Submission from David Bell
to the Murray-Darling Basin Royal Commission, 12 June 2018

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1. Background and my reasons for making this submission

I was the Director of Environmental Water Planning at the Murray-Darling Basin Authority (MDBA) from March 2009 to November 2017. My principle responsibility during that period was the preparation of the Environmental Watering Plan (EWP), which became Chapter 8 of the Basin Plan. Prior to joining the MDBA, I was the first Director with the Commonwealth Environmental Water Holder (CEWH) for approximately 12 months.

Earlier in my career I also worked:

I. for four years as a scientific officer employed by the (then) NSW Department of Water Resources; and
II. 14 years undertaking regulatory and management roles employed by the NSW Environment Protection Authority.

I am making this submission because I believe I have relevant qualifications and experience that may assist the Royal Commission (Commission).

In addition to my responsibility for the EWP, I also had responsibility for work towards determining the environmentally sustainable limit of take (ESLT) for approximately the first six to 12 months of my employment with the MDBA.

In the period leading up to the making of the Basin Plan in 2012 and especially the period leading up to the publication of the *Guide to the Proposed Basin Plan* in 2010, I was one of the group of MDBA Directors who were actively involved in much of the discussion and thinking about how to prepare and settle the Basin Plan which gave me considerable insight into that process. However, I do not want to imply that I had broader responsibility or decision making roles beyond those relating to the EWP. Rather, I was actively involved in providing leadership, shaping deliberations and integration between the various chapters of the Basin Plan. As time passed this my focus contracted mainly to the EWP and associated Basin Plan provisions (such as Part 6 of Chapter 10), rather than the earlier broader range of maters.

In addition to considering I am competent to comment on the Basin Plan and have information that may be of assistance to the Commission, I am concerned about how the Basin Plan has and is being implemented. I am of the view that the implementation of the Basin Plan (by the MDBA, the Commonwealth more broadly, and Basin States) is seriously undermining its effectiveness and the competent management of water resources in the Basin. I am concerned that, unchecked, the current Basin Plan implementation will lead to worse environmental outcome than would have arisen if there were no Basin Plan.

2. Judging the Basin water reforms

The management of water in the Basin is very complex – overly so in my view. However a degree of complexity is unavoidable due to the nature and scale of the Basin, the number of jurisdictional players, the yet greater number of agencies charged with various responsibilities, the dynamic agricultural industries operating in the Basin – seeking to exploit its water resources and the vicissitudes of weather and climate.

Any attempt to reform the management of the Basin's water resources is therefore also destined to be complex and contested.

In my opinion it is necessary to divide the elements of the reforms and their implementation to make judgements about them and those responsible for discharging them.

The Commonwealth Water Act 2007 was drafted in some haste. This is largely a political matter. Notwithstanding, the Water Act was a very big reform, accompanied by very large public funding. It would have been better had the Water Act been preceded by a comprehensive public, policy development process – green paper(s) and white paper(s). This would have helped to clarify the role and limitations of the Act and may have led to a clearer Act. For those charged with interpreting and implementing the Act, such a process would have been invaluable.

Further, due to the state of Victoria declining the Commonwealth's invitation to refer its constitutional powers to manage water to the Commonwealth, the Water Act relies heavily on the external affairs powers in the Constitution. Arguably, the external affairs powers focus the Act unduly on the international treaties that it invokes.

The Basin Plan is, arguably, the major implementation task of the Water Act. By its nature it seeks to address the balance between consumptive and non-consumptive uses of the Basin's water resources. Striking such a balance cannot avoid balancing different values and competing views. Unsurprisingly, the Basin Plan was vigorously contested, particularly by those with short-term and/or vested interests. It was also contested by Basin jurisdictions and their agencies, in part because it implied change and had the potential to erode status and power.

The 'settling' of the Basin Plan was, rightly or not, a negotiation between Basin jurisdictions. To some degree a compromise was inevitable, given the development and nature of the Water Act. For example, even if the Act were diligently applied as 'black-letter law' a determination of which environmental assets and ecosystem functions are / were "key" was required and this is, at least partly, a matter of judgement. The judgement about the compliance of the Basin Plan with the Water Act ought to be at least somewhat tempered by this reality. I am not suggesting that the Basin Plan (particularly the determination of the sustainable diversion limits (SDLs) is fully complied with the Water Act. Nor am I suggesting that the compromises were generally good ones or they were made in appropriate ways – that is not my view. Rather that some compromise was necessary.

Having settled the Basin Plan, its implementation falls to a number of parties. These include, the Murray-Darling Basin Authority (MDBA), the Commonwealth more broadly – including Minister(s) and departments, state governments and agencies, and, to a lesser degree, corporations and individuals. One might reasonably expect that, a compromise Basin Plan having been legislated after a long, tortuous process, best efforts would have been made to give effect to it. Sadly (predictably, perhaps) this has not, occurred. In my view the failure to properly implement the Basin Plan is of greatest concern as it undermines the entire reform process, notwithstanding the limitations inherent in the reforms.

3. The Basin Plan 2012

I support the Basin Plan as originally made. It was and is not a perfect plan. It was the product of many compromises. However, as made, the Basin Plan was a very substantial step forward. In my opinion the Basin Plan was a significant public policy achievement and a major advancement in natural resource management. It has rightly been lauded internationally.

I do not believe that the sustainable diversion limit(s) (SDL) set out in the Basin Plan were optimal. The SDL is generally referred to, in shorthand, by the volume of water that must be recovered to meet it. In the Basin Plan as made in 2012 that number was specified as 2,750 GL per annum (based on averages). In my opinion recovering only 2750 GL for the environment will not deliver environmental sustainability. However, '2750' represented a substantial step towards environmental sustainability. Properly implemented with adequate monitoring a Basin Plan that led to an additional 2750 GL for the environment could demonstrate progress and provide a basis for further consideration of the appropriate SDLs that would better reflect the ESLT. I was then (2012) and am now of the view that it was an acceptable compromise. [However, I am not suggesting that 2750 reflected or reflects the ESLT as required by the Commonwealth Water Act 2007.]

The Basin Plan (and associated intergovernmental agreements) anticipated changes to SDLs. In the northern Basin a review was to be undertaken to revisit the science in two catchments to, potentially, reassess the SDLs. In the southern Basin an adjustment mechanism was to be applied with the general expectation that some 650 GL less water would be required for the environment and an additional 450 GL more water would be sources for so-called enhanced environmental outcomes. Both these represent 'kicking the can down the road' because full agreement to '2750' could not be reached at the time. In essence these represent political negotiations rather than any scientific assessment about how much water the Basin's water-dependent ecosystems require.

The Basin Plan includes much more that a determination of the volume of additional water required for the environment. In my view, the Basin Plan should not be judged solely on the adequacy of the SDLs, the mechanism for their determination and the negotiations associated with them. Rather, judgments about the SDLs are matters that should go to the adequacy of powers and governance (and diligence in the discharge of duties) including matters of federalism, the independence of scientific and policy advice, the mechanisms for (necessary) social, economic and environmental trade-offs (not optimisation), monitoring, enforcement and transparency.

4. Comments on matters raised in the Commission's first issues paper

At paragraph 14, reference is made to long-term environmental watering plans (LTPs) and notes that they "be included in all water resource plans". My understanding of S.10.26 of the Basin Plan is WPRs have to be prepared having regards to LTPs (10.26(2)(a)) rather than LTPs being a part of WRPs. This is a small matter but relevant to how the two operate together. It is useful to note that unlike the accreditation of WRPs the Basin Plan does not provide for LTPs to be accredited – hence the requirement to 'have regard to' rather than be 'consistent with'. Of course, if LTPs have not been prepared or have not been prepared adequately then the work of the LTPs will need to be undertaken as part of the WRP preparation process if the WRP is to be fully compliant with the Basin Plan.

A. The ESLT, the SDLs, changes to SDLs and compliance with the Water Act

In my opinion *The Guide to the Proposed Basin Plan* (Vol 2) is still the best estimate of ESLT and the science underpinning it. Undoubtedly, better tools and techniques have been developed since the Guide was published in 2010 and more is known about the water-dependent ecology of the Basin. However, in my opinion these better tools and techniques were not applied properly – by which I mean independently and dispassionately. I covered this at some length in my conversations with Commission staff (as referenced above) and so do not propose to repeat that here.

I note that one of the Commission's focuses is whether the SDLs reflect the ESLT. As indicated above, I don't think they do. From a public policy perspective, setting the SDLs would be better undertaken through a transparent political process rather than being 'outsourced' to science. Ideally, such a process would be transparent about the trade-offs involved and would include unadulterated scientific input. I note however that the Water Act doesn't really provide for such a process. I think this is an error. To illustrate, contrast two 'deals' made about SDLs:

> The first was made by the then Chair of the MDBA Board Mr Craig Knowles and Queensland counterparts. As a result the SDL for the Condamine-Balonne was adjusted up by 50 GL (and the Basin-wide reduction amount went from 2800 GL to 2750 GL). While I don't personally agree with the outcome, the process was transparent and did not purport to be based on the best available science or to produce equivalent environmental outcomes (clearly it won't).
>
> The second is the 70 GL increase in SDLs in the northern Basin arising from the Northern Basin Review. In this instance it is claimed that environmental outcomes will be equivalent (again, clearly they won't be) and that the science supports – in my view it does not. The change is driven, in part, by social and economic analysis. Whatever the merits of the 70 GL increase in SDLs (again I don't personally agree with them) the negotiation is not transparent and the claim that it is supported by the science undermines the science and the credibility on the MDBA. It also makes future adjustment based on sound new science (including monitoring of environmental conditions) fraught with greater distrust.

It appears that there is a political deal to adjust SDLs in the southern Basin by increasing SDLs by 650 GL and decreasing them by 450GL (my simplified outline). It would be better, in my opinion, simply to do as Mr Knowles did and calculate that 650 less 450 equals an increase in SDLs of 200 GL and make the changes accordingly. The alternative is a conceit that suggests that the same outcomes can be achieved by various (often engineering) projects and so-called efficiency measures and that these works will have the same effect as more water overall.

This Northern Basin Review and the SDL adjustment processes have undermined the veracity of the other good work of the MDBA and other parties.

I strongly suggest that vandalising the environment (the Menindee proposal can only be described as vandalism) and wasting taxpayers' money on expensive works is a worse outcome than just making the change and moving on. Better to allow a period for the changes to take effect and the ecology to respond, monitor well, evaluate and revisit on the basis of evidence.

A Basin Plan properly implemented with good monitoring (there hasn't been adequate attention to monitoring) could have demonstrated the adequacy or otherwise of SDLs and lead to adaptive changes.

To the extent that the northern basin review and the SDL adjustment processes are signs that landing the Basin Plan was too hard and so elements were postponed, the 2024 reconciliation of SDL adjustment projects kicks the can it further down the road. This leads to the Basin Plan having a feeling of never being settled which is not good for anyone.

In my opinion it is probable that changes to the Basin Plan arising from the northern basin review and the SDL adjustment process are not consistent with the Water Act or the Constitution (as set out in the Commission's issues paper number two). While I think this is important, it seems to me that there is a broader problem with the construction of the Water Act 2007 and the mechanism for setting the SDLs and it would be good to address both rather than simply find that the Basin Plan is faulty or, worse, unsound.

B. How SDLs are understood

The Basin's water resources are extraordinarily complex and are demonstrably difficult to understand. However, as highly contested resources of great value held by the Crown on behalf of citizens, it is critical that efforts be made to make them understandable.

The Water Act requires that there are to be limits on how much water can be diverted on taken from rivers, that these limits must reflect the ESLT and that they be specified as long-term averages. The requirement to reflect the ESLT is one that I support. Not everyone does. Many consider that other matters should be taken into consideration. In my opinion the Water Act provides limited scope to do this, subject to reflecting the ESLT. Trading off various values is common in public policy decisions and arguably the Basin water reform would be better public policy if it provided for transparent trade-offs.

The requirement that SDLs be specified as long-term averages is unfortunate. The arithmetic mean is a very poor metric to use to quantify a limit where the underlying resource has the enormous variability that flows in the Basin do. Averages are not as well understood as many might imagine, let alone a long-term average. This leads to a limit that is very difficult to understand or measure.

This is further hindered by using a recovery volume (between the legislated limit and some earlier benchmark) of extraction as a short-hand for the limit.

By analogy: road speed limits are very clear. One is either complying or not. Everyone can easily ascertain the limit and make appropriate judgments. However if the speed limit were to be described by how much a driver passing from a 100 k/hr zone to a 70 k/hr zone has to slow down then it becomes much less clear. At what point are we to measure the approaching driver's speed? What if they are travelling at more or less than 100 k/hr? Do we need to model each driver's speed and set an average? We might expect those who set the speed limits to have many complex matters to consider. Similarly we might expect that a police officer measuring a driver's speed to have complex equipment, calibration and procedures to follow. But in the end the limit is clear. It is a matter for each driver to assess their need to slow down and how much time / distance they require. If a government wished to add other mechanisms to slow traffic it could, say, add speed bumps or narrow the roadway but these are ancillary to the actual limit.

SDLs should be more like speed limits. They should not rely on an assessment of take at some previous time (the so-called baseline diversion limit) although that might be useful information for some to have. Rather it should be a clear limit that is discernable without reference to other matters.

For example SDLs should not be only discernable using complex mathematical models[1] nor subject to adjustment using 'black-box' modelling or by reference to cap-factors and other matters (however SDLs were originally determined). For citizens to have confidence that SDLs are real and not some sort of vague notion subject to interpretation, they should set out clear limits (including limits that apply in specified places and /or at specified times). This would facilitate measuring, reporting and compliance and would lead to community confidence that they are real limits.

One effect of using the recovery amount as a short-hand for the SDLs is that the focus tends to move from the limit(s) and compliance with them to how compliance is being achieved. Governments have committed to recovery of water entitlements and other activities such a (so-called) efficiency works to achieve the SDLs but they could have approached the transition in other ways. This commitment has, in my opinion, placed too much emphasis on water recovery and insufficient emphasis on the limit - the environmentally sustainable level of take.

C. Efficiency works, water recovery and SDLs

Undertaking efficiency works as a method of water recovery relies on essentially 'creating' new water by being more efficient. Obviously new water is not actually created – rather existing water is counted differently and (notionally) repurposed. For example if a leaky, open irrigation channel is replaced with a pipe then, it is argued, there is more water because leakage and evaporation are halted. However, new water molecules are not created. Rather (ignoring evaporation) less soaks into the ground, to eventually return to rivers. How much reduced take arises from such works is debatable and relies on how the so-called recovery is calculated.

Notwithstanding, any recovery is much more expensive per unit of water than purchasing from willing sellers (even at the inflated purchased costs witnessed as part of Commonwealth recovery activities). The beneficiaries of such largess are generally private entities (rather than communities), including via capital appreciation of private assets.

Further, if the result of efficiency works is the creation of a new water right (to reflect the 'created' water) and this new entitlement is not offset somewhere else then this has the potential to undermining of the entitlement framework. Alternatively offsetting may lead to planned environmental water (PEW) being reduced – which is contrary to the requirement to protect PEW in s.21(5) of the Water Act.

D. Works and equivalent environmental outcome

The ESLT includes consideration of (key) ecosystem functions. The Basin's water-dependent ecosystems are underpinned by the functional relationships between species, biological and non-biological elements. Works to facilitate watering (irrigation) of selected parts of the floodplain (at the exclusion of others and/or at lower river flows) are claimed to achieve the same or better outcomes with less water. However these works almost always disrupt necessary ecosystem

[1] By definition models must contain assumptions. The assumptions have a big influence on the outputs. So if a model assumes compliance with a SDL (they generally do) then one output will be that SDLs are complied with. This has serious implications for how models are used, especially if they have a role in SDL compliance – which they will have under existing arrangements.

functions and result in changes to ecosystems that are usually not predictable – see http://arrow.latrobe.edu.au:8080/vital/access/manager/Repository/latrobe:35360;jsessionid=52732A98933E04B38C2A6BEE78D36D5E (copy attached)

In highly developed systems as exist in the Basin, changes to environmental assets and ecosystem functions will have to be accepted to some degree – obviously we cannot return to a pre-development system, even if it were considered desirable to do so. However, it would be better to be transparent about the trade-offs being made when we seek to manage the Basin with less water than it originally had. Arguably some of this is implicit in the concept of 'key' in ESLT definition but making it explicit would be good public policy. While this will be a difficult task it will be necessary if we are to effectively manage limited natural resources. Good long-term watering plans (in preparation by Basin States) will go some way towards making these objectives / trade-offs more transparent. Done well, this will help to better refine SDLs over time.

E. Illegal take

Illegal take, like any illegal activity, undermines confidence in rules / laws. In my opinion, this is the greatest risk associated with illegal take. Notwithstanding, the alleged theft is material and should be addressed. Appropriate regulation, compliance and enforcement are essential for establishing confidence in the reforms.

The Commonwealth should not (as it has until recently) wash its hands of responsibility for compliance. Even with a fully cooperative federal commitment to the reforms / Basin Plan I would expect one tier of the federation to transparently advise others of compliance matters it became aware of - without fear or favour. Where such commitment is missing (as it assuredly is) the Commonwealth's responsibilities in this respect are so much the greater.

When I worked at the MDBA I often heard it asserted that the MDBA either had few, weak regulatory powers or, worse, had no regulatory responsibility until 2019 (when it had a SDL compliance responsibility). Both are untrue as an examination of the Water Act will show. Of course, regulation has many forms and does not rely solely on powerful enforcement tools. In addition, no matter how good (or otherwise) an enforcement tool may be, it is of no value unless used. Should existing powers be used and prove insufficient then a case can be made to parliament for better powers. What was and is required is an instinct for regulation and the stomach (resolve) to act.

In this regard I am not only referring to alleged illegal take. Of greater concern is the Commonwealth's (including the MDBA's) preparedness to implement the legislation and the Basin Plan without fear or favour and to hold other parties, particularly Basin States, to account.

It has been argued that one or more state would withdraw from the Basin Plan and that this was a reason to overlook various poor performances. In my opinion, this was giving in to blackmail. Failing to act encouraged yet more blackmail. Basin States have not been held to account.

In the end the threats to walk away from the Basin Plan may have been hollow. Alternatively Commonwealth action may have resulted in States being embarrassed into action. In the end it has taken the media to expose inaction before governments and their agencies have acted, however inadequately. The external affairs powers of the Constitution may have prevailed or, perhaps, there would have been sufficient basis for other necessary changes – legislation, funding, etc. By not dealing with poor performance, the Basin Plan has been and is being undermined little by little. In some cases the 'compromises' are likely to lead to worse outcomes than had there been no Basin Plan. For an (egregious) example of how the Basin Plan can be undermined one need look no further than the nature and provisions of the Barwon-Darling Water Sharing Plan 2012.

An example of not taking an adequately strong approach to the responsibility of implementing the Basin Plan is approach the MDBA took to negotiating with NSW what constituted protection of planned environmental water (PEW) (see Water Act s.21(5) and Basin Plan 10.28). On the face of it there is no constitutional or legislative basis for agreeing that NSW water resource plans (WRPs) could be accredited with less protection for PEW. But finding a compromise was the subject of a many months work to which not inconsiderable resources were devoted. A specific example was a proposal that a particular rule in the Namoi water sharing plan be changed from protecting 90% of unregulated flows during winter months to protecting only 50% of such flows. It was immediately obvious that this proposal (by itself) should be dismissed. However, it became the subject of much debate and prevarication. A response took many months to formulate (12, I think) by which time NSW had proceeded. This remains a matter that will have to be dealt with when WRPs are presented for accreditation. (There are likely to be other examples such as this that will need to be addressed during the accreditation of WRPs.) A competent regulator, implementing the Basin Plan properly would have nipped this proposal in the bud – or at least drawn its line in the sand quickly and clearly.

The Basin Plan and the reforms more generally are, in my opinion, being undermined by the actions (and inactions) of Basin governments and their agencies.

F. WRP deadline and accreditation process

Five and a half years have passed since the Basin Plan was made. Basin States have had knowledge of the likely content of Chapter 10 for longer. There is now just 12 months until WRPs are supposed to be accredited and SDLs complied with. [It is important to note that the Basin Plan relies on WRPs to do much more than just give effect to the SDLs – so the content and function of WRPs is immediately critical to much of the Basin Plan.] Given how little progress Basin States have made it is difficult to conclude other than that there is little intention to meet the deadline. Further, it is difficult to imagine that anything produced in such a short period will be fully compliant with the provisions of Chapter 10 of the Basin Plan.

This has been apparent to the MDBA (and everyone else, I imagine) for some time and, before I retired, the likely need for extensions was being contemplated. However, with apparently so little evidence of commitment to WRP preparation from Basin States to date (with rare exceptions) it is hard to see how an extension will change this dynamic (or lack thereof).

There are some fundamental problems with the WRP requirements. Foremost would appear to be that the Water Act does not oblige Basin States to prepare and submit WRPs.

There is little evidence that the Commonwealth will take a robust assessment and regulatory approach to accrediting WRPs. Indeed it has prepared content for one jurisdiction rather than refuse accreditation. It would have been preferable in that instance to recommend that the Minister not accredit the WRP. At least it would have indicated to all jurisdictions that the MDBA was resolved to accredit properly. When I recommended such action the response was the effect that "the Department is not ready for that yet". I understand that Basin States were advised by the MDBA to the effect that "failing to have accredited WRPs by 30 June 2019 would be mission failure for the MDBA". If I were acting on behalf of a Basin State in relation to WRP delivery, such a message would cause me to be quite relaxed.

One strategy a Basin State might choose to employ could be to submit most or all their WRPs at the deadline. This would put enormous pressure on those charged with assessing the WRPs. Broadly two outcomes might be expected in such a case: one would be long delays and potentially many iterations before WRPs were suitable for accreditation; more likely would be a temptation to cut corners and recommend accreditation, perhaps in the hope that a better outcome could be pursued in 10 years (presumably by someone else).

G. Constitutional basis for the Water Act

I claim no specialist understanding of constitutional law. However, it is clear that the disparate approach to managing water / flows in the Basin provided for by the Constitution is problematic in the Basin. It is argued that this is one reason for the water reforms. Initially the Howard Government sought a referral of powers from the Basin States. All but Victoria agreed. It is not clear to me that it would have been possible for the Commonwealth to proceed, leaving Victoria out (including out of any funding) but I think it would have been preferable. No doubt this would have created its own set of challenges but it would have avoided the arbitrary separation of water from other natural resource management and the current inter-jurisdictional conflict and intransigence. Over time Victoria may have changed its view and joined. Of course that is now academic.

Whether there is sufficient power vested in the Commonwealth (to impose obligations on Basin States) under the Constitution is unclear to me but I suspect not. In any event the limit of the powers would appear not to have been tested. Rather agreement is sought via a range of processes, culminating in the Ministerial Council. This ultimately leads to a lowest common denominator approach to what is agreed and no process to follow up a failure to deliver / comply. Arguably this process of agreement / veto has, in part, contributed to compromises in setting SDLs rather than setting them solely on the basis of the ESLT.

What is clear is that the federated half-way approach is not efficient or effective. In theory it need not be – if all jurisdictions committed to the reforms and didn't subsequently renege on such commitments but that is not the world we live in. Intergovernmental agreements appear not to be enforced – perhaps they cannot be. Our systems of government might be better served by better cooperation underpinned by decent coercive powers / sanctions for failing to perform after agreeing.

H. Environmental and ecological health of the Basin

My view is that (using the short-hand) approximately 4,000 to 4,500 GL is the minimum additional water that the Basin's water-dependent ecosystems require. I think this would likely be sufficient to meet the spirit of the Water Act and to put the remaining natural (and semi-natural) areas on a sustainable footing. By sustainable I mean that they will remain in (or return to) a generally healthy and self-sustaining state and not transition into a much less diverse state. I think this would provide these ecosystems with enhanced resilience to climate change (although that will ultimately depend on the magnitude of such change and the speed of transition).

Part 2 of Chapter 8 of the Basin Plan sets out the overall objectives for the water dependent ecosystems of the Basin. These objectives are (in the main) necessarily general. However, they did, in my opinion, describe a sustainable end point. Achieving them will take some time and more efficient and effective water management practices than currently provided for. I don't think '2750' (or less) will achieve them. However, properly implemented with sound monitoring, using the additional '2750' (together with existing water) could help to better quantify the long-term ESLT.

Inevitably the question about the social and economic health of the Basin also arises. This is about much more that the exploitation of water for commercial gain although those gains are considerable and therefore of importance. One matter that seems not to have received much attention is the long-term viability of irrigation in the Basin (and thus the communities that depend in it). Much is made of the relatively modest impacts of water buy-backs but it seems probable that other impacts such as climate change, profitability of different crops, improved cropping practices and technologies will be much more influential in the longer-term. We can see some of these playing out now with reduced labour demands in cotton operations as a result of glyphosate resistant strains and harvesting into round bales. There is also the matter of the long-term history of irrigation around the world which leads me to suspect that maximal exploitation of water resources leads to failure. While (another) matter for judgement, it seems likely that a less highly exploited system is likely to have longer viability – and to thus fail the test of 'wise use'. In this regard I am of the opinion that 4,000 – 4,500 additional water for the environment may lead to a more sustainable irrigation sector overall. However, the transition would need to be much better planned and managed, with greater focus on broader communities. Irrigators are, after all, being fulsomely compensated for water they willingly give up.

5. Comments on matters raised in the Commission's issues paper no 2

Overall I am in strong agreement with the arguments set out in issues paper no. 2. Ultimately it is a matter for legal opinion and judgement but the arguments appear to be sound. Perhaps of more interest, the arguments do not seem to me to be in any way novel. I have heard them and (after a fashion) made them myself.

I note that paragraph 20 refers to 16 Ramsar wetlands. This would be more accurately stated as 16 listed Ramsar wetlands. It is an important distinction that is missed by many – the Ramsar Convention applies to all wetlands but has special application to those that are listed.

Paragraph 37 addresses the definition of ecosystem. The Water Act (s.4) defines water resources broadly and provides some useful context.

Paragraph 41 observes that "[a] Basin Plan that seeks to simultaneously grapple with economic, environmental and social outcomes might achieve the optimisation of none of them." I think this is true, not least because the tools one might ideally apply for any optimisation are broader than those available under the Basin Plan. More fundamentally though, the use of the term optimisation is often a conceit that pretends there are not going to be winners and losers in any change but rather everyone / all goals can be satisfied. I think this is false in a constrained world. Better therefore to be open about the existence of trade-offs so as to better address them, including via any compensatory / adjustment mechanism(s).

Otherwise, my views and experience in relation to the matters raised in issues paper no. 2 were the subject of conversations with counsels assisting the Commission and are addressed in a separate statement.

6. Further submissions on matters not raised in the Commission's issues papers and some recommendations

A. Independence of the MDBA

References to the MDBA, the Authority and the Board are often not very clear. For clarity, the Murray-Darling Basin Authority is created by Part 9 of the Water Act 2007. Division 2 makes it clear that the Authority is the six members described in s.177. For convenience this is generally described as the Board (although that name has no legal status). The Board is supported by an administrative agency headed by a Chief Executive who is also a member of the Board. This agency is made up of Commonwealth public servants (APS officers) who are granted certain responsibilities by delegation and this agency if often referred to as the MDBA. [The Chief Executive is also an APS officer.] In a practical sense (as distinct from a legal sense) references to the MDBA are a reference to the Board, the Chief Executive and agency staff.

The MDBA is often said to be independent. Rarely, if ever, is this further articulated – independent from what or whom? In my view it would be good if the MDBA were largely independent of political and other influences but I don't believe it is.

The Board is appointed by the Governor General. However, appointment recommendations come from the relevant Commonwealth Minister who therefore exercises some influence. Further, Basin States have a say in who is recommended (albeit that this is not a transparent process).

The staff are APS officers, obliged to serve the government of the day and the Board. This creates room of conflicts of interest and for influence to be exerted. Further, as many MDBA officers are sourced from the wider APS and likely to pursue their careers in the wider APS, this creates room for divided loyalties. This may be more so for more senior officers, particularly those whose employment is as a member of the Senior Executive Service.

The MDBA's activities are, in effect, overseen by the Department – currently the Department of Agriculture and Water Resources. The Board, the Chief Executive and the Department are all answerable to the Minister.

The MDBA's budget is made up of two components: Commonwealth appropriations that are part of the broader portfolio allocation and so-called joint funds that are provided by Basin Governments. Neither budget component has been stable over the last decade – this creates other points of influence.

The Department is said to 'own' the Water Act. Any changes to the Water Act and subordinate instruments (including the Basin Plan) are overseen by the Department. Similarly any legal advice that the MDBA may seek on the effect of the Water Act must be channelled via the Department.

The Department administers water recovery on behalf of the Government. Division 7 of Part 4 of Chapter 8 of the Basin Plan addresses planning for the recovery of additional water. These provisions essentially enable the MDBA to make environmental water recovery recommendations. What types of entitlements are recovered and where in the Basin these are recovered from can have a significant impact on the effectiveness of the environmental water – from an environmental perspective, not all water is equal. To my knowledge, these provisions have never been used.

The Water Act provides that the Minister may adopt the Basin Plan given to him (or her) by the MDBA and the Parliament may disallow the Basin Plan. The content of the Basin Plan was subject to extensive negotiation with Basin States in advance of it being given to the Minister. On the one hand this is only sensible. On the other, the equality of such negotiations has a big influence on the outcome. If Basin States have or are seen to have a veto (they were seen by the MDBA to have a veto, in my observation) then the nature and content of the Basin Plan cannot be said to be independent – whatever view one may take of the merits of independence.

The MDBA's implementation of the Basin Plan is overseen by the Basin Officials Committee, the Basin Plan Implementation Committee, the Senior Officers Committee, the Ministerial Council, the Department and the Minister. All these are all points of influence.

Further there were many consultations / negotiations with stakeholders, particularly water users groups. In my view this was proper but unbalanced as there was much less interaction with other stakeholders / interest groups. Further the focus was almost exclusively within the Basin, largely on irrigation areas. Rarely was the national interest actively considered nor was the broader Australian community actively engaged.

Much emphasis has been placed on the use of computer based, mathematical, models of the Basin's hydrology. These are useful tools, although the outputs are deceptively categorical when in fact they often have significant error bands associated with them. In any event, in most instances the models were the property of Basin States and so this limited the MDBA's independence in using them.

In my opinion the MDBA is not independent. It is also my opinion that the administration of the MDBA's responsibilities could have been / could be improved by strengthening its independence. Obviously there are limits to how independent the MDBA should be. However, I think the public policy and debates about the relative importance of different values would have been / would be enhanced by greater independence. In the end the final decision about the Basin Plan, the SDLs, etc should properly be ones for Parliament(s). It would be better if the debates and trade-offs were more transparent and much less influenced by vested interests.

B. Resources of the MDBA and preparedness for implementation

Particularly in the early years – leading up to the publication of the Guide the resources available to the MDBA were decidedly inadequate. The MDBA would have benefited from more expertise at all levels, more staff to undertake the complex work entailed in producing a Basin Plan from scratch and considerably more resources to fund external work. These limitations were exacerbated by rolling false deadlines that resulted in rushes and shortcuts that could have been avoided if a more measured approach had been adopted. The Basin Plan (as made) is an enormous credit to those who contributed to it, in some cases at considerable personal cost.

Making the Basin Plan and implementing it are vastly different tasks requiring different resources different skills and different structures. Unfortunately all that really changed was that the MDBA told itself it had become an implementation agency. This has meant that some important opportunities were missed. Chief amongst these, in my opinion, was the failure to adequately resource the WRP assessment teams, particularly with staff (at all levels) with assessment and accreditation expertise / experience. Another curious decision was to totally disband the Compliance Section after the Basin Plan was made. Similarly, inadequate attention and resources was given to the need for high quality monitoring and evaluation in place until, effectively, too late. Perhaps the failure to properly transform to an implementation agency can, in part, be put down to the finalisation of SDLs being kicked down the road and thus an ongoing focus on settling the Basin Plan. I think it also reflects an insufficient understanding to the fundamentally different task that implementation is.

There appeared to me to be a fearful approach to implementation. I think this must have been largely driven by threats from Basin States to walk away from the Basin Plan. It may have been exacerbated by simultaneously trying to finalise SDLs (via the NBR and SDL adjustment processes) while implementing other elements. In my opinion threats to abandon the Basin reforms were likely to have been hollow. In any event, they were matters for governments to deal with rather than an independent authority.

There also appeared to an over emphasis on one clause in the Basin Plan – s.6.14 – to the exclusion of others. That section deals with the effect of the Basin Plan on the reliability of water rights. My understanding is that it was inserted to protect the Commonwealth against compensation claims. Section 6.14 is notably different to s.6.13 and to the Water Act and its precursor, the National Water Initiative. Over time the significance of s6.14 may have become more prominent as awareness grew about growth in water use in the Basin and the potential for this to impact on the reliability of water rights. Arguments were strongly advanced that s6.14 'trumped' all others. When so-called position statements were published to explain the provisions of Chapter 10, all had to include reference to 6.14. It remains unclear to me what the motivations were for this. However, it certainly appears to be at odds with the general intent of the reforms and to be an unnecessary limitation.

Around the middle of 2016 senior officers in the MDBA prepared a document to assist staff in interpreting their roles in relation to the implementation of the Basin Plan. It was called something like 'Fundamental Principles'. The first version of this document was hotly contested as it appeared to some (myself included) to reinterpret the legislation by reading down the MDBA's responsibilities. An amended version was subsequently adopted by senior officers. It was not published externally. Whatever the merits of the document, the general approach seems to me to exhibit a degree if discomfort with the MDBA's regulatory challenges.

In my opinion, the MDBA needs additional resources and expertise to be able to meet the challenges of implementing the Basin Plan. This could help to strengthen its resolve to implement without fear or favour.

7. Recommendations

Based on my experience and observations to date, the following are matters I consider require change if the Basin reforms are to be put back on track. I doubt this is a comprehensive list and as the Commission gathers evidence other matters are likely to present as requiring change.

A. Clarify the Water Act provisions and their constitutional basis

Elements of the Water Act could be clearer. So too could the policy articulation of what the Act is meant to achieve. To the extent now possible, it would be helpful to address these issues. For example the definition of ESLT is somewhat circular – this could be improved. The meaning and effect of 'key' in the ESLT definition could be made clearer. Similarly, there appears to have been too much scope for interpreting the Objects of the Act (s.3). There appears to have been some scope to misinterpret s.20 of the Act to construe the seven sub-sections as having equal weight. In my opinion the intent is clear but, perhaps, it could be made clearer.

The reliance on the external affairs powers in the Constitution appears quite limiting. It would appear that s.22(9) of the Act is a direct result of this. This means that the Basin Plan is unable to sensibly address matters that go hand-in-glove with the management of water. For example the threatened status of silver perch can be addressed by providing water such as has been done to promote breeding; however, barriers to dispersal such as weirs without effective fish passage have been interpreted as off limits. Again a proper policy development process might have avoided many of these issues.

Recommendation: Clarify and strengthen the policy intent of the Basin water reforms and the legislation that provides for them.

The reliance on federated governance via the Ministerial Council (and sundry other committees), together with the multiple accountabilities arising from the current construction of the Water Act is unwieldy and ineffective. This is made all the more so where a jurisdiction claims to support the Act / Basin Plan but acts otherwise. There appears to be no effective mechanism currently available to deal with this situation. This has resulted in attempts (some apparently successful) to veto otherwise agreed or legislated positions and lowest common denominator negotiated outcomes. Worse still it leads to jurisdictional agreements followed by ignoring those agreements or actively undermining them.

Recommendations: Find a mechanism to bind all jurisdictions (even if it is only a financial mechanism) and use it. Hold all parties accountable and (at least) publicise behaviours that are not fully consistent with agreements.

The current partial commitment to federated management of the Basin is clearly failing. The Constitution may or may not provide sufficient powers to fully give effect to the intent of the water reforms. More effort should be put into gaining referral of (some) powers from states. Tying these efforts to ongoing funding may assist in persuading some change.

Recommendation: Reassess the adequacy of the Commonwealth's powers under the constitution. Seek the referral of additional powers to the Commonwealth and tie funding to performance and/or referral. Accept any referral rather than waiting for a full suite of referrals.

B. Separate environmental, social and economic outcomes

Asking the Basin Plan to optimise environmental, social and economic outcomes is unrealistic. These outcomes are in conflict, at least some of the time and particularly in the short term where there must be winners and losers. Balancing these outcomes cannot be achievable only via setting a magically optimal SDL. Rather a range of policy levers will be required.

Recommendations: Remove any reference to requirements or desires that the Basin Plan address all of environmental, social and economic outcomes. Ensure that where trade-offs are required that they be addressed openly, as a public policy matter (as opposed being hidden in a technical assessment), ideally not by the agency responsible for the technical work (currently the MDBA). Let technical assessments (of the ESLT) be considered unadulterated and undertake any compromises via a public process with a full consideration of all implications and any compensatory mechanisms. Compensatory or adjustment mechanisms should sit outside the Basin Plan / SDL setting process and be overseen by government or left to the market.

C. Bridge the gap at lowest cost

Governments initially decided to recover the additional water required to meet the SDLs by purchasing from willing sellers with a greater emphasis later on so-called efficiency measures. They did not have to approach the task in that manner. Cuts could have been made across the board (subject to the suitability of water entitlements) and compensation paid for those cuts. This would have allowed for market mechanisms to be the vehicle via which those who wanted more water to make their adjustments. This may have been simpler. It would probably have been much cheaper for taxpayers.

The recent focus on bridging the gap by ‘investing’ in so-called efficiency works appears to be an attempt to combine some sort of adjustment mechanism with water recovery. If so it assumes that works, often on private property which deliver private rather than public goods are the most effective adjustment mechanism. This seems most unlikely to me. Rather future gap bridging ought to be undertaken in the most cost effect manner – not by so-called efficiency works. If adjustment mechanisms are required (as they may be in some circumstance but perhaps not all) then this should be addressed separately and focussed on communities rather than individuals.

Recommendation: Immediately cease using efficiency works as a mechanism for bridging the gap.

It would be helpful for the public to understand not only what has been recovered but how that compares with all water rights. This is particularly so where new rights are being created (for example floodplain harvesting / interception entitlements) or where the reliability of rights is changing because of growth in use, activation of sleeper licences or other adjustments (such as to cap factors). A set of Basin accounts would help foster understanding and trust.

Recommendation: Conduct and publish periodic, fully independent audits into all water rights to determine what those rights are, the volumes of water they allow to be taken, how much is actually taken and what actions are required to ensure that the effectiveness of the Basin Plan is not being undermined.

D. Improve governance

As outlined above, the pressures acting on the MDBA have been such that various decision makers have felt the need to compromise on the requirements of the Water Act and, more recently, the Basin Plan. Those pressures have largely been to dilute the effect and content of the instruments. Apparently they have been irresistible. In my opinion this arises from a number of things: the possibility that the Water Act could be interpreted in less challenging ways, the messy governance arrangements arising in part from the apparent lack of powers in the Water Act, the potential conflicts of interest that employment and career arrangements may provide, the capacities of decision makers to resist pressure and the lack of countervailing pressures or incentives.

The board members are largely part time and so the Board is functionally part time. The Board is not sufficiently independent. Nor does it have the necessary range or depth of skills to adequately address the range of matters it is responsible for. Probably there are too few board members to establish adequate expertise across the broad range issues the Board needs to consider. This leaves the board members somewhat at the 'mercy' of the information presented to it. My observation was the Board's agendas were largely determined by the MDBA staff and that the Board had limited effectiveness in setting the agenda. The Board has explicitly no role in staffing. There is the possibility that if the Chair and CEO clash (as has happened) then a degree of impasse can result.

Recommendations: The MDBA board should be expanded and operate full time. The Board should take greater control of its processes and should exert some influence on staffing, particularly at a senior level. Board processes should be transparent and publically documented. Decisions should be voted on and votes recorded. Board appointments should be made at greater arms-length from governments and be more transparent. Board members should be and be seen to be non-representational. Board expertise should be expanded to include senior legal or judicial experience, greater depth of environmental technical expertise, and non-Basin expertise.

Recommendation: The Board should be held more accountable for their decisions (see further discussion below).

The Chief Executive, senior executive staff and all other employees of the MDBA are APS officers. While charged with implementing the Water Act, all are also accountable to giving effect to the wishes of the government of the day. This can lead to conflicts. MDBA officers have been placed under pressure by external influences – be that Basin States or various stakeholders. In my opinion there is too little support for MDBA officers to discharge their duties, to resist pressures and to be held accountable for their performance.

Recommendations: Employ MDBA officers (and appoint the Board) under separate legislation (with parity of employment conditions) which clearly sets out duties, responsibilities and establishes penalties for failing to comply. Penalties ought to be focussed on overall diligence and be on a sliding scale with greater effect for more senior decision makers. Criminal penalties ought to apply serious breaches of duty - for example for wilfully of negligently setting a manifestly improper SDL or for falsely representing data or for failing to address issues of compliance.

Recommendation: Ensure legislated independence from the Department. Require the MDBA to report to Parliament directly rather than via the Department / Minister. Potentially establish a

parliamentary committee that plays a similar role to the Minister as a mechanism for creating broader transparency.

Recommendation: Interactions with stakeholders, including Basin jurisdictions should be more transparent. Interactions, information sought or provided should be publishing to assist in ensuring that the exercise in influence is harder to hide.

The unreliability of funding has been a great distraction to the management of the MDBA. For an organisation with complex technical and policy responsibilities to attract and retain the necessary expertise and undertake its demanding work greater funding certainty is necessary. At present elements of the MDBA's budget (and responsibilities) are at the discretion of all Basin governments. This can and has been a source of great uncertainty and has diverted scarce resources from other matters.

Recommendation: Establish a more reliable and predictable funding arrangement that is commensurate with the 'value' of the overall reforms. In particular ensure there are sufficient funds for all elements of the MDBA's work, including regulatory responsibilities, monitoring and evaluation and maintenance of technical capabilities.

Whereas the National Water Commission (NWC) was charged with auditing the MDBA, this responsibility has been passed to the Productivity Commission (PC) following the abolition of the NWC. Overseeing the implementation of the Basin Plan and auditing it are both very complex tasks requiring particular expertise – it may be unrealistic to expect the PC to have such expertise. Rather a properly skilled audit agency is required. Ideally this should be established in a separate portfolio to the water portfolio and apply auditing standards.

Recommendation: Re-establish a competent auditing agency with both auditing and technical water expertise in order to effectively review the implementation of the Basin Plan. That agency should publish periodic reports with a view to (re-) establishing trust in the implantation of the Basin water reforms

E. Strengthen the national perspective

A critical concept in the Water Act is to manage the Basin water resources in the national interest. In my opinion insufficient regard has been given to this object. This might be seen as curious given the Water Act is a product of the national parliament and funded by the nation's taxpayers. It is likely that if more emphasis were given to this requirement (and relatively less to vested interests) that the policy balance would be easier to strike. The necessary adjustment mechanisms might be easier to identify and implement too.

Recommendation: Refocus on the national interest rather than the Basin interest or particular sectors within the Basin. Engage more effectively with the Nation and seek to describe the costs and benefits of the reforms in a national context, over the long-term, the Basin Plan and its implementation, and the conduct of water recovery.

Recommendation: Reinforce the long-term nature of the reforms and avoid expedient short-term decisions / policy settings that cannot be clearly shown to be leading actively to the long-term goal.

F. Other matters

At the time of writing there are 67 submission published on the Commissions web site and a further four specifically addressing Issues paper no.2. I have the opportunity to review only some of these.

I support the content and recommendations in the submissions form:

(22) Professor R. Quentin Grafton and Professor John Williams, dated 19 April 2018
(29) Terry Korn PSM, President, Australian Floodplain Association, dated 13 April 2018
(66) Professor Richard Kingsford, undated

I have insufficient expertise to arrive at an informed view on all the content the submission from (46) Professors Sarah Wheeler, Jeff Connor, Quentin Grafton, Lin Crase and John Quiggin, dated 30 April 2018 but am in agreement with their conclusions and recommendations.

8. List of attachments

Wallace, T. *et al* (2011) ***"'Natural' versus 'Artificial' watering of floodplains and wetlands"*** Final Report prepared for the Murray-Darling Basin Authority by The Murray-Darling Freshwater Research Centre.

‘Natural’ versus ‘Artificial’ watering of floodplains and wetlands

The Murray-Darling Freshwater Research Centre

Prepared by: Todd Wallace, Darren Baldwin,
Rick Stoffels, Gavin Rees, Daryl Nielsen,
Caitlin Johns, Cherie Campbell and Clayton Sharpe

Australian Government

MURRAY–DARLING BASIN AUTHORITY

The Murray-Darling Freshwater Research Centre

Final Report

June 2011

MDFRC Publication 10/2011

‘Natural’ versus ‘Artificial’ watering of floodplains and wetlands

Final Report prepared for the Murray-Darling Basin Authority by The Murray-Darling Freshwater Research Centre.

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Cover Images: Blackwater event during a managed, ponded flood at Woolshed Creek, Chowilla Floodplain
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Executive summary.

At a global scale, society's desire to control water for a range of purposes (e.g. irrigation, industry, stock and domestic supply, flood mitigation) has led to the regulation of a significant proportion of the world's rivers. Alteration of flow regimes is regarded as the most serious and continuing threat to ecological sustainability of rivers and their associated floodplain wetlands. Long-term drying has severely altered the ecology of many freshwater ecosystems, causing unprecedented, long-term or potentially irreversible damage (i.e. species extinctions). It is considered that much of the natural capacity (both resistance and resilience) of aquatic ecosystems to cope with drought has been lost.

Re-establishment of natural flow regimes represents a neat theoretical objective. However, the reality is that this is impractical as the demands of society preclude returning our rivers to natural flow. The existing impacts of regulation combined with future impacts of climate change imply that in many river systems, overbank flows may no longer occur frequently enough to maintain ecological processes, and many wetlands and floodplains will become increasingly reliant on targeted environmental water allocations (EWA).

New approaches to management will be essential in order to maintain a larger active floodplain than possible under the current water sharing arrangements. However, in order for managers to be successful in achieving the stated ecological objectives of river restoration and ecological management programs, it is necessary to have an appreciation of the role of flow in natural systems and the limitations of methods of delivering EWA. Within this synthesis we:

1. Briefly summarise the role of flow in unregulated floodplain ecosystems;
2. Define key state variables that characterise the flow regime of a floodplain system;
3. Discuss the major types of EWA currently in use;
4. Summarise key ecological processes and the impact of method of EWA delivery;
5. Outline the prevailing management paradigm; and
6. Identify management considerations for progress towards sustainable river systems.

Flow is regarded as the key driver regulating processes and diversity in river systems and can be regarded as the master variable. The processes which are influenced by flow and floodplain inundation include hydrodynamics, biogeochemistry and primary productivity. Higher order organisms respond to these habitat and primary productivity drivers. It is not just the presence of water that is important for maintenance of ecosystem function; the provision of water is a critical link in the ecology of wetland and floodplain systems but that does not automatically imply that the link is functional. Flow magnitude, frequency, timing, duration, variability, rate of change and sequence all hold major ecological significance. It is important to note that the quality of water (i.e. chemical and thermal properties) is equally as important as the quantity of water or the temporal patterns of flow. In this context, the method of maintaining inundation (i.e. ponded flood versus flowing flood) and the resultant dilution and downstream dispersal of carbon and nutrients will have a significant impact on water quality via biogeochemically mediated processes.

In unmodified catchments natural flooding regimes that are completely unaltered represent the reference condition. However, due to the extent of regulation and development throughout the MDB, there are very few sub-catchments that experience an unimpeded, natural flood. In modified catchments the closest approximation is an uncontrolled flow where the effects of storages and in-stream structures have largely been nullified. River management has skewed river channels and floodplains in opposite directions; towards an anti-drought an engineered drought scenario respectively. Regulated river systems are therefore likely to be in an extreme state of precariousness. Management needs to focus on reinstating resilience as the most pragmatic and effective way of managing ecosystems in order to withstand future droughts and provide ecosystem services.

The concept of downsizing rivers has some merit but in reality it is a process of reinstating the small floods that river regulation has removed. It also overlooks the role of the interface between the aquatic (regularly inundated) and terrestrial (never inundated) zones in subsidising terrestrial food webs. Abandonment of large sections of floodplain may create an extremely dysfunctional and potential hostile zone or 'no-man's land' that is neither aquatic or terrestrial, generating a new barrier to energy flux.

Enacted as an emergency measure, pumping water to targeted wetlands pumping water into individual sites has been highly successful in achieving a limited set of objectives. There is an emerging risk that construction and operation of new, large infrastructure specifically designed, constructed and operated for environmental outcomes is seen as an alternative to unregulated overbank floods to maintain ecosystems. It is essential to recognise that there there are a number of critical limitations associated with this approach; primarily related to spatial, connectivity and water quality issues. The expectation that fragmented sites will function as refuges that serve as the major sources of propagules and colonists for other areas and lead to improvement of the Murray-Darling Basin is unproven. Furthermore, it is critical to recognise that using a regulator to inundate large floodplains under low flow conditions has not been used as a restoration technique anywhere in the world. Consequently there is no precedence for this management activity and actual responses may differ from those expected.

Releases of large volumes of water from storages may lead to the provision of flow-associated cues and conditions otherwise absent during base flows. However, water released from an upstream storage and transferred as an EWA into an individual site during periods of in-channel flow may restrict the ecological outcomes as the productivity gains from upstream flooding are not available to be transported into the managed site. The "missing pieces" are likely to include plant and invertebrate propagules dispersed from upstream sites, increased carbon and nutrient concentrations and other chemical cues resulting from inundation of floodplain soils and plant material, eggs and larvae of fish and other organisms spawned at upstream sites.

We propose that there is a hierarchical time scale relationship between inundation events and ecological responses that is associated with all inundations. This relationship can be described as follows; Instantaneous (occur within minutes-hours of inundation), Fast (occur within hours-weeks of inundation), Slow (occur weeks-months after inundation), Delayed (processes that occur within months-years after inundation), and Cumulative (responses that may only occur/be realised after a series of events). We consider that the influence of any EWA delivery method will be related to the rate at which different processes occur. For example, chemically mediated processes occur very quickly (instantaneous) and are therefore unlikely to be affected by the method of delivery of EWA. In contrast, many biogeochemically mediated and biotic processes occur over longer time scales and are more likely to be influenced by the method of EWA delivery. This will be driven by the lag phase in ecological response providing opportunities for differences in responses/processes between natural and managed floods to cascade across multiple levels and manifest into large differences in the quality of outcomes. Methods of delivering environmental water that do not maximise (i) connectivity (i) the provision of appropriate habitat; and (ii) the development of appropriate food resources will deliver minimal benefits and compromise the ability of the EWA to achieve positive ecological outcomes.

It must be recognised that the use of EWA's is fundamentally a large-scale manipulative experiment. We currently lack sufficient ecological knowledge to predict how floodplains in different conditions will respond. This represents a major hurdle for managers as volumes of environmental water are limited and resilience is an ecosystem property that can be either created or destroyed. Investment in recovering water and construction of infrastructure for delivery of EWA's needs to be underpinned by investment in research to inform adaptive management to ensure that critical ecological processes and functions are reinstated. If this is not undertaken, there is no way that EWA's will be able to reinstate resilience.

The most appropriate method for delivery of an EWA to any site will vary accordingly with a range of factors including but not limited to; availability of water, connectivity of site to water source, and management targets. Environmental water allocations cannot replace the function of natural overbank flows and there is no 'Silver Bullet' for repairing water-dependant ecosystems deprived of a natural flooding regime. Consequently pragmatic solutions are required to ensure environmental watering at intervals sufficient to enable system preservation and recovery. Reinstating flows and reoperation of existing infrastructure should be actively used during wet and median conditions to build resilience at the system scale. Delivery of EWA to isolated sites should be relegated to use during dry and extreme dry conditions to avoid long-term or irreversible damage and maintain refugia. The use of these techniques as the primary tool for the long-term management of floodplains and wetlands is not recommended.

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Introduction

At a global scale, society's desire to control water for a range of purposes (e.g. irrigation, industry, stock and domestic supply, flood mitigation) has led to the regulation of a significant proportion of the worlds rivers (Dynesius & Nilsson, 1994). The impacts of river regulation, drought and climate change have been extensively reviewed (e.g. Walker, 1985; Bunn & Arthington, 2002; Arthington & Pusey, 2003; Poff & Zimmerman, 2010). Alteration of flow regimes is regarded as the most serious and continuing threat to the ecological sustainability of rivers and their associated floodplain wetlands (see Bunn & Arthington, 2002; Arthington et al., 2010). Removing floods can have flow-on effects on the whole foodweb, not only on individual species (Lytle & Poff, 2004).

In unregulated floodplain rivers, droughts caused by seasonal or supra-seasonal rainfall deficits extend the duration of dry spells, and the movement of water, nutrients and trophic subsidies from the catchment and the riparian zone into streams becomes weakened or may cease (Bond et al., 2008). In regulated systems, the “drought-proofing” regime of large storages and in-river structures leads to an anti-drought scenario (McMahon & Finlayson, 2003) in channels used for delivery of water. Use of storages and weirs secures supply for consumptive uses but also leads to a substantial reduction in the frequency of small and medium floods (Frazier & Page, 2006) creating an “engineered-drought” for floodplains and wetlands. Seasonal or supra-seasonal rainfall deficits remove the secondary source of moisture for floodplains leading to long-term (decadal) drying of floodplains that we regard as “hyper-drought” conditions. Long-term drying has severely altered the ecology of many freshwater ecosystems, stressing and reducing/fragmenting the distribution of fauna and flora. This has caused unprecedented, long-term or potentially irreversible damage (i.e. species extinctions), and it is considered that much of the natural capacity (both resistance and resilience) of aquatic ecosystems to cope with drought has been lost (see Bond et al., 2008).

Climate change modeling predicts that the frequency and severity of droughts will increase in the southern parts of Australia (CSIRO and BOM, 2007) leading to further stress on aquatic ecosystems in the Murray–Darling Basin (MDB) (Aldous et al., 2011). The effects of climate change will be severe, but not as severe as those resulting from river regulation (Kingsford, 2011). Consequently, it is predicted that free-flowing rivers that retain natural flow variability and connectivity will be more resilient and therefore less severely affected than regulated rivers (see Kingsford, 2011; Pittock & Finlayson, 2011). The existing impacts of regulation combined with predicted future impacts of climate change imply that natural overbank flows may cease in many rivers (Aldous et al., 2011) with ecological processes in many wetlands and floodplains becoming increasingly reliant on managed floods delivered as environmental water allocations (EWA).

Project Scope

New approaches to management of existing in-river structures (i.e. weirs) and new infrastructure will be essential for delivery of EWA (Aldous et al., 2011) in order to sustain a larger active floodplain than possible under the current water sharing arrangements. However, in order for managers to be successful in achieving the stated ecological objectives of river restoration and ecological management programs, it is necessary to have an appreciation of the role of flow in natural systems and the limitations of methods of delivering EWA.

The objectives of this synthesis are:

1. Briefly summarise the role of flow in unregulated floodplain ecosystems;
2. Define key state variables that characterise the flow regime of a floodplain system;
3. Discuss the major types of EWA currently in use;
4. Summarise key ecological processes and the impact of method of EWA delivery;
5. Outline the prevailing management paradigm; and
6. Identify management considerations for progress towards sustainable river systems.

The processes which are influenced by flow and floodplain inundation include hydrodynamics, biogeochemistry and primary productivity. Higher order organisms respond to these habitat and primary productivity drivers. Bunn and Arthington (2002) suggest that there are four guiding principles for considering how changes to flow influence aquatic biodiversity and we expand on these here;

- Flow is a major determinant of physical habitat. Diversity of habitat is important as biota within river systems have evolved associations with specific habitat types
- Flow regimes influence the natural patterns of longitudinal and lateral connectivity or riverine metapopulations. This connectivity is essential to the viability of populations of many species
- Aquatic species have evolved life history strategies tied to particular flow regimes
- Flow is a major driver of nutrient and carbon cycles in riverine ecosystems. Lateral and longitudinal transport of nutrients and carbon drive system productivity and food web structure
- The invasion and success of exotic species is facilitated by the alteration of flow regimes

Within this synthesis we have attempted to maintain a broad regional relevance. As the biotic groups present and therefore the responses observed to any EWA will regionally specific, we have focused on processes rather than biotic groups. However, we have documented some examples of potential changes to selected biota and these are presented in the supporting information section.

The role of flow in natural systems

Flow is regarded as the key driver regulating processes and diversity in river systems and can therefore be regarded as the 'master variable'(Power et al., 1995) or 'maestro' (Walker et al., 1995) of river ecology. The flow regime supports ecological functions such as nutrient spiraling, organic matter processing and food web dynamics (see Bunn & Arthington, 2002; Bond et al., 2008). Flood events are major drivers of the flux of energy and nutrients in floodplain river systems (Junk et al., 1989) that connect the channel, wetlands and woodlands as parts of one ecological system (Lytle & Poff, 2004; Walker, 2009).

Inundation of temporary wetlands creates conditions substantially more productive than those found in permanent wetlands (Junk et al. 1989) with the exchange between the river and the riparian zone regarded as a key component of riverine function (Vannote et al., 1980). During the rising limb of the hydrograph, material is transported from the river to the floodplain. In the recession phase, carbon, nutrients, plankton, propagules and fish are transported from the floodplain to the river; a fundamental process of rivers and floodplains (Junk et al. 1989). Transfer of allochthonous inputs is hypothesised to influence food-web dynamics by augmenting productivity, altering predator-prey relationships and triggering trophic cascades (see review by Ballinger & Lake, 2006). The productivity booms (Bunn et al., 2006) associated with floods provide abundant food resources for a range of higher order animals including fish (Arthington et al., 2005) and water birds (Kingsford et al., 1999), which are dependent on the provision of appropriate habitat and development of food resources (Rogers & Paton, 2008).

State variables that characterise the flow regime of a floodplain system

It is not just the presence of water that is important for maintenance of ecosystem function (Arthington et al., 2010); the provision of water is a critical link in the ecology of wetland and floodplain systems but that does not automatically imply that the link is functional (Jenkins & Boulton, 2003). Flow magnitude, frequency, timing, duration, variability, rate of change and sequence all hold major ecological significance (Lytle & Poff, 2004; Leigh et al., 2010). These factors are particularly important in floodplain river systems that are allogenic (i.e. where the hydrological regime is determined by upstream rather than local conditions). Extreme events (floods and droughts) represent key selective processes driving mortality and recruitment (Lytle & Poff, 2004).

Magnitude

The magnitude of a flow event is defined by the daily discharge (ML d^{-1}) recorded over a specified time. Magnitude affects physical variables including flow velocity and river height. Flow velocity reflects the energy available for basic geomorphological processes (e.g. scour, transport and deposition of sediments), rearrangement of structural (e.g. woody debris) and biotic (e.g. macrophyte community structure) habitat, and dispersal of material including biological propagules. River height alters longitudinal and lateral connectivity (extent of flooding) and therefore transfer of material between ecosystem components. Magnitude may directly or indirectly influence migration and spawning/breeding behavioral responses.

Frequency

Flow frequency is defined as the number of cycles (events) of a given magnitude within a specified period and is a function of flow magnitude; small flows typically having a higher return frequency. Flow pulses occurring at different frequencies serve different biological and biogeochemical functions. Relatively frequent flows are critical for maintaining connectivity, migration, dispersal, sustaining vegetation, sediment and nutrient exchange and water quality. Less frequent large flows may also reset ecological processes (see Leigh et al., 2010).

Timing

Thermal regime and day length shift with season and the consequences of seasonal timing has undergone extensive investigation (Bunn & Arthington, 2002). Temperature and day length has implications for most biotic groups through metabolic (animal energetics), endocrine (e.g. circadian rhythm), behavioural traits (Bunn & Arthington, 2002), and life history adaptations (Lytle & Poff, 2004). Thermal regime and day length also affect biogeochemical rates, shaping ecological patterns and processes in riverine ecosystems (Lytle & Poff, 2004; Arthington et al., 2010). Biota utilising behavioral adaptations (responses) to flow events are less likely to be affected by changes in timing than organisms that use life history adaptations. For example, for species that specifically avoid or capitalise on floods or dry periods, synchronisation of life history stages is linked to long-term flow regimes, not specific events (Lytle & Poff, 2004). However, the importance of any flow event is likely to be related to magnitude as rising flows combined with appropriate temperature/day length may be cues for reproductive activity (see Bunn & Arthington, 2002). Seasonal timing can have important ecological ramifications for large systems as a flood can take months to travel the course of lowland rivers (Jenkins & Boulton, 2003).

Duration

Duration refers to the number of days a flow event remains at a specified magnitude. It influences the ability of biota to exploit the longitudinal and lateral connections created. Long floods increase opportunities for productivity, breeding, recruitment and access to nursery habitats and food-rich environments (see Bunn & Arthington, 2002), providing maintenance reserves that allow communities and ecological function to persist through low flow periods (see Leigh et al., 2010).

Variability

Variability in frequency, timing, magnitude and duration is potentially more important than biological factors in structuring aquatic communities (see Leigh et al., 2010). Constant variations in flow combined with geomorphology (e.g. elevation, wetland commence to flow levels) function as a controlling agent of longitudinal and lateral connectivity to generate a spatially and temporally dynamic habitat mosaic with adjacent and distant areas inundated and exposed for different lengths of time leading to increased biodiversity (see King et al., 2003; Leigh et al., 2010). A dynamic, variable water regime maintains the biodiversity and ecological processes characteristic of every river and wetland ecosystem (see Arthington et al., 2010). Under any given flow scenario, a single river system will display a dynamically changing range of dry, drying, lotic, and lentic habitats. This spatio-temporal variability in habitats generates high biodiversity (Ward & Stanford, 1995; Ward et al., 1999) with the lateral expansion and connectivity of floodplain habitats during floods providing spawning, nursery and foraging areas for a variety of vertebrates (see Bunn & Arthington, 2002).

Rate of change

The rate of rise or fall in water level (mm day^{-1}) is important for a range of biota and processes. Rates of rise are not generally important for the establishment of flood-dependent plant species as many will not germinate until water levels are drawn down and the soil is exposed to the atmosphere but retains a high moisture content (Nicol, 2004). However, established stands of low-growing and emergent amphibious macrophytes are generally more vulnerable to rapid increases in water depth than submerged and free-floating aquatic species, as many of these species are unable to maintain sufficient rates of photosynthesis and gas exchange to survive extended periods of inundation (Siebentritt & Ganf, 2000). Slow rates of drawdown in the range 10-30 mm day^{-1} (<50mm) have the greatest benefit for amphibious and floodplain plant communities (Nicol, 2004) breeding waterbirds (Rogers & Paton, 2008), minimising the risk of stranding fish in connected wetlands (Mallen-Cooper et al., 2008) and minimising bank slumping (Gippel et al., 2008).

Sequence

The ecological outcomes from any flow event will be related to the antecedent conditions; frequent small floods maintain soil moisture and water levels in wetlands that increase the potential for subsequent flows to travel further downstream and/or inundate larger areas (see Leigh et al., 2010). In addition, sequential floods have cumulative, positive effects on recruitment of native fish (Puckridge et al., 2000; Arthington et al., 2005) and waterbirds (Kingsford & Porter, 1993; Kingsford et al., 1999).

Major types of environmental water allocations

Types of floods

Environmental flows “describe the quantity, timing and quality of water required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend upon these ecosystems’’ (Brisbane Declaration, 2007). In unmodified catchments natural flooding regimes that are completely unaltered represent the reference condition. However, due to the extent of regulation and development throughout the MDB, there are very few sub-catchments that actually experience an unimpeded, natural flood. In modified catchments the closest approximation is an uncontrolled flow where the effects of storages and in-stream structures have largely been nullified, either by direct removal of weirs or by water levels exceeding the crest height of structures. At the next level down are EWA that can be used either as sustaining flows, to slow the process of degradation (Lind et al., 2007), or to reinstate components of the natural flow regime in order to provide an opportunity for ecosystem recovery through the enhancement of recruitment and growth processes (see Arthington et al., 2003; King et al., 2010). Managed flooding occurs at range of spatial scales, ranging from the river reach and/or floodplain scale down to individual wetlands or sections of ephemeral creeks.

Controlled releases that generate flow peaks within channel

EWA held in storage may be released to simulate small flow peaks during base flow periods. Released at the right time of year, such flows may lead to provision of flow-associated cues and conditions otherwise absent during base flows. Such flows may also lead to enhanced ecological outcomes from processes already occurring at base flows. Anabranch channels should be a management target for this type of EWA as they typically have commence-to-flow levels below bank-full and therefore require relatively small amounts of water for connection. Pulse connections with anabranches increase the frequency and amount of allochthonous carbon subsidies to the river system with the type and amount of materials exchanged varying depending on the frequency, magnitude and duration of flow pulses. Managed, periodic connection of anabranch channels is an option that may provide significant benefits to the system at low cost compared to connecting large floodplains (McGinness and Arthur, 2011).

Controlled releases that engage floodplain (out of channel flows)

There is at least one substantial rain event driven high flow period in the MDB every year. Under the current management regime water from these events is captured and stored in large reservoirs. However, these rain-driven high flows can be utilized as a base upon which to build more substantial flows by releasing accumulated EWA, thereby providing a mechanism for the restoration of small and medium floods. For example, the release of a 500 GL EWA for Barmah-Millewa Forest in 2005 is considered to have imparted resilience to sites along the river that received some proportion of that flow, reducing the level of impact resulting from the Millennium drought (King et al., 2010).

Hybrid floods

Hybrid floods involve releases of EWA undertaken in conjunction with unregulated flow pulses. For example, the Barmah-Millewa Forest EWA is generally released from storage during periods of high river levels in order to maximise the delivery of water onto the floodplain (Ward, 2009). Management objectives include; (i) reducing the rate of recession of flow peaks (ii) prolonging the duration of the inundation period; and (iii) raising the magnitude of the flow peak to generate/extend lateral connectivity. This management technique has been described as “filling holes” (sensu King et al., 2010) and may be subsequently overridden by additional unregulated flows.

Utilisation of new structures to inundate large sections of floodplain(s)

There is growing interest in the construction and operation of new, large infrastructure specifically designed, constructed and operated for environmental outcomes as a management tool (Windsor Report, 2011(http://www.aph.gov.au/house/committee/ra/murraydarling/report/fullreport.pdf). In theory, this approach (i) improves the capacity of river managers to distribute water to high elevation sections of the floodplain during relatively low flows when these systems would otherwise remain in a drying phase; and (ii) is likely to generate greater wetland connectivity, potentially providing improved ecological outcomes than could be achieved by pumping water into discrete/individual sites (Veltheim et al., 2009). However, there is an emerging risk that this approach is seen as an alternative to unregulated overbank floods to maintain ecosystems. It is essential to recognise that there are a number of critical limitations associated with this approach; primarily related to spatial, connectivity and water quality issues: (i) there are few sites where this approach is achievable; (ii) the expectation that fragmented sites will function as refuges that serve as the major sources of propagules and colonists for other areas (sensu Arthington & Pusey, 2003) and lead to improvement of the Murray-Darling Basin is unproven; and (iii) high rates of water exchange are essential to avoid negative outcomes. Furthermore, it is critical to recognise that using a regulator to inundate large floodplains under low flow conditions has not been used as a restoration technique anywhere in the world (Nicol, 2007). Consequently there is no precedence for this management activity (Brookes et al., 2006) and actual responses may differ from those expected (Rogers & Paton, 2008).

Reoperation of river infrastructure – weir pool manipulation

Currently, weirs in the lower Murray are periodically removed, either for routine maintenance or during periods of high flow (moderate-large floods) to maintain structural integrity. However, there is little utilisation of these structures to impart variability in water levels during normal operation. The manipulation of weirs including; (i) temporarily raising weirs to maximum structural height and increase the area that can be inundated (this reduces velocity and longitudinal connectivity but increases lateral connectivity); and (ii) temporarily lowering weirs (this reduces lateral extent but increases longitudinal connectivity and velocity), needs to become a management priority.

Reoperation of existing infrastructure to instate frequent variation in weir pool levels would be beneficial for many plant species, promoting diversity by restoring a wider range of water regimes (see Bunn & Arthington, 2002). Research undertaken during weir pool raising trials in the lower Murray River has demonstrated positive outcomes for understorey vegetation (Siebentritt et al., 2004) and riparian trees (Souter et al., Submitted). We propose that this is a grossly under-utilised management technique that should become a key tool for improving condition of the riparian zone.

Retaining water from natural floods using constructed infrastructure to extend period of inundation

Many wetlands have had regulators installed to allow reinstatement of wetting and drying cycles. Closure of these structures upon recession of high flows may be used to ensure flood duration is sufficient for achieving ecological outcomes.

Gravity based delivery of water into discrete sites

In sites where the commence to flow level is at or below the normal weir pool or river operating height, the opening of regulators or breaching of earthern banks can be used to deliver EWA into specific sites. In some cases, very small increases in channel water level associated with flow spikes or weir pool raising can greatly increase the number of off-channel sites or the spatial area that can be inundated via this method.

Pumped delivery of water into discrete sites

In sites where it is not possible to deliver water via gravity (typically because the site is elevated above the normal weir pool or river operating height) EWA are often delivered using large pumps. A key advantage of using pumps is that relatively small volumes of water can be utilised to inundate targeted sections of the floodplain during low flow periods when inundation would otherwise not be possible due to low water availability.

Enacted as an emergency measure, pumping water into individual sites has been highly successful in achieving a limited set of objectives. However, the following factors are critical limitations; (i) the distance water can be efficiently pumped is limited; (ii) very few ecological requirements that depend on connectivity will be met from pumping; (ii) delivering EWA to wetlands via pumps and then drying them through evaporation provides extremely low connectivity to the river and provides no short-term benefit to the river channel; and (iv) there is an overwhelming number of sites to manage on an individual basis. For example, within the Murray Valley, the number of ephemeral wetlands that would have been connected to the river channel at least once every 3-4 years has fallen from 1305 under natural conditions to 657 under regulated conditions (Brookes et al., 2009a). Furthermore, repeated ponding and evaporation of water has the potential to accumulate salt in the managed sites.

Key ecological processes and the impact of method of EWA delivery

Hierarchical time scales

We propose that there is a hierarchical time scale relationship between inundation events and ecological responses that is associated with all inundations (irrespective of delivery method). This relationship can be described as follows; Instantaneous (occur within minutes-hours of inundation), Fast (occur within hours-weeks of inundation), Slow (occur weeks-months after inundation), Delayed (processes that occur within months-years after inundation), and Cumulative (responses that may only occur/be realised after a series of events). Examples of this hierarchy are provided in Table 1. We consider that the influence of any EWA delivery method will be related to the rate at which different processes occur. For example, chemically mediated processes occur very quickly (instantaneous) and are therefore unlikely to be affected by the method of delivery of EWA. In contrast, many biogeochemically mediated and biotic processes occur over longer time scales and are more likely to be influenced by the method of EWA delivery. This will be driven by the lag phase in ecological response providing opportunities for differences in responses/processes between natural and managed floods to cascade across multiple levels and manifest into large differences in the quality of outcomes.

Table 1. Hierarchical relationship matrix between process and temporal scale✓ indicates that the process if likely to occur within the respective time frame, ⌖ indicates that the process may occur within the respective time frame

Examples	Instantaneous (minutes –hours)	Fast (hours-weeks)	Slow (months-years)	Delayed (months-years)	Cumulative (serial impacts)
Chemically mediated processes; release of carbon/nutrients from inundated material	✓	⌖			
Biogeochemically mediated processes; Blackwater		✓	⌖		
Biogeochemically mediated processes; Algal blooms		⌖	✓		
Fish and birds; migration to spawning/breeding locations		✓			
Fish and birds; spawning/breeding		✓	✓		
Fish and birds; recruitment to young-of-year				✓	
Fish and birds; recruitment to recruitment to adult				✓	
Fish and birds; robust population demographic					✓
Plants; increased resource uptake		✓			
Plants; increased growth/vigour		✓	✓		
Plants; germination		✓	✓		
Plants; shift in dominant functional groups				✓	✓
Plants; shift in EVCs				✓	✓
Soils; stimulation of microbial activity	⌖	✓			
Soils; increase in soil moisture at depth(e.g. >0.3m)		✓			
Soils; soil derived salinity spikes	✓	✓			
Soils increase in soil salinity due to evapoconcentration					✓
Groundwater; freshening of saline groundwater		⌖	✓		
Groundwater; groundwater derived salinity spikes in creek/river				✓	
Micro-invertebrates; hatching from seed banks		✓	⌖		
Micro-invertebrates; succession shifts			✓		
Macro-invertebrates; succession shifts			✓		

Processes that are unlikely to be influenced by method of EWA delivery

Release of carbon and nutrients from inundated plant material

When floodwater first enters a floodplain there is immediate leaching of carbon and nutrients from natural organic material (e.g. leaf litter from floodplain trees - Baldwin 1999; O'Connoll et al. 2000), coupled with a pulse of carbon and nutrients from newly inundated soil - the 'Birch effect' (Scholz et al., 2002; Kobayashi et al., 2008; Banach et al., 2009; Wilson et al., 2010). Floodplain eucalypts, particularly river red gum (*E. camaldulensis*) and to a lesser extent black box (*E. largiflorens*) generate a large standing biomass of leaf litter (approximately 2,500 gm^{-2} and 600 gm^{-2} respectively (Wallace, 2009)) and represent a large source of allochthonous organic matter to floodplains and wetlands (Glazebrook & Robertson, 1999; Francis & Sheldon, 2002) much of which is rapidly (within hours) released into the water column when this material is inundated (O'Connell et al., 2000; Francis & Sheldon, 2002; Wallace et al., 2008).

Stimulation of microbial activity in floodplain soils

Stimulation of the resident soil microbial community is a rapid process. Wilson et al (2011) demonstrated that inundation of floodplain soils causes an immediate change in carbon turnover and rates of microbially driven processes. The activity of enzymes related to the degradation of carbohydrates (*a*-glucosidase, *b*-glucosidase and *b*-xylosidase) increased rapidly and reached a peak after 3 days, suggesting a rapid break down of large molecules for microbial utilisation leading to a rapid increase in carbon mineralization rate. In contrast, shifts in the microbial community structure were not observed until 7 days post inundation.

Salt mobilization from floodplain soils

The accumulation of salt in soils is driven by evaporative discharge of groundwater during dry phases. Flood inundation has the potential to wash salt from floodplain surface soils, entraining surface salts into surface water flows. Infiltration (due to precipitation, flood events or wetland watering) transports (i.e. leaches) salt back down the soil profile. The amount of salt that can be leached from soils during flooding is influenced by flood frequency, duration and soil type (Barber et al., 2011) with accumulated salt more readily leached from sandy soils than heavy clay soils (Overton & Doody, 2008).

Groundwater

In the lower Murray, regional groundwater gradients dominate groundwater discharge under low flow conditions. During high flows, bank recharge and localised vertical recharge, where the soil profile is sandy (Jolly & Walker, 1995), produce freshwater lenses that remain on top of the saline groundwater. This occurs due to limited mixing caused by density differences (Overton & Doody, 2008). Localised mounding of fresh water under the floodplain leads to the displacement of saline groundwater and discharge to connected channels and anabranches as floodwater recede (Jolly et al., 1994), contributing to groundwater-derived recession salt loads (Barber et al., 2011). During inundation, it is the spatial extent, hydraulic head and duration of inundation rather than method of EWA delivery that is likely to be important.

Biogeochemically mediated processes that are likely to be influenced by method of EWA delivery

It is important to note that the 'quality' of water (i.e. chemical and thermal properties) is equally as important as the quantity of water or the temporal patterns of flow (see Arthington et al., 2010). In this context, the method of maintaining inundation (i.e. ponded flood versus flowing flood) and the resultant dilution and downstream dispersal of carbon and nutrients will have a significant impact on water quality via biogeochemically mediated processes.

Cycling and metabolism of carbon and nutrients

The carbon and nutrients released from inundated material into the overlying water column can be rapidly incorporated into microbial and algal biomass (Schemel et al. 2004). Microorganisms can use about one-third of the dissolved organic carbon (DOC) leached from litter within ten days. Within hours to a few days, nitrogen and phosphorus undergo transformation and assimilation by organisms on the floodplain. Nitrate is either taken up by microorganisms and algae, or is respired through denitrification such that floodplains act as a sink for N (Forshay & Stanley, 2005). Phosphorus is assimilated by organisms with the overall movement and uptake of phosphorus dependent on the length of time water remains on the floodplain (Schramm et al., 2009). The assimilated carbon and nutrients are subsequently cycled though the food web to higher trophic level organisms (e.g. birds and fish) via multiple pathways, including via micro- and macro-invertebrates. This process is referred to as 'trophic upsurge' (Furch & Junk, 1997; Kern & Darwich, 1997; Geraldes & Boavida, 1999; Scharf, 2002; Talbot et al., 2006; Lourantou et al., 2007).

In Australian river systems the exact role and relative importance of autochthonous and allochthonous carbon remains largely unresolved, partially confounded by the fact that high variability in flow conditions (particularly in dryland rivers and wetlands) means there is considerable overlap in ^{13}C:^{12}C signatures between terrestrial and aquatic plants (Ballinger & Lake, 2006). However, under low flow conditions, autotrophic sources of carbon are believed to dominate foodwebs (Bunn et al., 2003; Hadwen et al., 2009). Oliver and Merrick (2006) and Oliver and Lorenz (2007) demonstrated that the River Murray is energy constrained with net production close to zero. Studies in the Logan, Gwydir and Ovens Rivers (Hadwen et al., 2009) and Lachlan River (Moran, 2011) have demonstrated that respiration of the heterotrophic bacterial community and DOC consumption is limited by the quality of DOC present. This is considered to be the case for the majority of Australian rivers during low flow conditions when allochthonous DOC supply is limited (Robertson et al., 1999).

Inputs of allochthonous DOC during periods of high flow and floods are likely to provide a short-lived but significant productivity boom. For example, measures of primary productivity on the Cooper Creek floodplain found that the amount of carbon produced by benthic algae on the floodplain during a single day of a flood was equivalent to over 80 years of aquatic production under dry conditions (Bunn *et al*. 2006*b*). Robertson et al. (1999) predicted that a flood inundating $44km^2$ would provide as much allocthonously derived carbon as produced from autochthnonous sources (i.e. phytoplankton) in one year. Gawne et al., (2007) considered that this effect could be produced by a smaller flood (34 km^2). A preliminary assessment has demonstrated that partial return of an EWA from a managed floodplain will return a measurable carbon and nutrient pulse (Wallace & Lenon, 2010) and a stimulation of heterotrophic activity in the receiving waters (Wallace, unpublished data).

Returning water, that contains a high biomass of prey items and increased nutrient loads, to river channels is likely to improve the recruitment success of fish inhabiting those river channels (Balcombe et al., 2007; King et al., 2009; Meredith & Beesley, 2009). A survey undertaken in 2008 revealed that 76.3% of EWA is left in wetlands to seep, evaporate or dissipate (Meredith & Beesley, 2009). This means that only a small proportion of the volume of EWA utilised is currently returned to the river. Managed floods that do not provide strong lateral and subsequent longitudinal transfer of allochthonous material minimise or even preclude the potential for transfer of productivity gains. Addressing this should be a key priority for managers.

Blackwater events

Blackwater events can be described as flood events where the surface water contains enough dissolved organic carbon (DOC) to discolour the water sufficiently to resemble dark “tea” and are often associated with low dissolved oxygen (DO) concentrations (Meyer, 1990; Howitt et al., 2007) caused by heterotrophic metabolism (microbial degradation) of organic carbon leached from flooded plant material. The managed flooding of Barmah Forest in 2000 released a pulse of hypoxic (DO <2 mg L^{-1}) water back to the Murray and Edward Rivers that led to a significant fish-mortality event (Howitt et al., 2007). The 2010-11 flood in the Murray system was also characterised by a system wide blackwater event distinguished by high DOC and low DO conditions.

Hypoxia is a major concern for the ecology of wetlands and receiving waters, as tolerance to hypoxia is species and life-stage specific, therefore changes in DO concentration can have significant impacts on biodiversity (Ekau et al., 2010). Hypoxia is associated with fish kills (Erskine et al., 2005), disruption of endocrine systems (Wu et al., 2003) embryonic development (Shang & Wu, 2004) and survival and hatch rates (Hassell et al., 2008) of fish and degradation of aquatic macroinvertebrate communities in streams (Walsh et al., 2001; Walsh, 2002; Feminella et al., 2003) and wetlands (Spieles & Mitsch, 2003). Anoxia may lead to the release of sediment bound material such as manganese, iron (Davison, 1993), ammonium (Lawrence & Breen, 1998; Boulton & Brock, 1999; Morin & Morse, 1999) and phosphorus (Mortimer, 1941; Laws, 1993; Martinova, 1993); conversion of dissolved organic nitrogen to ammonia and nitrate (Harris, 2001) and accumulation of redox sensitive compounds from anoxic sediments (e.g. Baldwin & Mitchell, 2000; Dahm et al., 2003) some of which (e.g. ammonium and sulfide) are toxic to many aquatic organisms (Vismann, 1996; Hickey & Martin, 1999).

A number of factors are critical in determining whether or not a blackwater event will result in a fish kill. The two most important factors are water temperature and carbon loading (Baldwin & Wallace, 2009). Organic loading (amount of carbon and nutrients and the stoichiometry of those nutrients) in water overlying floodplains is dependent on vegetation type and condition (Brookes et al., 2007; Wallace et al., 2008; Wallace, 2009) flood timing (Baldwin, 1999; Watkins et al., 2010a; Watkins et al., 2010b) and whether or not the accumulated litter has been flooded before (O'Connell et al., 2000). Flooding in late spring and summer is problematic as (i) peak litter fall for eucalypts occurs in summer (Briggs & Maher, 1983) and (ii) for every 10 °C increase in water temperature the rate of oxygen depletion approximately doubles (Howitt et al., 2007). Therefore, the warmer the temperature the more quickly oxygen is consumed. In addition to the factors outlined above, heat stress combined with hypoxic conditions is likely to be a lethal combination for native fish.

The risk of establishment of a blackwater event can be largely managed by (i) not utilising ponded floods for delivery of EWA; (ii) maximising water exchange when using large constructed infrastructure; and (iii) avoiding flooding during warm periods (Baldwin & Wallace, 2009). During managed inundations the volume of water and the exchange rate (turnover) are markedly lower than occurs during unregulated floods that inundate equivalent areas. Wallace and Lenon (2010) demonstrated that the rapid onset of hypoxic and anoxic conditions occurring in wetlands during ponded floods could be managed using conservative rates (<20% daily exchange) of dilution/exchange. Deep, long flooding will typically occur in low elevation areas that are flooded in order to inundate higher elevation ecological communities (i.e. black box) for relatively short periods. This type of flooding substantially increases the risk of stratification and water quality issues and is regarded as a critical risk with the potential for long-term damage. Managed floods using large infrastructure must maintain high rates of water exchange in order to maximize benefits and minimize risks (Brookes et al., 2007; Mallen-Cooper et al., 2008; Wallace & Lenon, 2010).

Harmful and or nuisance algal blooms

The release of nutrients from inundated material will produce a nutrient pulse capable of supporting significant phytoplankton biomass (Brookes et al., 2007; Wallace, 2008; Wallace & Lenon, 2010). There are two scenarios where the development of cyanobacterial blooms in managed sites represent a potential hazard to public health and/or water supply; blooms restricted to the wetlands that become isolated during drawdown, and those that may be connected to the river via return flows from the wetland/floodplain. High cyanobacterial abundance in isolated wetlands may be locally significant but will have little impact on the main river channel. However, if the wetland drains into the main channel this may act as a seed source (inoculum) to the main river channel and be a significant source of toxins or taste and odour compounds (Brookes et al., 2007). The risk associated with high cyanobacteria loads in wetlands draining into the river can be mitigated by ensuring that flows in the river are relatively high and generating "wash-out" and turbulent conditions conducive to the breakdown of blooms (see Brookes et al., 2007).

Biotic processes that are likely to be influenced by method of EWA delivery

The processes which are being influenced by flow manipulation and floodplain inundation include hydrodynamics, biogeochemistry and primary productivity. Higher order organisms respond to these habitat and primary productivity drivers. Detail on selected biotic groups is presented in the supporting information section. The following information is focused on the key processes; (i) connectivity; (ii) provision of food resources; (iii) influence of source water; and (iv) filling patterns.

Connectivity

Beyond microbial processes, aquatic micro-invertebrates re-generating from soil egg banks and downstream transport respond quickest to inundation (Jenkins & Boulton, 2003; Boulton et al., 2006). Macro-invertebrates and macro-crustacea (shrimp, yabbies, freshwater crayfish) may need to colonise from other nearby sites or be dependent on development of appropriate habitat (e.g. macrophytes) and food resources (Nielsen et al., 1999) prior to establishment in large numbers (see Kingsford et al., 2010).

We propose that there is a hierarchical relationship between connectivity and movement:

- 1D active movement
    - longitudinal (1D) movement that is undertaken by fish and macro-crustacea (shrimps, prawns, yabbies, crayfish)
- 2D active movement;
    - lateral (2D) movement that is undertaken by fish and macro-crustacea (shrimps, prawns, yabbies, crayfish)
- 3D active movement
    - movements that are undertaken by birds and macro-invertebrates that can fly in/out in response to changing conditions
- Passive movement
    - Primarily 1D and 2D movements undertaken by carbon, nutrients, phytoplankton, micro-invertebrates, plant propagules and early life stages (egg, larval) of fish

Longitudinal barriers bisecting rivers (e.g. weirs, dams) and lateral barriers between rivers and floodplains (diversion and flood protection levees) sever connectivity and can lead to isolation of populations, failed recruitment, local extinction and loss of aquatic biodiversity (Bunn & Arthington, 2002; Arthington & Pusey, 2003). Constructed infrastructure reduces transport of nutrients, biota and organic matter, often creating different conditions in each pool, such that each may become a distinctive lentic environment (Lake, 2005) cited by (Bond et al., 2008). Methods of delivering environmental water that further restrict connectivity compromise the ability of the EWA to achieve positive ecological outcomes and this is a major challenge for the effective delivery of EWA.

Provision of food resources

Factors that will influence the success (survival and recruitment) or failure of breeding events of key groups such as frog, fish and birds include the availability of appropriate food resources at the correct times via the productivity boom (Bunn et al., 2006) that occurs during floods. The productivity boom provides abundant food resources for a range of higher order animals and is therefore regarded as an ecosystem service. Invertebrates are a key food resource for breeding waterfowl as they provide the protein source required for egg and nestling development. The responses of guilds that are piscivorous, herbivorous, reliant on aquatic macro-invertebrates and terrestrial invertebrate/ insects, or utilise aquatic plants (e.g. sedges and rushes) for nesting material will depend on the provision of appropriate habitat and response/development of food resources (Rogers & Paton, 2008). It has been demonstrated (Boulton & Lloyd, 1992) that once the antecedent duration between floods exceeds 11 years, the diversity of invertebrates present in soil egg banks, and the number of animals hatching once soils are finally inundated decreases significantly. Methods and frequency of delivery of EWA that do not maximise (i) the provision of appropriate habitat; and (ii) the development of appropriate food resources will deliver minimal benefits.

Influence of water source

The source of water from which EWA are comprised may influence outcomes. Water released from an upstream storage and transferred as an EWA into an individual site (i.e. wetland) during periods of in-channel flow, particularly very-low flow periods may restrict the ecological outcomes as the productivity gains from upstream flooding are not available to be transported into the managed site. The "missing pieces" are likely to include plant and invertebrate propagules dispersed from upstream sites, increased carbon and nutrient concentrations and other chemical cues resulting from inundation of floodplain soils and plant material, eggs and larvae of fish and other organisms spawned at upstream sites.

Conditions within upstream storages can range from functioning as a sink or source of nutrients, with associated changes in speciation of chemicals leading to changes in phytoplankton community structure at downstream sites (Baldwin et al., 2010). This can lead to flow-on effects on primary productivity and food webs downstream (see Burford et al., 2011). The issue of thermal pollution resulting from hypolimnetic off-takes in storages must also be taken into account when considering the ecological outcomes that can be achieved during environmental flows (Olden & Naiman, 2010). The river that water is being sourced from may also have an impact. For example, under very low flow conditions turbidity in the Darling River can be as low 16 NTU (Wallace, unpublished data) but Sherman et al., (1998) report that turbidity is usually very high (>100 NTU). When the Darling is in flood, increased turbidity can cause the euphotic depth in the lower River Murray to be less than 0.2 m (Mackay et al., 1988). If EWA are comprised of high turbidity water the potential for the growth of aquatic plants is greatly reduced (Brookes et al., 2009a). Furthermore, the microfauna of water from the Darling and Murray Rivers are markedly different and the composition of microfauna varies between storages with short (e.g. Lake Mulwala) and long (e.g. Hume Dam) retention times (see Brookes et al., 2009a).

Filling patterns

During natural floods, the floodplain fills from upstream. In contrast, during floods generated by the use of large infrastructure, the floodplain is backfilled from the downstream end. The backwater curve generated leads to the maximum area inundated being located adjacent to the regulator at relatively high elevations (mAHD) compared to the area inundated at the tail end of the inundation zone where the water level will not rise as high (Nicol et al., 2010). The flow paths and deposition patterns of propagules (including larval fish) are therefore likely to be significantly altered (Mallen-Cooper et al., 2008). There will also be a lack of meteorological cues from rain events (high/low pressure systems) when high flows are generated by releases from storages.

The prevailing management paradigm

The scale of intervention needs to expand from the management of individual wetlands and preventing loss of populations of individual species, to ecosystem management at the landscape scale. However, the recent drought across southern and eastern Australia has revealed the contention within society for delivering water to the environment during drought (when it is widely although incorrectly perceived by society that floodplain systems would not have received water). The recovery of large volumes of water for environmental purposes is intended to find a balance between extraction of water for consumptive use and the environment. However, the social tensions surrounding development of the Murray-Darling Basin Plan (http://www.mdba.gov.au/basin_plan) the cost of water recovery ($3.1 billion over 10 years) and the cost of large scale restoration projects such as *The Living Murray* (http://www.mdba.gov.au/programs/tlm) demonstrate the cost and difficulty of restoring a desired state. Furthermore, there are critical risks of institutional failure in relying entirely on environmental flow arrangements during dry periods. This has been demonstrated by the 'suspension' of environmental flow agreements by the Victorian and New South Wales Governments in 2006 (see Pittock & Finlayson, 2011) and the 'loan' of the Barmah Forest EWA to the irrigation industry during the drought which had a low (10%) likelihood of being returned when required (King et al., 2010).

In addition to the issues outlined above, a key message reported by Meredith and Beesley (2009) from managers was that they are unlikely to be able to deliver an ideal water regime (timing, volume, rate, frequency) to wetlands because of engineering (channel capacity), and the social and political (intergovernmental) constraints associated with delivery of water. The logistics of delivering water has been shown to be the single most important factor in determining which wetlands receive EWA and when. Alarmingly, ecological objectives typically play a secondary role in this decision making process (Meredith & Beesley, 2009). Consequently, the current management approach can readily be described as one of "landscape gardening" where triage decisions are made about the delivery of relatively small volumes to discrete sites that both hold significance to managers or society and that "the garden hose can reach" (i.e. it is a short distance to pump and the legislative hurdles associated with construction of banks and establishment of pump locations are surmountable).

Management of systems for resilience

There is an urgently growing need to move away from maintaining stabilised conditions, where management interventions are focused on preventing irreversible damage once the system is already in an extreme level of precariousness (Scheffer et al., 2001; Scheffer & Carpenter, 2003). Instead, management needs to focus on reinstating resilience as the most pragmatic and effective way of managing ecosystems in order to withstand future droughts and provide ecosystem services (Scheffer et al., 2001; Scheffer & Carpenter, 2003; Folke et al., 2004; Bond et al., 2008). Holling (1973) defined resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables....”. Resilience has multiple attributes, but four aspects are critical (Walker et al. 2004 as cited by (Folke et al., 2004)):

- *Latitude*; the maximum amount the system can be changed and still reorganize within the same state.
- *Resistance*; how large a disturbance is required to change the current state of the system.
- *Precariousness*; how close the system is to a threshold that, if breached, makes reorganization difficult.
- *Cross-scale relations*; how the three attributes above are influenced by the states and dynamics of the system, at scales above and below the scale of interest.

Unregulated river systems are likely to have a very large degree of resilience, latitude and resistance, displaying a transient, dynamic regime (Holling, 1973) with two distinct extremes (Scheffer et al., 2001; Scheffer & Carpenter, 2003) in which wetlands are always drying or flooding (Kingsford et al., 2010). Rather than the wet and dry phase being two states with characteristic dominant biota, there is only a single state with two alternative phases interspersed by floods and droughts (Colloff & Baldwin, 2010); the system will progressively revert towards the preceding condition once the disturbance (flooding or drying) is removed. Once a driver (i.e. permanent inundation or very long drying) exerts sufficient pressure to exceed the threshold for change a catastrophic (rather than smooth) transition to an alternate state can occur (Scheffer et al., 2001; Scheffer & Carpenter, 2003). This concept is presented in Figure 1. River management has skewed river channels towards the left of this model (anti-drought) and floodplains to the right (engineered drought). Regulated river systems are therefore likely to be in an extreme state of precariousness.

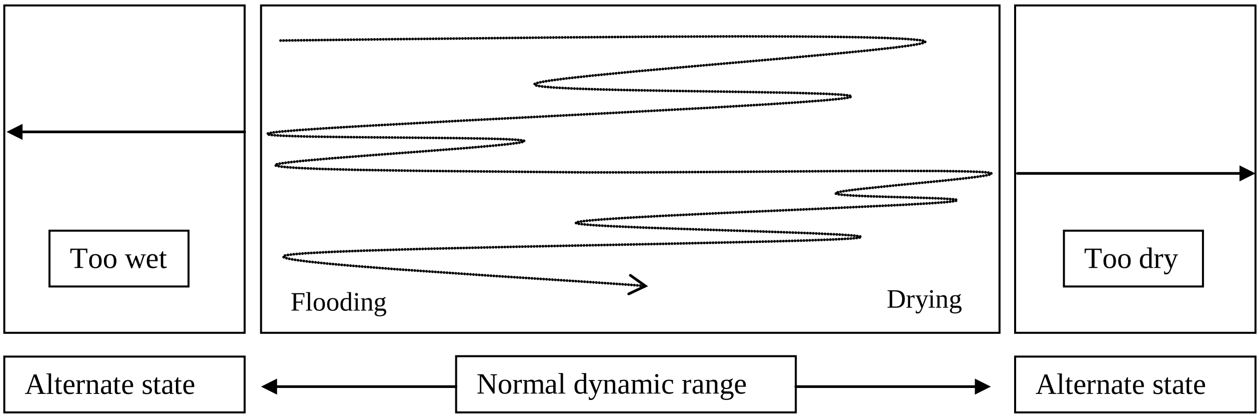

Figure 1. Conceptual model of the dynamic regime in which floodplains are always drying or flooding and the potential for excessive pressure to cause a transition to an alternate state.

Colloff and Baldwin (2010) suggest that the dramatic decline in condition of river red gums throughout the Murray-Darling Basin "have not yet reverted to an alternate stable state" implying that the system is approaching a tipping point. Assessments of population demographics demonstrate that in many areas there is insufficient recruitment to sustain the existing forest and woodland communities (George et al., 2005; Wallace, 2009). Furthermore the floodplain eucalypts (*E. camaldulensis* and *E. largiflorens*) retain the majority of their seed in the canopy, and trees in poor condition produce less seed than those in good condition (George et al., 2005; Jensen et al., 2008). Hence, once there is widespread loss of mature trees there is no soil seed bank for regeneration. Loss of forest/woodlands leads to increased likelihood of establishment of grassland areas (Scheffer et al., 2001); conversely, in grassland areas, droughts reduce grass cover decreasing the likelihood of fires which are a key control on the establishment of perennial shrubs (Folke et al., 2004). Once lost, costly restoration with extremely long lag phases will be required to reinstate "ecosystem engineers" such as river red gum and black box (Colloff & Baldwin, 2010). This situation where simply restoring the original environmental conditions (i.e. natural flow regime) is not likely to be sufficient to induce a switch back to the pre-existing condition and that conditions need to be established that create a second shift, back to the “desired” condition is known as hysteresis (Scheffer et al., 2001).

The concept of downsizing river systems

Re-establishment of natural flow regimes represents a neat theoretical objective. However, the reality is that this is impractical as the demands of society preclude returning our rivers to natural flow (Meredith & Beesley, 2009; Hall et al., 2011). Consequently there have been calls to downsize river systems (see Overton & Doody, 2008; Hall et al., 2011; Pittock & Finlayson, 2011). The potential for EWA delivered according to a hydrograph mimicking natural seasonal patterns but at a smaller magnitude has been demonstrated at the Bridge River in south-western British Columbia (Hall et al., 2011). This concept holds some merit but in reality it is a process of reinstating the small floods that river regulation has removed. Frequent small floods function as the primary source of water sustaining lowland river floodplains in arid regions and maintain soil moisture and water levels in wetlands that increase the potential for subsequent flows to travel further downstream and/or inundate larger areas (see Leigh et al., 2010).

The concept of downsizing rivers also overlooks the role of the interface between the aquatic (regularly inundated) and terrestrial (never inundated) zones in subsidising terrestrial food webs. Faunal transported fluxes of energy (e.g. macrophytes grazed by herbivores; emergent aquatic insects consumed by insectivorous birds, bats, reptiles, beetles, spiders etc.) may be extremely important for terrestrial foodwebs (see review by Ballinger & Lake, 2006). Abandonment of large sections of floodplain may create an extremely dysfunctional and potential hostile (e.g. highly salinised) zone or 'no-man's land' that is neither aquatic or terrestrial (i.e. occasional floods preclude the development of terrestrial communities but are at an insufficient frequency to maintain aquatic processes) generating a new barrier to energy flux.

Management considerations for progress towards sustainable river systems.

Selection of appropriate methods for delivery of EWA

The most appropriate method for any site will vary accordingly with a range of factors including but not limited to; availability of water, connectivity of site to water source, and management targets. The potential for the various methods outlined above to influence the different spatial components of river-floodplain systems is presented in Table 2. This demonstrates that relative to a natural large flood, few individual methods are capable of influencing the widest range of floodplain components. Methods that maximise connectivity and water exchange must be given priority.

Table 2. Relationship matrix between flow delivery method and interaction with river-floodplain components. ✓ indicates that the flow type is likely to influence the respective component, ✗ indicates that the flow type is not likely to influence the respective component, ⌖ indicates that the flow type is only likely to influence the respective component in limited (ie. specifically targeted) locations; (CTF = commence to flow).

Examples	Main river channel	Permanently connected wetlands	Ephemeral channels/floodrunners	Early CTF wetlands	Late CTF wetlands	Low elevation shedding floodplain	Low elevation retaining floodplain	High elevation shedding floodplain	High elevation retaining floodplain
Natural large flood (inundates entire floodplain)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Natural medium flood (inundates majority of floodplain)	✓	✓	✓	✓	⌖	✓	✓	✗	✗
Natural small flood (spills into ephemeral channels and low wetlands)	✓	✓	✓	✓	✗	⌖	⌖	✗	✗
Natural in-channel flow pulse	✓	⌖	⌖	⌖	✗	✗	✗	✗	✗
Medium flood utilising large constructed infrastructure	✓	✓	✓	✓	⌖	✓	✓	✗	✗
Small flood utilising large constructed infrastructure	✓	✓	⌖	⌖	✗	⌖	⌖	✗	✗
In-channel flow pulse using large constructed infrastructure	✓	⌖	⌖	⌖	✗	✗	✗	✗	✗
Controlled releases to generate in-channel flow peaks	✓	✗	⌖	⌖	✗	✗	✗	✗	✗
Controlled releases to reinstate flow	✓	✗	⌖	✗	✗	✗	✗	✗	✗
Controlled releases to engage floodplain	✓	✓	✓	⌖	✗	⌖	⌖	✗	✗
Hybrid in-channel flow pulse (piggybacking e-water on base flows)	✓	✓	⌖	⌖	✗	✗	✗	✗	✗
Hybrid flood (controlled release that is overridden by natural flows)	✓	✓	⌖	⌖	⌖	⌖	⌖	⌖	⌖
Weir pool manipulation – lowering weir pools	✓	✓	✗	✗	✗	✗	✗	✗	✗
Weir pool manipulation – raising weir pools	✓	✓	⌖	⌖	✗	⌖	⌖	✗	✗
Pumping water into discrete sites	⌖	⌖	✓	✓	✓	✓	✓	⌖	⌖
Gravity based delivery of water into discrete sites at base flows	⌖	⌖	✓	✓	✗	✗	✗	✗	✗
Retaining water from natural floods using constructed infrastructure	⌖	⌖	✓	✓	✓	✓	✓	⌖	⌖

Severity rating criteria

We believe that the management focus must move away from defining broad taxa like fish, birds, trees, understorey vegetation, water quality and assessing the risks/benefits around these artificial groupings. The focus must become one of using EWA to create resilient, sustainable ecosystems by reinstating biophysical diversity (Walker, 2009) and ecological processes. At the site scale, the influence of contrasting delivery methods on ecological processes can be assessed using a severity rating criteria as presented in Table 3 (adapted from Arthington et al., 2003) to provide managers with a tool to determine if a specific method is likely to achieve their objectives.

Table 3. Severity rating criteria for assessing the effects of flow delivery method on ecological outcomes (adapted from Arthington et al., 2003)

Severity	Criteria	Consequence
1	All natural ecological requirements/processes	Large, positive change in condition
2	Most natural ecological	Moderate positive change in condition
3	Some natural ecological	Change in condition likely to be small
4	Few natural ecological	Negative impacts may outweigh positive
5	Very few natural ecpumping water into	Increasing risk of negative impacts
6	No natural ecological requirements/processes	High risk of negative impacts dominating

Consideration of serial (cumulative) impacts

Serial impacts include outcomes (both positive and negative) that may not be revealed/detected until many events have occurred. Waterbirds and ground-foraging insectivorous birds are likely to respond behaviourally to inundation events rapidly but key long-term responses such as increased recruitment and strong adult survival during dry periods will occur at the highest temporal-scale of the flow-regime (Rogers & Paton, 2008). It has been demonstrated that diverse fish communities can establish in wetlands where EWA have been delivered via large pumps (McCarthy et al., 2009). In situations where the managed site is allowed to dry out via evaporation, these fish communities are denied return passage ultimately leading to fish mortality. The cumulative impact of repeated flood occurrences at a large number of managed wetlands needs to be taken into account.

The need for pragmatic solutions

The delivery of EWA to components of river systems cannot replace the function of natural overbank flows and there is no 'Silver Bullet' for repairing water-dependant ecosystems deprived of a natural flooding regime. Consequently pragmatic solutions are required to ensure environmental watering at intervals sufficient to enable system preservation and recovery (Brookes et al., 2009b). Crucial functions of rivers depend on hydrological connectivity. The engineering dominated approach to river management by necessity leads to the fragmentation of river systems. Yet few would suggest this is an appropriate way to manage complex natural systems. The way to reinstate a healthy floodplain-river ecosystem is by reducing, not increasing the number of barriers. Weirs and regulators do more than merely impound water, and it is our inability to predict and control the incidental effects that gives most cause for concern (Walker, 2009). In areas that are salt affected floods at higher than normal frequencies (meaning larger volumes of water) will be required to maintain vegetation communities (Nicol et al., 2010). Given the reality of trying to achieve more with less water, using opportunities to export salt out of the floodplain, rather than using floodplains as salt stores must become a management priority.

Are EWA management tools or environmental experiments?

The delivery of EWA to achieve strategic environmental outcomes is certain to become a key management tool (Windsor Report, 2011(http://www.aph.gov.au/house/committee/ra/murraydarling/report/fullreport.pdf). However, it must be recognised that the use of EWA is fundamentally a large-scale manipulative experiment. We currently lack sufficient ecological knowledge to predict how floodplains in different conditions will respond. This represents a major hurdle for managers as volumes of environmental water are limited and resilience is an ecosystem property that can be either created or destroyed (Colloff & Baldwin, 2010).

Higher order organisms respond to habitat and primary productivity drivers. Environmental flows need to focus on these key processes (Kingsford, 2011) in order to maintain ecosystems that will serve as the major sources of propagules and colonists for other areas (Arthington & Pusey, 2003). Investment in recovering water and construction of infrastructure for delivery of EWA needs to be underpinned by investment in research to inform adaptive management and to ensure that critical ecological processes and functions are reinstated. If this is not undertaken, there is no way that environmental water allocations will be able to reinstate resilience (Kingsford et al., 2010).

Key principles for consideration when planning the use of environmental water allocations

Landscape scale processes, connectivity and flow regime are key drivers of ecological systems. Methods of delivering environmental water that do not maximise (i) connectivity (ii) the provision of appropriate habitat; and (iii) the development of appropriate food resources will deliver minimal benefits and compromise the ability of the EWA to achieve positive ecological outcomes. The following provides a list of key principles that must be taken into account when planning the use of environmental water in order to maximise positive outcomes.

- **It is not just the presence of water that is important for maintenance of ecosystem function**
    - The 'quality' of water is an important feature in addition to the quantity of water or the temporal patterns of flow

- The method of achieving and maintaining inundation and the resultant dilution and downstream dispersal of carbon and nutrients will have a significant impact on water quality via biogeochemically mediated processes
- Managed floods using infrastructure must maintain high rates of water exchange in order to maximise benefits and minimise risks
- Ponded flooding should be avoided
- The delivery of EWA to components of river systems cannot replace the function of natural overbank flows

- **Lateral and longitudinal connectivity drive system productivity**
  - Crucial functions of rivers depend on lateral and longitudinal hydrological connectivity
  - Movement of propagules that can colonise sites and improve condition of degraded sites is dependent on connectivity
  - Lateral and longitudinal connectivity is essential to the viability of populations of many species
  - Managed floods that do not provide strong lateral and subsequent longitudinal transfer of allochthonous material minimise or even preclude the potential for transfer of productivity gains
  - Returning water, that contains a high biomass of prey items and increased nutrient loads, to river channels is likely to improve the recruitment success of fish inhabiting those river channels

- **Habitat and primary productivity drive ecological outcomes**
    - The processes which are influenced by flow and floodplain inundation include hydrodynamics, biogeochemistry and primary productivity
    - Higher order organisms respond to these habitat and primary productivity drivers
    - Differences in the quality of outcomes between natural and managed floods will be driven by the effects of processes that cascade across multiple trophic levels
    - It is essential to manage processes to influence outcomes
    - Trying to improve the condition of only a small subset of the ecosystem without considering the consequences of the intervention on the ecosystem as a whole may cause unwanted and potentially catastrophic effects

- **Variability is essential**
    - Flow magnitude, frequency, timing, duration, rate of change and sequence all hold major ecological significance
    - Variability in these factors is potentially more important than biological factors in structuring aquatic communities
    - Ensuring EWA's are delivered with variability in all of these factors is essential to achieve positive outcomes for multiple abiotic processes and biotic groups
    - Variability is essential to minimise the possibility for negative outcomes to become dominant over cumulative events

- **Ecological outcomes will be related to the antecedent conditions**
    - Sequential floods maintain soil moisture and water levels in wetlands increasing the potential for subsequent flows to travel further downstream and/or inundate larger areas
    - Sequential floods are likely to have positive cumulative effects on biotic responses
    - Meteorological cues may be important for some ecological processes
    - Timing of flooding will have a significant impact on outcomes
    - EWA's delivered into an individual site (i.e. wetland) during periods of low flow may restrict the ecological outcomes as the productivity gains from upstream flooding are not available to be transported into the managed site

- **Reinstate resilience in order to withstand future droughts**
    - Management needs to focus on reinstating resilience as the most pragmatic and effective way of managing ecosystems in order to withstand future droughts and provide ecosystem services
    - Reducing the persistence and severity of engineered droughts will increase the ability of floodplains to withstand climate derived droughts

- EWA's should be used to capitalise on outcomes from preceding flows to (i) ensure germination/spawning/breeding leads to recruitment, and (ii) build resilience, rather than being primarily used as a management tool after long-dry periods to prevent collapse of systems
- The scale of intervention needs to expand from the management of individual wetlands and preventing loss of populations of individual species, to ecosystem management at the landscape scale

Comments on the characteristics and a severity rating score for each of the major types of EWA is presented in Table 4. Severity scores presented are generic (non-site specific) and based on the criteria outlined in Table 3. It is proposed that those management techniques that are higher in the table and shaded grey are the preferred group of management activities. These activities should be actively used during wet and median conditions to build resilience at the system scale. Activities lower in the table have higher severity ratings and are less desirable. These actions can only be applied to isolated sites and should be relegated to use during dry and extreme dry conditions to avoid long-term or irreversible damage and maintain refugia. The use of these techniques as the primary tool for the long-term management of floodplains and wetlands is not recommended.

Table 4. Matrix of management techniques, comments on characteristics and severity rating criteria for delivery of EWA (severity rating scores are explained in Table 3)

Management technique	Comments	severity rating
natural flood in unregulated system	the reference condition	0
uncontrolled flow where effects of regulatory structures are largely nullified	closest achievable approximation of natural conditions flow events are minimally attenuated by management activities management of river reaches	1
controlled releases to generate flow peaks within channel and/or engage floodplain & hybrid floods	flows deliberately created or supplemented by management "filling" holes in the prevailing hydrograph management of river reaches	2
reoperation of existing infrastructure	weir pool manipulation under-utilised technique that needs to become a management priority large scale longitudinal impact management of river reaches	3
retaining water from high flow events to extend period of inundation	construction and operation of additional regulatory structures construction of additional barriers on floodplain primary use should be to ensure breeding cycles are completed exchange between wetland/floodplain and river is truncated management of fragmented sites	4
utilisation of new structures to inundate large sections of floodplains	construction and operation of additional regulatory structures construction of additional barriers on floodplain maximising water exchange is critical to achieving positive outcomes limited number of sites where this option is practicable management of fragmented sites meteorological cues likely to be missing productivity benefits from upstream likely to be missing no precedent for this activity - outcomes may differ from those expected	4
gravity based delivery of water into discrete sites	very low connectivity typically no benefit to river channel ponded floods generate poor water quality and soil condition meteorological cues likely to be missing productivity benefits from upstream likely to be missing limited number of sites where this option is practicable management of fragmented sites construction of additional barriers on floodplain	5
pumped delivery of water into discrete sites	extremely low connectivity typically no benefit to river channel ponded floods generate poor water quality and soil condition meteorological cues likely to be missing productivity benefits from upstream likely to be missing limited number of sites where this option is practicable management of fragmented sites construction of additional barriers on floodplain	5

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