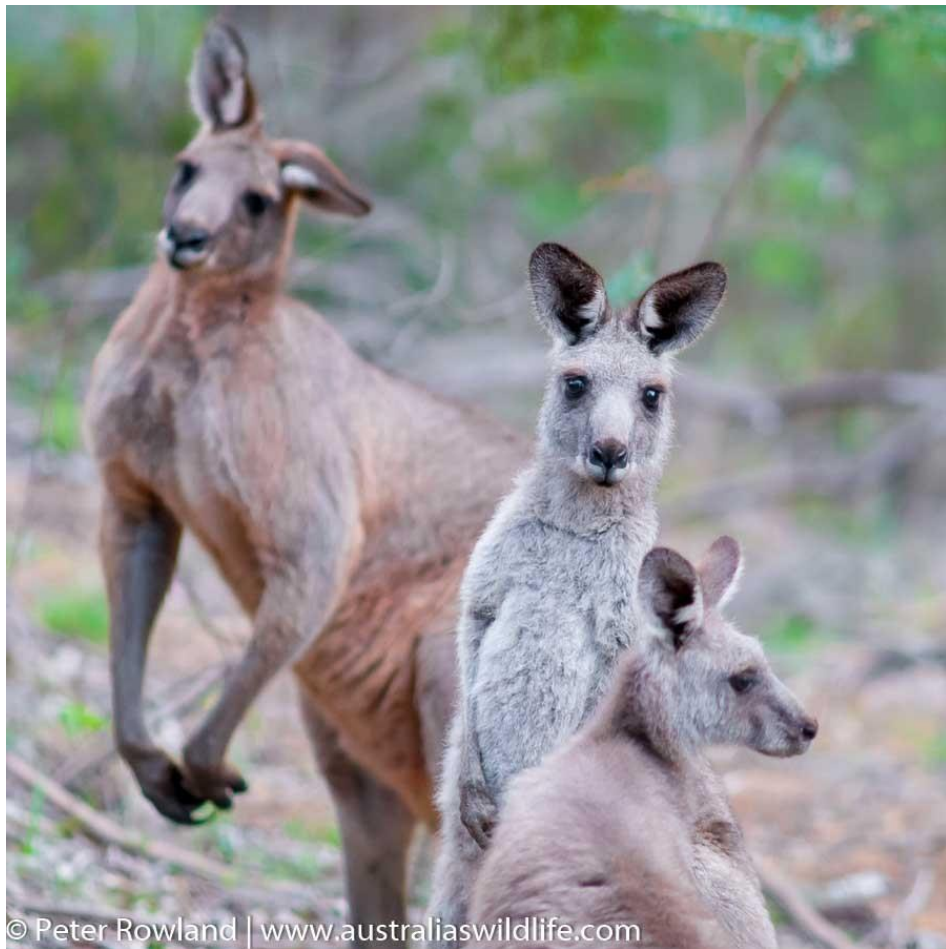


**Fig. 13** Turtle. Photo Credit: murrayrivertrails.com.au.

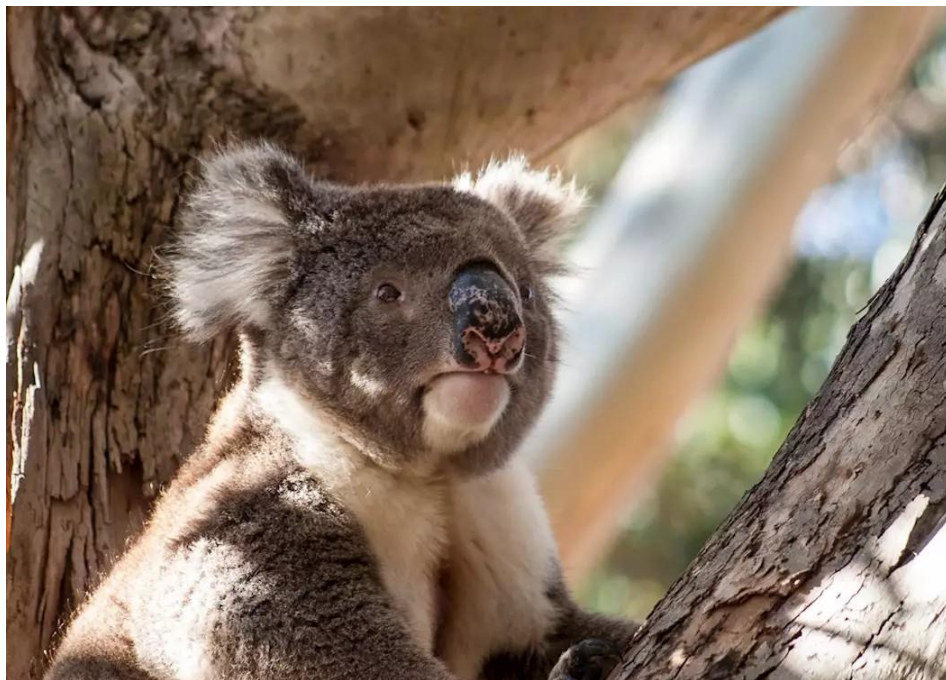


**Fig. 14** Crayfish. Photo Credit: murrayrivertrails.com.au.





**Fig. 15 Kangaroos.** Photo Credit: Peter Rowland, [australiaswildlife.com](http://australiaswildlife.com).



**Fig. 16 Koala.** Photo Credit: [murrayrivertrails.com.au](http://murrayrivertrails.com.au).



**Fig. 17** Porcupines. Photo Credit: [murrayrivertrails.com.au](http://murrayrivertrails.com.au).



**Fig. 18** Pelicans. Photo Credit: Klook Travel.





**Fig. 19** Ducks. Photo Credit: murrayrivertrails.com.au.



**Fig. 20** Murray River bend with ox bows. Photo Credit: Encyclopedia of Britannica.

problems which have threatened the river include the introduction of foreign species. Brown and rainbow trout, loach, redfin perch, and common carp are all introduced species which threaten the habitat and health of the other native species in the area. These intruder species quickly throw the ecosystems off balance and

decimate food supplies such as aquatic plants [3].

The Murray catchment area is heterogeneous; in some parts of the basin, ecosystems are relatively resilient to unfavorable climatic changes and resist the impacts of natural resource management, while others are in the “red zone” and require urgent conservation

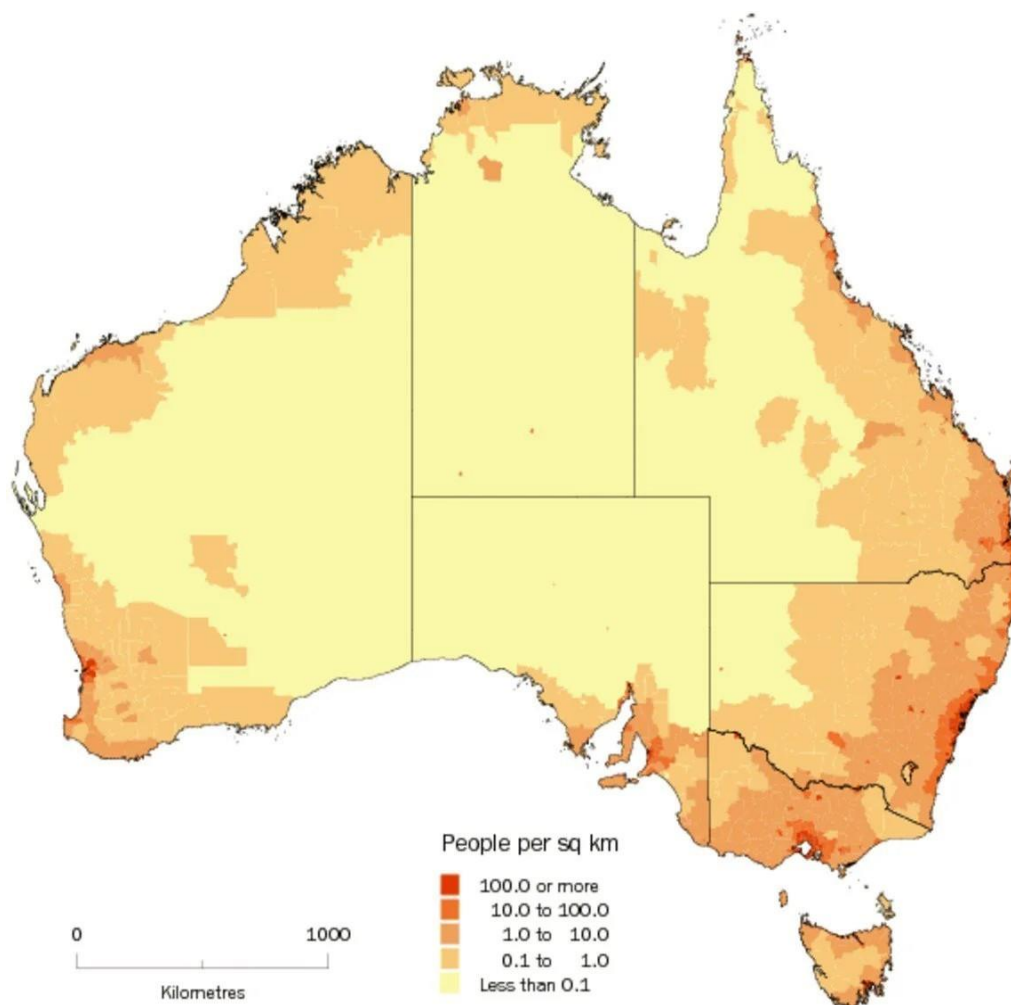
measures and adjustments to water management and agricultural practices (Fig. 9). The current subbasin-wide strategies (such as the Lachlan subbasin which is in the “red zone”) take into account the distribution of the most sensitive and/or adversely modified habitats to balance the different needs for natural resources and their conservation.

#### 4. Demographics of Australia

The population of Australia (Fig. 21) is estimated to be 27,285,400 as of 7 July 2024 [19]. Australia is the most populous Oceanian country and the 56th [20] most populous country in the world. Its population is expected to exceed 30 million by 2029 and is concentrated mainly in urban areas, particularly on the Southern, Eastern, and Southeastern seaboard [21]. Australia's

population has grown from an estimated population of between 300,000 and 2,400,000 Indigenous Australians, at the time of British colonization in 1788, due in part to numerous waves of immigration during the period. The European component's share of the population rose sharply in the late 18th and 19th centuries due to immigration but is now declining as a percentage [22].

The first European settlement on the River Murray in South Australia was Moorundie, settled in 1841 [23]. It was established by the explorer and Protector of Aborigines, Edward John Eyre, who monitored and attempted to allay the conflicts between the indigenous inhabitants and the overlanders who passed through the area. Eyre had discovered the area around Moorundie during his exploration in 1839 and later was granted 1,411 acres by the colonial government.



**Fig. 21 Australian population and distribution map. Photo Credit: Wikipedia.**



In 1853 the era of steam navigation of the River Murray began, and river ports grew. Then, in 1887, the Canadian Chaffey brothers established the first irrigation settlement in Australia at Renmark. Once the possibility of creating fertile land alongside the mighty waterway using irrigation was realized more European settlers began to take up land around the River Murray. The South Australian government saw an opportunity to assist those who lost their jobs in the depression of the 1890s by settling them along the Murray. This scheme intended that the village settlements would work along communal lines and, after a period of government support, would become self-supporting. The scheme was not a success. After the First and Second World Wars, the government again settled citizens in irrigation colonies along the River Murray—this time returned soldiers and their families. This period saw the flourishing of many of the communities that now exist along the Murray in South Australia.

Australia has an average population density of 3.6 persons per square kilometer of total land area, which makes it one of the most sparsely populated countries in the world. This is generally attributed to the semi-arid and desert geography of much of the interior of the country. Another factor is urbanization, Australia is one of the world's most urbanized countries with 89% of its population living in a handful of urban areas [24]. The life expectancy of Australia in 2015-2017 was 83.2 years, among the highest in the world [25].

#### *4.1 Economy and Water Management*

Murray-Darling Basin Authority [26] noted “The Murray-Darling Basin, occupying about one-seventh of Australia's area, is of immense economic significance, lying across the great wheat-sheep belt in its climatically most reliable section. During the second half of the 19th century, river shipping was of great importance, but, with growing competition from railways and demand for irrigation water (first used at Mildura in 1886), navigation practically ceased. The basin has by far Australia's greatest area of irrigated

crops and pastures, some 1.5 million hectares, more than 70 percent of the national total. It is the country's second largest wine-producing region; other major products include cattle, sheep, grains, and fruit.”

“In 1915 the River Murray Commission, comprising representatives from the three state governments and the commonwealth, was established to regulate utilization of the river's waters. The largest reservoirs are the Dartmouth on the Mitta Mitta River and the Hume on the Murray. The Dartmouth Dam, 180 meters high, is the highest dam of its kind in Australia. The multipurpose Snowy Mountains Hydro-Electric Scheme (completed in 1974) increased the amount of water available for irrigation and generated large quantities of electrical power for peak load periods. Irrigation, however, led to serious salinity problems, so much so that Adelaide, South Australia (which is almost completely dependent on the Murray for its water supply), on occasion received water that, by World Health Organization (WHO) criteria, was unfit for drinking [3]. The problem of Murray salinity has been recognized as of national significance to Australia. Legislative arrangements were drawn up in 1987 and 1992 to introduce comprehensive basin-wide responses to environmental crises and the demand for sustainable development” [26].

#### *4.2 Murray Mouth*

The Murray Mouth is the point at which the Murray River empties into the sea [27]. The interaction between its shallow, shifting and variable currents and the open sea can be complex and unpredictable. During the peak period of Murray River commerce (roughly 1855 to 1920), it presented a major impediment to the passage of goods and produce between Adelaide and the Murray settlements, and many vessels were wrecked or foundered there.

Since the early 2000s, dredging machines have operated at the Murray Mouth for 24 h a day, moving sand from the channel to maintain a minimal flow from the sea and into the Coorong's lagoon system. Without

dredging the mouth would fill up with silt and close. This would cut off the supply of fresh seawater into the Coorong National Park, which would then warm up, stagnate, and die.

Shipping cannot enter the Murray from the sea because it does not have an estuary. However, in the 19th century the river supported a substantial commercial trade using shallow-draft paddle steamers. The first trips were made by two boats from South Australia on the spring flood of 1853. The *Mary Ann*, captained by William Randell, reached Moama (near Echuca) and another The *Lady Augusta*, captained by Francis Cadell, reached Swan Hill [28]. In 1855 a steamer carrying gold-mining supplies reached Albury but Echuca was the usual turn-around point, though small boats continued to link with upriver ports such as Wahgunyah, Tocumwal, and Albury.

Rowland [29] found “The arrival of steamboat transport was welcomed by pastoralists who had been suffering from a shortage of transport due to the demands of the gold fields. By 1860 a dozen steamers were operating in the high-water season along the Murray and its tributaries. Once the railway reached Echuca in 1864, the bulk of the woolclip from the Riverina was transported via river to Echuca and then south to Melbourne.”

“The steam paddleship Etona [30] was launched as a mission steamer, replacing an earlier steam launch, also named Etona, which had been operating on the Murray since 1891. The vessel was based at Murray Bridge, and operated between Goolwa and the Victorian border, stopping at towns such as Mannum, Morgan and Renmark as well as isolated settlements and work camps.”

“The Murray was plagued by ‘snags’, fallen trees submerged in the water, and considerable efforts were made to clear the river of these threats to shipping by using barges equipped with steam-driven winches. In recent times, efforts have been made to restore many of

these snags by placing dead gum trees back into the river. The primary purpose of this is to provide habitat for fish species whose breeding grounds and shelter were eradicated by the removal of the snags.”

“The volume and value of river trade made Echuca Victoria’s second port and in the decade from 1874 it underwent considerable expansion. By this time up to thirty steamers and a similar number of barges were working the river in season. River transport began to decline once the railways touched the Murray at numerous points. The unreliable levels made it impossible for boats to compete with the rail and later road transport. However, the river still carries pleasure boats (Fig. 22) along its entire length.”

“Today, most traffic on the river is recreational. Small private boats are used for water skiing and fishing. Houseboats are common, both commercial for hire and privately owned. There are a number of both historic paddle steamers and newer boats offering cruises ranging from half an hour to five days.” [29].

#### 4.3 River Crossings

The Murray River has been a significant barrier to trade and land-based travel. Many of the ports for transport of goods along the Murray have also developed as places to cross the river, either by bridge or ferry. The first bridge to cross Murray, which was built in the town of Murray Bridge, formerly called Edwards Crossing in 1869. To distinguish this bridge from the many others that span the Murray River, this bridge is known as Murray River road bridge. All South Australian ferries paid Murray bridge tolls until abolished in November 1961 [30, 31].

#### 4.4 Reservoirs

Four large reservoirs were built along the Murray<sup>2</sup>. The first was Lake Victoria (completed late 1920s), then Lake Hume near Albury-Wodonga (completed 1936), Lake Mulwala at Yarrawonga (completed 1939),

<sup>2</sup> Only dams along the Murray flow are listed, with some of the tributaries having been regulated by dams and reservoirs as well.





**Fig. 22** Recreational boat on the Murray River. Photo Credit: National Geographic.

and finally Lake Dartmouth, which is actually on the Mitta Mitta River upstream of Lake Hume (completed 1979). The Murray also receives water from the complex dam and pipeline system of the Snowy Mountains Scheme. An additional reservoir was proposed in the 1960s at Chowilla Dam but was never built. It would have been built in South Australia and flooded land mostly in Victoria and New South Wales. It was cancelled in favor of building Dartmouth Dam due to concerns relating to increased salinity and costs.

#### *4.5 Barrages*

From 1935 to 1940 a series of barrages was built near the Murray Mouth to stop seawater entering the lower part of the river during low flow periods [3]. They are the Goolwa Barrage, with a length of 632 m built in 1869, Mundoo Channel Barrage 800 m; Boundary Creek Barrage 243 m; Ewe Island Barrage, 853 m; and Tauwichee Barrage, 3.6 km. These dams inverted the patterns of the river's natural flow from the original winter-spring flood and summer-autumn dry to the present low level during winter and higher in summer.

These changes ensured the availability of water for irrigation and made the Murray Valley Australia's most productive agricultural region. However, the changes seriously disrupted the life cycles of many ecosystems, both inside and outside the river, and the irrigation has led to dryland salinity. The salinity now threatens the agricultural industries.

#### *4.6 Wellington Weir*

In 2006, the Government of South Australia released a plan to investigate the construction of controversial Wellington Weir. Wellington Weir was a weir proposed for the River Murray several kilometers south of the town of Wellington, South Australia, immediately upstream from where the river enters Lake Alexandrina [4]. The proposed weir was suggested as an attempt to secure drinking water supplies for the city of Adelaide. The weir would perform two roles. It would maintain a pool of water upriver, sufficiently deep enough to allow continued use of the pumping station at Mannum during prolonged drought conditions. In addition, the weir would reduce the flow

of fresh water into Lake Alexandrina and Lake Albert which evaporates over 1,000 giganalitres of water a year.

Much of the river is already controlled by a system of locks and weirs. The lowering of water levels in the lake system would severely impact on all who rely on the lakes and river for their livelihood. This would include irrigators, such as those in the Langhorne Creek wine region, farmers on the Narrung Peninsula and Point Sturt, and fisher people at Meningie and Clayton.

Opponents of the weir contended that the planned weir would severely damage the environment of the lakes and Coorong, and that already endangered species in the lakes and Coorong could become extinct. Sim and Muller [32] trace the complex history of the area. Lloyd [33] argues the weir diverts attention from the real issue: the sustainability of the Murray-Darling system. There was no environmental impact assessment conducted for the proposed weir. The area that would have been impacted is subject to a Ramsar Agreement [34], as part of an international convention that aims to halt the loss of wetlands<sup>3</sup> and conserve those that remain through wise use and management.

Questions of over-allocation of water were significant in the debate regarding the cost of a weir [35]. For instance, why not spend money on buying water licenses from irrigators that use water from the Murray River system to grow cotton in Queensland, rather than build this weir? [36].

Local action groups, including the *River, Lakes and Coorong Action Group*, formed to oppose the weir. In addition to the many concerns above they also pointed out that the water held back by the proposed weir would be stagnant because “winds from the northwest to the south circulate oxygenated waters from the lakes up the river for many kilometers and winds from the north and northeast bring back freshened water benefiting both areas and precisely fitting in with our anti-clockwise wind rotation” [37, 38]. Additionally, there were

widespread concerns about the release of toxic metals and acidity through the drying out of the acid sulphate soils that are widespread around the lakes.

The Wellington Weir was officially dropped by the South Australian Rann government in 2009, primarily due to community pressure about the environmental damage it would result in and the construction of the Port Stanvac desalination plant. Drought-ending floods in the upper Darling River in late 2009 and the upper Murray River in April and May 2010 ended the matter.

#### *4.7 Locks*

Lock 1 was completed near Blanchetown in 1922. Torrumbarry weir downstream of Echuca began operating in December 1923. Of the many locks that were proposed, only thirteen were completed; Locks 1 to 11 on the stretch downstream of Mildura, Lock 15 at Euston and Lock 26 at Torrumbarry. Construction of the remaining weirs purely for navigation purposes was abandoned in 1934. The last lock to be completed was Lock 15, in 1937. Lock 11, just downstream of Mildura, creates a 100-kilometre long lock pool that aided irrigation pumping from Red Cliffs to Mildura [3].

Each lock has a navigable passage next to it through the weir, which is opened during periods of high river flow, when there is too much water for the lock. The weirs can be completely removed, and the locks completely covered by water during flood conditions [3]. Lock 11 is unique in that the lock was built inside a bend of the river, with the weir in the bend itself. A channel was dug to the lock, creating an island between it and the weir. The weir is also of a different design, being dragged out of the river during high flow, rather than lifted out.

### **5. Discussion: Drying Up Rivers of the World**

As a result of anthropic activities and climate change several great rivers of North America and the

<sup>3</sup> As many as 16 internationally recognized ecologically and biologically significant wetlands are associated with Murray-Darling catchment basin.



World are drying up and in need of restoration and mitigation. These included the Rio Grande on the Mexico-United States border with headwaters in Colorado and Colorado River which historically drained from headwaters located in Colorado to the Gulf of California. In both case studies, the rivers are now too low for navigation and often run dry. If these rivers are ever to recover the management successes and failures learned from the Native populations must be applied. Hopefully, historical lessons learned from these two case studies can also be applied to the Murray River watershed in Australia which is experiencing lower water levels and reduced navigation options.

### *5.1 Case Study 1: Rio Grande, North America*

Olson and Lang [39] found “The headwater source of the Rio Grande is in the Colorado San Juan Mountains as it flows southeast and south. The river crosses deserts and steppes, watering rich irrigated agricultural regions as it drains into the Gulf of Mexico near Brownsville, Texas. The river flow pattern is disrupted by hundreds of dams and irrigation diversions, which has left sections of the Rio Grande River dry. The lower Rio Grande Valley including the Rio Grande Delta is heavily irrigated and has become an important agricultural region. Since the mid-1990s, the flow has been reduced to 20% because of many large diversions, dams and consumption of water by cities and irrigated farmland. Even with a series of 2001 and 2002, Mexico-United States agreements administered by the International Boundary and Water Commission (IBWC) the Rio Grande River had continued to fail to reach the Gulf of Mexico. Mexico and United States share the river. Historically, the Rio Grande has provided limited navigation and border security. There is a need to restore navigation and shipping by creating a lock and dam system from El Paso, Texas and Matamoros, Mexico to the Gulf of Mexico. In addition, there is also a need to restore border security for the Lower Rio Grande, an international border river. If the Rio Grande

is ever going to recover, it will require a lock and dam system and an increased river flow. The increased flow needs to be achieved by adding additional water from feeder lakes, a water pipeline, and a balanced approach to water management must include efficiency measures and aggressive conservation in urban areas and on irrigation lands.”

“The longest section of the border is the 2020 km of the Rio Grande River and is the international border east of El Paso, Texas and extending to Brownsville, Texas. This part of the international boundary is a natural physical barrier created by the Rio Grande. However, the river often dries up and is no longer a natural barrier to illegal immigration. A lock and dam system with feeder lakes is needed to re-create navigation on the Rio Grande River and to re-establish shipping, commerce and international trade which would benefit both Mexico and the United States as well as the 6 million United States and Mexico residents living in the Rio Grande Valley. The creation of a lock and dam system on the Lower Rio Grande would have a secondary homeland security benefit. The Rio Grande River would again become a natural physical barrier to illegal immigration. When a wall is built, it is often followed by soil tunneling if the soil and parent materials and depth to water table are all favorable. Historically, there has been little tunneling under the Rio Grande River, due in part to the potential flooding of the soil tunnels. In addition, soil tunnels built in porous and unstable unconsolidated soil and parent material can flood. The Mexico and United States share the river under a series of IBWC agreements. The IBWC traces institutional roots extending back to 1889. Outdoor recreation is now the third leading industry behind only agriculture and mining. If the once mighty Rio Grande is ever going to be restored it will need a lock and dam system with feeder lakes and a water pipeline in addition to a balanced approach to water management, including efficiency measures and aggressive conservation.” [39].

### *5.2 Case Study 2: Colorado River, North America*

Olson and Lang [40] noted “Historic Native American and modern civilizations have been forcing the unstable use of the Colorado River and adjacent land resources for centuries. Much can be learned from past Native American cultures such as the Hohokam in the Colorado River watershed which can be applied to modern civilization. Over time, soil management difficulties increased. Soils became waterlogged because of a lack of drainage under the irrigation systems. Sediment filled the Hohokam canals and salts accumulated in the fields reducing the soil productivity and crop yields. The adobe walls of the villages were unstable because of salt erosion. Salt weathering of the adobe walls resulted in their crumbling and eventual collapse and the irrigated fields were largely abandoned. Many of the modern canals overlapped or paralleled the ancient Hohokam canals. Soil salinity and erosion problems remained a threat to the stability of the modern irrigation systems. Modern technology has enabled better crop production through improved water management and effective soil drainage under the irrigation systems to remove salt from the soil profiles. The Yuma tribes farmed and hunted the floodplain of the Colorado River. The river, with an irregular flow could not be used for canal irrigation. The agricultural and urban needs in the United States are continuing to grow and it appears the days of Colorado River flowing into Mexico and the Gulf of California are numbered after declining for decades. The Colorado River is disappearing, and restoration efforts appear to be too little too late. If the Colorado River valley is ever going to recover, previous lessons learned from the Native Americans, including the Hohokam, must be applied. A balanced approach to water management is needed and must include aggressive conservation and efficiency measures such as creating irrigation systems with underlying drainage systems to prevent the capillary rise of salty water to the soil surface.”

“If the Colorado River Valley is ever going to recover the management successes and failures learned

from the Native Americans, including the Hohokam, must be applied. We could learn a lot from their previous behavior and experiences and should apply the lessons learned to the disappearing Colorado River which often runs dry. The Colorado River flow has rarely reached the Gulf of California in the last few decades. Colorado River that discharges into the Gulf of California in Mexico is over-apportioned and the river is often only a trickle at best and at times it is totally dry. Most often all the water was used by ranchers, urban dwellers and farmers. The Mexico-United States boundary includes 1,600 km of the Rio Grande and 1,600 km of upland between El Paso and Tijuana with the Colorado River flowing across the border and through Mexico to the Gulf of California. However, in most years, the Colorado River runs dry and disappears” [40].

### *5.3 Drying Up Rivers of the World Case Study Applications to Murray-Darling Basin, Australia*

The Murray-Darling Basin, occupying about one-seventh of Australia's area, is of immense economic significance, lying across the great wheat-sheep belt in its climatically most reliable section. During the second half of the 19th century, river shipping was of great importance, but, with growing competition from railways and demand for irrigation water, navigation practically ceased. The basin has by far Australia's greatest area of irrigated crops and pastures, some 1.5 million hectares, more than 70 percent of the national total. It is the country's second largest wine-producing region; other major products include cattle, sheep, grains, and fruit.

In 1915 the River Murray Commission, comprising representatives from the three state governments and the commonwealth, was established to regulate utilization of the river's waters. The largest reservoirs are the Dartmouth on the Mitta Mitta River and the Hume on the Murray. The Dartmouth Dam, 180 m high, is the highest dam of its kind in Australia. The multipurpose Snowy Mountains Hydro-Electric Scheme increased the amount of water available for



irrigation and generated large quantities of electrical power for peak load periods. Irrigation, however, led to serious salinity problems, so much so that Adelaide, South Australia, on occasion received water that, by WHO (World Health Organization) criteria, was unfit for drinking. The problem of Murray salinity has been recognized as of national significance to Australia. Legislative arrangements were drawn up in 1987 and 1992 to introduce comprehensive basin-wide responses to environmental crises and the demand for sustainable development.

Current global environmental, water, and climate strategies are based on the implementation of a hierarchical approach that prioritizes avoidance of negative impacts and sequences minimization, restoration of recipients, and compensation for unavoidable impacts and outcomes that have already occurred. In this context, the Murray Basin is fortunate in that Australia has been at the forefront of this approach and can serve as an example of best practice.

Shortly after the Australian Government approved the Water Act in 2007, it established the Murray-Darling Basin Authority, a government body responsible for managing water resources at a catchment area scale rather than at regional administrative boundaries. Five years later, the Authority adopted the Murray-Darling Basin Plan, an important element of which was the Sustainable Diversion Limit Adjustment Mechanism—a form of offset whereby negative environmental impacts from water diversions are to be compensated by improving the effectiveness of environmental water in achieving environmental outcomes. This principle is in line with the concept of “equivalent environmental outcomes” (or “no net loss” in other terms) and, in the case of the river basin, suggests that “through various programmes, environmental outcomes equivalent to the target overall water intake can be achieved with less water” [41].

The Plan is supported by three types of local or basin-wide projects: (i) environmental works and measures involving building environmental

infrastructure, (ii) constraints management and relaxation measures that are intended to allow flows onto the floodplain while mitigating any adverse effects of flooding on private property and landholders; and (iii) the changes to operational rules system enhancements.

Progress on implementing the Basin Plan was initially monitored and audited by the National Water Commission and, after its abolishment, by the Productivity Commission of The Australian Government. But more importantly, the success of the Plan and the effectiveness of its local and thematic activities are closely tracked by Australia's expert community which has proposed an array of research-based initiatives to improve the Plan's outcomes and achieve its environmental targets.

More specifically, based on the review of the first five years of the Plan's implementation, it was proposed to expand the principle of ecosystem damage compensation from “no net loss” to a “no net loss” or “net gain” (i.e., ensuring environmental outcomes are equivalent or better) and to ensure greater integration of long-term climate forecasts into the Plan's targets and basin-wide activities [42].

The metric of the Plan, i.e. the system of quantitative indicators of proximity to its targets, is criticized not only for insufficient consideration of climate risks, but also for other uncertainties, with recommendations for more adequate consideration of cumulative and indirect effects, quantification of residual impacts, and the need for greater flexibility to adjust future actions to the monitoring data on the results already achieved and the actual conditions of the receptors themselves—water bodies, freshwater and the associated terrestrial habitats providing ecosystem services for a variety of stakeholders [41].

Australia is one of the world leaders in the development of environmental and carbon offset markets, and against this background there are sound proposals for integrating the benefits of water, carbon, and environmental projects, for which the Murray Basin is best suited. It is suggested that the economic

base of water-resource initiatives in the river basin could be broadened by trading carbon offsets for which there is continuing demand from greenhouse gas emitters [43].

But the biomass growth provided by measures to maintain the river basin's water cut ensures not only the capture and sequestration of carbon in vegetation, soils, and bottom sediments of the basin—confirming the sustainability of this trend, which slows down as the relevant ecosystems reach a state of maturity, is a separate and very complex monitoring task.

No less importantly, this creates opportunities for ecological offsets based on the growth of biodiversity components. The demand for such offsets will continue for all projects resulting in replacement of natural or critical habitats by modified ones or posing any negative impact on them that could lead to biodiversity loss. And in the case of natural habitats, offsetting should be performed on the No Net Loss basis, and in the case of critical habitats, on the Net Gain basis, as it is already required by a variety of standards coming from international financial institutions.

Given the value of ecosystem services based on biodiversity components, it can be expected that, for individual river basins, their offsetting can bring even more than carbon credits, but the difficulty in their implementation is the need to develop an additional ecological (biodiversity) metric that is much more multi-component than carbon models. At the scale of the Murray-Darling Basin, such a metric has already been developed [44], but for specific projects there is a need to scale it up and adapt the estimation algorithms to local natural and man-made (land and water use) conditions.

Thus, the Murray Basin which has experienced almost the full range of possible human impacts and is therefore partly in crisis, has a good chance of recovering both water resources and ecosystems, and can hopefully serve as an example of a successful basin strategy that integrates legal, water-engineering, agricultural and ecological (conservation) practices

into a single transparent management system whose object has natural rather than administrative boundaries.

## **6. Conclusions**

The primary objectives of this research were to: (1) document the history of the Murray River which became Australia's interior pathway for settlement, navigation, and trade and (2) encourage the creation of a Comprehensive Plan for Sustainable Development of the Murray-Darling Basin to Mitigate the Environmental Impacts. The struggling river trade was finally killed off after the First World War by the rise of road transport. But the river trade left a permanent mark on the river. The lower 878 km of the river became impounded in a continuous series of stepped pools. The weirs primarily became a resource for water supply. The weirs at Torrumbarry, Euston, Mildura and Wentworth each enabled major irrigation developments. South Australia's weirs were also used to develop extensive irrigation in the Riverland. The weirs provided a stable and reliable source of water from which to pump. However, this has become less important over time, as pumps have improved, and upstream storages have become more effective in regulating flow. Several weirs support little or no irrigation.

The Murray-Darling Basin, occupying about one-seventh of Australia's area, is of immense economic significance, lying across the great wheat-sheep belt in its climatically most reliable section. During the second half of the 19th century, river shipping was of great importance, but with growing competition from railways and demand for irrigation water, navigation practically ceased. The basin has by far Australia's greatest area of irrigated crops and pastures, some 1.5 million hectares, more than 70 percent of the national total. It is the country's second largest wine-producing region; other major products include cattle, sheep, grains, and fruit.

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### Conflict of Interest

The authors declare that there is no conflict of interest.

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