Part B - Workshop Outcomes 2: Threats

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Threats and Future Trends

Climate Change

A recent Pew Centre report on *Aquatic Ecosystems and Global Climate Change*[1] reported:

- *Increases in water temperatures as a result of climate change will alter fundamental ecological processes and the geographic distribution of aquatic species. Such impacts may be ameliorated if species attempt to adapt by migrating to suitable habitat. However, human alteration of potential migratory corridors may limit the ability of species to relocate, increasing the likelihood of species extinction and loss of biodiversity.*
- *Changes in seasonal patterns of precipitation and runoff will alter hydrologic characteristics of aquatic systems, affecting species composition and ecosystem productivity. Populations of aquatic organisms are sensitive to changes in the frequency, duration, and timing of extreme precipitation events, such as floods or droughts.*
- *Aquatic ecosystems have a limited ability to adapt to climate change. Reducing the likelihood of significant impacts to these systems will be critically dependent on human activities that reduce other sources of ecosystem stress and enhance adaptive capacity.*

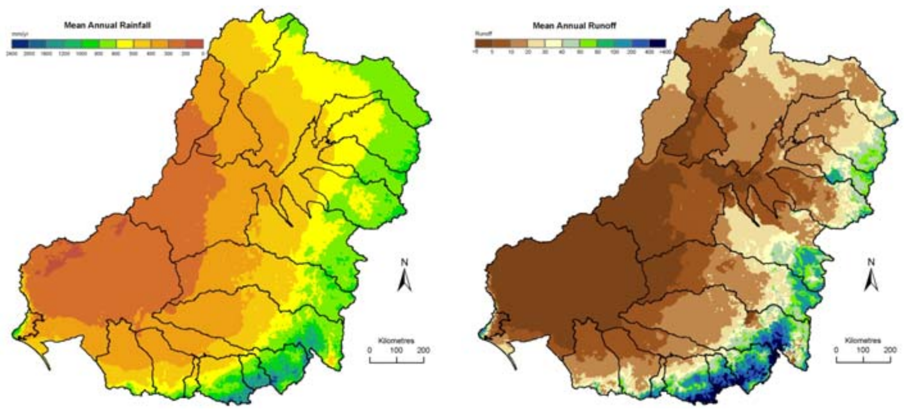
The impacts of anthropogenic induced climate change lead to increased temperature and reduced rainfall. Reduced rainfall and changed seasonality of rainfall can have a significant effect runoff (in general, a 1% decline in rainfall equates to a 2-3% decline in runoff). In addition, changes to local rainfall patterns can have an important influence on associated wetlands (averaged annual rainfall and modelled runoff are shown by figure below). The region of the River Murray - Darling to Sea is relatively small compared with the entire Murray-Darling Basin (MDB). However, being at the terminal end of the system it is almost entirely dependent on water inflow from upstream.

RAINFALL

457 mm averaged over MDB

RUNOFF

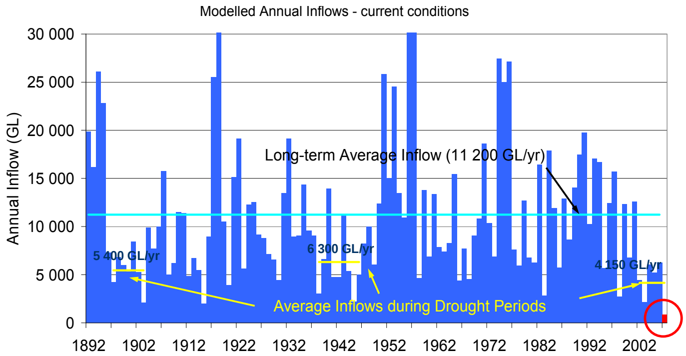
27 mm averaged over MDB



Note: There is a clear east–west rainfall and runoff gradient, with most of the runoff in the MDB coming from upland catchments in the south-east (Source: CSIRO).

River Murray inflows up to 2006 (the driest year on record to date (mid 2009) - see figure below), demonstrate that there have been dry periods in the past, however the recent extended dry period is the driest. The drought conditions in the south of the MDB worsened in 2007 and 2008[2]. In addition to the impacts of reduced rainfall on runoff, recent research has shown that a rise of 1° C leads to an approximate 15% reduction in the climatological annual MDB inflow[3]. It has been suggested that a 1 to 3° C temperature rise by 2050, as projected by the IPCC's 2007 Fourth Assessment Report, would lead to a 15 - 45% reduction of inflow to the MDB, which would greatly exacerbate the impact of a projected 10 - 15% rainfall reduction[4].

Murray-Darling River



The consequences of the drying trend for the Murray-Darling Basin are becoming particularly acute, with water levels and inflow at historical lows and insufficient to meet critical human and ecosystem needs for major regions of the system. The landmark Sustainable Yields Project of CSIRO reported that surface water availability across the entire MDB is expected to decline due to climate change, with a very substantial decline likely in the southern and south-east of the MDB where the impacts of climate change are expected to be the greatest[1]. Under continuation of current water sharing arrangements, much of the impact of reduced surface water availability would be transferred to the riverine environments along the River Murray, including the Lower Lakes and the Coorong[2]. Projections suggest flow at the Murray mouth would cease almost half of the time and severe drought inflows to the Lower lakes would occur in 13% of years[2].

By 2030 the median decline in flows for the entire Basin is projected to be 9 -11% in the north and 13% in the south[2]. Under a worst case scenario, the average annual runoff for the northern half of the Basin may reduce by 30 per cent and in the southern half of the Basin the average annual runoff may reduce by up to 40 per cent[2]. Importantly, the best estimate 2030 climate, while less severe than a continuation of the recent climate, would still lead to significant increases in the average period between beneficial floods for all assessed environmental sites[4].

Natural systems in the MDB, which are already under pressure from reduced inflows from a drying climate and over-allocated water for irrigation, are also likely to be further impacted by climate change. For example, climate change could accelerate woody weed invasion and when this is combined with overstocking of livestock such as cattle and sheep, is likely to lead to increased erosion and an overall loss of biodiversity. Major impacts are also expected to river red gum forests, due to decreased flooding events, and to nesting birds and aquatic species, particularly iconic species such as the Murray Cod.

River Murray near Murtho, South Australia. Photo: John Baker (MDBA website).

1. Poff, NL, Brinson, MM, Day Jr, JW. (2002) Aquatic Ecosystems and Global Climate Change: Potential impacts on inland freshwater and coastal wetland ecosystems in the US. Pew Centre on Global Climate Change Report. http://www.pewtrusts.org/our_work_report_detail.aspx?id=30677
2. CSIRO (2008) Water availability in the Murray-Darling Basin. Summary of a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia.
3. Cai, W., and T. Cowan. 2008. Evidence of impacts from rising temperature on inflows to the Murray-Darling Basin. *Geophysical Research Letters*, V35, L07701, doi: 10.1029/2008GL033390.
4. Cowan, T.D., and W. Cai. 2009. Are declining river inflows linked to rising temperatures? A perspective from the Murray-Darling Basin. 18th World WMACS/MODSIM Congress, Cairns, Australia 13-17 July 2009.

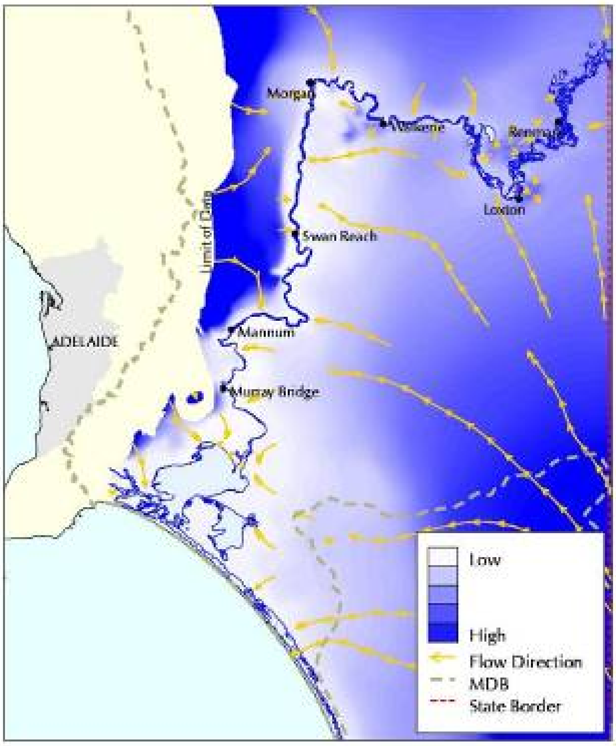
Salinity

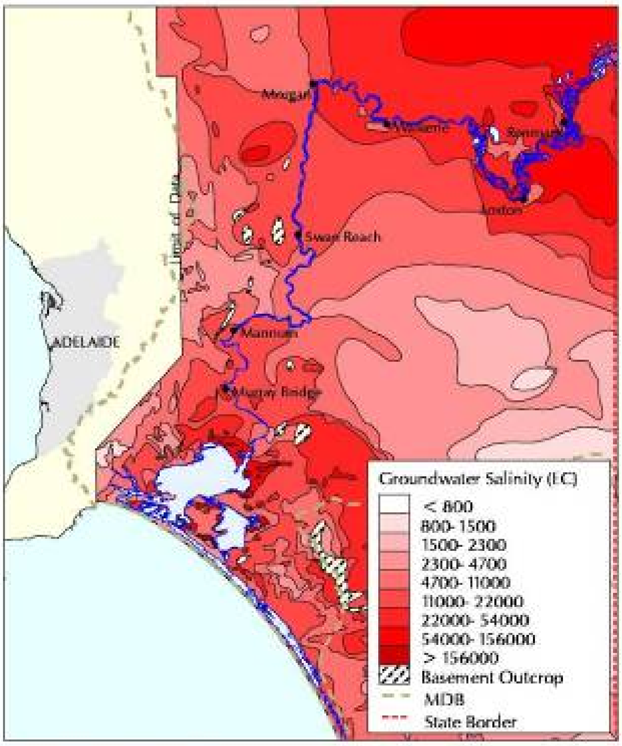
The MDB Salt Story

Over millions of years, the Murray Darling Basin's flat terrain, low rainfall and high levels of evaporation have combined to concentrate salt in the soil and groundwaters of the region. Prior to European settlement, native vegetation helped to keep the salt levels mostly in balance. However, human activities - particularly in the past 100 years, have had a major impact. Agricultural development and irrigation along the River Murray, land clearance (particularly of deep rooted vegetation), and the control of the river water by weirs and dams have caused large amounts of saline groundwater to rise and increased saline discharge into the river system. Rising groundwater is mobilising salt stored in sub-soils and bringing it to the soil surface or carrying it laterally into streams. The River Murray is the only 'drain' from the Murray-Darling Basin and provides a channel for the salt to exit the Basin. However, about 80% of the Basin's water is diverted for consumption, principally irrigation, resulting in less flow to dilute the saline water. As a consequence, large quantities of salt flow down the River Murray every day (for example, 4000 ML/day flowing past Morgan can carry about 1000 tonnes of salt). A program of six salt interception schemes is underway for the river, with four already in place in SA; when completed, an estimated 850 tonnes per day will be intercepted. (Note: Water > 800 EC is unsuitable for irrigating most horticultural crops, while 800 EC is the accepted maximum level for domestic consumption in larger towns and cities (Australian Drinking Water Guidelines); seawater is about 45 000 EC).

The River Murray is the lowest point in the landscape (i.e. bright blue areas are highland in the map below left). The river is capturing surface water from the 1 million square kilometres of the MDB catchment. The exit is the ocean at the northern end of the Coorong (i.e. when the mouth is open).

The river is also capturing groundwater. Flow lines of groundwater to the system are shown in yellow in the map below to the left. Importantly, the river is flowing through highly saline groundwater - with some regions of a salinity higher than seawater (see map below right). Therefore, changes to the dynamics of groundwater can change the salt loads into the river. On average, the river carries 1 to 2 million tonnes of salt a year out into the ocean. However, due to the low flows experienced over the last five or so years, salt is accumulating in the Basin - including both floodplains and river channel.



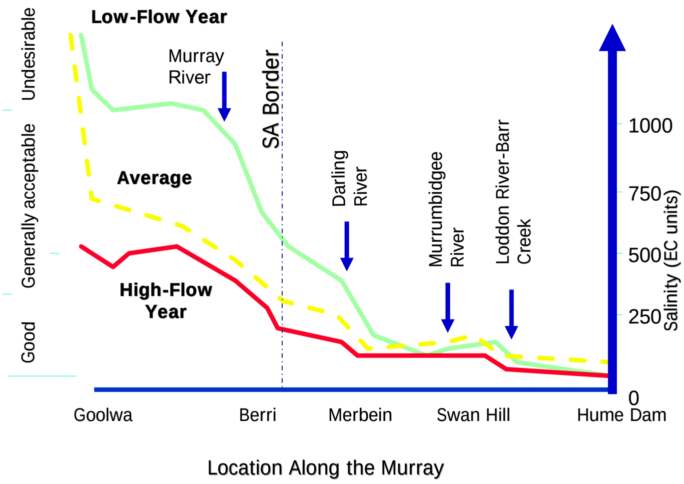


Maps of the Murray River in South Australia - showing to the left, landscape height directional flow of groundwater, and to the right, groundwater salinity (EC), (Source: Phil Cole, MDBA).

Examples of saline seepage to the Lower Murray floodplain (Source: Phil Cole, MDBA)

Salinisation of the landscape and river can be devastating (see above photos). The saline groundwater rising on the floodplain of the Pike River is emerging due to pressure (groundwater drainage) from adjacent irrigation farms. At the site just downstream of Lock 4 (Bookpurnong, near Berri), the wetland is bordered to the highland to the right by citrus irrigation. The salt load flows straight into the river - which could be 100 tonnes of salt per day in a non-drought year. These processes can happen quite quickly, for example, the site of the Pike River region was very healthy only some 30 years ago.

Importantly, salinity is the main determinant of diatom species composition in the Lower Murray, outweighing the effects of flow velocity, pH and nutrients[2]. As diatoms are the dominant phytoplankton in the Murray, salinity changes may prove to have indirect effects on grazing invertebrates, particularly zooplankton[2].



The figure above demonstrates the influence on salinity of high and low flow years in the river channel (i.e. excluding floodplain). Salinity of under about 500 EC is considered good water quality, which is achieved in the years of higher-flow. However, under low flow conditions, salinities are significantly higher, reaching hypersaline conditions in the Coorong. As the figure above demonstrates, the region of the River Murray - Darling to Sea is the region of the entire MDB system that is most impacted by salinity.

Overall, about a quarter of the salt comes down the Darling, about another quarter comes from the irrigation districts in Victoria and New South Wales, another quarter comes from the groundwater systems in South Australia, and the rest is diffuse from all throughout the system. The recent *Water Act 2007*, mandates for a 'Water Quality and Salinity Management Plan' under the 'Basin Plan' which will involve setting salinity objectives and targets.

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1. CSIRO (2008) Water availability in the Murray-Darling Basin. Summary of a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia.
2. Walker, KF. 2006. Serial weirs, cumulative effects: the Lower River Murray, Australia. In: R Kingsford (ed), The Ecology of Desert Rivers, Cambridge University Press: 248-279.

Acid Sulfate Soils

River Murray and ASS

Acid sulfate soils (ASS) are those soils and sediments that contain sulfuric acid, or have the potential to form sulfuric acid when exposed to oxygen in the air (or water) (i.e. from unoxidised iron sulfides (pyrite)). Acid sulfate soils form naturally when sulfate-rich water (e.g. saline groundwater, sea water) mixes with sediments containing iron oxides and organic matter. Potential for acidification was recognised in Lake Albert as early as 1929, which was a pre-barrage time (and the second oldest recorded observation of ASS in Australia). The river system has always had the 'raw materials' to form acid - sulfate, iron, organic matter, bacteria. Potentially acidic (sulfidic) soils are common in the River Murray; when sulfidic soils oxidise, their pH drops below 4. For example, at Wellington there is about 40 m of sulfidic (pyritic) clay in the river channel. Before European interference, acid would have formed seasonally when river levels dropped, and the acid products would be flushed to the sea at periods of higher flow. Biota would have adapted to these conditions. If left undisturbed and covered with water, sulfidic sediments pose little threat. However, when exposed to oxygen, such as under drought conditions, chemical reactions may lead to the generation of sulfuric acid. When these sulfuric sediments are re-wetted, there is a risk that significant amounts of sulfuric acid and heavy metals may be released into the water leading to acidification, deoxygenation (when monosulfides oxidise), contamination and the release of noxious gases. These risks can lead to irreversible damage to the environment and serous impacts on water supplies and human health. The extent and importance of ASS in the River Murray, lower lakes and adjacent wetlands has only recently been fully appreciated[1].

Current Status

The current drought (as at mid 2009) has lead to the exposure of large sections of river bank, wetlands and lakes that once contained high levels of unoxidised (reduced) iron sulfides. Many river and wetland sites between Wentworth (the Darling junction) and the Coorong have been evaluated for acid sulfate soils. These soils occur throughout this system, particularly in large stretches of the river in South Australia around Renmark, Blanchetown and Murray Bridge, as well as in lakes Albert and Alexandrina, near the mouth. Metavoltine, a yellow mineral previously only ever recorded in acid mine drainage, has been recorded near Murray Bridge. It has proved difficult to predict in advance whether wetland soils are likely to acidify.

The installation of weirs and barrages has provided for a stable pool level for about 70 years, and that has had the effect of producing wetland environments that have retained the sulfur as pyrite in their soils - i.e. instead of having the normal oxidation, reduction and flushing cycle - that cycle has been interrupted. The permanent inundation of the river, wetland and lake systems has therefore had a significant impact on the formation of soils in these ecosystems because of the loss of natural wetting-drying cycles, which is so important to biodiversity and wetland functioning. This change has promoted the significant build-up of sulfide minerals (mostly iron pyrite) and sulfidic materials in these newly formed subaqueous soils. Evapo-concentration and decreased flushing increases salt concentrations and alkalinity - high sodium in sulfidic soils results in formation of acidic minerals that are very water soluble.

Irrigated agriculture on river flats has also probably helped maintain subsoils in a reduced state and applied sulfate sourced from fertilisers. River banks are largely already mildly acidified due to past wetting and drying cycles, and removal of carbonate. Sulfidic groundwater systems that occur at depth may also impact on receiving environments.

Impacts

Jury Swamp, SA: CSIRO

Tareena Billabong, NSW: CSIRO

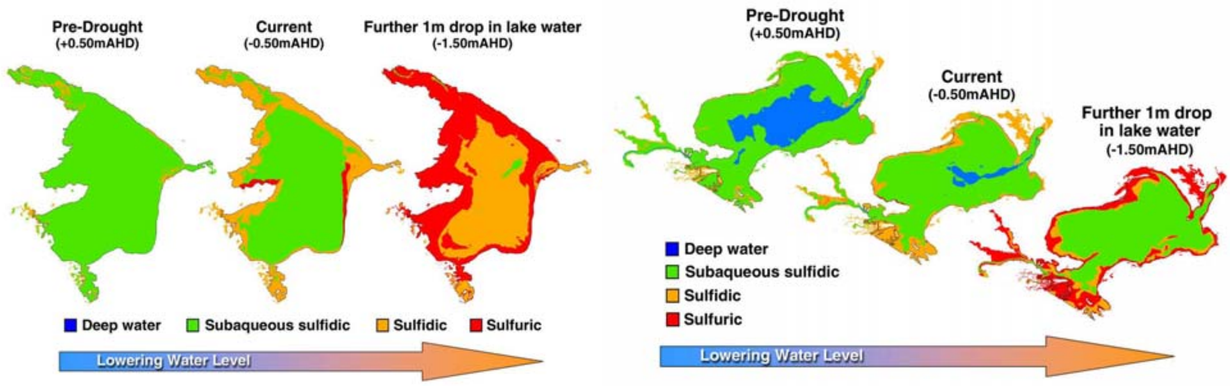
1. Fitzpatrick, R, Grealish, G, Shand, P, Marvanek, S, Thomas, B, Creeper, N, Merry, R, and Raven, M. 2009. Preliminary Assessment of Acid Sulfate Soil Materials in Currency Creek, Finniss River, Tookayerta Creek and Black Swamp region, South Australia. Land and Water Science Report CLW 01/09.

The presence of sulfidic materials can potentially have serious environmental consequences relating to: soil and water acidification if oxidation occurs; deoxygenation of water; or formation of malodours (e.g. H_2S). Previous work by CSIRO Land & Water and others in the MDB has identified occurrences of sulfidic, sulfuric and monosulfidic black ooze materials in a range of subaqueous soils and sediments[1]. Recent studies have also shown potential risks from the remobilisation of metals, especially following oxidation and re-wetting, including Al, As, Cd, Co, Be and Ni in oxidised ASS[1] - particularly when pH values drop below about 5. Re-wetting of exposed banks helps to absorb and counteract acidity from the slightly basic river water, but toxic metallic salts created during the process can also be washed into the main stream. Where residual alkalinity in ASS is used up, clays usually provide buffering at pH values between 3.5 and 4, but sandy materials have little buffering and pH values can be much lower.

Examples of extreme ASS impacts are shown by photos (above) of Jury Swamp - with exposure of sulfidic soils with pH values of 2.5, and at Tareena Billabong. In early 2007, Tareena Billabong (south-west NSW) was isolated by sandbagging from Salt Creek and the River Murray as an option to generate water savings and help mitigate drought-related problems in the MDB. In early 2008, a massive fish kill probably resulted from toxicity and deoxygenation caused by acidification from nutrient-rich submerged banks exposed to air for the first time in decades.

Future Trends

The prolonged drought has caused water levels to recede in the river and wetland systems of the Murray, including the freshwater Lower Lakes which have begun to dry, uncovering extensive areas of sulfidic material in the subaqueous soils. Alkalinity and pH are being monitored in exposed soils to assess the risk from acid sulfate soils (critical alkalinity values set). The focus is on mapping soil acidity and understanding the future risks by monitoring how acid is generated, transported and neutralised, as well as assessing the effectiveness and practicality of alternative management strategies such as seawater, liming, re-vegetation, or re-flooding. A decrease from -1m to -1.5m AHD may expose up to 20-30 000 ha of potentially sulfidic soils.



Lake Albert ***Lake Alexandrina***

Combined bathymetry, soil and vegetation mapping in GIS was used to predict the distribution of the various subtypes of ASS according to predictive scenario maps (Note: -0.5 m is the approximate level during early 2008, and -1.5 m AHD is an extreme case, should Lower Lake inflows persist. Source: CSIRO .2009).

Abatement Potential

With a return of 'normal' flows, acidified soils should be covered with water and re-establishment of reducing conditions should result in re-formation of iron sulfides, a process which creates alkalinity and is usually benign. This process is expected to be much slower than oxidation/ acidification. Significant 'flushing' flows are needed to help move acidification products to the sea. Introduction of sea water with its alkalinity (about half that currently found in Lower Lakes) has the potential to re-establish reducing conditions, but it is difficult to predict effectiveness without adequate tidal flushing. The contribution of groundwater alkalinity is difficult to assess. If water levels decrease further (as of mid 2009), the application of lime, currently used to try to treat hot spots, may not be adequate to neutralise the expected rapid increase in acid production (often large). It is likely that the river and wetland environment have experienced these current conditions in the past and recovered, though river management and the confounding influence of climate change have changed the baselines. The aim should be to reproduce something of the seasonal variations and ensure flushing flows.

Flow Regulation

Operational Flow and Infrastructure of the River Murray

The Murray-Darling Basin is one of the most intensively regulated river systems in the world, reflected in the extent of diversions and the numbers of dams, weirs, barrages, bunds, blocking banks, causeways, levees and other regulating structures. The Lower River Murray (below the Darling junction) has 10 weirs from Wentworth (Lock 10) to Blanchetown (Lock 1), built originally (1922-1937) to promote year-round riverboat transport, but is now used mainly to preserve stable levels for irrigation[1](and see Appendix 2). The weirs have little effect on through-flow but exert a major influence on water-level variability in the channel and on connectivity with floodplain wetlands and woodlands. In general, the effect of weir operations is to maintain a steady upstream pool level except when flows exceed storage capacity. During high flows the panels and `stop logs' forming each weir are removed, then reinstated during the flood recession. At other times the river level is maintained near a target 'pool level'. The degree of control increases downstream towards Lock 1, as successive weirs dampen flow variations[1]. There are also levees, offstream regulators, and tidal barrages near the river mouth, and 'temporary' weirs and other structures were recently installed (mid 2009, or are planned) in Lake Alexandrina.

Over the last century, diversions of water from the Murray channel have increased, chiefly for agriculture. Today, these diversions, 95% of which are used for irrigation, account for more than two thirds of the Basin's mean annual runoff. Water storage capacity and diversions have increased greatly since the 1920s, and especially since the 1950s. This storage capacity provides the ability to influence the flow regime. In addition, private storage capacity (particularly farm dams) has increased in recent decades. Increased storage provides greater opportunity to modify flow patterns relative to natural conditions.

Flows in the River Murray Channel can be classified into three operating 'modes'[2]:

• Supplying mode - *when some or all of major storages (Dartmouth and Hume reservoirs, Lake Victoria or the Menindee Lakes) are drawn down;*

• Storing mode - *when the large storages are filling and the flows downstream of these storages are confined to the Channel but meet or are in excess of that required to meet downstream requirements;*

• Spilling mode - *when flow exceeds Channel capacity at some site, typically when at least one of the headwork storages is spilling.*

Different operating modes can operate simultaneously in different reaches of the river. This classification provides a useful framework for understanding current river operations, and, in the future, environmental flow procedures could be tied to a mode of operation on a reach-by-reach basis, and coordinated between reaches. There are a number of operational and environmental issues and uncertainties that increase the complexity of meeting flow targets (e.g. diversions, minimum flows, environmental targets) along the channel (including those associated with the use of environmental water allocations) during each operating mode. There are many rules for management of flows along the channel applied to protect specific environmental values.

Lock 6, near Renmark (Source: K. Walker).

Hume Dam (Source: MDBC).

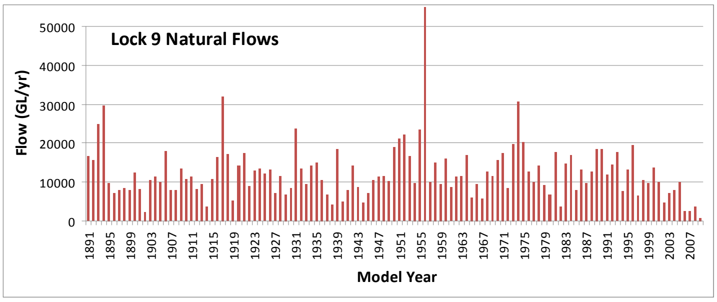
Implications

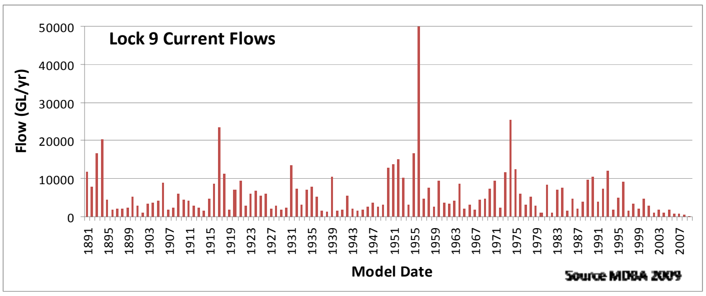
Flow is considered the 'master variable' (or maestro) for the Lower Murray system (i.e. RM-DS). As a consequence of flow management and operation of infrastructure, changes to the flow regime of the Murray have been considerable at annual, seasonal and daily scales. The extent of impacts depends on the location along the river. The proportion of flow within the river channel as opposed to on the floodplain has changed, with the greater proportion of flow now contained within the river channel. There are significant threats to the environmental values of the floodplain-river ecosystem associated with these changes to flow regime.

The main impact of regulation in the South Australian section of the Murray is the reduction in overall flow volume (Increased stability of water level and reduced variability are also important impacts). There are eight months (November - June) when the median monthly flow is less than the minimum median monthly flow in any month under natural conditions. The seasonality is similar to the natural pattern, although the duration of high flows is considerably truncated under current operating conditions[2]. Before river regulation there was a high degree of seasonal and inter-annual variability in the flows and/or water level in the channel. Regulation has reduced variability at this scale, although water levels may now fluctuate more rapidly as a result of weir operations. Small floods with a return time of less than seven years have been almost eliminated in much of the Lower Murray, and once-temporary floodplain areas below normal pool levels are now permanently inundated. The Lower Murray is virtually a series of cascading pools (weir pools occupy 52% of Murray length[3]). Regulation has extended the area of permanently flooded wetlands, with 70% of wetlands in the Lower Murray now connected to the river at pool level[3].

Hydrographic Signature

River ecosystems are governed by the flow regime. The Lower Murray has no major tributaries, and its hydrographic behaviour is usually determined by flows from the middle and upper Murray rather than from the Darling River[3]. The Murray has a highly variable regime with an erratic pattern of highs and lows. Over the past 100 years, there have been significant shifts in climate, with dry and wet periods at decadal scales, and a series of significant droughts (e.g. Federation drought, World War II drought) and floods (e.g. the 1950s) – see graphs below. In the latter part of the 20th Century, the river flow regime was dominated by low flows (<5000 Ml/day), owing to intensive regulation. High flows (>20 000 ML/day) were little affected, because the river would overflow the weirs. Ecologically, the most significant changes to the natural pattern were from the reduction in the frequency of moderate flows (5000 to 20 000 ML/day).





Disconnection and Future Trends

Each dam, weir or other flow regulator, represents a disconnection for a floodplain-river ecosystem, and the cumulative effects for the Murray have been profound. This challenges the task of managers concerned with recovery or restoration. The natural flow regime should persist as the template, because it contains the cues for reproduction of the biodiversity we are seeking to preserve. The last decade or so may represent a foretaste of the future to come under climate change. CSIRO research projects a possible 30 to 45% reduction in flow[3].

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1. Walker, KF. 2006. Serial weirs, cumulative effects: the Lower River Murray, Australia. In: R Kingsford (ed), The Ecology of Desert Rivers, Cambridge University Press: 248-279.
2. Living Murray Foundation Report, 2005: Chapter 7 Information Base for the River Murray Channel. **http://www.mdbc.gov.au/subs/dynamic_reports/foundation_report/7.html**
3. CSIRO (2008) Water availability in the Murray-Darling Basin. Summary of a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia.

Invasive (Problem) Species

Definition and Traits

An invasive species is generally considered as a non-native species whose introduction does, or is likely to, cause economic or environmental harm or harm to human, animal, or plant health. Often excluded from this definition are:

- *overabundant native species (e.g. crown-of-thorns starfish)*
- *plants and animals under domestication or cultivation and under human control (e.g. cats)*
- *species whose beneficial effects are deemed to outweigh any negative impacts (e.g. cows).*

However, for the purposes of this EC assessment - all of the above are considered under the 'invasive species' banner. Common traits of invasive species are:

- *biologically hardy, i.e. tolerant of broad environmental conditions, generalist diet*
- *ecologically hardy, i.e. fast growth, early maturation, high reproductive output, short generation times*
- *opportunistic, i.e. move into disturbed environments and out-compete native species which may have already impaired resilience*
- *often are relieved from the pressures of predation or parasites of their native territory/country.*

European Carp from Lower Murray (Source: Ben Smith, SARDI)

Noogoora burr (Xanthium occidentale) (Source: Castlereagh Macquarie County Council website)

Range of impacts

Invasive species can have a broad range of impacts and can potentially be 'ecosystem engineers', causing significant environmental changes which alter the composition and abundance of native plant and animal communities. Specific impacts may include:

- competition for food, nutrients, light, nest sites or other vial resources
- dislocation of native species from preferred habitats
- predation
- causing or vectoring diseases
- spreading weed seeds
- reducing agricultural/horticultural production.

Invasive species are often a key threat (after habitat loss) to species of conservation concern. A priority should be the identification of high risk taxa and keeping them out. Once established, invasive species are extremely difficult to eradicate.

Scope of the Problem in the Lower Murray (RM-DS)

Rivers such as the Lower Murray naturally have a distinctive, erratic hydrographic signature. A consequence of this is that the native flora and fauna are likely to include species with wide tolerance to environmental change, opportunistic life cycles and a capacity for rapid dispersal. Most native species of plants and animals rely on variability of conditions to cue for reproduction and dispersal. However, engineering has increased the stability of seasonal and inter-annual water levels (although daily levels may be more variable) and this has discouraged native species and favoured non-natives.

Weeds
There are about 150 invasive plant species, but only a small fraction are abundant and widespread in the Lower Murray. Willows (*Salix* spp.) form dense monospecific stands along the banks in the highly regulated conditions; weeds like noogoora and California burr (*Xanthium* spp.) form large persistent soil seed banks on the floodplain awaiting the next over-bank flow; lippia (*Phyla canescens*) is another species of concern that can form extensive dense mats on the floodplain that exclude almost all other species. Native species that have increased in abundance due to river regulation include the bulrush (*Typha* spp.) and common reed (*Phragmites australis*), which are well adapted to stable water levels.

Mammals & Birds
There are 8 key species of pest mammals in the region, e.g. rabbits, foxes, wild cats, wild dogs, mice. Pest birds include, for example, starlings, blackbirds, sparrows, etc.

Fish
There are at least 11 introduced fish species in the MDB (plus tilapia is a close-by, potential invader) with 6 key species for the Lower Murray): common carp, redfin perch, eastern gambusia, brown and rainbow trout, oriental weatherloach (not yet in SA). Of these, carp is the one of the greatest threats to the ecosystem.

The spread of carp (*Cyprinus carpio*) throughout the Murray-Darling Basin coincided with widespread flooding in the 1970s[1]. Introduced carp are now the most abundant large freshwater fish in the MDB. Carp can tolerate a range of water temperatures, salinity levels and polluted water (they prefer dark, murky waters). Higher carp densities have been found to be closely linked with riverine systems affected by dams and agriculture. There are about 10 different strains of carp in the MDB. It is likely that carp do not spawn in the Murray upstream of Barmah-Millewa Forest. Research in SA found that carp are always the first fish into wetlands when waters rise, but the last to leave. Carp can increase water turbidity and damage aquatic plants and insect populations through their bottom-feeding behaviour, degrading aquatic systems including wetlands. They may displace native fish species and make aquatic habitat less suitable for native fish breeding and survival, and compete for resources. Estimates suggest that carp generates an annual cost impact of close to $16 million per year[1].

Invertebrates, Diseases and Parasites
An important marine invader is the tubeworm (Polychaeta: Serpulidae) *Ficopotamus enigmaticus*. It forms calcareous masses on submerged hard surfaces in brackish water, and has killed many turtles in the Lower Lakes. Other invertebrate pests include, for example, locusts/grasshoppers. Many invasive species carry diseases and parasites.

Related Policy Initiatives and Strategies
A range of policies and strategies (underpinned by considerable investment in containment, incursion control and research) have been developed to address various aspects of invasives:

- Australian Pest Animal Strategy (DEWHA) – a national strategy for the management of vertebrate pest animals.(released in 2007)
- Australian Weeds Strategy (DEWHA) – a national approach for weed management.
- Native Fish Strategy for the MDB (MDBA) – controlling alien fish is one of the six 'Driving Actions' required to achieve the goal of rehabilitating native fish populations to 60% of pre-European levels in 50 years
- Draft Regional Pest Management Plan (SA MDB NRM Board) – priority given to terrestrial vertebrates and weeds but also includes recognition of aquatic pests
- National Threat Abatement Plans for some species (DEWHA) e.g. European red fox
- AusBIOSEC (Whole of Government) - the Australian Biosecurity System for Primary Production and the Environment, which covers all invasive plants, animals and diseases, of the terrestrial and aquatic environment that could be harmful to primary industries, the natural and built environments, and public health.

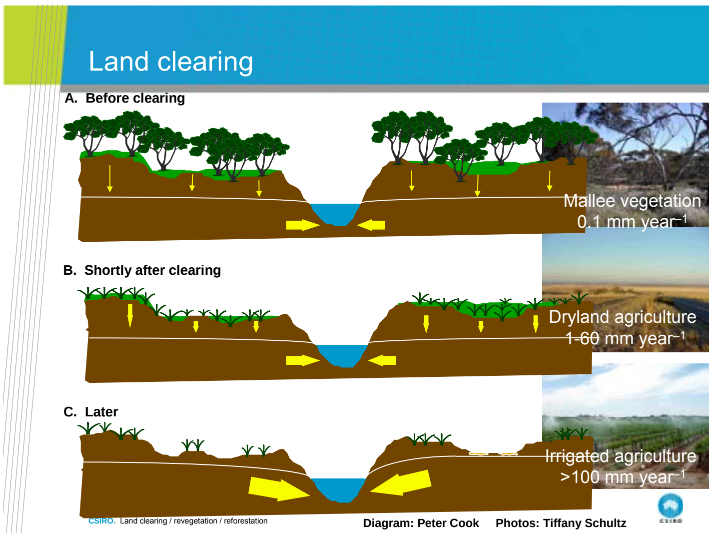
1. European Carp, Invasive Animals CRC
http://www.invasiveanimals.com/invasive-animals/fish/european-carp/index.html, viewed 19/10/2009.

Land Clearing/ Revegetation

Historical aspects

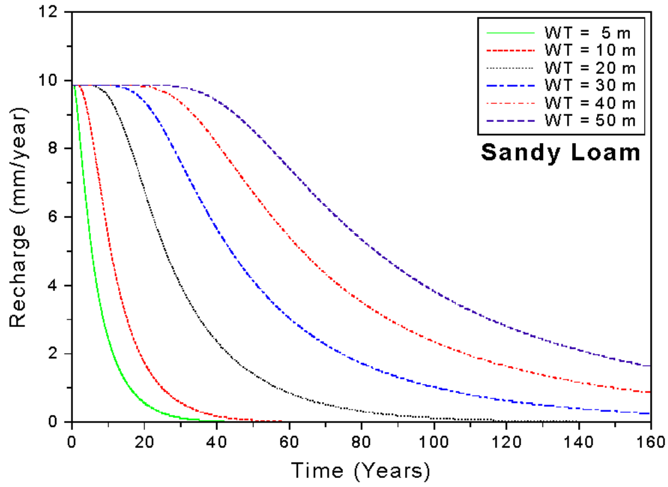
Since European settlement, the Murray-Darling Basin has been the location of some of the most extensive and dramatic vegetation cover changes in Australia. For Australia as a whole, some 20% of the native vegetation has been cleared for agricultural and other purposes[1]. By comparison, at least half of the Basin's pre-European vegetation cover has been removed[1]. Some of the major changes for the Basin have been the clearing of eucalypt woodland and shrubland in the drier areas and their replacement by crops and pastures. South Australia, in particular, has experienced significant land clearance (>80%), with some of the worst problems in the Mallee areas that were cleared for grazing. In addition, large areas of native vegetation have also been thinned rather than cleared – usually in relation to agricultural activities, but also at times for urban development. Overall, the most dramatic change in the Murray-Darling Basin's vegetation cover and land use is that from one of natural vegetation (though not unmodified) to agricultural landscapes. Much of the clearing has occurred relatively recently, i.e. over the past 50 years. Land clearing continues in parts of the Basin, but measures are being taken to stop or reduce it. For example, in South Australia, farmers have to obtain planning permission before they can clear native vegetation and applications are often rejected. Also, large numbers of trees are now being planted by government and community supported revegetation programs across the Basin.

About 80% of land in the MDB lies in arid and semi-arid regions. Vegetation clearance has resulted in widespread degradation of the land, including: loss of habitat for native plants and animals; deteriorating soil structure; acidification; loss of topsoil through erosion; and river siltation. Widespread dryland salinity is also a major consequence of vegetation clearance. Changes to the vegetation cover, primarily the removal of the native grasses, shrubs and trees, have changed the natural water balance. In particular, the clearing of native vegetation in has led to increases in groundwater recharge of up to two orders of magnitude in some locations in South Australia [3]. Clearing and replacing of deep rooted native trees and grasses with annual crops and pastures have meant that naturally occurring salts are brought to the land surface with rising groundwater and the watertable gradient may drive groundwater (and salt) towards the river. Importantly, recent research suggests that land clearance and loss of vegetation may be a significant contributing factor in climate change and exacerbation of droughts at a regional scale[2].



The figure above demonstrates the relative time delays in soil saturation to the water table and then transmission by pressure to the river valley. For example, with the Mallee vegetation in place, most of the rainfall is used up by the plants. However dryland and irrigated agriculture results in more saline laden groundwaters entering the river channel, and this is probably exacerbated by low surface water inflows due to drought and water extraction from the river.

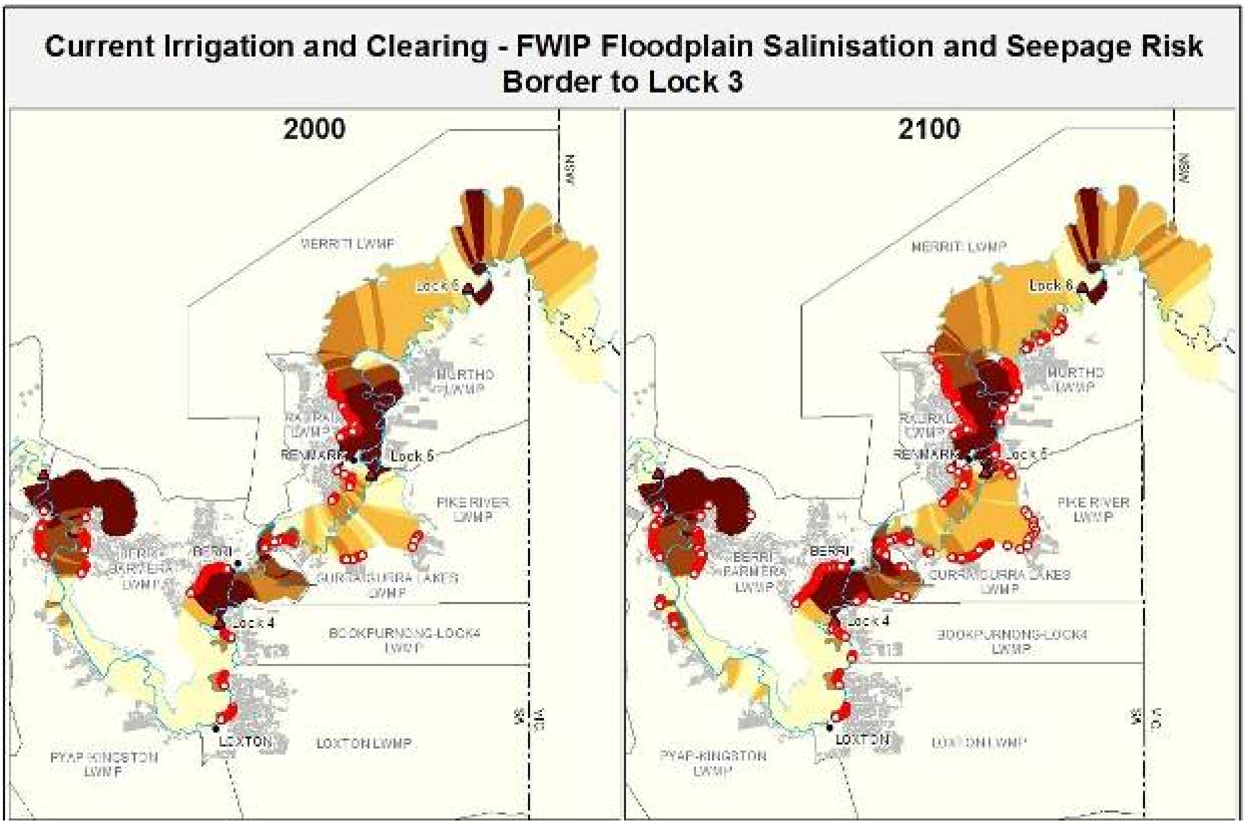
1. Land and its Changing Use http://kids.mdbc.gvo.au/encyclopedia/lang_and_its_changing_use
2. McAlpine CA, Dyktus, J, Deo, RC, Lawrence, PJ, McGowan, HA, Watterson, IG, Phinn, SR (2007) Modelling the impact of historical land cover change on Australia's regional climate. Geophysical Research Letters 34. L22711 doi: 10.1029/2007GLO31524 http://dx.doilorg/10.1029/2007GLO31524
3. Allison, GB, Cook, PG, Barnett, SR, Walker, GR, Jolly, ID and Hughes, MW. (1990) Land clearance and river salinisation in the western Murray Basin. Journal of Hydrology, 199 (1-4): 1-20.



Recharge (mm/year) versus water table depth (Source: Peter Cook, CSIRO)

There are significant time delays for recharge of groundwaters from the surface. For example, soil profiles in the Mallee can be 30 - 40 metres, which would take in the order of 100 years for a 5 mm recharge.

CSIRO is undertaking modelling of revegetation in the River Murray corridor to assess potential benefits to addressing the salinity problem. When the models tested revegetation effects 100 years out, the outcome was a very small benefit at Morgan. This suggests it takes much longer than 100 years to reduce salt inflows to the valley by revegetating the highland. When the modelling includes salt interception schemes (SIS) there is significant reduction in risk (although there are still some residual risks from floodplain salinisation from weir pool levels).



Floodplain salinisation risk (Source: Kate Holland, CSIRO)

The issue of carbon benefits is also being investigated with respect to revegetation of the region, which may provide incentives to farmers in the future (i.e. potential increase in profits to farmer from selling carbon permits).

Plenary Panel General Discussion - Key Points and Issues

Climate Change – key points and issues

- The important aspect of climate change as a threat is that it is likely to exacerbate the impacts of all the other threats - like, altered flows, salinity, ASS, etc.

- There is likely to be distributional change among biota, with a north to south shift. If ecosystems start moving on a trajectory of change with climate change, then a) how do we recognise that? and b) should we try to interfere with it? Are we going to try to hold the clock stationary at 2009 or accept the reality that the system is changing? We should not say we are necessarily going to lose a lot of species, we are just going to get a redistribution of them (particularly the floodplain species). A critical point here, however, is that vegetation types can only move if they have somewhere to move to (i.e. thin blue/green line concept).

- The challenge from climate change is bigger than that of addressing existing over-allocation. Climate change is going to reduce inflows to the system to such an extent that we need to totally renegotiate the sharing of water and decide what is the minimum amount needed for environmental health. All the calculations we have to date were based on the old inflow equations.

- There is the aspect of increasing temperatures as well. We need to keep a watching brief on that. We are now getting temperature thresholds on extreme hot days that biota are not used to. The number of days over 35° C and 40° C are a real threat, and according to CISRO and the Bureau of Meteorology they are likely to increase.

- Phenotypic change will also be important - e.g. flowering times, match-mismatch between predator and prey, etc.

- We need to enhance system resilience (as we cannot micro-manage everything). For the Lower Murray region, connectivity to the water is the critical aspect (i.e. rather than temperature gradients). The issue of water sharing is also important.

- It is likely that what we are facing now, in terms of climatic trend, is likely to persist (i.e. warmer, drier). That is what we should be planning for (across the whole MDB) - that should be our baseline (for 5 years at least).

- We should not be so pessimistic as to write-off (or sacrifice) parts of the ecosystem yet, even considering the climate record of the past decade. We don't want to lose valuable habitats.

- It could be that a possible consequence of climate change is that the main channel becomes a refuge area for many of the species which were perhaps out on the floodplain. You may also get encroachment closer to the river of floodplain vegetation. Therefore, the main channel is a really important 'refuge' area (especially for plants), particularly under climate change. However, this may not be the case for small-bodied fish, particularly if they do not have appropriate habitat to hide from predators (we are seeing that at present in the lower sections of the Lower Lakes and below Blanchetown).

- There is great concern that we might lose whole ecosystems, e.g. entire wetlands, including iconic and Ramsar wetlands could potentially disappear. Some are already very threatened and there is a large investment in research and restoration for some of them. An important question may be - is a triage approach appropriate for directing effort and investment?

- Under a climate change future, there may be increased pressure in from landholders to maintain lifestyle and livelihood at the expense of the environment.

Salinity – key points and issues

- In the river channel, what is important is the salinity tolerance of freshwater organisms and their critical thresholds beyond which you would lose members of the freshwater community.

- There is also a salinity threshold for vegetation on the floodplains - particularly the threat from rising regional groundwater which is as saline as the sea in most of the area that we are looking at. We know the tolerance levels for black box and red gum, and they are highly vulnerable to salt.

- The whole life-cycle of a species needs to be considered with respect to salinity tolerance. Often the juveniles or the propagating individual are more susceptible to salinity than the adults. Indeed, the big issue is recruitment. We need to make sure that reproduction occurs on a scale that is sufficient to sustain the populations into the future.

- Salinity is exacerbated by flow conditions. Salt will concentrate if not flushed out under higher flow conditions. Therefore it is the periods of low flow that are the problem. Flow management is important to help address the salinity issue and could also be considered a joint threat. Similarly, acid sulfate soils issue can be considered a joint threat.

- There is a long-term impact apart from the impact on species themselves and their local extinction. There are also impacts on long-term habitat. For example, the habitat values associated with long-lived trees like red gum and black box, which support a whole range of other species. Regarding replacement, it would take hundreds of years to provide trees with similar habitat complexity.

- Abatement strategies are flushing flows and floods. Is the average flushing of the river system enough to remove average inflows of salt into the system? Not at present.

- Salt interception schemes (engineering options) can delay or reduce the impact of salinity moving into and through the river system. Regarding removal of the weirs, that would be likely to have a short-term increase in river salinity due to the accumulated salt in the floodplain soil being purged into the river.

- Given that there may always be salt in the system, what would the acceptable situation be? Vegetation such as the long-lived big trees (i.e. species that cannot move) are a major indicator. Another indicator may be persistent salinity gradients between fresh to hypersaline between the Lower Lakes and Coorong. Another may be water quality or EC or the channel water - acceptable levels would probably be something like 'what we can drink'. However, it would be important to define a salinity level from an ecological point of view, because that is probably different from what is defined for human use.

Seepage. Photo: Kate Holland

Salinisation. Photo: Kate Holland

Acid Sulfate Soils – key points and issues

- Specific effects of acid on biota is generally not good (some invertebrates and single celled organisms an exception). One of the main impacts of acid sulfate is the point source impacts on local areas which can interrupt physiologically and behaviourally the migration pathways of things such as young fish. This in turn leads to recruitment impacts.

- There are thresholds for biota. For fish and other fleshy organisms it is about a pH of 5.

- Nutrient pathways are affected by acid, e.g. in agriculture, when pH drops below about 6 - 4 things like nitrifiers (i.e. that put nitrate into the system) progressively stop working.

- Monosulfides (MBOs) in acid sulfate soils also mean a risk of deoxygenation on disturbance, with related implications to biota.

- There is no silver bullet solution. Solution may be similar to that for salinity, i.e. getting the area back under water again - although there may be a lag involved in benefit. But it is never a simple solution, there is a need to tailor it to the particular circumstance. Adding lime and revegetation are other abatement strategies - particularly for 'hot spot' locations. There may be places where you want to control the surface condition by growing plants; you may want to put organic carbon into the system to provide energy to drive reduction processes on re-flooding. When acidification is reversed, you reduce the system again, and you create alkalinity. So in a closed system there is no net gain or loss - but these are open systems.

- A combination of approaches, carefully thought through, is probably best, but the ideal solution is to keep those acid sulfate soils wet. There is a caution however, as constructing more weirs to keep the soils wet is somewhat ironic, as a large proportion of the accumulation of ASS is caused by weirs and barrages in the first place.

- There is also caution regarding the timing and duration of wetting and the need to control refill. If the exposed areas are wet too quickly, the acids and associated heavy metals move into the water and affect biota. The system naturally has evolved under a wetting and drying regime. What are the differences of returning to a wetting and drying regime as a long-term solution, as opposed to just keeping them wet in the short term? It depends on the aim, however it would be possible to get it back to the system in place before the current drought. There needs to be flushing flows to keep the burden of sulfur moving along the system. It is also important to be aware of how that material moves downstream - i.e. in an acidic sludge or mixed and diluted? This will in turn affect riverine pH and the precipitation of dissolved metals, and subsequently, how aquatic biota respond. For example: at high levels precipitated aluminium can clog fish gills and create a fish kill; wetting of monosulfidic ooze can create a deoxygenation event downstream. There needs to be care with how acidic material is flushed and mobilised.

ASS with accumulation of white & yellow Na-Mg-Fe-Al-sulfate-rich minerals; pH 2.5 (Source: CSIRO).

Monosulfides (monosulfidic black ooze) able to remove most of the oxygen, Paiwalla wetland (Source: CSIRO).

Flow Regulation – key points and issues

- The current 'drought' in the River Murray is principally by a lack of rainfall/runoff combined with diversions (over-allocation). To reclaim the Lower River Murray, there needs to be provision made for water for the environment.

- Extraction of water is the number one threat to the system; the major threat to all ecological values. Over-use of water from the system is a huge problem (includes farm dams high in catchment). Extraction should be seen as a separate class of threat to loss of flow variability.

- We need to consider pumping/abstraction from the regulated and unregulated parts of the system. There is a proportion of abstraction that remains unregulated.

- Modelling work supports that it is the extraction levels rather than the current drought that is the major problem for the terminal end of the system (i.e. Lower Lakes and Coorong).

- The loss of flow variability is a major issue for the system. For example, the ASS problem may not be as severe if we had variable lake levels. Recreating some of that flow variability is going to be extremely important - we need to keep the range of variability there.

- We have lost the small floods; we have lost the over-bank flows getting the water onto the floodplain and leaving it there long enough for lifecycles to play out. To repair the system we need to reinstate those over-bank flows. We need pulsed flows. We do not need some average annual amount that is just going down the main channel.

- Issue of raised water levels from the weirs and what that means for floodplain groundwater levels. The hydraulic effects of the weir pools are believed to be responsible for significant salt accessions to the river – the saline groundwater is forced down under the pools, but forced nearer the surface in areas downstream of each weir, and is entrained by the river.

- We have a highly regulated system, for which some aspects can be used to advantage. On the Chowilla floodplain there are creeks that bypass Lock 6 - so we can get flow into that part of the system. In the Pike there are creeks that bypass Lock 5; the Katarapko Creek bypasses Lock 4; and the Banrock system bypasses Lock 3. So there are parts of the system that can be operated in a way to better mimic natural processes.

- It is unlikely that we would ever get rid of the weirs. We need to think about how we use them to manipulate water levels etc, to get water onto the floodplain. All of the weirs are of the overflow type - and you get a lot of sedimentation behind these. If you could open up the bottom of the weirs and get a lot of that organic material going downstream, there may be some ecological advantage. We need to use the weirs to provide ecological benefit at a minimal cost. However, some consider over-engineering of this system as a threat, even if aimed at providing environmental benefit, and it may not be a sustainable solution in the longer-term.

- The infrastructure involved in flow regulation creates barriers for migration and dispersion of biota - which is causing ecological fragmentation. This needs to be mitigated.

- What is a sustainable solution for flow management? How do we know when we have got it right? Perhaps we wouldn't have dredges in the Murray Mouth; it would be opened by river flow. We would have the organisms and communities that we would expect to find, with none lost. Also, there would be no need to artificially pump wetlands.

- There may also be more pipelines supplying irrigation districts rather than natural environments. Considering the Lower Lakes integrated pipeline - where there is flowback, we may be able to disconnect the lake level management from irrigation supply. The same applies for the river reach. A lot of weir pools can't be manipulated because of off-take pipes.

Invasive (Problem) Species – key points and issues

- One of the key potential threats is an invasion of the fish, tilapia - which is currently not in the system. Also weatherloach and similar species are progressively moving down towards the South Australian border. There is already carp in the River Murray, which is a significant, if not the main, current threat from an invasive species.

- A lot of damage to vegetation has been done by cattle, sheep and horses in some places - with the survival of young plants limited by grazing.

- There is agreement that invasive species should include or be renamed 'problem' species for the purposes of the EC assessment. In addition to exotic species (invasives), over-abundant native animals and domestic stock can pose a serious threat the system.

- Vectoring of disease - for example, *Lernaea* is a particularly vicious parasitic copepod which badly affects Murray cod and probably causes cryptic mortality.

- With climate change there is the potential for pests such as the cane toad to reach SA. There are increasing reports of changes in 'invasive' ant community structure - some are responding to permanent water and food supplies (i.e. becoming invasive) .

- Two native species, *Typha* and *Phragmites,* are 'invasive species' in wetland environments.

- With the current drought, it is apparent in the Lower Lakes that marine invaders (like the tubeworm *Ficopotamus enigmaticus*) are coming in. If the future of the Lakes is that they become a more estuarine environment then there may be an increase in marine invaders.

- Consider there are two types of invasive plant species in the Murray-Darling Basin:

    - those that are symptomatic of what we have made of the river system e.g. willows, *Typha*, *Phragmites*, carp - i.e. species that are very well adapted to the stable water levels due to river regulation. If you look at photos of the river banks in the 1930s they are bare - not a blade of grass on them (but not for Lower Lakes). Now there are quite often monospecific stands of *Typha* and *Phragmites*. It is not a natural situation - even though they are native species, they must be having an impact on the biodiversity, as nothing grows under a dense stand of *Phragmites*. Willows have an enormous impact on habitat structure and nutrient flows in the Valley section.

    - those species well adapted to the current natural environment - particularly the floodplain environments. Species like burrs - *Xanthium (e.g. occidentale, californicum)* and heliotropes - *Heliotropium* (e.g. *curassivicum, europaeum, supinum*). These plants germinate as the water levels recede, and they like it hot. They have quite deep root systems and are quite drought tolerant. Lippia (*Phyla canescens*) is also a major floodplain weed that is well adapted to various conditions.

- If there is a return of environmental flows or an increase in variability, as in a recovery phase - we are likely to see an increase of species that are from areas with similar hydraulic regimes and similar climates.

- Other exotic invasive plants of concern are: exotic *Juncus* (spiny rush; highly saline tolerant, can obstruct water flow) - taking over the exposed acid sulfate soils in the Lower Lakes, and Lippia (*Phyla canescens*) which competes with the native grasses.

- Australia is showing an evolving flora . Assemblages of plant species are adapting to the type of environment that we have produced (e.g. different flow regimes). If we don't want them (e.g. weeds), then we need to change the system of regulation.
- Risk assessment of 'invasives' should take into account the species likely to be big ecosystem engineers, i.e. that affect the recruitment of other species that are native to the system and have ecological 'flow on' effects downstream (e.g. replacement of lignum).

Land Clearing/ Revegetation – key points and issues

- Land use change impacts on water resources at a sub-catchment level can be as significant as those projected for climate change, i.e. 20 - 45% change in water availability over a 30 - 50 year time frame. For example, in Victoria dairy, crops, viticulture and forestry have all moved into traditionally broad-acre grazing land.

- Forestry development in the Eastern Mt Lofty region is important. It has the potential to draw down water tables and affect flows in Eastern Mt Lofty streams and therefore RM-DS EC.

- Land clearing has virtually ceased in South Australia, so the broad-scale matters are now over. There is an issue, however, in the one or two kilometres back from the river, particularly the river slopes and in the valley part of the system - where recharge from rainfall could be quite high (i.e. lesser depth to groundwater). There is a concomitant issue regarding revegetation and recharge management very close to the valley zone.

- While land clearing has been stopped, there is tree clearing/dying on the floodplain from the extended drought. That is a really big threat at present - the loss of trees across the floodplain due to drought.

- A general issue related to change in water resources is a change in habitat and energy resources for food webs. Just putting back particular types of trees may not necessarily underpin ecological recovery. Need caution when using the terms ‘revegetation’ and ‘reforestation’.

- Future considerations of carbon credits need to consider appropriate species selection for the region and potential impacts on local biodiversity.

- Other threat related issues include nutrient runoff (nutrient pulses) and recovery from bush fire (including ash fall and impacts on biological oxygen demand).

- Although reforestation might reduce sediment loss and improve groundwater control, there is greater concern that it will reduce flow.

- Threats from revegetation and reforestation can be limited if managed appropriately. However, that could change in the future, e.g. with biofuel production. It would depend on how much water is used and what the reduction to runoff is.

- There is site specificity for this issue. There is current consideration of redirecting fresher water from further south to get a larger volume of water into the southern part of the Coorong. Between the source of that water and the Coorong there is about 50 000 hectares of blue gums being planted. There are also large plantings across the border in Victoria that intercepts the water that would normally go into Mosquito Creek, Morambro Creek and a couple of others. Hence, attempts to get the water into the southern part of the Coorong are being frustrated by some of these forestry activities.

- The current process by MDBA of assessment of risks to runoff in the MDB is looking at a range of factors, including climate change, bush fires, farm dams, groundwater and plantations. Each of these five factors is showing up as being significant in total runoff in the Basin. So, in terms of what we are considering for the Lower Murray, anything that is reducing runoff into that sector, therefore, is a threat.

PART B – Workshop Outcomes 3: Fitting Listing Criteria to Aquatic Systems & RM-DS EC

Universal Key Findings

For aquatic systems in general

- The 'Ecological Community' (EC) of a large complex aquatic system often consists of sub-units of different biophysical complexity – therefore it may be considered as a 'constructed' EC – however these components are united/connected by common functionality features.
- There is a need to ensure legally defensible boundaries and attributes.
- Flow regime (surface and groundwater) is a key (integral) ecological process – there is a need to consider 'natural' versus 'managed' flows and wetting-drying cycles.
- Connectivity is critical – as is the rate of disconnection and fragmentation.
- Changes in water quality and source is also a central aspect for the assessment process.
- It is important to demonstrate (proof of concept) a species is 'keystone' or 'foundation'.
- Need to investigate where/how the assessment can link into Indigenous mapping and knowledge.
- The assessment process should not just be about population sustainability, but it should also be about demographics e.g. age structure (old riparian trees or fish), recruitment levels, etc.
- There is a need to consider/allow for time-lag effect between disturbance (threat) and impact on functionality (may take years) – 'lag time between action and outcome'.
- Flexibility with times and sizes for criterion thresholds may be important.
- 'Uniqueness/rarity of community or components should be considered when applying criteria.

Challenges

- Natural variability - temporal and spatial; natural versus anthropogenic (e.g. climate change, engineering interventions and uncertainty of how flow regime affected by engineering works/interventions).
- Data availability and lack of knowledge (e.g. hydrological models, stygofauna, etc).
- Consider and differentiate/demonstrate trophic cascade effects (i.e. flow-on effects).
- Dealing with cumulative impacts of threats in aquatic systems – likely to be more magnified/complex than with terrestrial systems.
- Identification of triggers and tipping points – understanding when shifts to different states occur – also hysteresis (time lag) effects (including irreversible outcomes).
- Incorporating a 'zone of influence' concept - geographically based but temporally variable.

For the River Murray – Darling to Sea EC in particular

- Establish a quality baseline (reference condition) – options: 1956 floodline; hydric soils (to few m); 1970's high flow period; pre-regulation; pre- European (but last two are harder to quantify).
- Keystone/foundation species – Murray cod (*Maccullochella peelii peelii*), Murray River crayfish (*Euastacus armatus*) river red gum (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*), *Ruppia* sp.
- Key indicators of decline – spread of salinisation, acid sulfate soils/pH, fish fauna, old trees, water level, invasive species (invasion by carp a standout), groundwater extent.

Listing Criteria Analysis

CRITERION 1: Decline in geographic distribution

This criterion refers to:

- a decline in total area of the EC without necessarily a concomitant contraction in its range, or
- a decrease in the range over the whole or part of the area in which the community originally existed, or
- fragmentation of the community through a decrease in the size of patches.

In order to meet this criterion there needs to be a measurable change. To determine this we need to know what was the original extent of the EC, what is its current extent, and how the decline relates to the criteria thresholds (see Table 4, page 18).

Question	C1: Response
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• overall does not work well for large complex and dynamic aquatic systems • may work well for components (sub-units) of these systems or discrete aquatic systems, e.g. wetlands • linear nature of rivers is an issue (i.e. won't get contraction in linear geographic extent compared to contraction in area) • loss of geophysically important ecological functionality is more important (i.e. change in functional extent compared to geographic extent)
2. How do we best measure this Criterion in aquatic ecosystems?	• mapping key elements like hydric soils (to few metres deep), vegetation/state change, flow/flooding regime change • biotope edge effects and change • map decrease from pre-European perspective (assume this reference condition)
3. What are the challenges/impediments/ issues for applying this Criterion to aquatic systems?	• quality of baseline critical (acknowledge assumptions) • lack of knowledge (e.g. stygofauna) • engineering works affect flow regime • natural variability (temporal and spatial) and climate change • different components of system (sub-units) have different conditions and complexity (may change) • needs to be legally defensible • endeavour to link to Indigenous mapping and knowledge
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• use a 'likely to occur' delineation for an indicative approach • recognise temporal variability and extent • take into account community 'rarity' value • identify & understand when shifted to a different state (e.g. intermittent to permanent wetlands) • need a legally defensible line • consider importance (and a measure) of connectivity • quality needs to be considered as well as extent • incorporate 'zone of influence' concept
5. How does the Criterion work for the RM-DS EC?	• this criteria doesn't work well for RM-DS EC as a whole • Coorong and Lower Lakes very different components than River Murray corridor – may work for sub-units • deliberate disconnections (e.g. some wetlands) and indirect (e.g. estuary to sea) • spread of salinised floodplain a good indicator and decline in groundwater extent due to rising salinity • massive range constrictions of fish distribution (e.g. Murray cod, golden perch (*Macquaria ambigua*), Murray hardyhead (*Craterocephalus fluviatilis*) in wetlands) • loss of woodland habitat in floodplains • other baseline options – pre-regulation, 1956 floodline

CRITERION 2: Small geographic distribution coupled with demonstrable threat

This criterion applies to ECs that have a small geographic distribution (on a national scale) and for which a threatening process exists within an understood or predicted timeframe. A small geographic distribution implies an inherently higher risk of extinction from the threat. This criterion does not apply to small ECs that are not subject to a threatening process – the intent is rather to capture naturally rare or highly fragmented communities under threat.

Question	C2: Responses
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• overall it is difficult to argue that geographical distribution is small for a large, complex river system • could work for small, isolated aquatic systems or even long, linear streams with a small surface area • could work well for naturally rare or fragmented wetlands
2. How do we best measure this Criterion in aquatic ecosystems?	• could potentially use surrogates, such as certain characteristic life forms e.g. fish distribution • change to hydrology, e.g. lotic (flowing) to lentic (still)
3. What are the challenges/impediments/ issues for applying this Criterion to aquatic systems?	• does 'small' depend also on a temporal or climatic aspect as well as geomorphology? • hydrological (and ecological) disconnect • change to frequency or size of key flow events a threat that can lead to changed state • how do we deal with cumulative impacts of threats with aquatic systems? – likely to be more magnified than with terrestrial systems
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• rarity of community composition and/or fragmentation could be critical (and measurable) features • measures of flooding frequency and intensity – demonstrable threat • scope to change concept of small size – e.g. river/stream a narrow, linear band in landscape • allow for well defined area of occupancy
5. How does the Criterion work for the RM-DS EC?	• as a whole, the RM-DS EC would not trigger this criterion as it stands because it's difficult to demonstrate (legally) 'small' geographic distribution, except for components (sub-units) downstream in the system (e.g. Coorong, Lower Lakes, some specific wetlands) • threats are undeniable • key 'trophic' species disappearing from specific sites (e.g. small fish, turtles) • flow-on effects to Indigenous icons, e.g. pelicans

CRITERION 3: Loss or decline of functionally important species

This criterion refers to native species that are critically important in the processes that sustain or serve a major role in the EC, and whose removal would potentially precipitate a negative structural or functional change that may lead to extinction of the EC. This criterion has two inseparable components for assessment: there must be a decline in the population of the functionally important species (FIS), and restoration of the EC is 'not likely' to be possible within a specified threshold timeframe (see Table 4, page 18). The decline of the FIS must be halted or reversed to ensure continuation of the EC.

Question	C3: Responses
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• yes, a potentially powerful criterion which describes the situation well • need to postulate how the species is/are important and this is data dependent (i.e. foundation or functionally important)
2. How do we best measure this Criterion in aquatic ecosystems?	• need to demonstrate a keystone species (by concept is OK, e.g. apex predator) • look at health or population dynamics of key elements (e.g. fish, trees, migratory birds, invertebrates), i.e. canopy extent, distribution, abundance, biomass, productivity, size/age class, demographics, level of recruitment, etc. • landuse and occupancy mapping of Indigenous people
3. What are the challenges/impediments/ issues for applying this Criterion to aquatic systems?	• defensibility • defining how functionally important species linked to processes • how to differentiate trophic cascade (flow-on effects) from disturbed state? • Indigenous consultation a key component but not explicitly stated for criterion • knowledge limited on functionally important species of groundwater systems • not just about population sustainability – demographics important too, e.g. need 'old' trees • species are already becoming extinct – what if there are none left of the keystone species? • connectivity issues – e.g. diadromous fish
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• need proof of concept of keystone and foundation species • may need flexibility with generation times for criterion thresholds e.g. invertebrates, annual plants, etc. • rather than just loss or decline in numbers, changes to other aspects of functionally important species need consideration e.g. age class structure, distribution, canopy extent, productivity, level of recruitment, etc. • allow for time-lag between disturbance (threat) and impact on functionality (i.e. may sometimes take years, but generally good understanding exists of likely effects) and time-lag to get functionality back • compare to other case studies i.e. where there have been re-introductions
5. How does the Criterion work for the RM-DS EC?	• keystone/foundation species may be functionally important to a certain component (sub-unit) rather than the entire EC • Murray cod a functionally important species (apex predator) • records of early fishers would be useful • cultural issues and connections need to be factored in • strong argument for river red gum – important habitat for so many other species and processes (homes, nesting, nectar, soil stability, nutrients, woody habitat, etc.), level of seed set driven by frequency and timing of flooding • Black Box may be just as or more important than River Red Gum – juvenile release rates better
6. What are the keystone species or assemblages for the Lower Murray – Darling to Sea EC?	• potential keystone species are Murray cod, Murray River crayfish, freshwater turtle (*Emydura*), mussels/snails, small native fish assemblage • potential foundation species are river red gum, black box, melaleucas, coobah, lignum, *Ruppia tuberosa* (in Sth Lagoon of Coorong)

CRITERION 4: Reduction in community integrity

This criterion recognises that a EC can be threatened with extinction through on-going modifications. Changes in integrity can be measured by comparison with a benchmark state that reflects the 'natural' condition of the EC with respect to its abiotic and biotic elements and processes that sustain them. The criterion recognises detrimental change to component species and habitat, and to the processes that are important to maintain the EC. (Note, changes do not necessarily have to lead to total destruction of all elements of the community). Importantly, this Criterion allows for recognition of a problem at an early state/stage (e.g. disruption of process evident but no measurable decline in integrity of EC as yet). Regarding the regeneration aspect of thresholds (see Table 4) this relates to re-establishment of an ecological process, species composition, and community structure within the range of variability exhibited by the original community.

Question	C4: Responses
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• yes – very applicable to aquatic systems at a range of scales and levels • provides opportunity to pick up the overarching significance of flow regime as an integral ecological process • loss of connectivity (e.g. to the sea)
2. How do we best measure this Criterion in aquatic ecosystems?	• flow is linked to a number of processes and is well documented (with large body of evidence to support that flow is important) – can describe changes in many facets e.g. frequency, size, etc. • dominance of invasive species, or, relative abundance of native versus exotic species (e.g. carp, willow, etc) • water level • native fish populations • number and intensity of algal blooms • changes in species abundance and composition
3. What are the challenges/impediments/ issues for applying this Criterion to aquatic systems?	• in general a lack of data for most aquatic ECs (i.e. in many catchments hydrological models are poor, lack of flow data, no calibration, etc.) • time lag in getting functionality/integrity back (e.g. long time for 'old' trees) – some threats have long lag effects e.g. groundwater, salinity • irretrievable loss of native species • changes to substrates • trophic flow-on effects (cascades) • macrophytes very important – regeneration impacted by carp • biophysical impacts – connectivity important • changes to landscape impact on system resilience • engineering interventions – effects difficult to identify • cultural input to criterion – e.g. *Cyprus gymnocaulos,* a sedge used for weaving – how is this captured?
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• criterion thresholds – consider short generation times for invertebrates; 'past/future' concept timing • build in flexibility • need to determine critical timelines for linking flooding and organism lifecycles
5. How does the Criterion work for the RM-DS EC?	• works very well (Murray unique in that a lot of historical data on flow and other aspects – back to 1891) • estuarine species have been reduced or lost • algal blooms and weeds (e.g. *Lippia*) a threat • recruitment potential affected – seed/egg bank function • invasion by carp is a standout – massive alteration to community composition, key species loss • flow regime critical • appropriate salinities (& pH) need to be re-established within 10 years or integrity gone – trigger 'critically endangered'

CRITERION 5: Rate of continuing detrimental change

Continuing detrimental change refers to a recent, current or projected future change for which the causes are not known or not adequately controlled, and so is liable to continue unless remedial measures are taken. Detrimental change may refer to either i) geographic distribution or populations of critically important species, or ii) degradation or disruption of an important process. The detrimental change can be observed, estimated, inferred or suspected. Natural fluctuations do not normally count as continuing change, but an observed change should not necessarily be considered to be part of a natural fluctuation unless there is evidence for this. 'Ecological judgement' may be exercised to apply this criterion if adequate data are not available.

Question	C5: Responses
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• yes – decline is accelerating
2. How do we best measure this Criterion in aquatic ecosystems?	• lag effects are a complicating factor and need to allow for them – partial disconnect between flow and community change • diversions versus inflows – difference between natural and managed river condition (but difficult to quantify pre-European hydrology) • natural flows versus un-natural flows – measure of water movement through system (e.g. flooding of river red gums dropped from once every X years historically, to once in Y years now) • shift in salinity regime • connectivity – increasing disconnection of the system • water quality and source
3. What are the challenges/impediments/ issues for applying this Criterion to aquatic systems?	• natural variability in Australian landscape • demonstration • lag effect of threats and ongoing impacts • rate of change of health can spiral and have flow-on effects (e.g. trophically) • pace of regulatory change; water management plans • climate change coupling to inflows • lack of monitoring of threats e.g. groundwater usage
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• flexibility to allow for lag effects of both impacts and restoration/recovery times • recognition that impacts operate over long time scales • tipping points need to be factored in
5. How does the Criterion work for the RM-DS EC?	• rate of disconnection (e.g. to wetlands, river to sea) • proportion (%) of inflow compared to extraction • significant detrimental change (70%) occurred in last 10 years on river floodplain • decline in river red gums well documented • cap established in MDB flows in 1994-95 (dry since then) • acid sulfate soils a potential indicator • salinity in Lower Lakes • disconnection with ocean

CRITERION 6: Quantitative analysis showing probability of extinction

This criterion can include any form of analysis that estimates the extinction probability of an ecological community based on known characteristics of: important species or components, habitat requirements, ecological processes, threats, and any specified management options. The Threatened Species Scientific Committee recognises that this is an emerging area of science and will examine any acceptable modelling (with the concomitant use of peer review).

Question	C6: Responses
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• yes – potentially • could be applied conceptually • need well defined community and understand when it changes to something different (i.e. flips to another state)
2. How do we best measure this Criterion in aquatic ecosystems?	• data dependent • proof of role of keystone species • if no data or examples, could use conceptual modelling
3. What are the challenges/impediments/ issues for applying this Criterion to aquatic systems?	• data availability • proof of keystone species • it is not a challenge that river red gum (or whatever) also occurs outside nominated area • could be useful for applying 'tipping points' to a system • climate change
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• trying it out – robust method needed for ecological communities • how is extinction defined? – complete extinction versus local extinction – both are relevant for consideration of EC • scope to apply PVA type analysis to selected species but that may not capture the sense of community
5. How does the Criterion work for the RM-DS EC?	• Coorong modelling from Flinders University has good potential (Rebecca Lester and Peter Fairweather) • use species listed under Criterion 3 (i.e. keystone or foundation species) to try it out • focus on river red gum and/or black box as there is more literature and data and they have complementary roles • black box is a classic example of the sliding baseline – on the way out since 1956

Appendix 1: Workshop Agenda and Delegate List

Department of the Environment, Water, Heritage and the Arts

'River Murray-Darling to Sea' Ecological Community Assessment: Expert Technical Workshop

Wednesday 1 July 2009

Workshop Session One: Prelude and Process
Chair: Bob Beeton

4.0 Welcome and housekeeping
Bob Beeton and Gina Newton

4.15 The EPBC Act, processes for listing and protecting threatened species and ecological communities.
Matt White

4.45 The Threatened Species Scientific Committee Perspective – historical facets and lessons learnt from large, complex nominations (e.g. Littoral rainforest) & Key Concepts
Bob Beeton

5.20 Outcomes sought from this workshop. How we would like you to contribute.
Matt White

5.30 Questions and Discussion

6.00 Workshop Dinner: The Monastery (Note: BYO)
Presentation: *'A virtual field trip of the River Murray – Darling to Sea'*
Judy Goode

Thursday 2 July 2009

Workshop Session Two: Setting the Scene
Chair: Bob Beeton

9.00 Paleo-history of the Lower Murray
Jennie Fluin

9.15 Groundwater connections and Aerial Electro Magnetic surveys
Jane Cooram/BRS TBA

9.30 Sustainable Rivers Audit 2004-2007 – How did the Lower Murray Valley fare?
Keith Walker

9.45 Coorong and Lower Lakes – Status report
Kerri Muller/ Rebecca Lester

10.00 Current major research initiatives, including bioremediation
Russell Seaman/Tony Herbert

10.15 MORNING TEA

10.35 Workshop Session Three: Breakout Groups I – Describing the EC of the River Murray – Darling to sea
[Note: Each group has a different topical focus, but addresses the same set of questions. Questions will have aspects related to Data; Connectivity/interactions; Functionality; Key Characteristics – species, geology, soils, climate, elevation, landscape, etc.; Boundaries – what's in, what's out?]

Group 1: Connecting Groundwater
Chair: Phil Cole
Rapporteur: Jane Coram

Group 2: River and Tributaries
Chair: Ian Overton
Rapporteur: John Sherwood

Group 3: Floodplain and Wetlands
Chair: Anne Jensen
Rapporteur: Glen Scholz

Group 4: Biota
Chair: Keith Walker
Rapporteur: Michelle Kavanagh

12.30 to 1.30 LUNCH
[Rapporteurs prepare reports via PowerPoint]

1.30 Workshop Session Four: Report Back and Discussion
[Rapporteurs report back with PP presentations: 10 mins each + 5 mins for questions]

1.30 – 1.45 Group 1: Connecting Groundwater
Rapporteur: Jane Coram

1.45 – 2.00 Group 2: Rivers and Tributaries
Rapporteur: John Sherwood

2.00 – 2.15 Group 3: Floodplains and Wetlands
Rapporteur: Glen Scholz

2.15 – 2.30 Group 4: Biota
Rapporteur: Michelle Kavanagh

2.30 – 3.00 Plenary General Discussion 1: Challenges, Gaps & Issues
Chair: Bob Beeton

3.00 – 3.30 AFTERNOON TEA

3.30 Workshop Session Five: Plenary Panel - Threats to the Lower Murray – Future Trends
[panel of 6 experts speak for 5 minutes each on threats to the Lower Murray system]
Facilitator: Paul Dalby

3.35 Climate Change
Roger Jones
3.40 Salinity
Phil Cole
3.45 Acid Sulfate Soils
Richard Merry
3.50 Flow regulation/irrigation/management
Keith Walker
3.55 Invasive Species
Ben Smith
4.0 Land Clearing/revegetation/reforestation
Kate Holland

4.05 – 5.15 Plenary General Discussion 2: Threats to Lower Murray – Threats Matrix (see below)
Facilitator: Paul Dalby

6.30 Taxi's ordered for trip to pre-booked restaurant dinner for those wanting to attend

Friday 3 July 2009

9.0 Workshop Session Six: Breakout Groups 2 – Fitting Criteria to River Murray – Darling to Sea EC

9.05 A new approach to classification of Aquatic Ecosystems
Chris Auricht

9.20 Background to Six Ecological Community Listing Criteria and how criteria applied in practice; Instructions for Breakout Groups and Required Outcomes
Gina Newton/Matt White

9.45 – 10.45 Group 1: Criteria 1, 2, 3, 4, 5, & 6
Chair: Peter Harrison
Rapporteur: Gina Newton

Group 2: Criteria 1, 2, 3, 4, 5, & 6
Chair: Bob Beeton
Rapporteur: Anthony Hoffman

Group 3: Criteria 1, 2, 3, 4, 5, & 6
Chair: Rosemary Purdie
Rapporteur: Matt White

Group 4:Criteria 1, 2, 3, 4, 5, & 6
Chair: Keith Walker
Rapporteur: Vishnu Prahalad

10.45 – 11.15 MORNING TEA

11.15 – 12.30 Report Back and Plenary General Discussion 3
Chair: Bob Beeton
[Rapporteurs provide 5 minute report back each with no questions, followed by general questions and discussion]

12.30 – 12.45 Workshop Wrap Up by Chair, Bob Beeton

12.45 Workshop Close

1.00 – 2.00 Light LUNCH provided for those who can stay.

Threats Matrix (e.g. indicative guide for Session 5 discussions)

Aspect	Climate Change	Salinity	Acid Sulfate Soils	Flow regulation/ irrigation	Invasive species	Land clearing/ revegetation
Original state						
Current state						
Future trend/ Scenario						
Abatement potential						
Acceptable level?						
EC considerations						

Delegate List

Lower Murray, Sea to Darling – Invitees for Technical Workshop – 1-3 July 2009

Name	Affiliation/Expertise
☺Dr Chris Auricht	Habitat mapping; Aquatic Ecosystem Classification
☺ Steve Barnett	Groundwater/ SA DWLBC
☺ Paul Barraclough	DEWHA Ecological Communities Section
☺Prof. Diane Bell	Consultant/Social anthropology/ Indigenous
☺Prof. Bob Beeton	Chair, Threatened Species Scientific Committee (TSSC)
☺Dr Tumi Bjornsson	SA Dept. Water, Land and Biodiversity Conservation (DWLBC)
☺Deb Callister	DEWHA/ Coorong, Lower Lakes, Wetlands
☺Phil Cole	Murray Darling Basin Authority; Salinity, local knowledge
☺Dr Marcus Cooling	Consultant/ floodplain vegetation
☺Dr Jane Coram	Geoscience Australia/groundwater
☺Dr Paul Dalby	Consultant/wetlands/Fleurieu Peninsula
☺Joe Davis	MDBA, flow patterns in Lower Murray, engineer
☺Angela Duffy	SA Dept. Environment and Heritage, TECs
☺Prof Peter Fairweather	Freshwater biodiversity, ecology
☺Dr Mike Fleming	NSW DECC – Biodiversity Conservation, terrestrial
☺Dr Jennie Fluin	University of Adelaide/ paleolimnologist
☺Dr George Ganf	University of Adelaide, vegetation
☺Judy Goode	SANRM Board/River Murray Environmental Manager
☺Dr John Harris	River Sustainability Audit/ Consultant
☺ Prof. Peter Harrison	Threatened Species Scientific Committee
☺Dr Michael Hammer	Consultant, Murray Fish
☺ Steve Hemming	Flinders University/ Indigenous
☺Tony Herbert	SAMDBNRM Board/ Chowilla management
☺ Anthony Hoffman	DEWHA Ecological Communities Section
☺Dr Kate Holland	Groundwater, Landuse, Mallee clearing/CSIRO
☺Dr Anne Jensen	University of Adelaide/ floodplain vegetation
☺Dr Roger Jones	Victoria University/ climate change and water resources
☺ Simon Kaminskas	DEWHA Species Listing Section/ fish ecology
☺Michelle Kavanagh	Murray Darling Freshwater Research Centre, Knowledge Broker
☺ Dr Sebastien Lamontagne	CSIRO Land and Water, SYP, local knowledge
☺Remko Leijis	SA Museum/ Groundwater biota
☺Ben Leonello	InfraPlan/ SAMDBNRM Board/ Wetland, climate change
☺Dr Rebecca Lester	Flinders University / Hydrological modelling
☺Lance Lloyd	Loyd Environmental Services/ Env. Flows, Chowilla ECD
☺Kate Mason	SAMBBNRM/ lake ecology
☺Dr Richard Merry	Acid Sulphate Soils/CSIRO
☺Dr Kerri Muller	Consultant, Lake Alexandrina, sediments
☺Dr Gina Newton	DEWHA Ecological Communities Section/ aquatic ecologist
☺Dr Jason Nicol	SARDI/ aquatic + floodplain vegetation
☺ Colin O'Keefe	DEWHA ERIN/ mapping
☺Dr Rod Oliver	CSIRO WfHC/ Primary Production, water quality, nutrients
☺Dr Ian Overton	CSIRO WfHC, Leader Environmental Water/ Flow, Vegetation
☺Marcus Pickett	SA Conservation Council/ ornothologist
☺ Vishnu Prahalad	University of Tasmania/ HCVAE process
☺Dr Rosemary Purdie	Threatened Species Scientific Committee
☺Dr Julian Reid	ANU Fenner School/ Coorong birds
☺Grant Rigney	SA NRMBoard/ Indigenous
☺Dr Dan Rogers	DEH/ birds, restoration ecologist
☺Glen Scholz	DWLBC SA/ habitat classification, wetlands
☺Russell Seaman	DEH, Lower Murray Futures, habitat mapping
☺As. Prof. John Sherwood	Deakin University/Estuarine Hydro-Chemist
☺Emily Slatter	BRS Water Sciences - groundwater
☺Nerida Sloane	DEWHA/ Coorong, Lower Lakes, Wetlands

☺Dr Ben Smith	Invasive species, fish/SARDI
☺Dr Nick Souter	Consultant/DWLBC; modelling ecological function
☺Tracey Steggles	SA MDBNRM – wetland ecologist
☺Alys Stevens	SA Conservation Council/ criteria Fleurieu Peninsula wetlands
☺Dr John Tibby	University of Adelaide
☺Dr Eren Turak	Ecological river typology/condition/Dept. Env. & Climate Change
☺Rebecca Turner	SA MDBNRM Board
☺Paul Wainright	SA DEH, Senior Wetlands Officer
☺As. Prof. Keith Walker	TSSC Uni. of Adelaide, EWSAC/ water quality, invertebrates
☺Dr Todd Wallace	CSIRO/MDFC, Mildura Lab., vegetation, nutrients, River Murray
☺Peter Waanders	SA DWLBC/ Wetlands
☺Mark Walter	DWLBC RM Assessments
☺Matthew White	DEWHA/ Director Ecological Communities Section
☺Dr Qifeng Ye	SARDI – Environmental Management Rivers & Lakes
☺Brenton Zampatti	SARDI (formerly ARI, Vic) - Fish

Appendix 2: Characteristics of weirs and weir pools on the Lower River Murray. Source: MDBC (2004).

Structure name	Year built	Upper level (m)	Dist. from Murray Mouth (km)	Weir pool length (km)*	Storage capacity (GL)	Removal lowest flow (ML/d)	Removal highest flow (ML/d)	Reinstatement lowest flow (ML/d)	Reinstatement highest flow (ML/d)
Lock & Weir 1 - Blanchetown	1922	3.3	274	88	64	49,000	59,000	74,000	84,000
Lock & Weir 2 - Waikerie	1928	6.1	362	69	43	58,000	68,000	56,000	66,000
Lock & Weir 3 - Overland Corner	1925	9.8	431	85	52	58,000	68,000	66,500	76,500
Lock & Weir 4 - Bookpurnong	1929	13.2	516	46	31	58,000	68,000	68,000	78,000
Lock & Weir 5 - Renmark	1927	16.3	562	58	39	62,000	72,000	72,000	82,000
Lock & Weir 6 - Murtho	1930	19.2	620	77	35	55,000	65,000	67,500	77,500
Lock & Weir 7 - Rufus River	1934	22.1	697	29	13	24,000	34,000	30,500	40,500
Lock & Weir 8 - Wangumma	1935	24.6	726	39	24	40,000	50,000	47,000	57,000
Lock & Weir 9 - Kulnine	1926	27.4	765	60	32	48,000	58,000	55,000	65,000
Lock & Weir 10 - Wentworth	1929	30.8	825	53	47	48,000	58,000	55,000	65,000

*Weir pool length is generally the distance between the weirs (i.e., the river is a series of ponded lakes at low flow), except for Weir 6, which is shorter, but of an unknown length.

Appendix 3: Workshop breakout groups for Listing Criteria session and detailed results

'Lower Murray' EC Assessment: Expert Technical Workshop **Session Six:** **Fitting Listing Criteria to Aquatic Ecosystems**	
Group 1 **Chair:** Peter Harrison **Rapporteur:** Gina Newton	**Group 2** **Chair:** Bob Beeton **Rapporteur:** Anthony Hoffman
Chris Auricht Marcus Cooling Peter Fairweather Kate Holland Remko Leijs Julian Reid Grant Rigney Dan Rogers Nerida Sloane Ben Smith Eran Turak Todd Wallace Brenton Zampatti	Tumi Bjornsson Deb Callister Jane Coram Mike Flemming Laura Gow Anne Jensen Lance Loyd Jason Nicol Glynn Ricketts Glen Scholz Tracey Steggles Mark Walter
Group 3 **Chair:** Rosemary Purdie **Rapporteur:** Matt White	**Group 4** **Chair:** Keith Walker **Rapporteur:** Vishnu Prahalad
Joe Davis Jennie Fluin John Harris Roger Jones Richard Merry Colin O'Keefe Rod Oliver John Sherwood John Tibby Rebecca Turner Qifeng Ye	Angela Duffy George Ganf Michael Hammer Steve Heming Simon Kaminskas Michelle Kavanagh Kerri Muller Dr Ian Overton Emily Slater Peter Waanders Paul Barraclough Phil Cole

Criterion One - Decline in geographic distribution. (AS = Aquatic Systems)

Questions	Group 1	Group 2	Group 3	Group 4
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• Not well for entire AS but yes for elements of AS • AS linear & principally defined by landform & subject to change • extent & fragmentation • may work with components • hydrological change (dead trees) • contraction of 1956 floodline • mixing zone declined • connectivity with sea lost	• Not for large complex AS • yes for small discrete systems • e.g. Lower Lakes OK for geographic distribution and extent • rather than extent and decline, the loss of geophysically important functionality is important for AS	• Yes works for some AS like wetlands. • won't get contraction in linear geographic extent for this EC, but may get contraction in area • geomorphology important in determining extent [of this EC] (rather than water levels) - & will not change much	• Not particularly appropriate - ecological functionality rather than geography • ecological parts contracted, not the physical components (i.e. ecological functionality more important than geographic extent)
2. How do we best measure this Criterion in aquatic ecosystems?	• mapping key elements • hydric soils key (down to few metres) & shows historical • vegetation change, e.g. map decline in red gum & black box trees (~saline soil) • flow regime change • state change, e.g. wetland from sedge to sandfire • baseline? maybe last 30 yrs vegetation or pre-regulation (past & future 50 yrs) • Surveyor General mapped ~1900 • 1956 formation of clay • biota - pre European too hard • fish community altered - got baseline data (size class data) • 2004-2007 best wetland data • natives compared to exotics instream	• patterns of flooding regime (frequency) have changed • the system is zoned and there is a contraction of zones due to changes in flooding • conductivity and pH measures have changed • edges of the community being driven by changes in characteristics of the water body	• 1750 perspective - old floodplain areas may be determined (decrease can be measured) • old irrigation farms going back to original vegetation	• riverine components not changed, but Palustrine (wetland) components have • 50% loss of wetlands compared to 'natural' (pre-European) • assume reference condition is pre-European • natural versus current distribution and quality • satellite imagery - hydric soils • aerial photography
3. What are the challenges, impediments & issues for applying	• quality of baseline critical (get right data as baseline & acknowledging assumptions) • impediment is having a defensible threshold for a change in state	• engineering works are affecting flow regime • groundwater stygofauna distribution - lack of knowledge	• would not stand up well to a legal challenge • good evidence that can interpret natural variation in geographic distribution	• mobility of aquatic components • temporal and spatial variability scales important • applying criterion for different components is difficult as they

this Criterion to aquatic systems?	• deeply connected lotic systems are difficult • allow for variability in system between different components • link to cultural (Indigenous) land use mapping process - fish, medicine plants, swanning sites, etc.	• loss of variability becomes an important threshold consideration • change in structural complexity of components (e.g. channels, ephemeral lakes, floodplain) • AS naturally dynamic - do we seek to manage dynamics or reduce?		have different physical conditions
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• change in functional extent more important than geographical extent • understand when shifted to a different state • recognise temporal variability (and extent) - temporal element critical for AS • use of modifiers and core set of attributes • hydrological change cycles - timeframe important • doesn't take into account rarity value	• need a legally defensible line • use a 'likely to occur' delineation for an indicative approach • change in ecotype (e.g. temporary intermittent wetlands increased to permanent wetlands by barrages 30%, etc.)	• importance of connectivity • quality needs to be considered as well as extent	• rarity - composition of the flora (community rather than species) across the entire EC system (i.e. community rarity rather than species rarity) • water regime - provision of water to habitat types that shape and sustain the community • 'zone of influence' (water regime) - extent
5. How does the Criterion work for the RM-DS EC?	• Lower Lakes and Coorong so different from Murray corridor • levies & flood mitigation works (no more 1956 floodline!) • wetlands deliberately disconnected (disposal basins) • if use elements of AS, e.g. estuary, Lower Murray swamps • spread of salinised floodplain • Murray cod and golden perch - massive contractions, no recruitment since 2004 • loss of woodland habitat in floodplains (historical mapping) • Murray hardyhead in disconnected wetlands	• lower swamps down to 7%; reclamation work altered nutrient & sulphate regimes • deliberate disconnection of wetlands (will they restore?) • groundwater ecosystem declining in extent due to rising salinity • unless major change in water regime, restoration time for red gum & black box is not likely • probably also for flood dependant perennials • system driven by saltwater-freshwater flooding interaction	• for Lower Murray - connectivity is critical • won't apply to Chowilla, White Cliffs section • may apply to wetlands around Coorong (but not broadly to Coorong) • don't consider this criteria will work well for RM-DS EC as a whole	• wetlands most affected and lost (50%) - from levees and agriculture • diversity lost to monocultures • 1956 flood boundary a useful consideration of the boundary for this EC

Criterion Two - Small geographic distribution combined with demonstrable threat.

Questions	Group 1	Group 2	Group 3	Group 4
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• Yes may work for small isolated AS (e.g. terminal lakes approach) • would work quite well for naturally rare and fragmented wetlands • EC of RM-DS not small, but may have small components • rules for demonstrability? - on a case by case basis - but must be legally defensible	• May apply to long, linear (narrow) fast flowing streams (i.e. in terms of area is small GD)	• Yes - for certain AS	• No - difficult criteria to apply, hard to argue that geographical distribution is small for large, complex river systems
2. How do we best measure this Criterion in aquatic ecosystems?	• could measure and depend on lifeforms • change in hydrology, e.g. lotic habitats - Anabranch only example left as lotic, main river is now lentic	• surrogate - freshwater fish distribution - substantially reduced from changes to flooding regime		
3. What are the challenges, impediments & issues for applying this Criterion to aquatic systems?	• if a big and complex system then cannot have a 'small' geographic distribution • does 'small' depend also on phase of climate or a temporal aspect? • what about ecological or hydrological disconnect?	• missing key flow events could cause changed state e.g. wet state change may affect seed bank		• EPBC Act not retrospective before 2000 • continuing actions like irrigation, grazing, etc - still a diffuse continuing threat • how deal with cumulative impacts in terms of AS?
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• rarity and/or fragmentation could be critical features • any scope to change concept of size (i.e. river channel a narrow band, e.g. aquatic corridor in Mallee landscape) • allow for well defined area of occupancy	• changes in flooding frequency and intensity may affect species		
5. How does the Criterion work for the RM-DS EC?	• as a whole the RM-DS EC would not trigger on this criterion, except for elements downstream in system (e.g. Coorong, Lower Lakes)	• key 'food' species disappearing from specific sites, e.g. Coorong • Indigenous icons affected – e.g. pelicans	• threats are undeniable • difficult to demonstrate (legally) 'small' geographic distribution • RM-DS EC likely not 'small'	• government actions (e.g. Wellington Weir EIS; Basin Plan is an 'action')

Criterion Three - Loss or decline of functionally important species.

Questions	Group 1	Group 2	Group 3	Group 4
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• Yes but need to postulate how important species are and this is data dependent	• Yes	• Yes	• Yes - potentially powerful criteria which describes the situation
2. How do we best measure this Criterion in aquatic ecosystems?	• what is the test for a suitable criteria? (i.e. demonstrate a keystone species, etc) • look at health or population dynamics of key elements, e.g. extent, distribution, size class demographics (e.g. fish, trees)		• current status of fish community - well documented native fauna in general 10% abundance/diversity • need to consider age class, canopy extent, distribution and abundance, biomass, level of recruitment	• early records of fish abundance (including anecdotal?) • land use and occupancy mapping of Indigenous people • components and processes through floods • migratory birds • floodplain trees • estuarine macroinvertebrates
3. What are the challenges, impediments & issues for applying this Criterion to aquatic systems?	• how to defend? • EPBC Act - indigenous consultation a key component - embedded in criteria but not explicitly stated (particularly important aspects of iconic species) • restoration tricky for groundwater systems • how to differentiate trophic cascade from disturbed state? • not just about population sustainability - need old versions of trees (i.e. versus restoration of new which may take 100s of years)	• species are becoming extinct in the wild, e.g. pigmy perch (EPBC listed) restricted to highly engineered areas like irrigation systems • change of substrates is influencing species like catfish, trout cod, gudgeons - affected by sedimentation (demersal egg layers); small prey fish reduced - What are the flow-on effects?	• what if there are none left of the functionally important species (e.g. Murray cod)? • diadromous fish (i.e. that need to migrate to sea and back - system no longer connected to sea)	• trophic level interactions and productivity associated with pelagic community - autochthonous (very little allochthonous) - starved for food and energy → key threshold value • how functionally important species linked to processes
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• compare to examples like Yellowstone National Park where wolves reintroduced • need proof of concept of keystone and foundation species • need to be more flexible with	• allow for time lag between disturbance and impact on functionality	• not just general decline in species abundance, but also need to consider how age class, canopy extent, distribution, biomass, level of recruitment, productivity, etc.	

	generation times for thresholds - e.g. invertebrates, range of lifeforms, *Ruppia* an annual		have all been affected by the threatening process	
5. How does the Criterion work for the LM-DS EC?	• Murray cod - apex predator - keystone concept (keystone species) • Cultural issues need to be factored in i.e. cultural connection to Murray cod and red gum (e.g. shields, canoes) • strong argument for red gum (critically endangered) - important habitat for so many species (homes, nesting, nectar, soil stability, woody habitat, etc)	• decline in red gum and black box (time criteria may not be relevant as are long lived species) - salt into root system, reduced freshwater - recruitment down and insufficient to replace old trees → time lag in getting functionality back	• Murray cod a functionally important species but bony herring (bream) also very important to ecosystem function but they are not badly affected to date • refer to RAMSAR listing • loss of riparian vegetation in general	• records of early fishers may be useful (even anecdotal)
6. What are the keystone species or assemblages for the River Murray-Darling to Sea EC?	• *Ruppia tuberosa* in Coorong lagoon • black box may be just as or more important - juvenile release rate • red gum as foundation species, also coobah, *Lignum*, *Ruppia* • biofilm snails (Keith Walker)	• red gum - differential mortality, level of seed set driven by frequency and timing of freshwater • suspect submerged vegetation could be organising system (e.g. in Lower Lakes → fish)	• mussels - data on significant changes but may not be functionally important to whole EC • big trees like red gum and black box (for nutrients, habitat, insect and bird fauna, snags, etc) - river red gum and possibly black box likely to trigger this criteria. • Potentially a range of other species may trigger also, e.g. Lignum, Ruppia (critical at Coorong end; impact on Murray hardyhead and other aquatic fauna), Melaleucas removed in a lot of areas	• Murray cod; golden/silver perch, catfish, small native fish, Murray River crayfish • all submerged aquatic plants e.g. *Ruppia* • snails and other invertebrates • river red gum, black box, floodplain trees • Murray turtle, *Emydura*

Table 5: Criterion Four - Reduction in community integrity.

Questions	Group 1	Group 2	Group 3	Group 4
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• Yes - totally applicable at a range of scales and levels • provides opportunity to pick up the overarching significance of flow regime as a key ecological process	• Yes - widespread loss of functional integrity • flood dependant species and community level in decline	• Yes - very important for aquatic systems • loss of connection to sea (changes to fish fauna)	• Yes
2. How do we best measure this Criterion in aquatic ecosystems?	• flow linked to a number of processes and well documented (i.e. huge body of evidence to support that flow is important and can describe changes in many facets of flow - temporal, frequency, size, etc.)		• dominance of invasive species • number of algal blooms • changes in species abundance and composition (especially vertebrates) • changes (balance) between native and non-native species - aquatic and terrestrial	• relative abundance of native versus exotic species (e.g. willow, carp) • native fish populations • water level
3. What are the challenges, impediments & issues for applying this Criterion to aquatic systems?	• in general lack of data for most aquatic ECs would be an impediment (in most catchments hydrological models poor and no natural flow data, no calibration, etc)	• time lag in getting functionality back • irretrievable loss of native species (but not any immediate invasion of invasive/exotic species RM-DS) • change to substrates • trophic flow-on effects	• algal blooms - managed by flow regimes but a potential threat • macrophytes very important - regeneration impacted by carp (is there evidence?) especially in lagoons and wetlands • biophysical impacts - connectivity important • some threats have long lag effects e.g. groundwater, salinity • to reinstate age structure would require a lot of time (e.g. old trees) • system has natural resilience but changes to landscape have impacted on this immensely	• processes of connectivity affect integrity - e.g. allochthonous versus autochthonous (energy and carbon) • timescales involved in changes - what is appropriate to what community or process? • engineering interventions - effect of each is difficult to identify

4. How can the Criterion be better adapted for aquatic Ecological Communities?	• regarding thresholds - similar to restoration issue of timeframes, etc. • consider short generation times for invertebrates and some plants - particularly with respect to thresholds • flexibility		• generally, appropriate thresholds for aquatic systems (such as Coorong) • need to work out critical time when need to get floods for lifecycles •	
5. How does the Criterion work for the RM-DS EC?	• works very well • the River Murray is unique in that there is a lot of historical data on flow and other aspects (back to 1891) • *Lignum* should be listed, distribution declining	• estuarine species have been restricted, reduced or lost • recruitment affected - seed and egg bank function • system is zoned and there's a contraction of zones due to changes in flooding regimes (decline in geophysically important functionality)	• invasion by carp is a standout - caused massive alteration in community - loss of several important aquatic species and changes in invertebrate composition • flow regimes critical • Keith Walker studies on mussels and spiny crayfish - replacement of fluvial systems (flowing river turned into pools) → profound changes in distribution and abundance • *Lippia* another key threat • estuary dependent organisms lost or declining due to hypersalinity in Coorong (need to restore integrity within 10 years or less) - including barrage fishways shut for 3-4 years → huge decline in recruitment • what are the critical timeframes to reinstate red gums to appropriate age structure? • overall - appropriate salinities need to be re-established within 10 years or integrity gone - so would probably trigger 'critically endangered'	• carp - lot of biomass and productivity locked up - lot of habitat degradation • willows

Table 6: Criterion Five - Rate of continuing decline.

Questions	Group 1	Group 2	Group 3	Group 4
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• Yes and no - nature of Australian variability	• Yes - accelerating (e.g. tree health)	• Yes	• Yes - e.g. rates of decline in the Lower Lakes rapid in the last 5 years (substantial period of low flow and disconnection)
2. How do we best measure this Criterion in aquatic ecosystems?	• partial disconnect between flow and community change - lag effects a complicating factor • diversions versus inflows • connectivity (increasing disconnection of the system)	• shift in salinity regime	• natural flows versus un-natural flows better measure of effect of water movement through system (e.g. flooding of red gums dropped from once every X years to once in Y years) • difference between natural and managed river condition (but can't quantify 1750 hydrology)	
3. What are the challenges, impediments & issues for applying this Criterion to aquatic systems?	• demonstration • natural variability • lag effect and ongoing impacts • rate of change of health can spiral and have flow-on effects (e.g. trophically) • pace of regulatory change • climate change coupling to inflows	• adaptive management research exists • water management plans exist	• can argue natural climate and anthropogenic influences (i.e. climate change coupling) • some threats have long lag effects, e.g. groundwater, salinity	• 30,000 ha of irrigation development in SA - intensifying degradation • groundwater usage not well monitored
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• lag effects around recovery time • impacts operate over long time scales • tipping points need to be factored in			
5. How does the Criterion work for the RM-DS EC?	• rate of disconnection • % of inflow compared to extraction (rather than just extraction) • appropriate extraction %	• significant detrimental change (70%) has rapidly occurred in last 10 years on river floodplain -	• decline in red gums well documented • cap established in MDB in 1994-95 flows - system	• decline caused disconnect to wetlands and ocean • water allocation problem - rapid allocations in 1980s and

	• is the rate of diversions still increasing? - but not much more to take	documented information about decline from 1985 to current date	depauperate then and worse since (dry decade since 1997, especially last few years) • acid sulfate soils potential indicator - critical for Lower Lakes - timeframe, impact of re-flooding on fish etc. unknown • salinity in Lakes and Coorong - work done on projections	1990s - no surplus in the system

Criterion Six - Quantitative analysis showing probability of extinction.

Questions	Group 1	Group 2	Group 3	Group 4
1. Does this Criterion work for (complex, dynamic) aquatic ecosystems?	• Yes - possible if have a well defined community and understand when it changes to something different (i.e. demonstrate that flip to other state is permanent)	• Yes - potentially	• Yes - can be applied conceptually (e.g. Coorong)	Yes - some scope for application
2. How do we best measure this Criterion in aquatic ecosystems?	• data dependent • proof of role of keystone species • if no data or examples use modelling (Moktop?)		• data needs to be available	
3. What are the challenges, impediments & issues for applying this Criterion to aquatic systems?	• data availability • proof of keystone species • not a challenge that red gum also occurs outside nominated area • cultural input to Criterion - *Cyrpus vegiatus* and sedge used for weaving		• how is extinction defined? - complete extinction or local extinction in EC? (e.g. could lose things from Coorong forever, but they occur somewhere else) • local extinction is relevant in consideration of EC	• scope to apply PVA type analysis to selected species but that may not capture sense of community as well as Lester modelling • cultural aspect - have to keep it a living system or we will lose something immeasurable
4. How can the Criterion be better adapted for aquatic Ecological Communities?	• trying it out - robust method needed for Ecological Communities			
5. How does the Criterion work for the RM-DS EC?	• Coorong modelling (Flinders University) has potential • use species listed under Criterion 3 (i.e. those identified as potential keystone species) to try it out • focus on red gum &/or black box as more literature/data and a stronger case • argument for having red gum and black box together as they have complementary roles	• modelling work being done for Lower Lakes (Rebecca Lester, Peter Fairweather - Flinders University) • Murray Futures Project will be looking at Murray River up to SA/VIC border		• Coorong conceptual modelling by Lester and Fairweather a good start

	• black box is a classic of the sliding baseline - on the way out since 1956 floodline • river coobah and black box both important to water bird breeding but to a different suite of birds than breeding in river red gum - published data on this • Ruppia - historic data- potentially something could be done with this			