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CONSEIL INTERNATIONAL DES MONUMENTS ET DES SITES
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МЕЖДУНАРОДНЫЙ СОВЕТ ПО ВОПРОСАМ ПАМЯТНИКОВ И ДОСТОПРИМЕЧАТЕЛЬНЫХ МЕСТ

Our Ref. GB/AS/1577-Add.Inf_1

Charenton-le-Pont, 10 October 2018

H. E. Mr Angus Mackenzie
Permanent Delegation of Australia to UNESCO
Ambassade de l'Australie
4, rue Jean-Rey
75724 Paris CEDEX 15

World Heritage List 2018
Budj Bim Cultural Landscape (Australia)

Dear Sir,

ICOMOS is currently assessing the nomination of "Budj Bim Cultural Landscape" to the World Heritage List, and an ICOMOS evaluation mission has visited the property to consider matters related to protection, management, conservation and interpretation. ICOMOS is very grateful for the time, expertise and support given to the evaluation mission by the State Party, local experts and other involved in the nomination process.

In order to help with our overall nomination process, we would be grateful to receive further information to clarify several points and to augment the material that has already been submitted in the nomination dossier.

We would be grateful if the State Party could consider the following points and kindly provide additional information on these matters:

Selection of serial components
ICOMOS notes that the Budj Bim landscape in its interaction between people and environment is based on a few continuous landscape features, such as waterflow and the aquaculture system as well as the lava flow. Yet, ICOMOS notes, that these features continue between the serial components. Could the State Party please elaborate why it opted for a serial nomination instead of presenting a property which includes the continuous lava stream and waterflow elements between the northern and southern component as well as, eventually, towards the Portland Bay.

Factors affecting the property
The ICOMOS technical evaluation mission expert reported observing recent damages to selected parts of the property which were caused by wild boars. Could the State Party kindly provide information as to how it anticipates controlling the wild boar populations within the property to prevent damages caused by the boars rooting.

Australian Government

Department of the Environment and Energy

Dr Mechtild Rössler
Director
UNESCO World Heritage Centre
7 Place de Fontenoy, 75352
FRANCE

Dear Dr Rössler,

As you may know, ICOMOS has requested additional information to support Australia's nomination of the Budj Bim Cultural Landscape to the World Heritage List.

On 8 November 2018 Australia provided the additional information (as enclosed) regarding the decision to nominate the Budj Bim Cultural Landscape as a serial nomination, and how Australia will address the ground disturbance caused by pest animals.

As requested by ICOMOS, we are pleased to be able to provide two hardcopies of the additional information to the World Heritage Centre so that it can be submitted as part of the nomination.

Should you have any further questions regarding these matters, or any other matter relevant to the nomination, please do not hesitate to contact Ms Mahani Taylor, Director International Heritage (australiaworldheritage@environment.gov.au).

Yours sincerely

David Williams

David Williams
First Assistant Secretary (Acting)
Heritage, Reef and Marine Division
Department of the Environment and Energy

8 November 2018

Ms Gwenaëlle Bourdin
Director
ICOMOS Evaluation Unit
11 rue du Séminaire de Conflans
94220 Charenton-le-Pont

Dear Ms Bourdin,

I am writing to you in response to your letter of 10 October 2018, in which you request additional information to support Australia's nomination of the Budj Bim Cultural Landscape to the World Heritage List.

Please see the additional information provided at Attachment A regarding the decision to nominate the Budj Bim Cultural Landscape as a serial nomination, and how Australia will address the ground disturbance caused by pest animals.

Should you have any further questions regarding these matters, or any other matter relevant to the nomination, please do not hesitate to contact Ms Mahani Taylor, Director International Heritage (australiaworldheritage@environment.gov.au).

Please note that we will provide two hardcopies of the additional information enclosed to the UNESCO World Heritage Centre so that it can be submitted as part of the nomination.

Yours sincerely

David Williams

David Williams
First Assistant Secretary (Acting)
Heritage, Reef and Marine Division
Department of the Environment and Energy

7 November 2018

ATTACHMENT A

Additional Information submitted by Australia in support of the nomination of the Budj Bim Cultural Landscape to the World Heritage List

Selection of serial components

As stated in the Budj Bim Cultural Landscape nomination dossier, the three components of the serial property incorporate intact and outstanding examples of aquaculture complexes at Tae Rak (Lake Condah), Tyrendarra and Kurtonitj. Each complex includes all the physical elements of the system (that is, channels, weirs, dams and ponds) that demonstrate the operation of Gunditjmara aquaculture. The property is sufficient in size to incorporate the cultural features and ecological processes that illustrate the ways multiple systems – social, spiritual, geological, hydrological and ecological – interact and function.

The authenticity of the Budj Bim Cultural Landscape is also best represented in the three components of the serial nomination. Authenticity is evidenced in the continuing association of the Gunditjmara with the landscape, their knowledge of, and practices associated with the harvesting of kooyang, and their maintenance of the aquaculture complexes. The high degree of authenticity is enabled by Gunditjmara's ongoing and unbroken connection to Country and which is most credibly represented in the lands owned or co-managed by the Gunditjmara. These lands form the three components of the serial nomination.

The other two attributes that comprise the Gunditjmara aquaculture system are Gunditjmara cultural traditions, knowledge and practices (which are enabled by Aboriginal ownership, management, and control of the property), and the interconnected geological, hydrological and ecological systems of the lava flow. It is the interconnection of these three attributes that carry the Outstanding Universal Value of the nominated property, and are fully and adequately represented within the boundary of the serial nomination.

Since 1984 the Gunditjmara have gradually regained ownership of their traditional Country and their aquaculture system. In reclaiming their traditional Country, the Gunditjmara purposefully pursued ownership of those lands that included the most extensive and intact physical features of the Gunditjmara aquaculture. The physical aquaculture features, identified through over 40 years of archaeological survey, excavation and analysis, are one of the attributes that comprises the Gunditjmara aquaculture system.

Protection and Management

The entire Budj Bim lava flow and the associated water system are culturally significant to the Gunditjmara Traditional Owners, who are legally recognised as native title holders across the entirety of the lava flow. The entire lava flow and the water flows on the lava are protected and managed to ensure that kooyang continue to thrive and provide a sustainable resource for Gunditjmara people.

The majority of the Budj Bim Cultural Landscape is included on Australia's National Heritage List, and is protected from potential significant impacts under Australia's *Environment Protection and Biodiversity Conservation Act 1999*. Additionally all Gunditjmara cultural heritage on Budj Bim Cultural Landscape is protected by Victoria's *Aboriginal Heritage Act*

2006. The lava flow itself is specifically defined as an area of cultural heritage sensitivity under the Victorian Aboriginal Heritage Regulations 2018 and protected accordingly.

Gunditj Mirring Traditional Owners Aboriginal Corporation ensures environmental conditions and seasonal water flows of Killara (Darlot Creek) are maintained through proper operation of the cultural weir at Tae Rak (Lake Condah) according to the environmental conditions set out in the permit issued by the Glenelg Hopkins Catchment Management Authority (CMA). The Glenelg CMA is the responsible water authority for the entirety of the nominated property, and maintains the quality of the water that flows through the Budj Bim Cultural Landscape.

However it is in the three nominated components of the serial property, which covers a total area of 9,935 hectares and represents over 70 per cent of the lava flow, that the cultural landscape of the Gunditjmara aquaculture system is fully evidenced in the aquaculture complexes created by Gunditjmara ancestors and which continue to be used and maintained by Gunditjmara in the present.

The Outstanding Universal Value of the nominated property is reflected in Gunditjmara cultural traditions, knowledge and practices, the physical features of the aquaculture system, and the interconnected geological, hydrological and ecological systems. Although the water and lava flows connect the serial properties, they do not hold the Outstanding Universal Value on their own. The three components of the serial property together comprise the Gunditjmara aquaculture system, which is fully represented in the proposed boundary.

Factors affecting the property

The emergence of feral pigs (wild boars) in the area of the Budj Bim Cultural Landscape is a very recent problem. Feral pigs are a declared 'pest animal' under Victoria's *Catchment and Land Protection Act 1994*. Land owners are legally responsible to prevent the spread of, and eradicate as far as possible, feral pigs on their land. As noted in the nomination dossier, the Budj Bim Rangers have an ongoing control program for pest animals across the nominated property, including for feral pigs.

Since 2016 the Victorian Government has carried out an intensive trapping program on crown land properties and adjoining neighbours including the Indigenous Protected Areas. The Victorian Government has trapped and destroyed approximately 160 pigs in the district during this period. A total of 15 feral pigs have been caught and destroyed at Kurtonitj property, which forms part of the Budj Bim Cultural Landscape. The Victorian Government will continue to carry out the intensive trapping program on the Budj Bim Cultural Landscape to ensure feral pig numbers are reduced.

Most damage caused by feral pigs on the Budj Bim Cultural Landscape is confined to the clearer areas absent of volcanic rock and consequently the aquaculture systems are not impacted. Despite this, the Victorian Government continues to actively reduce feral pig numbers on the Budj Bim Cultural Landscape.

BUDJ BIM CULTURAL LANDSCAPE, AUSTRALIA

RESPONSE TO THE ICOMOS INTERIM REPORT AND REQUEST FOR ADDITIONAL INFORMATION

28 FEBRUARY 2019

Australia would like to thank ICOMOS for the opportunity to discuss the World Heritage nomination of the Budj Bim Cultural Landscape at the ICOMOS World Heritage Panel meeting in Paris, France in November last year.

Australia received the ICOMOS interim report for the Budj Bim Cultural Landscape on 21 December 2018. Australia and the Gunditjmara Traditional Owners appreciated that ICOMOS recognised the significance of the Budj Bim Cultural Landscape as likely the oldest, continuous aquaculture system in the world. In the report ICOMOS raised specific questions regarding protection mechanisms for the property and we are pleased to provide additional information on these matters. Our response to each question is addressed below.

The Budj Bim Cultural Landscape has an established and robust management system in place to ensure the highest level of protection. As outlined in the nomination dossier (Part 5), this is achieved through integrated protection mechanisms ranging from the Gunditjmara Traditional Owner customary rights and obligations, Aboriginal ownership and cooperative management and legislative and regulatory controls at all levels of government (Australian, Victorian and local government). These mechanisms are supported by a complimentary suite of management plans and strategies that combine Gunditjmara knowledge and practices with contemporary science and adaptive management.

Should the Budj Bim Cultural Landscape be inscribed on the World Heritage List, the Gunditj Mirring Traditional Owners Aboriginal Corporation (Gunditj Mirring), Winda-Mara Aboriginal Corporation and the Australian and Victorian governments will develop and implement the Budj Bim Cultural Landscape Strategic Management Framework. While the Budj Bim Cultural Landscape is already comprehensively managed and protected under the current system, a strategic management framework will synthesise and further consolidate these arrangements. The implementation of the Framework will be managed by a joint Steering Committee of key stakeholders for the World Heritage property. This commitment is reflective of the strong relationships forged by the Gunditjmara with all management stakeholders to ensure the protection of their land and culture for future generations.

RESPONSE TO QUESTIONS RAISED IN THE ICOMOS INTERIM REPORT

Contents

PROTECTION

Legal mechanisms guaranteeing the continuity and quality of the water system

The continuity and quality of the overall water system of the Budj Bim Cultural Landscape is protected by several legislative frameworks at both the Australian Government and State Government levels. These frameworks include protection under the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) and the Victorian Government's *Catchment and Land Protection Act 1994, Water Act 1989* and *Environment Protection Act 1970.*

The EPBC Act protects the Outstanding Universal Value of all World Heritage properties in Australia

The EPBC Act is Australia's principal piece of environmental legislation. The Act is overseen by the Australian Government Minister for the Environment who ensures the protection of the Outstanding Universal Value (OUV) of Australia's World Heritage properties to meet Australia's obligations under the UNESCO World Heritage Convention. Any proposal likely to have a significant impact on the values of a World Heritage property is subject to rigorous environmental assessment. The assessment and approval processes under the EPBC Act provide for public transparency and engagement. Where appropriate, approval decisions by the Australian Government Environment Minister impose conditions to ensure that a project is consistent with the long-term protection of the OUV of the property. Any conditions imposed are strictly monitored and enforced. The EPBC Act includes significant civil and criminal penalties for non-compliance with provisions relevant to protecting World Heritage properties.

The EPBC Act does not only operate within World Heritage property boundaries, but also considers potential impacts on the OUV from activities outside the boundary, irrespective of the distance from the World Heritage property. This is because under the Act, it is the potential significant impact caused by the proposed activity to the OUV that triggers an assessment under the Act. In the case of the Budj Bim Cultural Landscape, this ensures that *any* proposal likely to impact the OUV associated with the Budj Bim Cultural Landscape, including the continuity and quality of the overall water system, will be considered by the Australian Government under the EPBC Act, irrespective of the location, size or scale of the proposed activity.

***Catchment and Land Management Act 1994* ensures the environmental conditions of the Budj Bim Cultural Landscape are maintained**

The *Catchment and Land Protection Act 1994* is the State of Victoria's principal legislation for controlling noxious weeds and pest animal management. Controlling noxious weeds and managing pest animals contributes to improving environmental conditions of the Budj Bim Cultural Landscape and the quality and continuity of the water flows.

Under this Act, plants and animals can be declared as noxious weeds and pest animals respectively, the movement and sale of noxious weeds and pest animals is prohibited. All land owners have legal obligations to eradicate and prevent the spread of prohibited plants and animals on their land. The Budj Bim Rangers carry out land management and monitoring activities across the Budj Bim Cultural Landscape and ensure the responsibilities under the *Catchment and Land Protection Act 1994* are met. As identified in the additional information provided to ICOMOS on 8 November 2018, feral pigs have been declared a 'pest animal' under this Act, which has led to the introduction of pest eradication measures to significantly reduce their numbers in and around the nominated property. Additionally, the Budj Bim Rangers are currently delivering the Budj Bim Connections Project, which includes improving fencing along the riparian zones to control wandering stock, and pest plant removal to improve water flow and quality.

The Act also sets up a framework for the integrated management and protection of catchments by establishing regional Catchment Management Authorities (CMA's) for each of the land protection regions and allowing the creation of special area plans to deal with specific land management issues in a particular area. The Glenelg Hopkins Catchment Management Authority is responsible under this Act for the catchment area that includes the nominated property. Gunditj Mirring work closely with the Glenelg Hopkins Management Authority to ensure the future quality and continuity of the water flows that are vital to maintaining the Budj Bim Cultural Landscape. Gunditj Mirring and the Glenelg Hopkins Management Authority are working together on various projects to better understand the hydrology of the Budj Bim Cultural Landscape and surrounding region, with the aim of improving cultural and ecological outcomes. Responsibilities and functions of Catchment Management Authorities are set out in the *Water Act 1989* and described below.

***The Water Act 1989* establishes the legal framework for water management in Victoria**

The legal framework established by the *Water Act 1989* (the Water Act) ensures the continuity and quality of the water flows of the Budj Bim Cultural Landscape. The flows and water bodies of the Budj Bim Cultural Landscape are sustained by Killara (Darlots Creek), Palawarra (Fitzroy River), and the Eumeralla River. These waterways are designated waterways under the Water Act. Consequently, a license must be issued by the Glenelg Hopkins Catchment Management Authority for any proposed works or activities on or near any of these waterways. This protects the quantity and health of the water flows of the Budj Bim Cultural Landscape.

The Act also establishes the Victorian Government's water corporations to oversee water management services. Southern Rural Water is the relevant rural water corporation for the Budj Bim Cultural Landscape and surrounding area and is responsible for ensuring sustainable water use in the region. Across the Budj Bim landscape, these provisions and protections are implemented at the local scale through the *Portland Groundwater Catchment Statement* (Southern Rural Water, 2017) and the *Portland Basin Local Management Plan* (Southern Rural Water, 2013).

The Water Act requires Southern Rural Water to issue and monitor licenses for water users to take and use water from natural water sources and catchment dams. Water users must comply with any conditions set out in these licenses, thereby ensuring sufficient volumes of water are present in the catchment for environmental requirements. Southern Rural Water is also responsible for preparing Local Management Plans to ensure long-term sustainability of water in declared Water Supply Protection Areas.

Under the Water Act, the Condah Water Supply Protection Area (WSPA) has been declared over a broad area north of Tae Rak (Lake Condah) from which the water flows of the Budj Bim Cultural Landscape are sourced. The Local Management Plan for the Condah WSPA ensures the long-term sustainability of water flows to the Budj Bim Cultural Landscape by setting a limit on how much water can be taken by water users. Water users who take water from the Condah WSPA must apply to Southern Rural Water for a license to do so. Southern Rural Water meters the water use of license holders to confirm land users comply with the conditions set out in their license. This ensures sufficient water is set aside for the environment, and ensures the long-term continuity of water flows at the Budj Bim Cultural Landscape.

The quality and continuity of water flows throughout the Budj Bim Cultural Landscape are also protected and maintained under the *Environment Protection Act 1970*

The *Environment Protection Act 1970* establishes the Environment Protection Authority (EPA), which has statutory responsibilities for improving water environments and controlling pollution. The Act also establishes the State Environment Protection Policies (Protection Policies), which provide a framework for protecting and managing water quality throughout the State of Victoria. The Protection Policies define rules for statutory decision makers and obligations for industry.

Specifically, works that would result in the discharge of waste water into the environment, require a works approval from the EPA. In issuing a works approval, the EPA must be satisfied the proposed activity would not adversely affect the quality of any segment of the environment. The EPA may require the license holder to carry out ongoing monitoring to ensure the action does not negatively impact the water quality.

These rules and obligations include the management of potential agricultural pollutants such as pesticides, fertilizer, animal manure, and dairy effluent. These rules and obligations ensure regional farming practices do not impact the quality of the water flows of the Budj Bim Cultural Landscape.

Legislative frameworks that protect the cultural heritage values and mechanisms that prevent potential future conflict with other land uses

As discussed above, the cultural values associated with the continuity and quality of the overall water system is protected by legislative mechanisms at all levels of government, including in cases where a change in land use may be proposed in the future. In addition to the cultural values associated with the continuity and quality of the overall water system, the cultural values associated with the geological and ecological systems of the lava flow, as well as Gunditjmara cultural traditions, knowledge and practices, are also protected under the following mechanisms.

The EPBC Act protects the Budj Bim Cultural Landscape from future land uses that would impact its OUV

As discussed above, the EPBC Act protects the OUV of World Heritage properties in Australia. It does not only operate within property boundaries, but also considers potential impacts on the OUV from activities outside the property. This includes changes in land use that could have a negative impact on any aspect of the cultural values and attributes of the Budj Bim Landscape, including the water quality or volume within the nominated property.

As such, any proposal that may have a significant impact on the OUV of the Budj Bim Cultural Landscape (including proposed actions as a result of changes in land use outside of the World Heritage boundary), would be assessed under the EPBC Act. This protection is afforded on the basis of the OUV for which the property is inscribed and includes consideration of direct or indirect impacts and protection of physical landscape features, water flows and intangible values alike. If the Australian Government Minister for the Environment approves an activity, any conditions imposed are strictly monitored and enforced.

The *Aboriginal Heritage Act 2006* protects all Aboriginal cultural heritage in and around the Budj Bim Cultural Landscape, including from proposed changes to land use or land developments

The *Aboriginal Heritage Act 2006* (Aboriginal Heritage Act) is Victoria's principal legislation for protecting Aboriginal cultural heritage. The Act protects all Aboriginal cultural heritage in Victoria, regardless of whether it has been recorded in the Register established under the Act. Under the Aboriginal Heritage Regulations (the Regulations), which give effect to the Act, the entirety of the Budj Bim Cultural Landscape is a defined area of 'cultural heritage sensitivity'. This protects the nominated property from development or land use activities that could harm the cultural values of the property.

Further, the Gunditj Mirring are responsible for evaluating, approving or refusing Cultural Heritage Management Plans and Cultural Heritage Permits for activities within and adjacent to the nominated property. This includes Gunditj Mirring's native title determination area and beyond; encompassing 14,000 square kilometres of land that surrounds the Budj Bim Cultural Landscape. As such, Gunditj Mirring would not allow proposed land uses or developments that would cause harm to significant

Aboriginal cultural heritage. The Cultural Heritage Management Plan and Permit processes are described in greater detail below.

The Regulations include a provision exclusively for the future protection of the Budj Bim Cultural Landscape. Under the Regulations, a Cultural Heritage Management Plan is required for any rock clearing proposed on the lava flows of the Budj Bim Cultural Landscape. This means that any proposed land use that would require disturbance to the surface rocks of the lava flows of the area, both within and outside of the nominated boundary, would require a Cultural Heritage Management Plan approved by Gunditj Mirring.

The Regulations require a Cultural Heritage Management Plan for land developments and land use changes proposed in areas where Aboriginal cultural heritage is likely to exist. It does this by defining areas of cultural heritage sensitivity, which include land within 200 metres of all named waterways, lakes and swamps in Victoria. Further, it defines the types of land uses and developments that could impact Aboriginal cultural heritage if the land use or development was to occur in these areas. The activities range from construction of a new road or utility to industrial, commercial, and residential developments. All other actions that have the potential to impact an Aboriginal place require a Cultural Heritage Permit, which must be considered by Gunditj Mirring for activities located in and around the nominated boundary.

In approving a Cultural Heritage Management Plan, Gunditj Mirring must be satisfied all Aboriginal cultural heritage is protected and managed during and after the proposed development. Gunditj Mirring must also be satisfied with the archaeological investigations carried out in preparing the Cultural Heritage Management Plan, and with any management conditions, which become legal requirements on the Cultural Heritage Management Plan's approval. Gunditj Mirring has the authority to refuse to approve a Cultural Heritage Management Plan if significant Aboriginal cultural heritage would be harmed by the activity. If Gunditj Mirring does not approve the Cultural Heritage Management Plan, a planning permit will not be issued, and the proposed development will not proceed. The Aboriginal Heritage Act establishes significant penalties for non-compliance.

Hydrological studies support and maintain the continuity and quality of the water system

As discussed during the ICOMOS panel meeting of 23 November 2018 and raised in the interim report, ICOMOS has requested the hydrological study for the analysis of the interrelation of water sources and water flows. Please find attached the *Lake Condah Water Restoration Project Hydrological Feasibility Study* (Fluvial Systems, 2006) at Attachment A; and the *Environmental Water Requirements of Darlot Creek and Lake Condah* (Fluvial Systems, 2008) at Attachment B to this document.

The 2006 and 2008 reports informed the construction of the cultural weir in 2010 to increase water quality and flows throughout the northern component of the nominated property. *The Lake Condah Water Restoration Project Hydrological Feasibility Study* (Fluvial Systems, 2006), the most comprehensive hydrological investigation of the Budj Bim landscape, was used to inform the first stage of restoration of Lake Condah and the construction of a new cultural weir at the outfall of the lake. Further hydrological investigations outlined in the *Environmental Water Requirements of Darlot Creek and Lake Condah* 2008 report, specifically addressed environmental flows, identified as requiring additional analysis in the 2006 report. These reports informed the construction of the cultural weir in 2010, to increase water levels and water retention in the lake and support the re-activation of some culturally significant eel traps in the area.

Similarly, the *Tyrendarra IPA Water Survey and Restoration Works Hydrological Feasibility and Concept Plan* (Fluvial Systems, 2014) is being updated to incorporate additional hydrological investigations currently underway, that aim to improve our understanding of water movement across the Budj Bim lava flow to inform potential restoration of water flows in the southern and central components of the nominated property. These investigations are funded and scheduled for completion by June 2020. When finalised, these reports will be integrated and inform the World Heritage strategic management framework for the property.

Mechanisms to protect current and future land use changes

The area surrounding the Budj Bim Cultural Landscape is dominated by rural (farming) industry, principally grazing, which does not impact the proposed OUV of the Budj Bim Cultural Landscape. There are no proposals to change the land use of the areas within or surrounding the nominated property. Should a change in land use be proposed in the future, there are several mechanisms functioning at the Federal, State and local levels that protect the Budj Bim Cultural Landscape.

The Budj Bim Cultural Landscape has been managed effectively for over a decade alongside the neighboring property owners as a National Heritage property protected under the EPBC Act (the same legislative protection afforded to World Heritage properties in Australia). If inscribed on the World Heritage List, the EPBC Act would require that any proposed changes to land use that are likely to have a significant impact on the World Heritage values, in addition to the National Heritage values, must be assessed by the Australian Government. If a proposed land use is assessed under the EPBC Act as likely to have a significant impact on the OUV of the Budj Bim Cultural Landscape the Australian Government will either stop the activity from going ahead, or it may be that the impact can be mitigated by a change in the proposal or the establishment of certain conditions. If conditions are put in place these are closely monitored to ensure compliance and protection of the OUV.

As noted in the nomination dossier Gunditj Mirring actively engages with the local community to address and solve issues before they escalate. In particular, the Budj Bim Rangers have established and maintained excellent and collaborative relationships with land owners neighbouring the nominated property, over a period of more than a decade. As such, potential issues such as wandering cattle from neighbouring properties are quickly addressed and any damaged fences are repaired. Through its 'Yarns on Farms' Program, Gunditj Mirring also shares knowledge about traditional land management and raise local awareness about the significant Aboriginal cultural heritage values throughout the broader region. This has proven to be an effective way for the Traditional Owners to actively engage at the property level to build relationships with neigbouring property owners and develop broad awareness and respect for the cultural values of the Budj Bim Cultural Landscape to achieve positive management outcomes.

Planning Schemes protect the values of the Budj Bim Cultural Landscape from adverse impacts of potential changes to land use and developments

The Victorian *Planning and Environment Act 1987* (Planning and Environment Act) establishes the process for local government agencies to create planning schemes. Planning schemes are statutory documents which regulate the use and development of land by establishing zones, objectives, and policies. Planning schemes define which land use activities are allowed in a given area and which are prohibited or require a permit. In most cases, a Cultural Heritage Management Plan approved by the Gunditj Mirring, to protect and manage cultural heritage, is required before a planning permit can be issued. Two planning schemes under the Planning and Environment Act apply to the Budj Bim Cultural Landscape - the Shire of Glenelg and the Shire of Moyne planning schemes. Together they provide a legal mechanism to ensure any proposed development would not impact the values of the Budj Bim Cultural Landscape.

Changes to the planning scheme must be authorised by the Victorian Government Minister for Planning. A legislated function of Registered Aboriginal Parties, including Gunditj Mirring, is to advise the Minister for Planning on proposed changes to a planning scheme which may affect the protection, management, or conservation of places of Aboriginal cultural heritage significance. However, should the local government planning schemes be amended in any way, the legislative protections afforded under the EPBC Act, the Aboriginal Heritage Act, the Catchment and Land Protection Act, and the Water Act would continue to ensure the protection of the Budj Bim Cultural Landscape's cultural values, including the continuity and quality of its water flows.

The Shire of Glenelg and Shire of Moyne planning schemes establish three different types of planning zones over and adjacent to the Budj Bim Cultural Landscape – a Farming Zone, Special Use zone and Public Conservation Resource Zone. The Farming Zone applies to private land where agricultural uses are expected. Non-farming uses, such as residential development or industry, within the zones are prohibited or require a planning permit. In circumstances where a planning permit may be issued, any new proposal must demonstrate it would not adversely impact water quality. A Cultural Heritage Management Plan, developed to protect and manage cultural heritage, is required before the planning permit could be issued and must be approved by Gunditj Mirring.

A special use zone and a public conservation zone exists over parts of and adjacent to the Budj Bim Cultural Landscape. A 'special use zone' is established over parts of the Budj Bim (northern) component of the Budj Bim Cultural Landscape, including Tae Rak (Lake Condah) and the Lake Condah Mission. The purpose of the special use zone is to provide for the development of land consistent with the protection, conservation and management of the natural and Aboriginal cultural values. The special use zone also provides for the continuation of Aboriginal cultural practices. The types of development activities permitted in the special use zone are restricted to those which support its purposes.

A 'public conservation and resource zone' established over the Budj Bim National Park which provides for the development of the Park consistent with the protection and conservation of the natural environment and its historic, scientific, landscape, habitat and cultural values. The zone allows for the development of facilities that assist in public education and interpretation of the Park; so long as these have minimal impacts on the natural environment or natural processes.

Two additional planning overlays provide an extra layer of consideration for any proposed new development. The Bushfire Management Overlay is to manage fire risks while the Environmental Significance Overlay, prevents pollution by limiting inappropriate development and land use adjacent to significant wetlands and waterways.

The Environmental Significance Overlay covers Killara's riparian zone, which connects the three serial components of the nominated property. The stated objectives of the Environmental Significance Overlay include maintaining the environmental diversity and quality of the area, preventing inappropriate development adjacent to water ways, and preventing pollution and degradation of habitat areas. A permit application, under the Planning and Environment Act, for land adjacent to Killara must include an assessment of the proposal's impact water flow or quality, as well as the proposal's impact to flora, fauna, and landscape features. The Shire of Glenelg, in deciding on a planning permit application, must also consider the objectives of the Environmental Significance Overlay, and the comments of the Catchment Management Authority.

BUFFER ZONE

Protection through Australia's legislative buffer zone – the EPBC Act

As demonstrated above, the EPBC Act is Australia's national legislation that protects the OUV of all of Australia's World Heritage properties. If an action is proposed that may have a significant impact on the OUV of a World Heritage area, it must be referred to the Australian Government. If it is considered that a significant impact is likely, the proposed action will undergo a rigorous environmental assessment. Where appropriate, approval decisions impose conditions to ensure that the project is consistent with the long-term protection of the OUV of the property. Any conditions imposed on an approval by the Australian Government Minister for the Environment, are strictly monitored and enforced.

The EPBC Act does not operate only within property boundaries, but also considers potential impacts on the OUV of a World Heritage property from activities outside it. The legislation does not specify a geographical 'limit' to its protection of a World Heritage property. Any activity, irrespective of its proximity to the World Heritage property, will still be subject to assessment if the action is likely to cause a significant impact to the World Heritage values. The legal protection provided by the EPBC Act relates specifically to the OUV of the World Heritage property; delineating a Buffer Zone around the property would not result in any greater level of protection.

Many of Australia's World Heritage properties do not have Buffer Zones because of the protection afforded by the EPBC Act. The ongoing protection of these properties is testament to the strength of the EPBC Act and the values-based approach to protect the OUV, irrespective of the location, size or scale of the proposed activity.

Australia takes its responsibilities under the World Heritage Convention to protect the OUV of our World Heritage properties very seriously. Since 2011, Australia has committed to advising the World Heritage Centre on a quarterly basis of any proposed action assessed under the EPBC Act for potential impacts to World Heritage areas in accordance with our responsibilities under Paragraph 172 of the *Operational Guidelines for the Implementation of the World Heritage Convention*. This is in addition to advising the World Heritage Centre of significant projects between quarterly reports, as necessary.

Principles of a World Heritage Environs Area

Under the Victorian *Heritage Act 2017*, a World Heritage Environs Area (WHEA) can be declared in the vicinity of a World Heritage property to protect the OUV of that property. This system was developed to provide planning controls and to protect settings and sight lines in cities and urban areas. Once declared, a WHEA Strategy Plan must be prepared for surrounding buildings and high rise developments. The WHEA Strategy Plan may propose changes to the local government planning schemes and polices for the area outside the boundary of the World Heritage property to ensure that the World Heritage values are protected.

Declaration of a WHEA is not useful for the long-term protection of the potential World Heritage values of the nominated property. The Budj Bim Cultural Landscape is in a rural environment where the protection provided by declaration of a WHEA is already achieved through the existing comprehensive framework for legal protection, in particular, the planning schemes and polices of the Glenelg and Moyne Shire Councils.

The Environmental Significance Overlay is directly relevant to ensuring proposed land uses that could adversely impact the values of the Budj Bim Cultural Landscape are not allowed in the vicinity of the nominated property. Proposed land use and development on land adjacent to Killara must be consistent with the stated objectives of the overlay, which include maintaining the environmental quality of the area and preventing inappropriate development adjacent to significant waterways. All other land immediately adjacent to the nominated boundary is subject to the requirements and restrictions of the Farming Zone.

As discussed above, the existing protection afforded by Australia's EPBC Act and Victorian legislation (in particular the *Catchment and Land Protection Act 1994,* the Water Act and the Aboriginal Heritage Act) ensures development outside the nominated boundary would not impact the OUV of the Budj Bim Cultural Landscape, or the continuity or quality of its water flows.

As outlined in the nomination dossier, the nominated property is protected and managed through an adaptive and participatory management framework of overlapping and integrated customary, governance, legislative and policy approaches. We hope this additional information clarifies in further detail the integrated and comprehensive nature of the management of the Budj Bim Cultural landscape.

Australia looks forward to the consideration of the Budj Bim Cultural Landscape at the 43rd Session of the World Heritage Committee.

Hydrological Studies

Attachment A - Lake Condah Water Restoration Project Hydrological Feasibility Study (Fluvial Systems, 2006)

Attachment B - Environmental Water Requirements of Darlot Creek and Lake Condah (Fluvial Systems, 2008)

LAKE CONDAH WATER RESTORATION PROJECT HYDROLOGICAL FEASIBILITY STUDY

Report to

Glenelg-Hopkins Catchment Management Authority

by

Christopher Gippel
Phil Macumber
Geoff Fisher
Lance Lloyd
Marcus Cooling

December 2006

FLUVIAL SYSTEMS
GEOMORPHOLOGY • CATCHMENT HYDROLOGY
RIVER REHABILITATION • ENVIRONMENTAL FLOWS

Lake Condah water restoration project hydrological feasibility study

For Glenelg-Hopkins Catchment Management Authority

Fluvial Systems Pty Ltd

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Executive Summary

Introduction

The objective of this report is to assess the feasibility of restoration of the hydrology of Lake Condah to a regime that is closer to natural, and which restores desired ecological values and raises lake water levels to enable re-activation of eel traps.

The objective of this report is to assess the feasibility of restoration of the hydrology of Lake Condah. The objective of the restoration is not necessarily to achieve a “natural” regime, but one that restores desired ecological values and raises lake water levels to enable re-activation of the eel traps, while maintaining required downstream flows for the Darlot Creek environment and water users.

This report developed a series of numerical models:

- A hydrological model that predicted the runoff from the Lake Condah catchment under a range of current and future land use and climate change scenarios.
- A hydraulic model that predicted the behaviour of Condah Drain, Lake Condah and the lower part of Condah Swamp under conditions of filling, draining and flood, for a range of past, current and future hydraulic scenarios (i.e. altered natural and structural controls over water levels).
- A water balance model that predicted the time series’ (115-year long) of daily water levels in Lake Condah under a range of current and future land use and climate change scenarios, and a range of hydraulic scenarios (i.e. altered natural and structural controls over water levels).

A hydrological model of Lake Condah was developed in order to test a range of possible future scenarios, including climate change, land use change, various Weir crest heights, and various minimum environmental flows.

Some aspects of the study involved more uncertainty than others. Overall, the surface water hydrology was well characterised, although there remains some doubt about the accuracy of the baseflow predictions. While there is a host of information available on the hydrogeology of the region, specific knowledge of the rate at which water is lost from the Lake to the underlying fractured rock, its flow pathways, and its ultimate fate, is lacking. The Lake’s bathymetry was very well characterised. The ecology of the Lake is reasonably well understood, but the environmental flows needs of Darlot Creek remain a knowledge gap.

A hydrological model of Lake Condah was developed in order to test a range of possible future scenarios, including climate change, land use change, various Weir crest heights, and various minimum environmental flows. The model generated predictions of 115 years of daily lake water levels under these scenarios. The results were presented graphically, as time series plots of just the final 10 years in the time series; this period was noticeably dry, so potential issues with maintaining Lake water levels would be most apparent in this period. Other results were presented in the form of flood frequency plots, flow duration curves and spells analysis.

Climate, Land Use and Water Utilisation

The period 1945 to 1960 was noticeably wetter than average and also had lower than average potential ET. Another wetter than average period occurred from 1967 to 1978, while the present is part of a noticeably dry period that began in 1992.

In order to represent the full range of hydrological conditions in the modelling, data covering long periods were sought. The Bureau of Meteorology DataDrill daily climate series’, which covered 100+ years, compared positively with locally observed data sets; the DataDrill time series’ were considered ideal for the purpose of hydrological modelling.

The period 1945 to 1960 was noticeably wetter than average and also had lower than average potential evapotranspiration. Thus, memories by long-term local residents of Lake Condah being generally full from the 1930s until the drain was deepened in 1954 are understandable. Another wetter than average period occurred from 1967 to 1978, while the present is part of a noticeably dry period that began in 1992.

Climate change scenarios were based on predictions of potential change in seasonal and annual climate by CSIRO for the year 2030 relative to 1990.

The major feature of predicted land use change from a hydrological perspective is the "perennialisation" of the landscape.

Licenced diversions and stock and domestic water use, farm dams, environmental flow requirements and winterfill diversions can all affect current and future water resource utilization.

Five basic hydrological scenarios were modelled.

The 2005 Photogrammetric DEM is the preferred source of survey data for this study.

Parts of Condah Swamp are low-lying, and it is all below 53 m AHD. Unexpectedly, the more northerly sections (most upstream) are the lowest in elevation.

In general, the deepest parts of Lake Condah are found on the western side of the Central and Southeastern sections of the Lake.

Climate change rainfall and evaporation scenarios for conditions in the year 2030 were developed in 2005 by SKM for the Glenelg-Hopkins CMA region in the *Climate Change and Natural Resource Management Scoping Study*. The scenarios were based on predictions of potential change in seasonal and annual climate by CSIRO for the year 2030 relative to 1990. The CSIRO predictions were also adopted for this study.

The *Water and Land Use Change (WatLUC) Study* by SKM in 2005 modelled the impact of land use change on hydrology for the Corangamite and Glenelg-Hopkins CMA regions. The land use change scenarios developed by the WatLUC study operated over the period 1990 to 2030. The major feature of land use change from a hydrological perspective is the "perennialisation" of the landscape. This change is due to establishment of forestry plantations, native vegetation restoration and a predicted increase in the use of perennial species in pastures. With respect to the relative impact of converting from pasture to forest land use, the WatLUC study produced estimates that are high compared to what would be expected from the literature. The future land use scenario adopted for this study was less severe in its hydrological impact than that assumed in the WatLUC study.

Factors affecting current and future water resource utilization in the Lake Condah catchment are licenced diversions and stock and domestic water use, farm dams, environmental flow requirements and winterfill diversions.

For this study, five basic scenarios were modelled:

- Natural (historical climate and 1750 land use)
- Current (historical climate and 1990 land use)
- Future Neutral (historical climate and 2030 land use)
- Future Dry (future dry climate and 2030 land use)
- Future Wet (future wet climate and 2030 land use)

Lake Condah Bathymetry, and Observed Hydraulic Behaviour

A comparison of the 1980 SR&WSC Plan and the 2005 DEM revealed that the SR&WSC Plan was consistently 0.3 – 0.5 m lower across the floor of the Lake. The 2005 Photogrammetric DEM is the preferred source of survey data for this study. The density of points, the vertical accuracy, spatially referenced data, and accurate ground control survey makes it superior to the other surveys. The disadvantage in adopting the 2005 DEM survey levels is that the 1980 SR&WSC Plan has been exclusively used for Lake Condah management and planning up to this point.

Parts of Condah Swamp are low-lying, and it is all below 53 m AHD. Unexpectedly, the more northerly sections (most upstream) are the lowest in elevation, which highlights the flatness of this landscape feature. Although parts of Condah Swamp are lower in elevation than 52 m, this does not necessarily mean that water levels above 52 m in Lake Condah will cause inundation in Condah Swamp – if water is contained within the Condah Drain, then the Swamp will not be flooded. Cross-sections indicate that the levees protect the Swamp against inundation for levels below 52.28 m AHD.

In general, the deepest parts of Lake Condah are found on the western side of the Central and Southeastern sections of the Lake. Most of the Northern and all of the Western sections of the Lake are higher than 50.6 m AHD. At a water level of 50.9 m AHD, most of the inundated areas in these sections are <0.3 m deep. At 50.9 m AHD, the Central and Southeastern sections contain significant areas of water 0.5 m and deeper. The four main sections of Lake Condah are separated by sills. The main sections of the Lake

Lake Condah is fully connected above 51 m. Below this the Central and Southeastern sections become independent, and their levels can fall below that of the Northern and Western sections.

contain other internal sills that control water distribution within these sections.

The available observations suggest that Lake Condah is fully connected above 51 m. When the Lake level falls to around 51 m the Central and Southeastern sections become independent, and their levels can fall below that of the Northern and Western sections. The highest flood in memory occurred in 1946 before the Condah Drain was deepened. This flood reached a level of 55.0 – 55.5 m AHD in Lake Condah. It appears that the floods frequently reached a level of 54.5 m prior to deepening of the Drain in 1954.

The highest flood, in 1946, probably reached a level of at least 55 m. Prior to the drain being constructed, levels probably reached 54.5 m on a regular basis.

The Lake Condah volume and surface area estimates made by SR&WSC in 1980 compare quite well with those made in this report using the 2005 DEM. The latter are more accurate, because the earlier SR&WSC survey had far less surveyed points, and the contours were generalised.

Lake Condah water levels were recorded from 16/02/1988 to 10/03/1993. There is a strong relationship between discharge at Myamyn and Lake Condah water levels. A hydraulic relationship (i.e. rating curve) was established between discharge and water level in the Drain. The five years of recorded data suggest that Lake Condah water level falls rapidly after the event that caused the rise has ceased.

Observations indicate that Lake Condah water level falls rapidly after the event that caused the rise has ceased.

There were two basic types of water level recession: rapid and slower. The slower rates of water level fall occurred over the first 0.4 m, from the sill level at 51 m AHD down to around 50.6 m AHD. Below 51 m AHD the Lake separates at the sill between the northern and central sections. At a level of around 50.4 m, the rate of fall accelerated considerably. This level corresponds to the level when the gauge pool becomes isolated. At this level the rest of the Lake is virtually dry and does not supply the gauge pool with inflows. The gauge pool is probably a sinkhole, so water seeps away at a rapid rate. The evapotranspiration rate is far too low to be an important factor explaining the drop in water level. Likewise, when the Lake level rose, the volume of rainfall on the Lake bed surface was insufficient to account for the water level rise. It is likely that when significant local rain occurs, the adjacent Stony Rises contributes a significant volume of water to Lake Condah through springs.

It is likely that when significant local rain occurs, the adjacent Stony Rises contributes a significant volume of water to Lake Condah through springs.

A problem with the previous estimate of seepage rate is that it was based on a description of the fall in Lake level over the entire 4-month long recession period, when in fact, for much of this time the Lake would have been connected to the Drain, and falling and rising with the Drain water surface level. So, when connected to the Drain, the Lake is probably leaking water to the subsurface, but the rate cannot be determined because any water lost from the Lake is being replaced from the Drain.

Darlot Creek Catchment Surface Water Hydrology

Very low flows at Myamyn gauge does not mean similarly low flows at Homerton, indicating boosting of low flows between these stations. The largest source of the water to Darlot Creek downstream of Myamyn is groundwater inflow.

A total of 42 years of data for Homerton Bridge gauge revealed that the average annual discharge of Darlot Creek was 61.5 GL (83 mm). A comparison of flows at Myamyn and Homerton (23.6 river kilometres apart) for identical periods shows that very low flows at Myamyn does not mean similarly low flows at Homerton Bridge, indicating considerable boosting of low flows between these stations. It appears that the largest source of the water to Darlot Creek downstream of Myamyn is groundwater inflow emerging from the Stony Rises basalt/Tertiary limestone located to the east, south and southwest of Lake Condah. The reason why this geology would be relatively high yielding is that when it rains, water rapidly enters subsurface through fractures and sinkholes, thereby minimizing evaporative losses. The water then flows to downstream areas, emerging through springs.

The licenced volumes are nominal values and may not reflect the actual water use. The stock and domestic use is poorly known.

A review of the licenced diversions and stock and domestic water use revealed a complex situation. The licenced volumes are nominal values and may not reflect the actual water use. The stock and domestic use is poorly known. In this study, an estimate of the potential diversions upstream of Lake Condah was made on the basis of a simple water balance. The model was calibrated to give a long-term average annual diversion loss equal to the licenced allocation of 531 ML. The mean annual loss from stock and domestic was 192 ML. These are potential diversions – the actual diversions cannot be predicted, as they depend on factors that cannot be readily modelled.

The impact of farm dams on streamflows was modelled using the Tool for Estimating Dam Impacts (TEDI).

The impact of farm dams on streamflows was modelled using the Tool for Estimating Dam Impacts (TEDI). For flows higher than 100 ML/d, both diversions and farm dams had a relatively minor impact. The impacts of diversions and farm dams are greatest in summer and autumn, when demands are highest and when stream flows are lowest. Thus for flow of around 80 ML/d and lower, farm dams and diversions have lowered the discharge by around 5 – 10 ML/d, with the diversions accounting for around 2 – 3 ML/d of this.

An average 12% runoff reduction was adopted for the 2030 land use scenario. This value is not presented as the most likely eventuality; rather it is an arbitrary value that lies within the range of possibilities.

This study makes no pretence to “know” what the impact of land use change on runoff might be for the Lake Condah catchment. Predictive models suggest that the WatLUC Base case 2030 land use change scenario could result in a reduction in runoff ranging from 4% to 38%. In this study, an average 12% runoff reduction was adopted for the 2030 land use scenario. The rainfall-runoff model was calibrated to produce this degree of impact. The value of 12% reduction is not presented as the most likely eventuality should the predicted 2030 land use change take place. Rather, it is an arbitrary value that lies within the range of possibilities.

A Boughton-type model was used to predict Darlot Creek runoff from rainfall. The model was run for 115 years from 1890 to 2004 on a daily time-step. Calibration was based on 5-years of available data.

For this project the WC-1 model (within WaterCress) was used to predict runoff from rainfall. WC-1 is based on the typical lumped parameter Boughton model using a partial area method. The model was run for 115 years from 1890 to 2004 using daily potential ET_O and rainfall time series’ derived from DataDrill files. The modelling procedure involved a data gathering and model calibration phase, followed by various modelling steps to produce five daily time series of 115 years duration. It should be noted that the calibration procedure was less than ideal, due to the very short length of gauged record available at Myamyn. It was possible to closely reproduce the gauged record at Myamyn (adjusted to remove effects of diversions and farm dams) using the WC-1 model. Annual discharge was closely predicted.

The major hydrological impact is for the Future Dry climate scenario and the 1750 scenario, which reduced all flows.

Flow duration curves reveal that the major hydrological impact is for the Future Dry climate scenario and the 1750 scenario, which reduced all flows. Only the Current scenario did not exhibit cease to flow.

An algorithm was devised to simulate possible future daily winterfill diversions.

An algorithm was devised to simulate possible future daily winterfill diversions, assuming that diversions were always made at the maximum allowable rate (taking notice of the minimum flow requirement), with diversions in any particular year ceasing once the SDL annual volumentric cap was reached. The algorithm was applied to three flow scenarios: Current climate and land use, Current climate and Future 2030 land use, and Future Dry climate and Future 2030 land use. Winterfill diversion rules prevent impacts on low flows, and the upper limit on diversion rate means that the impact on flood distributions is minimal. The main impact of winterfill diversions is to reduce annual flows and shift the main body of the flow duration curve downwards.

Hydrogeology of Lake Condah Area

It has long been recognized that there is much that is speculative about the nature of the direct lake-groundwater relationship at Lake Condah. This is especially the case with the process and rates of outseepage, and the flow

As no groundwater data from the vicinity of the Lake are available, comment is limited, and is based mostly on observations from surface water systems.

path taken by the Lake water once it enters the groundwater regime dominated by the fractured rock stony rises aquifer system. As no groundwater data from the vicinity of the Lake are available, comment is limited, and is based mostly on observations from surface water systems. The current understanding of groundwater interactions with the Lake is therefore largely determined by the Lake observations from earlier periods such as that recorded in Hand (1973), and from the Lake Condah/Darlot Creek surface water monitoring, especially that between 1987 and 1993.

There is an initial gain then major loss of groundwater from the regional Clifton Formation aquifer on passing southwards across the Condah WSPA with perhaps as much as 90% being lost between the central and southernmost areas. Losses are likely to be into both the underlying aquifers and into the overlying Port Campbell Limestone and then to the surface.

Much of the Darlot Creek Valley lies within a zone of regional and perhaps local groundwater discharge.

Much of the Darlot Creek valley including Condah Swamp and probably tributary systems such as Whittlebury Swamp lie within a zone of regional and perhaps local groundwater discharge with groundwater levels in the deeper aquifers having higher potentiometric heads than those in shallow aquifers indicating upwards flow towards the surface. Bores located within the large natural depressions are commonly artesian. This may also be the case at Lake Condah, however it requires confirmation.

Groundwater levels in the regional Clifton Formation aquifer are falling across the Condah WSPA in response to extractions, yet they remain artesian with respect to lower points in the landscape such as the Condah Swamp.

Some indication of likely broader processes influencing groundwater/lake/surface interactions at Lake Condah may be had from the behaviour of the regional groundwater systems in the Condah WSPA. Groundwater levels in the regional Clifton Formation aquifer are falling across the Condah WSPA in response to extractions, yet they remain artesian with respect to lower points in the landscape such as the Condah Swamp. The vertical flow pattern within the Condah WSPA is likely to carry over into the Lake Condah basin and the Darlot Creek. Groundwater levels across the WSPA continue to decline largely in response to pumping with no indication of any new equilibrium being reached.

It is unlikely that there is any short-term threat to the hydrology of Lake Condah from the falling groundwater levels in the regional aquifer. However, a drilling program is needed to confirm this.

It is unlikely that there is any short-term threat to the hydrology of Lake Condah from the falling groundwater levels in the regional aquifer, but this cannot be fully assessed without deep groundwater monitoring bores in the vicinity of the Lake. Therefore, a drilling/monitoring program such as that suggested below is recommended.

The loss of Lake water into lake-side sinkholes is a strong indicator of the importance of the pseudo-karst aquifer developed in the stony rises basalt. The observation that this water re-emerges to the southwest of the Lake was a concern to the SR&WSC (1980). It is likely that this is the source of Deep Creek.

By comparison with outseepage, evaporation and precipitation are only very minor contributors to the Lake water balance, which is dominated by creek inflow and outflow, and outseepage to the groundwater system.

Available data suggest a strong connection between all the surface and groundwater systems.

The periodicity of seasonal oscillation in Darlot Creek flow and Lake Condah level on the one hand, and limestone sinkholes and bores to the south on the other, suggests a strong connection between all the surface and groundwater systems.

A similarly close connection between the surface and groundwater systems is also suggested by the similarity of the salinity of distinct surface water systems such as Darlot Creek (from Myamyn to Homerton), upper Deep Creek and pools in soutwest Lake Condah. The range and level of salinities in these systems at the time of testing in July and September 2006 is not far removed from that of the groundwater systems, indicating a strong groundwater component.

Groundwater monitoring programs are crucial in establishing the nature of lake-groundwater interactions. Such a program is required for Lake Condah.

It has been shown across much of northern Victoria that groundwater monitoring programs are crucial in establishing the nature of lake-groundwater interactions e.g. at Lake Elizabeth, the Avoca Marshes, Lake Tutchewop, Lake Tyrrell, Cullens Lake etc. A drilling/monitoring program as proposed in SR&WSC (1980) is clearly essential to best understand the nature and process of lake-groundwater interactions. This monitoring program was also recommended by the Dept of Mines at the time. Unfortunately, the recommended program was never adopted, and instead a program of monitoring of bores and sinkholes situated 2.5 – 7 km from the Lake was inexplicably substituted. After 6 years of monitoring this program was deemed to be providing no understanding of lake-groundwater interactions and was abandoned.

Ecology of Lake Condah and Darlot Creek

Most native shrub and sedge vegetation has been cleared from Lake Condah.

The central and deepest areas of Lake Condah are occupied by Aquatic Herbfield Complex, which is a remnant of the former permanent water habitat.

Cape Barren Goose and Yarra Pygmy Perch are the only fauna species of conservation significance that have been recorded in Lake Condah. This probably reflects of a lack of observations rather than the potential of the Lake to support threatened species.

Despite disturbance, Darlot Creek retains some highly significant aquatic and riparian habitat. This is partly attributed to the permanent flow in the Creek. Many species of waterbirds, frogs and fish have been recorded in or near Darlot Creek.

Most native shrub and sedge vegetation has been cleared from Lake Condah. The Lake bed has a long history of grazing. The original structure of the Lake Condah ecosystem can be interpreted from remnant vegetation geomorphology, hydrology and historical records. The deepest pools would have provided permanent habitat for aquatic fauna and would have supported aquatic macrophytes. Beds of macrophytes would have provided habitat for fish, dabbling duck, piscivorous waterbirds and other fauna groups. The perimeter of these pools would have been permanently waterlogged but seasonally inundated. This environment would most likely have supported dense stands of sedges. Reed beds would have provided seasonal feeding and breeding habitat for small fish and breeding habitat for waterbirds which build nest platforms on flooded reed beds.

The central and deepest areas of Lake Condah are occupied by Aquatic Herbfield Complex, which is a remnant of the former permanent water habitat. The deeper areas are flooded to 1.5 m and support soft-leaved aquatic species. The surrounding mud flats are regularly exposed and support aquatic herbs. The intermittently flooded parts of the lake bed are occupied by an Amphibious Herbfield Complex. This plant community is a highly modified remnant of the former sedgelands and *Leptospermum* shrublands and has been affected by the reduction in flood duration and depth, the reduced persistence of waterlogging and the long history of grazing. The vegetation supports a high proportion (45%) of weed species. Yarra Pigmy Perch (*Nannoperca obscura*), Common Galaxias (*Galaxias maculatus*), Southern Pigmy Perch (*Nannoperca australis*) and the exotic species Tench (*Tinca tinca*), were recorded in the Lake in 1990. Cape Barren Goose (*Cereopsis novaehollandiae*) and Yarra Pygmy Perch (*Nannoperca obscura*) are the only fauna species of conservation significance that have been recorded in Lake Condah. This probably reflects of a lack of observations rather than the potential of the Lake to support threatened species, particularly when in flood.

There is little information to describe the original habitat of Darlot Creek below Lake Condah. It is known to have flowed permanently with infrequent flood events generated by overflow from Lake Condah, and more frequent events generated from the catchment downstream of Lake Condah. The Creek is likely to have supported a range of semi-emergent, flow-tolerant macrophytes in the permanently flowing reaches, with dense marshy vegetation on the creek banks. The vegetation is likely to have comprised salt-tolerant species due to the salinity contributed by groundwater inflows. Despite the disturbance, Darlot Creek retains some highly significant aquatic and riparian habitat. This is partly attributed to the permanent flow in the Creek. Many species of waterbirds, frogs and fish have been recorded in or near Darlot Creek.

Hall (1991) recommended a minimum environmental flow of 30 ML/d for Darlot Creek downstream of Lake Condah, on the basis of maximising fish habitat, with regard to the natural flow regime.

A previous study recommended a minimum environmental flow of 30 ML/d for Darlot Creek downstream of Lake Condah.

In determining the environmental flows for Darlot Creek it is important to consider the fish community and the life history of key species, together with other organisms.

Fish passage will be required to allow eel migration upstream during spring and summer and downstream in summer and autumn.

To allow a cost and performance comparison, two alternative structures were evaluated. Both would be similar in form to a conventional rock chute. Option 1 would have a fixed crest; Option 2 would be partially adjustable.

It would be a simple process to allow for increasing the height of the structure in the future.

For passage of baseflows, this report recommeds a single pipe through the weir.

Maintenance of Lake Condah's existing ecological values, including habitat for threatened aquatic plants and animals requires: permanent flooding with a median seasonal depth range of 1 m in the Aquatic Herbfield habitat; and seasonal inundation to the greater Lake bed between August and November.

In determining the environmental flows for Darlot Creek it is important to consider the fish community and the life history of key species, together with other organisms. Low flows (or base flows) are required to support the marsh vegetation in Darlot Creek [which is particularly important fish habitat for Dwarf Galaxiids and both Pigmy Perch species (Yarra and Southern)]. Flows arsing from spills or base flows will be required to support the maintenance of pools over summer. These pools are critical to the sustainable population of eels and other freshwater fish in this section. Freshes during spring will provide triggers for breeding and then recruitment. It is known that the instream habitat of Darlot Creek immediately downstream of Lake Condah is degraded, being formed into a drain. These altered habitats do not provide the range of habitats required by diverse fish populations, reducing the smaller fish species through habitat loss or reducing breeding potential.

Fish passage will be required to allow eel migration upstream during spring and summer and downstream in summer and autumn. Most other fish species would be opportunistic about movement requirements past any structure built on Condah Drain, as they would be for the natural barrier near Condah Mission.

Control Structure for Restoration of Lake Condah Hydrology

The objective of the Lake Condah water restoration project is to achieve a reasonable depth of water in Lake Condah for as long as possible throughout the year, avoiding drying of the Lake if possible. This can only be achieved through structural intervention.

To allow a cost and performance comparison, two alternative structures were evaluated. Option 1 is a fixed weir crest grouted rock structure that cannot be adjusted. Option 2 is the same as Option 1, but with either an over top adjustable regulator plate or a lay flat regulator gate inserted into the weir structure. For both options, a weir style structure is envisaged that would be similar in form to a conventional rock chute. The best location for the structure is at the downstream end (south west) of Lake Condah, where the Condah Drain is most hydraulically constrained.

It would be a simple process to allow for increasing the height of the structure in the future. The way that this would be done would be to increase the width of the crest of the structure so that the additional height could be added on at a later stage and not compromise the downstream slope.

For passage of baseflows, this report recommeds a single pipe through the weir. The pipe would pass up to 30 – 40 ML/d depending on the head behind the weir, which covers the range expected for baseflow releases. If higher flow rates were required, to release freshes downstream for example, this could be achieved by inserting multiple pipes, each with a level controller so that the through flow rate could be increased as desired to pass the freshes. This would require the levels to be adjusted at the end of summer (to allow the freshes to pass) and then again once break of season flows had occurred (to wind the environmental flow release back to baseflows – spill could still occur). This could be done by one person with no need for plant or equipment (just a specific but simple lifting tool). An alternative (and in some respects a better) approach would be to insert a lay flat regulator gate in the weir crest. This would require a higher level of ongoing maintenance and operation. This approach will not guarantee passage of the early wet season freshes, because the Lake may be at a low level, with enough airspace to absorb the fresh.

Option 1 (simpler structure) is the preferred option.

A risk assessment suggested that Option 1 presents no greater risks to the environment than Option 2, and in some respects the risks are lower. On the basis of the above evaluation of the structural alternatives, Option 1 is the preferred option because it provides overall equal or lower risk at lower cost than Option 2.

The structure will cost around $250,000

The indicative cost of installing and maintaining the simpler structure (Option 1) over a 30 year time frame is in the order of $250,000. Costs will be a little higher if the structure is built so as to facilitatate later raising of the crest height.

Hydraulics of Lake Condah Under Flood Conditions

When a flood event occurs, the structure causes a backwater effect, which raises the level of the water over the crest; this raised water surface elevation extends a considerable distance upstream.

The height of the afflux and extent of the backwater were predicted by the HEC-RAS hydraulic model.

With a weir structure in place, under conditions of a full lake and steady relatively low to moderate inflows water will spill gently over the crest of the weir. However, when a flood event occurs, the structure causes a backwater effect, which raises the level of the water over the crest (known as the afflux) and this raised water surface elevation extends a considerable distance upstream. This is important, because although the weir crest height is set to the desirable steady lake level, on occasions the lake level can exceed this, resulting in local and upstream impacts. The height of the afflux and extent of the backwater were predicted by the HEC-RAS hydraulic model.

Models were run to simulate the 1, 2, 5, 10, 50 and 100 year Annual Recurrence Intervals (ARIs). The magnitude of these events was calculated on the basis of flood frequency analysis of 115 years of modelled daily flows for Condah Drain at Lake Condah, under the "Current" scenario. The relative impact of a weir in Condah Drain on water elevations is much greater at Lake Condah compared to Condah Swamp.

Daily Water Balance Model of Lake Condah

The numerical water balance model known as SWET was used to model the water level time series' in Lake Condah.

Uncertainty in the model predictions arises from unavoidable inaccuracies in the modelling process. However, possibly a greater source of uncertainty, from the management perspective, is the uncertainty of future climate and runoff.

The future Dry climate scenario creates reasonably frequent dry periods in the Lake.

The numerical water balance model known as SWET was used to model the water level time series' in Lake Condah. The only calibration undertaken on the model was to adjust the groundwater parameters in order to achieve the best possible model fit to the observed Lake level data from 1988 to 1993. After calibration, the model fitted the 1992/93 data very well, but was less than ideal for the other years. However, considering the difficulty of the modelling task, the model makes adequate predictions of water levels. Once the parameters that determine the rate of groundwater seepage were optimized to achieve the best model fit, these parameters were not adjusted for other model runs. The model predicted water level should be interpreted as the Lake level in the southwestern part of the Lake, where the gauge is located. This area has sinkholes and is known to experience rapid drawdown (the model was calibrated to fit the observed pattern of drawdown). The northern and western parts of the Lake (which do not have sinkholes) should be expected to recede slowly from a level of 50.9 m while the southwestern section is receding rapidly.

Uncertainty in the model predictions arises from unavoidable inaccuracies in the modelling process. However, possibly a greater source of uncertainty, from the management perspective, is the uncertainty of future climate and runoff. A number of scenarios were generated, but there is no guarantee that any of these scenarios will eventuate in the future. Overall, the predicted Lake water levels are regarded as an adequate basis for decision making.

The climate and land use change scenarios suggest that future conditions would not be favourable for maintaining year-round high water levels in Lake Condah. The future Dry climate scenario in particular creates reasonably frequent dry periods in the Lake. This can be offet to some degree by selecting a high weir crest and adopting a low value for the minimum environmental flow.

The higher the weir crest, the closer is the regime to the natural regime. However, the higher the crest, the less complete are the flood hydrographs passing to downstream.

Weir heights of 51.6 m to 53 m will produce different Lake water level regimes. The higher the weir crest, the closer is the regime to the natural regime. However, the higher the crest, the less complete are the flood hydrographs passing to downstream to Darlot Creek. A higher weir crest will maintain Lake levels longer, but a higher weir crest will also have shorter and less frequent periods of spill (when fish passage is open).

Winterfill diversions will not have a drastic impact on the hydrology of a restored Lake Condah.

The calculated SDL winterfill volume for Darlot Creek catchment, if diverted, will result in a reduction in the mean annual flow of around 11% - 16%, depending on the future flow scenario. The SDL rules prevent impact on low flows and they have a relatively minor impact on the magnitude of high flows, so winterfill diversions will not have a drastic impact on the hydrology of a restored Lake Condah. The impact of winterfill diversions on the hydrology of a restored Lake Condah is greater the drier is the future runoff regime and the higher is the weir crest.

There is a direct trade-off between the objectives of releasing environmental flows to Darlot Creek and maintaining high water levels in Lake Condah.

There is a direct trade-off between the objectives of releasing environmental flows to Darlot Creek and maintaining high water levels in Lake Condah. Management of these conflicting objectives requires careful consideration by stakeholders.

Depending on the combination of weir height and environmental flow, the simple fixed weir design will provide fish passage for much of the critical migration period – spring and early summer.

Presently, the private land floods relatively frequently, but for very short periods. Restoration will increase the duration and frequency of flooding.

Up to 40 ha of the northwestern corner of the Lake bed is privately owned land. This area applies during extreme floods, while for the 1 in 1 year flood the area is 15 ha. Presently, the private land floods relatively frequently, but for very short periods. For example, 10 ha or more is flooded for 10% of the time. Restoration of the hydrology of Lake Condah increases the duration and frequency of flooding of the private land. The higher is the weir, the greater is the effect; the drier is the future runoff regime, the less is the effect. For example, for a 52.4 m weir, for current runoff conditions, 10 ha or more will be flooded for 90% of the time, while for future dry climate conditions 10 ha or more will be flooded for 65% of the time.

Conclusions

The natural Lake Condah appeared not to spill very frequently, but it is likely that sub-surface flows maintained baseflow in Darlot Creek virtually year-round.

[1] It is possible to restore the water regime of Lake Condah to a close to natural regime. The natural regime can be fully recreated but this would require a very high structure (around 54.5 m AHD) that would pose difficulties for fish passage, and generate flooding over much of Condah Swamp. The natural Lake Condah appeared not to spill very frequently, but it is likely that sub-surface flows maintained baseflow in Darlot Creek virtually year-round.

[2] The climate and land use change scenarios suggest that future conditions would not be favourable for maintaining year-round high water levels in Lake Condah. The future Dry climate scenario in particular creates reasonably frequent dry periods in the Lake. This can be offet to some degree by selecting a high weir crest and adopting a low value for the minimum environmental flow.

A higher weir crest will maintain Lake levels longer, but a higher weir crest will also have shorter and less frequent periods of spill (when fish passage is open).

[3] Weir heights of 51.6 m to 53 m will produce different Lake water level regimes. The higher the weir crest, the closer is the regime to the natural regime. However, the higher the crest, the less complete are the flood hydrographs passing to downstream to Darlot Creek. A higher weir crest will maintain Lake levels longer, but a higher weir crest will also have shorter and less frequent periods of spill (when fish passage is open).

[4] The calculated Sustainable Diversion Limits (SDL) winterfill volume for Darlot Creek catchment, if diverted, will result in a reduction in the mean annual flow of around 11% - 16%, depending on the future flow scenario. The SDL rules prevent impact on low flows and they have a relatively minor impact on the magnitude of high flows, so winterfill diversions will not have a drastic impact on the hydrology of a restored Lake Condah. The impact of winterfill diversions on the hydrology of a restored Lake Condah is greater the drier is the future runoff regime and the higher is the weir crest.

Depending on the combination of weir height and environmental flow, the simple fixed weir design will provide fish passage for much of the critical migration period.

[5] There is a direct trade-off between the objectives of releasing environmental flows to Darlot Creek and maintaining high water levels in Lake Condah. Management of these conflicting objectives requires careful consideration by stakeholders.

[6] Depending on the combination of weir height and environmental flow, the simple fixed weir design will provide fish passage for much of the critical migration period – spring and early summer.

[7] Up to 40 ha of the northwestern corner of the Lake bed is privately owned land. This area applies during extreme floods, while for the 1 in 1 year flood the area is 15 ha. Presently, the private land floods relatively frequently, but for very short periods. For example, 10 ha or more is flooded for 10% of the time. Restoration of the hydrology of Lake Condah increases the duration and frequency of flooding of the private land. The higher is the weir, the greater is the effect; the drier is the future runoff regime, the less is the effect. For example, for a 52.4 m weir, for current runoff conditions, 10 ha or more will be flooded for 90% of the time, while for future dry climate conditions 10 ha or more will be flooded for 65% of the time.

Restoration of Lake Condah could mean reducing the outflows to Darlot Creek, but this could well be compensated by increased groundwater inflows to the Creek. Restoration could improve the security of supply for licence holders.

[8] There are two licenced diverters downstream of Lake Condah. Their requirements are to each pump around 15 ML/d from the Darlot Creek for 2 – 3 days per month during February and March (for an annual total of 90 ML per licence). The pumps are all located downstream of Homerton. The low flow hydrology of Darlot Creek at Homerton and further downstream is partly determined by flows from above Lake Condah and partly by groundwater inflows (which comprise a significant component of the flow). Restoration of Lake Condah could mean reducing the outflows to Darlot Creek, but this could well be compensated by increased groundwater inflows to the Creek. In fact, storage of water in Lake Condah (which is known to be leaky) could increase the duration of the baseflow recession in Darlot Creek, perhaps improving the security of supply for these licence holders. If, under conditions of a restored Lake Condah, baseflows in Darlot Creek are lower than present, one option might be for pumpers to reduce their pumping rate, and pump for longer. These issues are best resolved through adaptive management.

Seepage from the Lake is the most uncertain aspect of the study.

[9] Of all the aspects investigated in this study, seepage from the Lake is the most uncertain. There was very little calibration data available, so it is not known whether the assumed seepage function applies over the wider range of Lake levels.

Until more gauged flow data are collected from Myamyn and more gauged Lake level data are collected, nothing more can be done to improve on the knowledge of the hydrology.

[10] The surface water hydrology of Lake Condah and Darlot Creek was reasonably well characterized by this study, although only a few years of reliable calibration data were available. Until more gauged flow data are collected from Myamyn and more gauged Lake level data are collected, nothing more can be done to improve on the knowledge of the hydrology.

The environmental flow needs of Darlot Creek are known only to a rudimentary level.

[11] The ecology of Lake Condah was reasonably well described in this study, but the environmental flow needs of Darlot Creek are known only to a rudimentary level.

[12] In terms of the plants and animals (fish and macroinvertebrates) becoming adapted to the last 50 years of altered hydrology, the ecosystem will have adjusted to some degree (it may still be in some sort of transition). It is likely that all or most of the components of the original system are still in

existence, but in a different combination or abundance. The native species have a deal of resilience and ability to survive (although not necessarily flourish) under altered hydrological conditions.

When the hydrological regime is restored to something more closely resembling its previous condition, the species present will re-adjust to this regime, with a likelihood of increased abundance and diversity. The predicted changes do not present a substantial risk to the native species that are present.

[13] When the Lake Condah regime is restored to something more closely resembling its previous condition, the species present will re-adjust to this regime, with a likelihood of increased abundance and diversity. In Darlot Creek, the upper section immediately downstream of Lake Condah was once fed almost exclusively by groundwater, although the flow rate would have varied seasonally, and occasionally a large flood event would overtop the Lake and pass into the Creek. Downstream of around Homerton, inflows from tributaries would have added to flow variability. Under conditions of a restored Lake Condah, the flow regime of the section of Darlot Creek from Lake Condah to around Homerton will become more groundwater dependent, but still have more freshes and floods than under the natural regime. Flow from the outflow pipe from the Lake will vary slightly with lake level, and additional variability will be added by seasonal variations in groundwater contributions. Downstream of around Homerton, the regime will be similar to the current regime, but with more extended baseflows, a few less early season freshes (i.e. those sources exclusively in the upper catchment) and some freshes muted in magnitude (i.e. lacking the stormflow contribution from the upper catchment). These changes do not present a substantial risk to the native species that are present.

Recommendations

The Lake Condah hydrological restoration project should proceed.

[1] The results of the modelling undertaken in this study should be viewed with a degree of caution, but not necessarily more so than is normally warranted for a study of this type. The results are an adequate basis on which to make management decisions. It is recommended that the Lake Condah hydrological restoration project proceed, using the results presented in this report to help guide the planning.

If the negative impacts of high Lake water levels can be tolerated or ameliorated, then a weir crest towards the high end should be selected.

[2] There are tradeoffs involved between weir height, environmental flows, Lake levels and flooding of Condah Swamp and private land on the lake bed. In general, the results of this study suggest that the higher the weir crest, the closer will be the flow regime to the former "natural" regime. If the negative impacts of high Lake water levels can be tolerated or ameliorated, then a weir crest towards the high end should be selected.

Given the range of factors considered, a weir crest height of 52.4 m is recommended. This aligns with previous recommendations made in respect to potential weir height.

[3] Given the range of factors considered in this study, a weir crest height of 52.4 m is recommended. This aligns with previous recommendations made in respect to potential weir height. A weir of 52.4 m is a good balance between the need to: maintain generally high water levels in the Lake for ecological restoration (i.e. provide fish habitat and conditions suitable for weland vegetation); activate existing eel trap systems; maintain a large surface area of inundated Lake bed; provide seasonal spills over the crest to Darlot Creek (also allowing open fish passage); and minimize the impact on uncontrolled flooding of Condah Swamp. The restoration project should be reviewed periodically (say every 5 to 10 years), and the desirability, or otherwise, of raising the weir crest height can be investigated then.

A simple fixed crest weir structure is recommended.

[4] A simple fixed crest weir structure is recommended over a more complex and expensive structure that requires operational attention. The structure should be built in such a way that it would be relatively strightworward to raise the crest height at a later date if it was so desired.

There is uncertainty with environmental flow requirements.

[5] The issue of environmental flows to Darlot Creek is not fully resolved. It is recommended that a FLOWS study be commissioned for Darlot Creek. This should be completed prior to final design and construction of a weir at Lake Condah.

The diversion weir should be decommissioned.

[6] At present the required environmental flows is unknown, so any structure that is being considered should include a facility for passing flows up to 30 ML/d as a minimum requirement.

[7] The diversion wier on the northern end of Lake Condah will become obsolete once a weir is installed on the southwestern end of the Lake. This weir should be decommissioned, thereby removing a potential barrier to fish movement (when the Lake is at a low level).

A program of groundwater monitoring bores, and flow gauging in Darlot Creek is recommended.

[8] Improved understanding of the hydrogeology will be gained by implementing a program of monitoring bores, and flow gauging in Darlot Creek.

Management of Lake Condah will require an adaptive approach.

[9] Ultimately, management of Lake Condah will require an adaptive approach. Some aspects of the Lake's hydrology (under a future scenario) can only be known through observation. It is recommended that any attempt to restore the Lake's hydrology be incorporated into a well planned and well funded adaptive management program.

Future management of the Lake will need to embrace uncertainty.

[10] There will be risks and uncertainties associated with hydrological restoration. A continued dry climate period may result in a managed Lake drying out for periods of time, regardless of the type of structure installed. Future management of the Lake will need to embrace uncertainty, and an effort will be required to ensure that community expectations are aligned with this principle.

Further work

A FLOWS study should be commissioned for Darlot Creek.

[1] A FLOWS study of Darlot Creek from Lake Condah to, and including, the Estuary should be undertaken prior to construction of works.

A coordinated groundwater and surface water monitoring program is required.

[2] A groundwater monitoring program is required to help fill knowledge gaps. Five sites should be located at lake Condah and three in the Stony Rises to south of Lake Condah.

[3] Surface water monitoring should continue at Myamyn, and the Lake Condah gauge should be re-commissioned and maintained. A study of inflows to Darlot Creek from Lake Condah to Homerton (during non-storm flow conditions) should be undertaken.

A coordinated ecological monitoring program is required.

[4] It is recommended that the ecosystem is monitored to measure how plant and waterbird habitat responds to changes in water regime. Fish monitoring is obviously required, as restoration of eel populations is one of the main objectives of the Lake Condah water restoration project.

1 Introduction

1.1 Lake Condah water restoration project

Lake Condah, in the Darlot Creek catchment in Western Victoria (Figure 1), as well as being recognised as a Wetland of National Importance, once supported an internationally recognised Kooyang (Eel) aquaculture system. The history of Lake Condah from the 1800s was documented by Ruge (2004): During the late 1800s the first drainage scheme was undertaken to reclaim areas of Condah Swamp for local landholders. However, the water regime of Condah Swamp remained largely intact and it was a permanent wetland with seasonally fluctuating water levels. In 1908 flood water in Condah Swamp was attributed to the blockage of flow in Lake Condah. In response the Lake was partly drained. It was around this time that the last regular Aboriginal fishing of the Lake was reported, although this was probably a result of Mission restrictions, rather than the draining *per se*. After years of not maintaining the drains, the 1946 flood extensively damaged the Condah Swamp area and drainage system. In 1954, Darlot Creek was canalised from Condah Swamp to below Lake Condah. Since then the Lake has retained little water and is now flooded only during and immediately after periods of high rainfall and creek flow (Figure 2 and Figure 3).

Efforts to rehabilitate the hydrology of Lake Condah have a long history (Hall, 1991; Ruge, 2004), and in recent years the effort has intensified. Reinstatement of a more natural inundation regime to Lake Condah is expected to restore ecological, biodiversity and cultural values, including enabling traditional owners to reactivate the Kooyang (Eel) aquaculture system (Ruge, 2004). Hydrological restoration of Lake Condah is central to the broader Lake Condah Sustainable Development Project. From the perspective of hydrological restoration, a number of uncertainties remain; resolution of these uncertainties is the focus of this report. The findings of this report will assist the Lake Condah Facilitation Group in the decision-making process regarding the hydrologic feasibility of restoring a more natural, or more appropriate, hydrological regime at Lake Condah.

The Lake Condah water restoration project has been divided into two stages: Stage 1, which is the topic of this report, involves compilation of data relating to the hydrology, hydrogeology and environmental flows of Lake Condah/Darlot Creek in order to develop a water balance model; Stage II (not part of this report) is concerned with engineering works and development of operational guidelines for operating a constructed water outlet regulator.

1.2 Objective of this report

The objective of this report is to assess the feasibility of restoration of the hydrology of Lake Condah. The objective of the restoration is not necessarily to achieve a “natural” regime, but one that restores desired ecological values and raises lake water levels to enable re-activation of the eel traps, while maintaining required downstream flows for the Darlot Creek environment and water users.

This report developed a series of numerical models:

- A hydrological model that predicted the runoff from the Lake Condah catchment under a range of current and future land use and climate change scenarios.
- A hydraulic model that predicted the behaviour of Condah Drain, Lake Condah and the lower part of Condah Swamp under conditions of filling, draining and flood, for a range of past, current and future hydraulic scenarios (i.e. altered natural and structural controls over water levels).
- A water balance model that predicted the time series’ (115-year long) of daily water levels in Lake Condah under a range of current and future land use and climate change scenarios, and a range of hydraulic scenarios (i.e. altered natural and structural controls over water levels).

Development of the numerical models required collection of input data (some of which itself was modelled) and calibration data, and review of all existing knowledge on Lake Condah and Darlot Creek (so that the models were based on best available information, and the predictions at least matched or were consistent with past observations).

The ecology of Lake Condah and Darlot Creek was investigated from the perspective of documenting the ecological assets, and determining the likely requirements for environmental flows. A full FLOWS study was not performed, but the issues relevant to a FLOWS study were considered. The focus was on the flow component that will impact maintenance of Lake levels and flows in Darlot Creek (i.e. summer baseflows), and design of the control structure (i.e. fish passage).

Restoration of the hydrology of Lake Condah requires a control structure. This report recommends a design for such a structure; one that will most efficiently achieve the required Lake water level regime, and also satisfy a range of required practical and aesthetic criteria.

Figure 1. Location of Lake Condah. Source: Ruge (2004).

Figure 2. Waterbirds using isolated temporary pool on central section of Lake Condah. View to south, south of sinuous lava ridge. Photo: C. Gippel, 19/07/2006.

Figure 3. Temporarily ponded shallow water on northern section of Lake Condah. View to northwest from sinuous lava ridge. Photo: C. Gippel, 19/07/2006.

2 Climate, Land Use and Water Utilisation

2.1 Climate

2.1.1 Available data

As a general rule, the longer is the period of over which hydrological modelling is undertaken, the greater the range of conditions that will be covered, and the less likely it is that the modelled conditions are unrepresentative of past and/or future conditions. In this study, the objective was to model of 100+ years, up to around the current date. Climate data (rainfall and evaporation) are critical inputs to both rainfall-runoff modelling and also water balance modelling, but climate data are not available for Lake Condah and the Lake Condah catchment over the past 100 years. The alternative to using local gauged data is the Bureau of Meteorology SILO DataDrill service.

The DataDrill (http://www.nrm.qld.gov.au/silo/datadrill/datadrill_frameset.html) accesses grids of data derived from interpolation of point station records from the Bureau of Meteorology. Interpolations are calculated by splining and kriging techniques. The surfaces are interpolated to 0.05 degrees (i.e. 3 minutes, around 5 km). It is NOT actual recorded data; it is derived from actual recorded data as provided by the Bureau of Meteorology. DataDrill provides a synthetic data set covering popular meteorological data including rainfall, pan evaporation and FAO56 Reference Crop Potential Evapotranspiration (ET_O).

Pan evaporation based on daily measured values is only available in DataDrill from 1970 onwards; prior to that the data series is based on long-term averages, so it has a muted daily variation, and no yearly variation, compared to the post-1970 data. FAO56 ET_O is calculated using the FAO Penman-Monteith formula as described by Allen et al (1998). The FAO56 method requires average daily temperature and sunshine hours, and estimates of long-term average relative humidity and daytime wind run. Where actual wind data are not available, reasonable estimates of mean daytime windspeed and relative humidity may be used without compromising the results (Grayson et al., 1996).

Pan evaporation is subject to considerable day-to-day variation. This is partly due to real variations in evaporation, but it is widely recognized that the variation is partly due to measurement difficulties. In some respects an estimate of ET_O based on the FAO Penman-Monteith formula could be considered superior, especially as it is available from DataDrill for the entire period from 1891 to present. Morton's shallow lake evaporation has not been evaluated for use on Australian lakes and wetlands.

Seven DataDrill files of daily data covering the period from 01/01/1889 to 15/09/2006 (117.7 years) were obtained to represent the Lake Condah catchment (Figure 4, Table 1). Some local climate data were available, and these data were compared among each other and with the DataDrill data:

- Daily rainfall and Pan evaporation from gauge SINO 237801 recorded at Site A, Condah Mission from 01/11/1987 to 30/11/1989 and Site B, Allambie from 01/11/1989 to 28/02/1993. Site locations given by Browning (1990). Data supplied in the form of handwritten hard copy Rural Water Commission data sheets. Data were digitized from the hard copies.
- Station No. 2370101 daily rainfall and monthly evaporation (presume ET_O) from 1960 to 2002 as used to represent the Darlot Creek catchment in the *Climate Change and Natural Resource Management Scoping Study* by SKM (2005a). Digital data were supplied by SKM for historical and future climate scenarios.
- Bureau of Meteorology Station No. 090048 Heywood Forestry monthly mean rainfall data calculated for 1949 to 2004. Data downloaded from Bureau of Meteorology website.
- Macarthur Post Office monthly mean rainfall data calculated for 1936 to 1977. Data taken from Fig. 6 in Coutts et al. (1978).

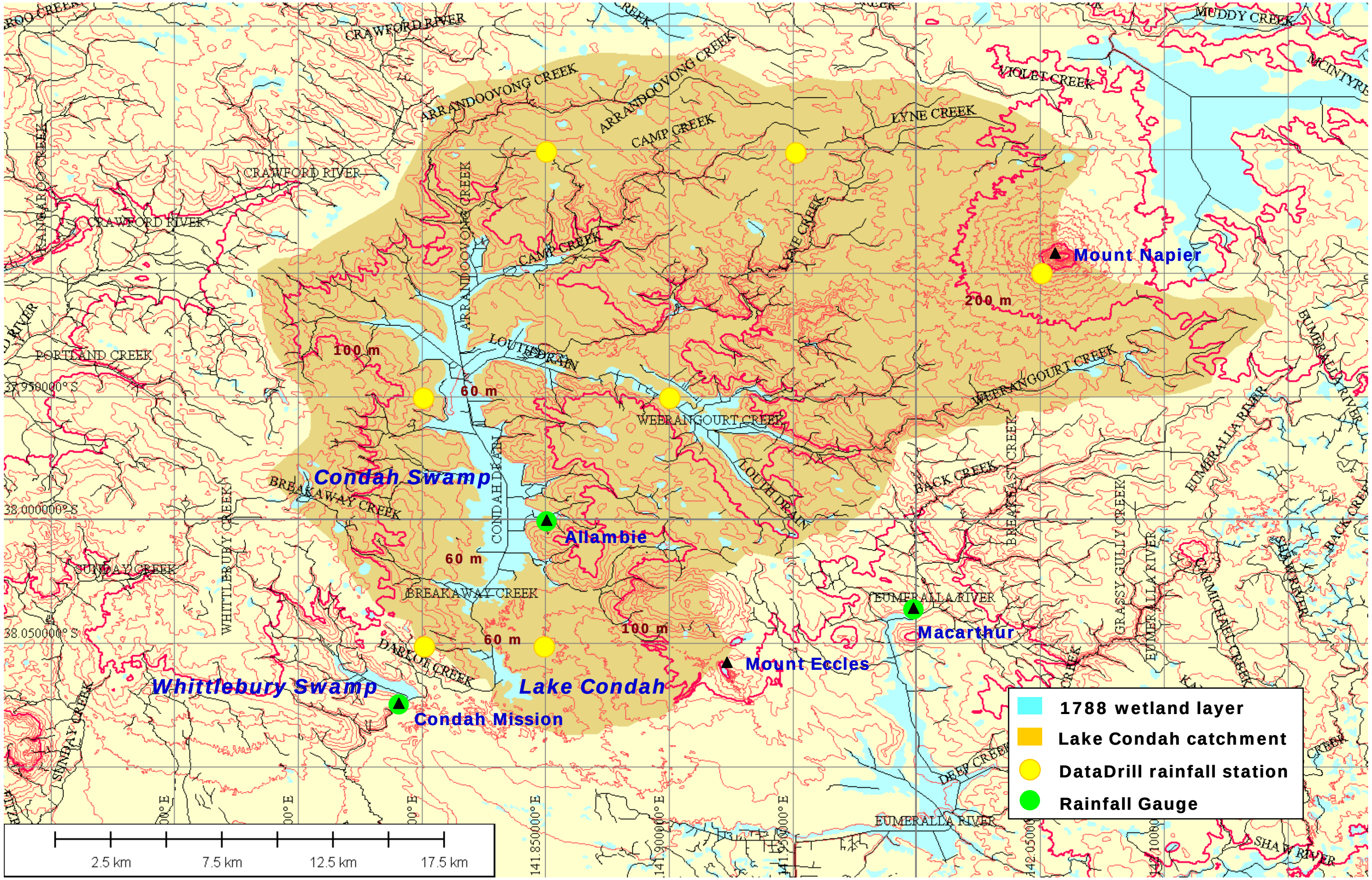


Figure 4. Lake Condah and Condah Swamp catchment, showing Lake and Swamp as represented in DSE 1788 wetland layer. Locations of rainfall stations referred to in this report are indicated. Contour interval is 10 m. North is vertical.

Table 1.
Location of DataDrill climate files representing Lake Condah catchment.

Area represented	Latitude	Longitude
Condah Mission	-38.05	141.80
Lake Condah/Mt Eccles	-38.05	141.85
Condah Swamp	-37.95	141.80
Camp Ck/Arrandoorong Ck	-37.85	141.85
Weerangourt Ck/Louth Drain	-37.95	141.90
Lyne Ck	-37.85	141.95
Mt Napier	-37.90	142.05

2.1.2 Comparison of available data

2.1.2.1 Condah Mission and Allambie (SINO 237801) 1987 –1992 versus DataDrill

The monthly data from gauge No. 237801 generally correlated closely with the DataDrill data (Figure 5). There were some obviously incorrect data in the data sheets for gauge No. 237801, especially when the gauge was located at Condah Mission. For example the June – August 1989 evaporation data are too high (Figure 5), and the rainfall data for this period are noticeably higher than data from any other location in the catchment. Regrression relationships suggested that overall, DataDrill monthly rainfall was about 90% of the gauged rainfall and DataDrill monthly Pan evaporation was about the same as the gauged data.

Although the monthly gauged and DataDrill data were closely correlated, there was a lot of scatter in the daily data, especially for Pan evaporation (Figure 6). However, scatter is not unusual when daily gauged rainfall and evaporation data are compared, even when the gauges are in close proximity. The scatter was largely eliminated by a 14-day moving average, which revealed a close correlation between the gauged data and the DataDrill data. The departures in the evaporation data were largely associated with what appeared to be errors in the gauged data. FAO56 daily evaporation data exhibited less scatter than the Pan evaporation data, but the two variables were closely correlated.

Overall, it was concluded that the DataDrill data for Lake Condah were a good representation of locally gauged data.

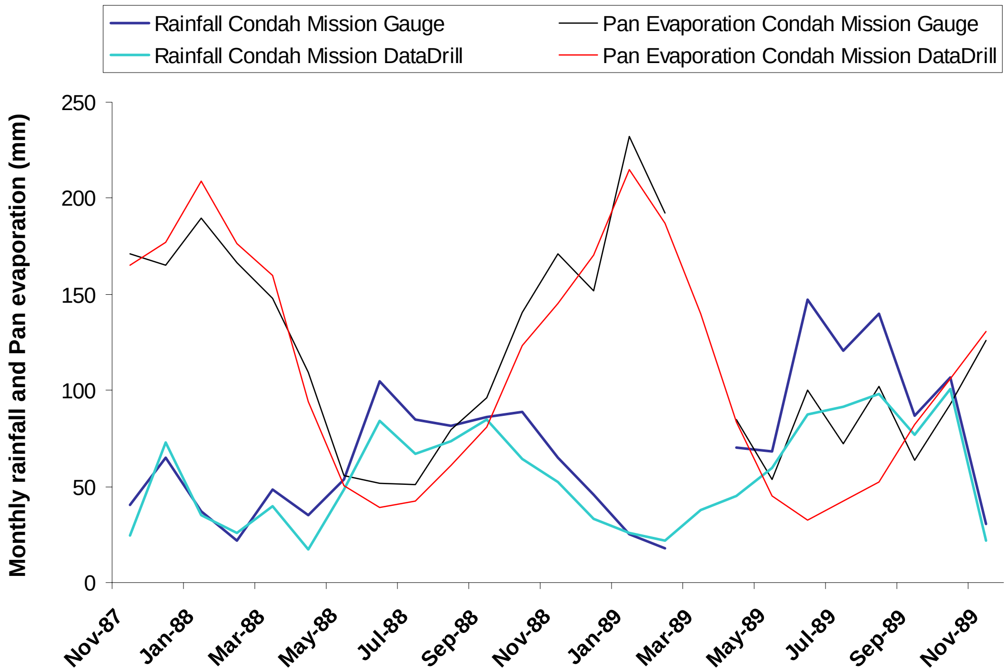
2.1.2.2 SKM Station No. 2370101, Heywood Forestry and Macarthur P.O. versus DataDrill

A comparison of mean annual rainfall and evaporation data was undertaken using data from 1960 to 2002. The DataDrill locations revealed that the highest elevation and most eastern station, Mt Napier, had the highest rainfall (756 mm) and lowest evaporation, while the northwestern site, Camp and Arrandoorong Cks, had the lowest rainfall (656 mm) (Figure 7). The site closest to Lake Condah had an annual rainfall of 711 mm. A composite DataDrill station was generated by averaging the daily data for six of the seven stations (Condah Mission station, being just outside the catchment, and close to the Lake Condah/Mt Eccels station, was omitted). The average annual rainfall of the combined data for the period 1960 to 2002 was 695 mm.

SKM (2005b) specified that "*Climate inputs were prepared using daily rainfall records from Bureau of Meteorology gauges nearest to the sub-catchment, and spatial data sets from the Bureau of Meteorology for average annual rainfall and potential evaporation*". It is not known what Bureau of Meteorology station SKM Station No. 2370101 represents, nor is it known what is meant by "potential evaporation".

SKM Station No. 2370101 had a higher average annual rainfall (715 mm) than all but one of the DataDrill stations. The SKM (2005) potential evaporation variable is closer to Reference Crop Potential Evapotranspiration (ET_O) than Pan evaporation (Figure 7). The average rainfall for Macarthur Post Office and Heywood Forestry are based on different periods of data, but they do show significantly higher rainfall that the sites within the Lake Condah catchment (Figure 7). Evaporation data were not available for these stations.

The seasonal distribution of rainfall was similar for all stations (Figure 8). Annual rainfall variation over the period 1960 to 2002 was similar for all DataDrill stations, and SKM Station No. 2370101 (Figure 9). Over this period, the annual rainfall for the composite DataDrill station ranged from 941 mm (1964) to 388 mm (1967).



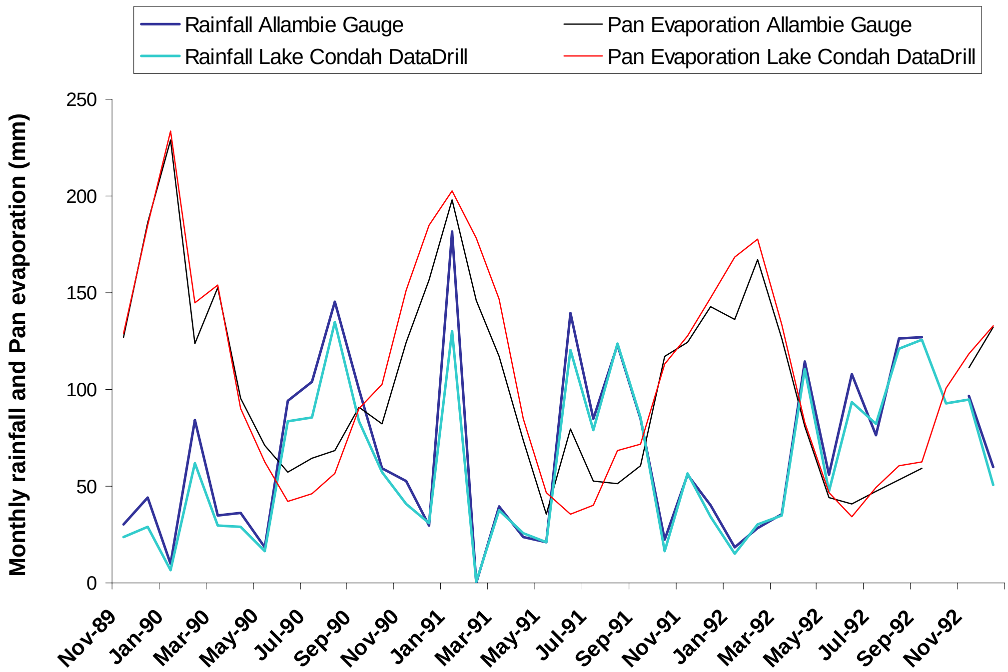


Figure 5. Monthly rainfall and Pan evaporation measured at gauge 237801 (Condah Mission 1987 – 1989 and Allambie 1989 – 1992 locations) and predicted by the closest DataDrill time series'.

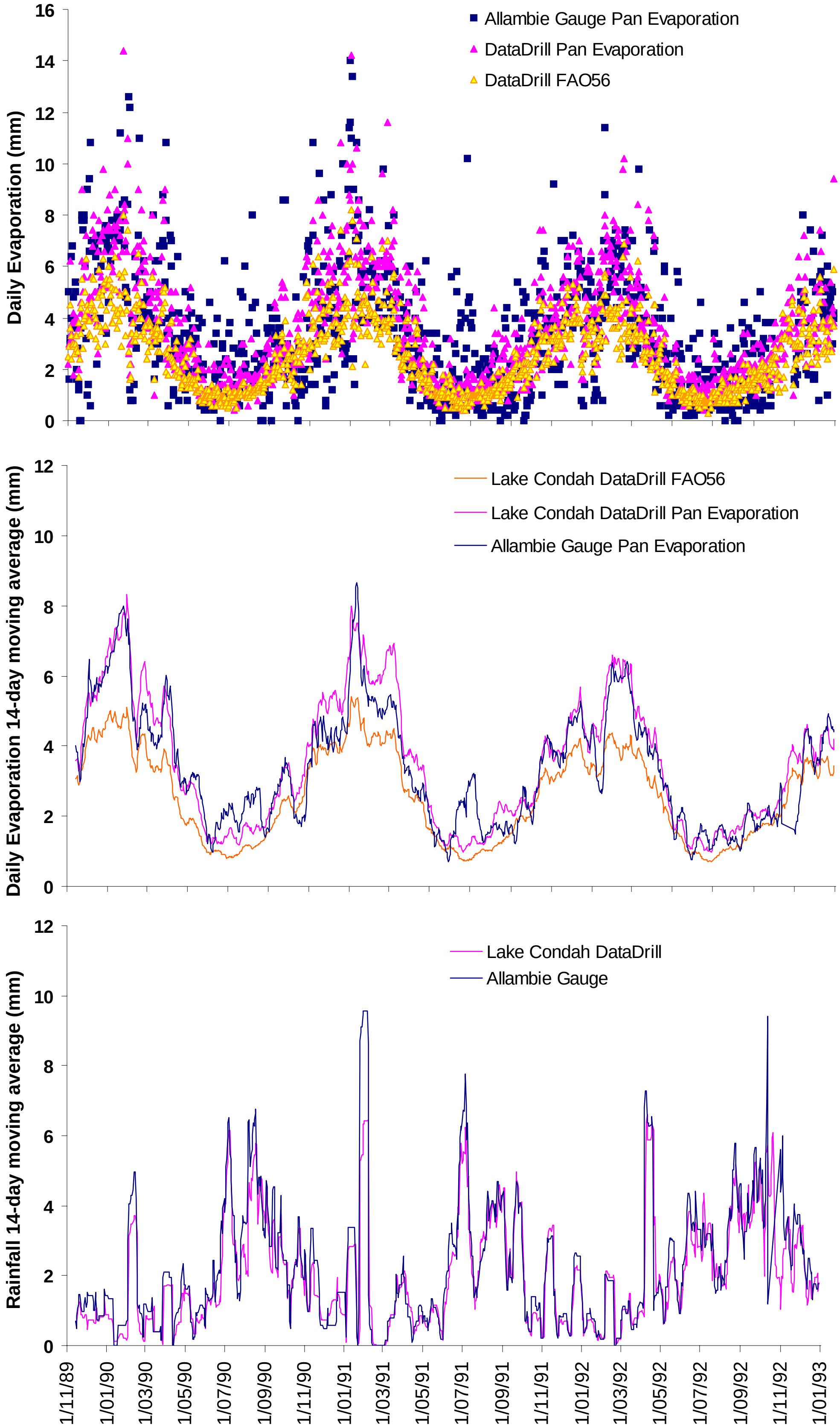


Figure 6. Daily rainfall and Pan evaporation measured at gauge 237801 (Allambie 1989 - 1992) and predicted by Lake Condah/Mt Eccles DataDrill time series'.

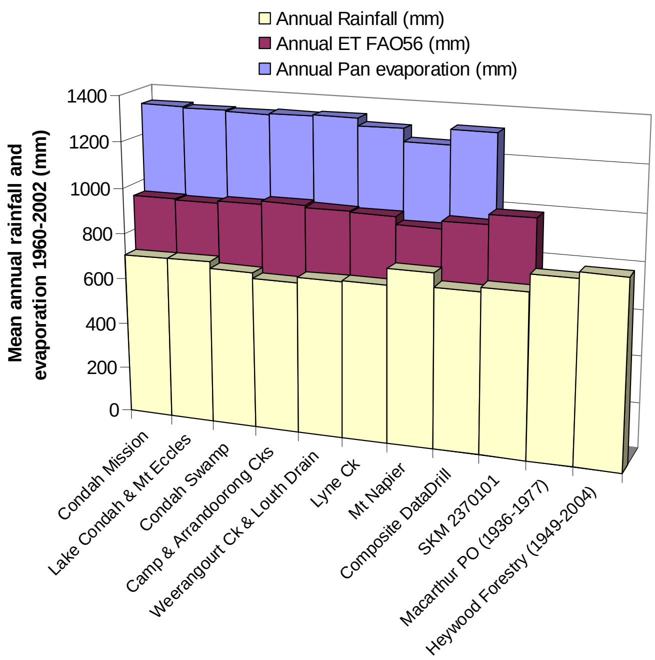


Figure 7. Mean annual rainfall, Pan evaporation and FAO56 ET_O for the period 1960 to 2002 for DataDrill stations and SKM 2370101, and for available data for Bureau of Meteorology stations Macarthur P.O. and Heywood Forestry.

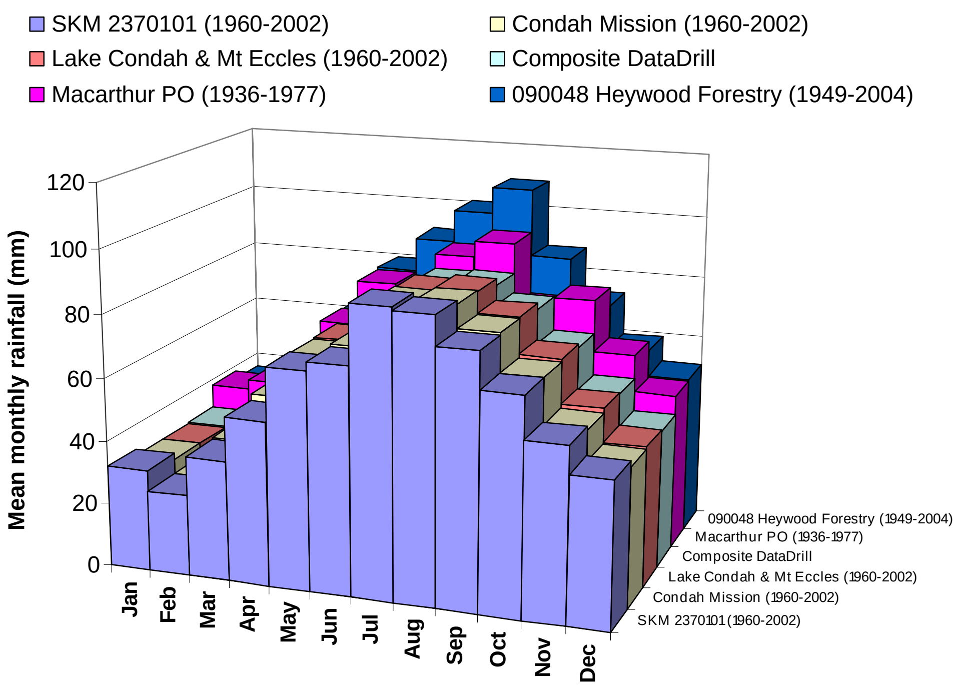


Figure 8. Mean monthly rainfall for two DataDrill stations, the combined DataDrill data, SKM 2370101, Macarthur P.O. and Heywood Forestry stations.

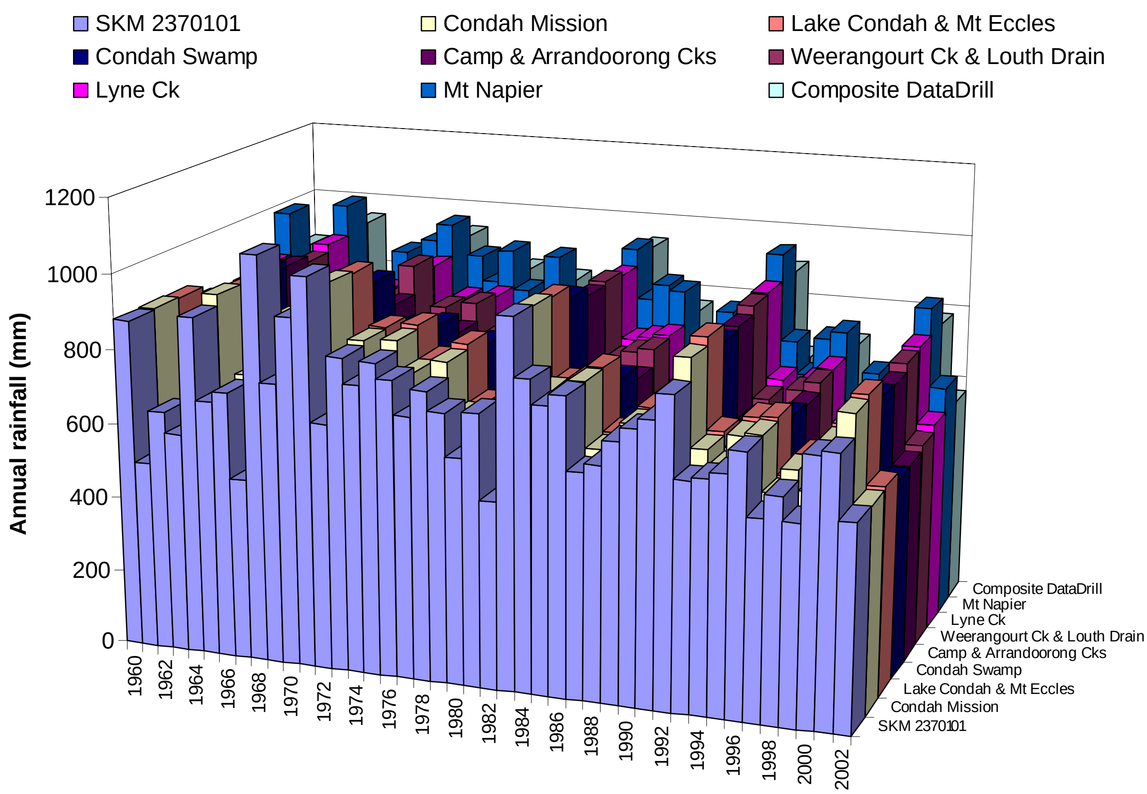


Figure 9. Time series of annual rainfall from 1960 to 2002 DataDrill stations and SKM Station No. 2370101.

Overall, it was concluded that the Lake Condah catchment was better represented by the composite DataDrill station than SKM Station No. 2370101. The data from Macarthur P.O. and Heywood Forestry suggest a significantly wetter climate in those locations compared to the Lake Condah catchment.

2.1.3 Lake evapotranspiration

Whether using Pan evaporation or FAO56 ET_O, these data have to be factored to suit the wetland situation. Recommendations for Pan to open water factors are provided in Gippel (2005a), but there is always uncertainty because the empirically derived factors were measured on wetlands and lakes that may be quite different in characteristics and location compared to the site of interest (Hoy and Stephens, 1979).

When the Lake Condah DataDrill Pan evaporation data and FAO56 ET_O were compared, it was found that FAO56 ET_O could be factored by monthly variable coefficients, being higher in the growing season than in the winter, so as to closely match average monthly Pan evaporation data factored according to Lake Wyangan monthly coefficients (Table 2) (from Hoy and Stephens, 1979) (which is an alternative approach to using the factored FAO56 ET_O data). Morton's shallow lake evaporation was significantly lower than both the factored Pan data and factored FAO56 ET_O data. It was decided to represent wetland evapotranspiration by the factored FAO56 ET_O daily time series, because it approximated the best alternative (factored Pan data), and it had the advantage of being available for the entire 115-year modelling period (the first and last year of data were not used in the modelling).

Table 2.
Monthly Pan to open water coefficients for Lake Wyangan, Griffith (Hoy and Stephens, 1979) and open water factors used to convert Lake Condah DataDrill FAO56 ET_O to open water ET.

Month	Pan Evaporation to open water ET factors for Lake Wyangan Hoy and Stephens (1979)	FAO56 ET_O to open water ET factors to simulate Lake Wyangan
January	0.86	1.31
February	0.86	1.39
March	0.87	1.33
April	0.92	1.33
May	0.78	1.07
June	0.69	0.96
July	0.66	0.92
August	0.68	0.92
September	0.82	1.02
October	0.97	1.21
November	0.85	1.10
December	0.83	1.15

2.1.4 Temporal patterns in climate over modelling period

Rainfall data were available from 1899. A time series plot of annual deviation from the long-term mean annual rainfall indicates that from 1889 to 1944 rainfall fluctuated from year to year about the average (Figure 10). The period 1945 to 1960 was noticeably wetter than average and also had lower than average potential evapotranspiration. Thus, memories by long-term local residents, as reported by Ruge (2004, p. 10), of Lake Condah being generally full from the 1930s until the drain was deepened in 1954 are understandable. Another wetter than average period occurred from 1967 to 1978, while the present is part of a noticeably dry period that began in 1992.

2.1.5 The Climate Change and Natural Resource Management Scoping Study

2.1.5.1 Methodology

Climate change rainfall and evaporation scenarios for conditions in the year 2030 were developed for the Glenelg-Hopkins CMA region by the *Climate Change and Natural Resource Management Scoping Study* (SKM, 2005a). The water balance modelling procedures used in the study were almost identical those used in the *Water and Land Use Change (WatLUC) Study* (SKM, 2005b) (see below). A soil water balance model (SoilFlux) was used to predict the amount of unevaporated water under various vegetation types (representing the land uses), soil types, depth to water table conditions and climate for each sub-catchment.

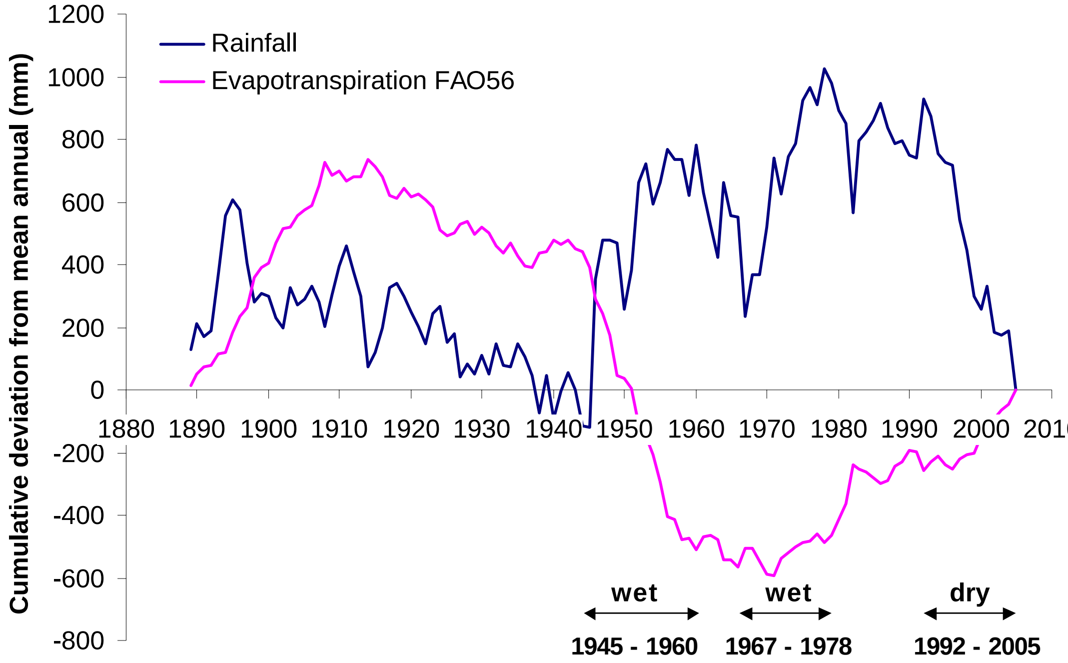


Figure 10. Time series of cumulative deviation in annual rainfall and FAO56 ET_O, highlighting notable periods of wetter and drier than average conditions. Data for composite Lake Condah catchment DataDrill data.

The scenarios were based on predictions of potential change in seasonal and annual climate by CSIRO for the year 2030 relative to 1990. The predictions for rainfall are based on work undertaken by Whetton et al (2002), McInnes et al. (2003) and Suppiah et al (2004), reported in DSE (2004). The predictions for potential evaporation were read from Figure 20 in McInnes et al. (2003), which reported climate change predictions for South Australia, but their maps also included the far west of Victoria. These sources indicated a possible range over which the climate might change for each season, and a range for the annual climate. SKM (2005a) generated a Dry scenario and a Wet scenario, each representing the extreme of the ranges of the predicted change in climate (Table 3). The procedure first scaled the historical daily rainfall and evaporation data using the season-specific factors (one for the Dry, and one for the Wet scenario) and then a small uniform adjustment was applied to all values in each data set to ensure that the changes in annual rainfall and evaporation were equal to the extremes of the annual predicted changes in climate.

Table 3.
Scaling factors for generating future 'Dry' and 'Wet' climate scenarios from historical climate data. Taken from SKM (2005a).

Period	'Dry' scenario		'Wet' scenario	
	Rainfall	Potential ET	Rainfall	Potential ET
Spring	-20%	9%	0%	2%
Summer	-15%	7%	3%	2%
Autumn	-10%	7%	3%	2%
Winter	-10%	9%	3%	2%
Annual	-10%	8%	3%	2%

2.1.5.2 Results

The Climate Change study (SKM, 2005a) predicted the results of climate change on runoff for the year 2030, assuming that land use change *will* occur. Thus, the predictions of the WatLUC study (SKM, 2005b) were incorporated into the climate change predictions. In these studies, the Darlot Creek sub-catchment was assumed to have a mean annual flow of 72.2 GL (SKM, 2005b, p. 65). Under the Dry climate change plus land use change scenario the loss would be 50 – 100 GL/yr by 2030 and under the Wet climate change plus land use change scenario the loss would be 10 – 20 GL/yr by 2030 (SKM, 2005a, p. 15). So, the Dry climate change plus land use change scenario was predicted to severely reduce the flow in Darlot Creek – at best it would be left with a mean annual flow of around 20 GL.

SKM (2005a, p. 18) predicted the change in the annual flow stress index (FSI) for each sub-catchment. Under the Current scenario, Darlot Creek sub-catchment was the only sub-catchment in southwest Victoria with a close to unmodified annual flow. Changes in land use between 1990 and 2030 were predicted to result in increased flow stress, with annual FSI value for Darlot Creek declining to the class 0.5 - 0.75. There was a minor recovery in annual FSI value under the Wet climate sequence to the class 0.75 – 0.9. The Dry sequence resulted in annual FSI falling to the class 0.5 - 0.75.

2.1.5.3 Review of results

The predicted changes in annual flow from Darlot Creek catchment under the climate change and land use change scenarios are high enough that they would be cause for consternation among catchment managers and resource users. It is reasonable to question how reliable are these predictions, and how do these predictions compare with other studies undertaken elsewhere. The study by SKM (2005a) does not address these questions. Indeed, the report makes no reference to the results of any other similar study, even though many have been undertaken, both in Australia and elsewhere.

Jones and Durack (2005) provides estimated ranges of changes in mean annual runoff for all major Victorian catchments in 2030 and 2070 as a result of climate change. The authors noted that the predicted changes are "…very approximate and are best used [to] indicate the direction and magnitude of possible changes to water supply…" and "…are intended for general guidance only." Jones and Durack (2005) used two rainfall-runoff models in this analysis, SIMHYD (Chiew et al., 2002) and AWBM (Boughton and Chiew, 2003), to assess change in mean annual runoff resulting from changes in mean annual precipitation and potential evapotranspiration. Baseline data on runoff were taken from the 1997–2001 National Land and Water Resources Atlas. Patterns of climate change per degree of global warming ten global climate models were scaled by low (Wettest), median and high (Driest) estimates of mean global warming from IPCC (2001) for 2030 and 2070. Darlot Creek catchment was lumped in with the "Portland Coast" catchment (Surry River, Fitzroy River and Darlot Creek, Eumeralla River, and Back Creek and Moyne River). For 2030, the Wettest scenario predicted a 5% reduction in runoff and the Driest scenario predicted a 40% reduction in runoff. For 2070, the Wettest scenario predicted a 10% reduction in runoff and the Driest scenario predicted a >50% reduction in runoff. Thus, for Darlot Creek catchment, the indicative impact of the 2030 Driest climate change scenario is a reduction of 29 GL to around to 45 GL/year; the indicative impact of the 2030 Wettest climate change scenario is a reduction of 3.6 GL to around to 69 GL/year.

Boorman and Sefton (1997) noted that many studies of climate change impacts on runoff couch their results in uncertain terms, and do not claim to produce definitive results. For example, Chiew and McMahon (2002) and Peel et al. (2003) noted the difficulty in estimating accurately the impacts of climate change on streamflow. This is because the climate system is governed by many interrelated factors, and the change in climate variables, particularly precipitation, cannot be estimated reliably. In addition, the hydrological processes themselves may be different in a greenhouse-enhanced climate. Chiew et al. (1995) warned that the reliability of any estimation of the impact of climate change on surface hydrology is always questionable because of the limitations of hydrologic models and the shortcomings of GCM (General Circulation Model) simulations of climate change. Chiew et al. (1995) preferred not to refer to the quoted values as predictions, but as model simulations of the plausible changes in runoff and soil moisture based on the current state of science.

For the global studies completed to date, the wide range of methodological detail employed, and the wide geographic range covered, prevents a comprehensive synthesis of results. However, Boorman and Sefton (1997) noted that the most common conclusion is that changes in rainfall produce, in factorial terms, greater effects on stream flows, with the "amplification factor" possibly as high as 4.5. For Australian catchments, simulations by Chiew et al. (1995) using arbitrary changes in the climate showed that changes in rainfall were always amplified in runoff, the amplification being greater in drier catchments. In the wet and temperate areas, the percentage change in runoff can be twice as much as the percentage change in rainfall, while in the arid areas, large increases in rainfall can enhance runoff by more than five times the change in rainfall (Chiew et al., 1995).

It appears from a review of global and Australian studies (Gippel, 2005b) that under a climate change scenario, baseflows are affected more than stormflows (in terms of percentage change). This can be linked to a decline in conceptual groundwater levels and soil moisture under a future lower rainfall climate regime. The impact of climate change scenarios on extreme runoff events (storm events) are difficult to predict with any degree of certainty, largely because the GCMs do not necessarily model short-term variations in rainfall with a high degree of accuracy. Changes in precipitation pattern are difficult to estimate because of the high spatial variability in precipitation and its dependence on local terrain.

On the basis of the published literature it would be reasonable to expect that a 10% reduction in rainfall (i.e. the Dry scenario referred to above) would produce at least a 20% reduction in annual runoff, but with increasing evaporation this impact would be higher. The Climate Change study (SKM, 2005a) predicted a reduction in runoff of around 40% for the Dry climate scenario for Darlot Creek sub-catchment, which is the same impact for the Driest scenario modelled by Jones and Durack (2005) for the Portland Coast catchments.

2.2 Land use

2.2.1 The Water and Land Use Change (WatLUC) study

2.2.1.1 Methodology

The *Water and Land Use Change (WatLUC) Study* (SKM, 2005b) modelled the impact of land use change on hydrology for the Corangamite and Glenelg-Hopkins CMA regions. One objective of this current Lake Condah project was to estimate the volume of water that the Lake Condah catchment would yield to the Lake under natural conditions, current conditions and for three probable future combinations of climate and land-use change. Thus, it was necessary to consider land use from the perspective of how land use impacts runoff. The relationship between land use and runoff is complex. For the WatLUC study, SKM (2005b) attempted to simulate this complexity using a model called SoilFlux.

With respect to changes in land use in the Corangamite and Glenelg-Hopkins regions, the WatLUC study (SKM, 2005b) found:

> "*The most striking features of land use change since 1990 have been the expansions in broadacre cropping, dairying and Blue Gum plantations. Most change has been at the expense of broadacre grazing of sheep and beef cattle. Over the coming 30 years, broadacre cropping is the only major land use expected to continue to expand at close to its recent historical rate. The area of land given to dairying is likely to remain static and beyond the next few years there is only likely to be incremental expansion in the Blue Gum plantation estate. With some new hardwood plantation development, intensification in grazing operations and implementation of regional native vegetation restoration plans, there is likely to be a marked increase in the area of land covered by both non-woody and woody perennial vegetation. Increased water use associated with these changes is likely to lead to reduced recharge to shallow and deep aquifers and reduced flow in streams.*" (page 2)

> "*An empirical relationship development through WatLUC predicts that for every 10 percentage point increase in woody vegetation and perennial pasture or grassland cover within a sub-catchment, total potential water yield would fall by around 20 and 2.8 mm/y, respectively. For each 1% increase in urban and commercial land uses, potential water yield would increase by about 2.6 and 3.5 mm/y, respectively.*" (page 4)

"*WatLUC has identified several 'hot spot' areas for hydrologic change. Further work is required in these areas to improve land use change predictions and to assess the extent and implications of hydrologic change. Hot spot areas include sub-catchments 49 and 51 in the Portland Coast basin…*" (page 4)

The sub-catchment 49 referred to above is Darlot Creek catchment, the upper part of which drains to Lake Condah.

The land use change scenarios developed by the WatLUC study operated over the period 1990 to 2030. A total of 10 scenarios were developed. The scenarios represented the combination of land uses under a range of industry and demographic change outlooks and government policy and program settings. The extent of change in land use for the Base case scenario was based on industry estimates of the likely rate of change or future extent of relevant land uses. The major feature of land use change from a hydrological perspective is the "perennialisation" of the landscape (SKM, 2005, p. 39). This change is due to establishment of forestry plantations, native vegetation restoration and a predicted increase in the use of perennial species in pastures. The hardwood plantations industry believe that they will achieve their target plantation area for the region within the next few years and are likely only to expand incrementally beyond that level (SKM, 2005, p. 74). The minimum targets set by the Catchment Management Authorities in the region for native vegetation restoration are to increase all endangered EVCs to 15% of their pre-European coverage – this will increase the area of land under woody vegetation.

2.2.1.2 Results

The hydrogeological assessment conducted for WatLUC determined that there were seven sub-catchments within the Glenelg Hopkins region in which there was any significant recharge to deep aquifer systems that did not connect with surface drainage networks – the Darlot Creek sub-catchment was one of them (SKM, 2005b). However, under the Base case scenario, for the year 2030, losses for Darlot Creek sub-catchment were predicted to be less than 1 GL/y. Thus, for this project on Lake Condah hydrology, the impact on recharge to deep aquifer systems was considered too small to warrant consideration.

WatLUC modelling found that in general there was little difference in the hydrologic change associated with the ten land use change scenarios, at least at a drainage basin level. For Darlot Creek sub-catchment, the mean annual flow for the sub-catchment was given as 75 mm. The WatLUC study (SKM, 2005b, their Appendix I, p. 143) found that 2030 annual stream flow was reduced from 1990 stream flow by between 37% and 45%, depending on land use change scenario. The High Forestry scenario predicted a 45% reduction and the Base case a 38% reduction [the reduction for the Base case was confirmed by the plot in SKM (2005b, their Appendix F, p. 121)]. For the Base case this translates to a reduction in the mean annual flow of Darlot Creek sub-catchment of 27 GL (from current of 72.2 GL).

2.2.1.3 Review of results

The results of the WatLUC study were checked against predictions made by the Sustainable Diversion Limits project (also run by SKM), a model called the ForestImpact Model and the empirical model of forest and grassland water use first published by Zhang et al. (1999) and later by Zhang et al. (2001).

When the predictions of the SoilFlux model were compared against the relationships of Zhang et al. (2001) (Figure 11), the values for grass land cover were in general agreement, although the SoilFlux model predicted that catchment runoff would be effectively zero for catchments with annual rainfall less than 500 mm. The SoilFlux predictions for evaporation from forest cover were generally higher than the model of Zhang et al. (2001). Oddly, the SoilFlux model predicted that for many catchments with average annual rainfall less than 800 mm, under forest plantation the evaporation equaled the rainfall, or in other words, runoff was zero. While this prediction may appear doubtful, several catchments are plotted with average annual evaporation *exceeding* rainfall (Figure 11), which is physically impossible (unless water was supplied from outside the forested catchment, and SoilFlux did not model lateral movement of water). Examination of the data used to develop the relationships of Zhang et al. (1999) [i.e. the data provided in the Appendix of Zhang et al., (1999)] reveals that only one of the more than 250 catchments had zero runoff, so it would be unreasonable to predict such a result from SoilFlux The catchment with zero runoff was one under "crops" in Yemen (a country that comprises a large area of desert), and it had a mean annual rainfall of only 35 mm. Yemen also provided to the dataset a few other catchments under "crops" with very low rainfall and runoff. Other catchments with runoff less than 10 mm per year were the most downstream gauges on the Condamine-Culgoa, Bogan, Barwon, Marthaguy, Darling, Murrumbidgee and Moonie catchments, under "pasture/crops" or "mixed vegetation" – explainable because these western NSW rivers originate in humid areas and then flow through very dry landscapes with high evaporation rates; four USA catchments under "pasture" with less than 5 years of record; and one other Australian catchment, Mt Hope Creek, under "mixed vegetation" with low annual rainfall and only 3 years of record.

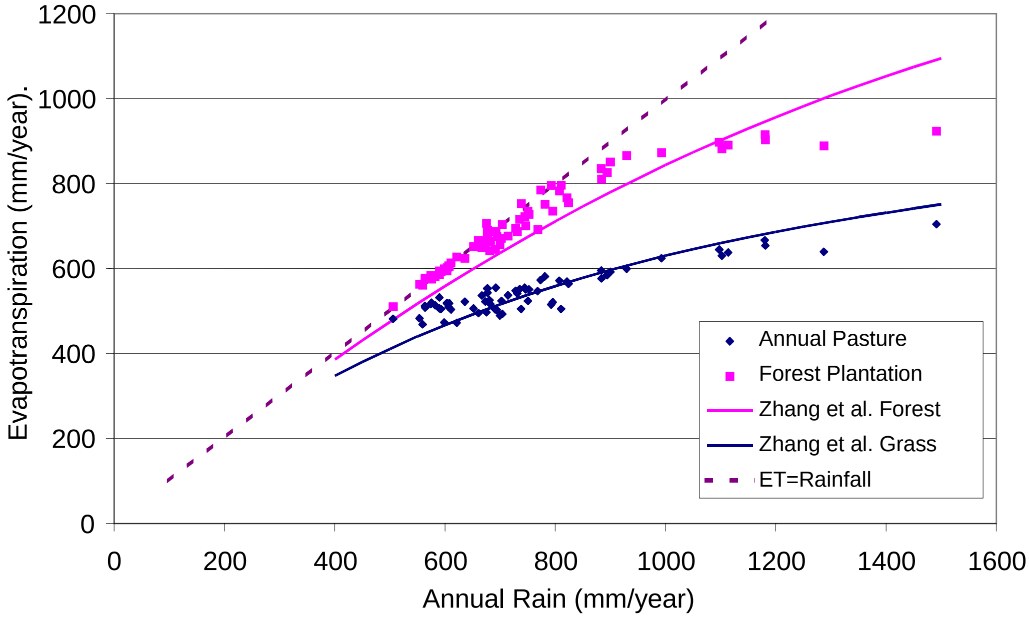


Figure 11. Average annual evapotranspiration plotted against rainfall in all sub-catchments for 'annual pasture' and 'forest plantation' modelled by SoilFlux. Generalised functions for ET of forest and grassland (Zhang et al., 2001) are shown as lines. Figure taken directly from SKM (2005b).

The comparison of SoilFlux and ForestImpact model showed that for catchments in the annual rainfall range 600 – 900 mm the ForestImpact model generally predicted a greater difference in runoff between forest and pasture, compared to SoilFlux. The reason for this is unclear. SKM (2005b) noted that "*Below 600 mm/y average rainfall, stream flow from a forested catchment is approximately zero for both models, however ForestImpact estimates about 100 mm/y streamflow under grassland*". Once again, the prediction of effectively zero flow from a forested catchment with below 600 mm rainfall would appear to be unrealistic.

To conclude, there is a suggestion that, with respect to the relative impact of converting from pasture to forest land use, the WatLUC study produced estimates that are high compared to what would be expected from the literature.

2.2.2 Estimated current and future land use in Darlot Creek catchment

The main land use categories in Darlot Creek sub-catchment were read from plots in SKM (2005b) (Table 4). There may be some inaccuracies in the digitized values, but not so great as to significantly impact the results of this study. The land use for 1990 was not provided in SKM (2005b). However, SKM (2005b, p. 29) assumed that in 1990 there were no Blue Gum plantations, and reported that these plantations essentially replaced broadacre grazing. Thus, the 1990 land use distribution was set to be the same as the 2003 distribution, but with Blue Gum plantations set to zero area, and the area of broadacre agriculture increased by the 2003 area of Blue Gum (Table 4).

Table 4.
Percentage cover of major land uses in Darlot Creek sub-catchment. 2003 and 2030 values taken from plots in SKM (2005b, p. 107-108). 1990 values are the same as 2003 values except that f oh category set to zero and area attributed to agg_b category.

Land use code	Land use category	Percentage cover		
		1990	2003	2030
agc	agriculture: crop	0.9%	0.9%	2.4%
agg_b	agriculture: broadacre	58.0%	52.1%	37.9%
agg_d	agriculture: dairy	22.1%	22.1%	24.6%
nvg	native vegetation - does not include new native vegetation on rural residential land (2010-2030)	14.6%	14.6%	19.8%
f oh	forestry: hardwood (blue gum plantation)	0.0%	5.8%	10.6%
f os	forestry: softwood (pine)	0.6%	0.6%	0.8%
t ra	transport (roads and railways)	3.8%	3.8%	3.8%

2.3 Water resource utilization and environmental flow requirements

2.3.1 Licenced diversions and stock and domestic water use

2.3.1.1 Weirs

There are 6 weirs on Condah Drain and are all actively operated except the Lake Condah diversion weir. SR&WSC (1980 noted that the Shire of Portland sought and was granted approval from the SR&WSC to build seven weirs on the Condah Main Drain upstream of Lake Condah. Approval for the weirs was granted prior to 1970 (Ruge, 2004, p. 15) but SR&WSC (1980) reported that by August 1980 only three had been installed. The weirs are used to divert water for flood irrigation of pastures. Boards are placed in weirs from December/January to April/May (O'Brien, 2006). Around 5-10 ha of land is irrigated by each licence holder for a total of 62 ha of land irrigated (Angus Ramsay, SRW, pers. comm., Sep 2006). Weirs on Condah Drain are operated according to rosters and restrictions.

Southern Rural Water (SRW) manages annual licences to take and use water in the Condah Drain and Darlot Creek catchment. Licences are held by water users who may take water directly from the waterway or from a dam according to the conditions of their licence. The *Condah Drain and Darlots Creek, Local Management Rules for Water Use Licences* (Southern Rural Water, 2006) is in draft form. Licence allocation limits define the maximum volume that licences may be transferred into, or held within the catchment.

A maximum allocation of 711 ML may be held within the catchment (entire Darlot Creek catchment, to the junction with the Fitzroy River) under all licence types (i.e. combined allocation of all year and winter-fill licenses but not including stock and domestic licenses) (Southern Rural Water, 2006). This is broken down into three reaches as follows:

- Louth Drain allocation (to the confluence of the Condah Drain): 158 ML
- Condah Drain allocations (Main Drain to the Lake Condah diversion weir): 373 ML
- Darlot Creek allocations (2 licences downstream of the Lake Condah diversion weir): 180 ML

The above does not include allocations that have been transferred from amended licences issued under section 51(1A) of the Water Act 1989. Licences upstream of Lake Condah obtain their water through manipulation of the weirs. There are a total of 9 licences and 531 ML of annual allocation upstream of Lake Condah. The 2 licences downstream of Lake Condah have to pump the water as there are no weirs in that part of the Creek (O'Brien, 2006). The above quoted licenced volumes can be considered as nominal volumes that were calculated by conversion from area. Usage is currently not metered, and actual usage may be greater than the annual licenced volume (Robin Millard, SRW, pers. comm., Sep 2006, as cited in O'Brien, 2006).

Southern Rural Water has adopted a roster system to assist in the delivery of a more equitable allocation of the water resource for all licence holders. When flows are greater than 30 ML/d at the Darlot Creek @ Homerton gauge there are no restrictions on how individual landholders operate the boards, but they are generally operated to allow stock access for drinking without causing bank erosion problems (O'Brien, 2006). A restriction roster commences when flow falls to 30 ML/d at the Darlot Creek @ Homerton gauge (Southern Rural Water, 2006). This has the outcome of a reduction in the diversions from the drains/streams. The roster has five stages, with Stage 1 being no restrictions, and Stage 2 being implemented when the 30 ML/d at Homerton gauge threshold is reached. The restrictions are eased one stage at a time when the flows increase to 35 ML/d at Homerton gauge after one complete cycle of the diversion roster period. The stages are as follows:

- Stage 1 – Unrestricted diversion from drain from designated weir
- Stage 2 - 100% or 24 hr diversion from weirs on rostered day
- Stage 3 - 50% or 12 hr diversion from weirs on rostered day
- Stage 4 - 25% or 6 hr diversion from weirs on rostered day
- Stage 5 - Irrigation ban

When the roster is active it works as follows. The most upstream user is notified of a nominated day for diversion. On that day the weir can be used for the 24 hour period from 8.00 AM until 8.00 AM the following morning (for Stage 2). After that the weir must be running unrestricted until the next nominated 24-hour period for weir operation. The day following the first day of water diversion on the roster no licence holders can divert. The next day the second licence holder can divert water for a 24 hour period, followed by a lay day and then the next licence holder can divert, and so on, until all diverters have had a turn. This cycle takes about 2 weeks to complete).

The roster was first introduced in year 2000. Prior to that the irrigators used their own water sharing system. It would appear that summer/autumn water supply is often limited. Certainly, rostering has been required for the past three seasons (i.e. 2003/04, 2004/05 and 2005/06) (Angus Ramsay, SRW, pers. comm., Sep 2006).

2.3.1.2 Stock and domestic diversions

There are 8 stock and domestic licences on Condah Drain (totaling 17.6 ML) upstream of Lake Condah and 3 licences (totaling 6.6 ML) downstream of Lake Condah (O'Brien, 2006). These totals are likely to be an underestimate for two reasons:

- The are based on a nominal 2.2 ML allocation per licence when Southern Rural Water advise that it is likely to be closer to 6 – 10 ML per property (O'Brien, 2006).
- Licences are only required when title access is not available. Most stock and domestic users have title access and therefore do not need a licence (O'Brien, 2006).

2.3.1.3 Sustainable Diversion Limits (SDLs)

The Sustainable Diversion Limit (SDL) of a catchment is a rapid estimate of the winterfill diversion potential, above which there is an unacceptable risk that additional extractions may degrade the environment (DNRE, 2002). The SDL is defined by four components, the winterfill period, the minimum flow below which diversions are not permitted, the maximum diversion rate, and the volumetric cap.

The winterfill period means the period between 1 July and 31 October in any year. Under the Darlot Creek Plan, there is no allocation allowed for winterfill licences (Southern Rural Water, 2006). There are however large volumes potentially available within the Darlot Creek catchment for allocation over the winterfill period. SDL volumetric caps are (O'Brien, 2006):

- 6,256.9 ML upstream of Lake Condah

- 2,470.3 ML downstream of Lake Condah

Given this relatively large availability of winterfill resource, at some time in the future, allocations may be made for winterfill licences.

2.3.1.4 Farm dams

There are 4 registered dams totalling 115.1 ML in Darlot Creek catchment, all being located upstream of Lake Condah (O'Brien, 2006). Farm dam registration only accounts for dams that are used for irrigation, which in the Darlot Creek catchment is a very small proportion compared to those used to supply stock and domestic (O'Brien, 2006). Therefore the volume and impact of farm dams on catchment hydrology were determined using the TEDI methodology.

2.3.1.5 Water requirements for users downstream of Lake Condah

Restoring water levels in Lake Condah has the potential to cause losses to Darlot Creek by way of evaporation losses and seepage losses. Decreased downstream flows could directly impact the two licenced users downstream of Lake Condah, and indirectly impact annual licences upstream through more restrictions/rostering for users upstream based on flows at Homerton Bridge gauge.

SR&WSC (1980) assessed the requirements for diversions and compensatory flow downstream of Lake Condah as 18 ML/d from December to March and 8 ML/d from April to November. Hall (1991) estimated that an instantaneous flow of at least 21 ML/d was required downstream of Lake Condah "to satisfy riparian diverter's water rights". At that time, Hall (1991) reported that there were four irrigation permits for water diversion, but currently there are two annual licences downstream of Lake Condah.

There are three pumping points associated with the two licences downstream of Lake Condah; all are located downstream of Homerton, between the Woolsthorpe-Heywood Rd and Settlers Rd. The water is used for flood irrigation of pasture. For the most downstream licence, pumping occurs over the February to March period, for 2 to 3 days per month, at a rate of 15 ML/d (Angus Ramsay, SRW, pers. comm., 20 December, 2006) (each licence is for a total annual allocation of 90 ML). Flow at Homerton is nearly always greater than flow at Myamyn (Figure 67), so a release of 10 – 20 ML/d at Lake Condah should be adequate to meet the pumping requirements as they arise. However, the diversion demands are sporadic, and it may be better to manage flows in Darlot Creek downstream of Homerton on a needs basis, rather than supplying the Creek with a fixed minimum flow from Lake Condah throughout the entire low flow period.

2.3.2 Environmental flow requirements

In 1991 a recommendation was made by Hall (1991) that 30 ML/d should be maintained downstream of Lake Condah, unless the natural flow in Condah Drain at the northern end of Lake Condah was lower than this, in which case the lower flow should be passed in its entirety (i.e. no diversions to Lake Condah). This was based on information received from the Rural Water Commission that during low flow periods (Summer) 35% of the flow at Homerton is sourced from groundwater inflows between the northern (i.e. inlet) end of Lake Condah and Homerton. Hall's (1991) examination of the 1963 – 1990 flow record at the Homerton gauge (237205) suggested that mean daily flow during the summer months was around 50 ML/d. If 35% of this entered downstream of the inlet of Lake Condah, it was reasoned that mean flows at the inlet to Lake Condah would be around 30 ML/d.

In this Lake Condah hydrology study, environmental flow requirements for Darlot Creek were re-assessed. This is covered in the ecology section of this report.

2.4 Climate and land use change modelling scenarios

2.4.1 Climate change scenarios

For this project, climate change scenarios were generated using the procedure of SKM (2005a) (Table 3). One minor difference was that the adjustment of the data to fit the annual change values was only done for the Dry scenario rainfall because this is the only scenario where applying the seasonal factors as given caused the annual maximum degree of change to be exceeded (Table 3). In this report, the Wet scenario rainfall values were not adjusted upwards so as to achieve the maximum allowable annual degree of change, as this would have required the seasonal limits to be exceeded.

The climate change scenarios generated here are highly contrived. The CSIRO predictions refer to climate in 2030 relative to 1990, with climate change occurring on a continuum (i.e. changes are less severe prior to 2030 and more severe after 2030). The scenarios generated here do not purport to represent what the climate will be in 2030. Rather, they represent what the climate might have been like over the 115-year long modelling period had the degree of climate changed predicted by CSIRO from 1990 to 2030 occurred. So, there is no gradual climate change in these time series' – each one represents a quantum climate change. At this stage there is no way of knowing which scenario is more likely.

One major problem with the climate change scenarios is that the CSIRO predictions are for seasonal and annual change, but here they were applied to daily data. The issue is that climate change may not affect daily rainfall and evaporation in an even way. For example, peak rainfall intensities might increase substantially, while moderate and low rainfall intensities might be unchanged, or even lower. The average seasonal change of this scenario could be same for a scenario where all rainfall intensities were increased by the same proportion. However, the impact of these two hypothetical scenarios on runoff would be very different. At present, the climate change predictions are not sufficiently detailed to make reliable predictions about how daily rainfall and evapotranspiration might be impacted.

The long-term climate outcomes from the two climate change regimes suggest that in the future, rainfall might be higher than historical under the Wet scenario, but evapotranspiration will be higher regardless of the scenario (Figure 12). Over the 115-year modelling period, the Dry scenario has an 8,000 mm rainfall deficit compared to the historical series.

2.4.2 Land use change scenarios

In this project, runoff to Lake Condah was modelled using a daily rainfall-runoff model. For the purpose of determining if in the future there will be sufficient water to achieve and maintain a particular water level in Lake Condah, plus provide water for licence holders and for environmental flows downstream, a monthly runoff model would have been adequate. However, a daily model was required in order to investigate the backwater influence of the future structure, i.e. the influence of the structure on upstream water levels and flood extent during times of high inflows. The SoilFlux model used to predict runoff in the WatLUC project was apparently run at a monthly time-step (SKM, 2005b, p. 64), with the key results reported as impacts on annual flow. The modelling approach used for the WatLUC study is quite sophisticated but would require considerable development work to predict runoff on a daily time step for a range of future climate change and land use change scenarios. This was well beyond the scope of the current project. Here, an alternative approach was taken to generating future runoff series'.

The approach used to generate future runoff series' was to classify the land use into four major categories for which a hydrological response can be defined from the literature: forest, mixed vegetation, grass (pasture) and bare land. Reference was made to Davey et al. (2006, Table A1), who classified various common land use classes according to an evapotranspiration related index. Using information in SKM (2005) (Table 4), the percentage cover of these categories was determined for 1990 (also termed "Current") and 2030 (also termed "Future") (Table 5). The 1750 (also termed "Natural") coverage was measured from Department of Sustainability Interactive Maps Mapshare 1750 EVCs. Approximately 50% of the Lake Condah catchment was classed as belonging to a woodland-type class, approximately 39% belonging to the "tree cover" class, and the rest (approximately 11%) belonging to a swamp, scrub or plains class. Gibbons and Downes (1964) noted that the original vegetation of the Condah Swamp Land System was a dense wet scrub of woolly tea-tree (*Leptospermum lanigerum*). Approximately half of the area of this group was assigned to the "grass" evapotranspiration class and the rest to the "mixed vegetation" class.

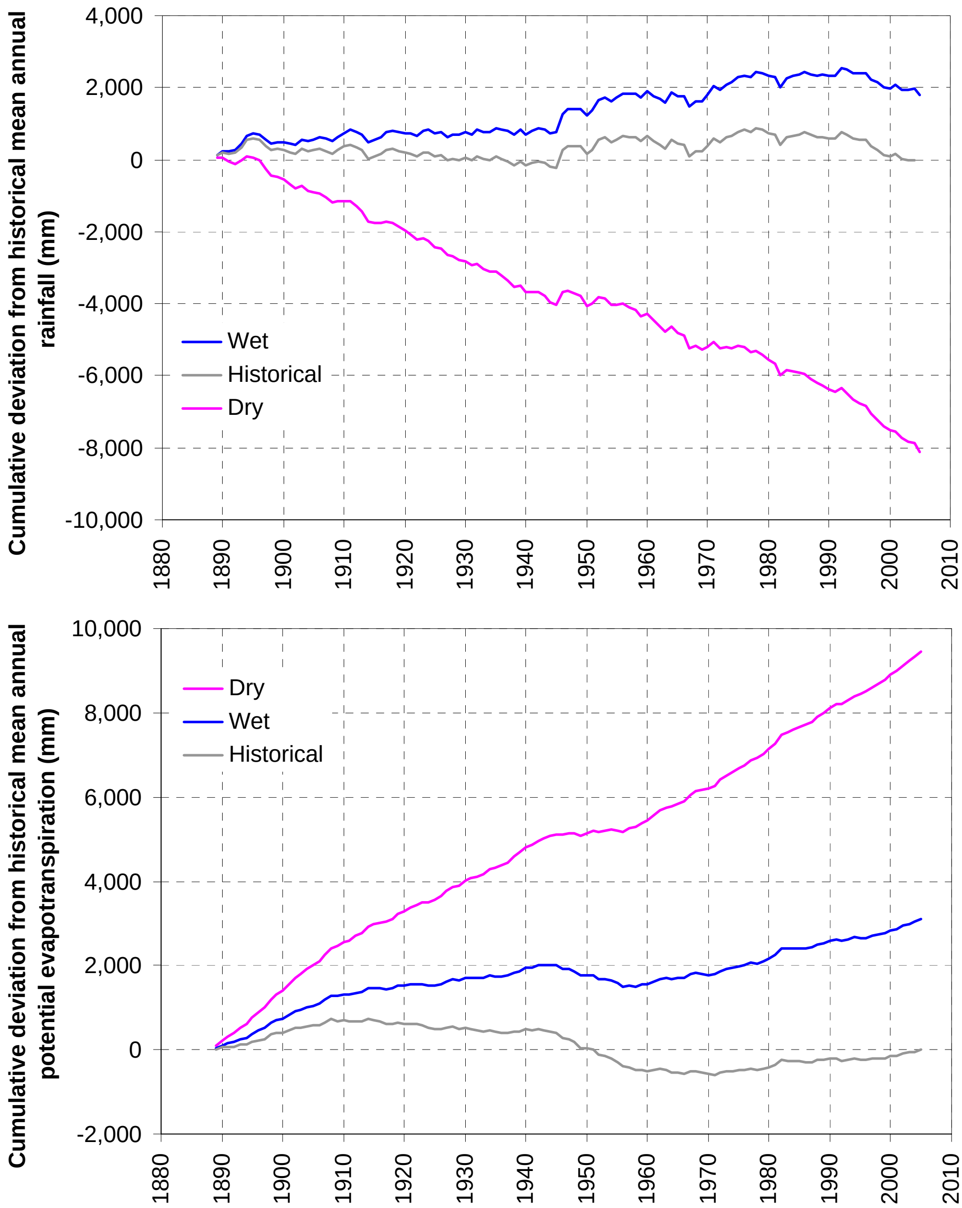


Figure 12. Time series of cumulative deviation from historical mean annual rainfall and potential evapotranspiration (FAO56 ET_O) for historical and for Dry and Wet climate change scenarios. Series' derived for composite Lake Condah catchment DataDrill data.

Table 5.
Estimated percentage cover of land uses evapotranspiration classes in Darlot Creek sub-catchment for four time periods.

Land use evapotranspiration class	"Natural" 1750	"Current" 1990	"Future" 2030
Forest	39%	15.2%	31.3%
Mixed vegetation	56%	0.9%	2.4%
Grass	5%	80.1%	62.5%
Bare	0%	3.8%	3.8%

2.4.3 Combined land use and climate change modelling scenarios

Five runoff modelling scenarios were considered (Table 6). The Natural scenario assumed no water abstraction and 1750 vegetation cover; the climate was assumed to be the same as for the historical period. For the future scenarios it was assumed that land use change would take place [assumed to be the Base case scenario of SKM (2005b)], but that climate change could be neutral, on the wet extreme of CSIRO predicted change or the dry extreme of CSIRO predicted change. These future scenarios assumed that water abstraction would remain at current levels.

The hydrological model was initially calibrated for "Current" (1990) conditions using available gauged data. Future runoff scenarios were generated by altering the rainfall and evapotranspiration inputs (for climate change scenarios) and altering the mix of land uses (for land use change scenarios). The model predictions for the land use change scenarios were checked against, but not calibrated to, the results of SKM (2005a) and SKM (2005b).

Table 6.
Conditions of climate, land use and water diversions for the five runoff modelling scenarios.

Modelled scenario	Climate	Land use	Diversions
Natural	Historical	1750	None
Current	Historical	1990	1990 farm dams and licenced diversions
Future Neutral	Historical	2030	1990 farm dams and licenced diversions
Future Dry	Dry 2030	2030	1990 farm dams and licenced diversions
Future Wet	Wet 2030	2030	1990 farm dams and licenced diversions

2.5 Summary

In order to represent the full range of hydrological conditions in the modelling, data covering long periods were sought. The Bureau of Meteorology DataDrill daily climate series', which covered 100+ years, compared positively with locally observed data sets; the DataDrill time series' were considered ideal for the purpose of hydrological modelling.

The period 1945 to 1960 was noticeably wetter than average and also had lower than average potential evapotranspiration. Thus, memories by long-term local residents of Lake Condah being generally full from the 1930s until the drain was deepened in 1954 are understandable. Another wetter than average period occurred from 1967 to 1978, while the present is part of a noticeably dry period that began in 1992.

Climate change rainfall and evaporation scenarios for conditions in the year 2030 were developed in 2005 by SKM for the Glenelg-Hopkins CMA region in the *Climate Change and Natural Resource Management Scoping Study*. The scenarios were based on predictions of potential change in seasonal and annual climate by CSIRO for the year 2030 relative to 1990. The CSIRO predictions were also adopted for this study.

The *Water and Land Use Change (WatLUC) Study* by SKM in 2005 modelled the impact of land use change on hydrology for the Corangamite and Glenelg-Hopkins CMA regions. The land use change scenarios developed by the WatLUC study operated over the period 1990 to 2030. The major feature of land use change from a hydrological perspective is the "perennialisation" of the landscape. This change is due to establishment of forestry plantations, native vegetation restoration and a predicted increase in the use of perennial species in pastures. With respect to the relative impact of converting from pasture to forest land use, the WatLUC study produced estimates that are high compared to what would be expected from the literature. The future land use scenario adopted for this study was less severe in its hydrological impact than that assumed in the WatLUC study.

Factors affecting current and future water resource utilization in the Lake Condah catchment are licenced diversions and stock and domestic water use, farm dams, environmental flow requirements and winterfill diversions.

For this study, five basic scenarios were modelled:

- Natural (historical climate and 1750 land use)
- Current (historical climate and 1990 land use)
- Future Neutral (historical climate and 2030 land use)
- Future Dry (future dry climate and 2030 land use)
- Future Wet (future wet climate and 2030 land use)

3 Lake Condah Bathymetry, and Observed Hydraulic Behaviour

3.1 Available survey data

There are five available sources of survey data for Lake Condah and the surrounding area:

3.1.1 Coutts et al. (1978) feature transects

Coutts et al. (1978) surveyed levels for various features in parts of the south-eastern area of the Lake, benchmarked to an arbitrary datum. The relative levels and distances of the transects are probably adequate, but the spatial detail on the maps is not accurate.

3.1.2 1980 SR&WSC topographic plan with 0.5 m contours

15th April 1980 State Rivers and Water Supply Commission (SR&WSC) Water Supply Investigations Lake Condah Capacity Survey, Corr No. 69/643. Plan, based on November 1979 field survey. The survey comprised 15 transects, with levels taken at approximately 20 m intervals. The levels were superimposed onto a 1972 aerial photomontage and 0.5 m contours interpreted. The benchmark given is Australian Height Datum (AHD), but this could be in error if the local benchmark used to reference the survey was not AHD. The benchmarks are not noted on the map, but it may be possible to obtain this information from the original survey books. The map also includes a few values of bed elevations for Condah Drain in the southern section of Condah Swamp, and three cross-sections of the Drain between Stones Bridge and Malseed Weir (Myamyn gauge). The scale on the map is noted as being “approximate”, suggesting the possibility of spatial errors, which could be due to uncorrected photographic distortion on the basemap, or lack of control points to line up the survey data with the basemap.

3.1.3 1989 Lake Condah Vicmap 1:5000 topographic map with 1.0 m contours

The 1: 5000 topographic mapsheet Lake Condah, Vicmap 1989, Ministry for Planning and Environment Victorian Archaeological Survey 1:5000 mapsheet has 1 m contour intervals and shows the locations of sinkholes. The stated accuracy is conforming to “National Mapping Specifications and classification AA1 of the survey Coordination (Surveys) Regulations 1981”. Thus, elevations are quoted as AHD, but these could be in error if the local benchmark used to reference the survey was not AHD.

3.1.4 2000 NASA Shuttle Radar Topographic Mission (SRTM)

The Shuttle Radar Topographic Mission (SRTM) consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during the 11-day STS-99 mission beginning 11th February 2000 (URL: http://www2.jpl.nasa.gov/srtm/). The SRTM data set for Australia is sampled at 3 arc-seconds, which is 1/1200th of a degree of latitude and longitude, or about 90 metres. These data can be downloaded free of charge, but require processing in order to be mapped or analysed. The stated relative vertical height accuracy of SRTM is ±6 m and absolute vertical error is ±16 m. Error in the SRTM data is strongly influenced by topography, being larger in high-relief terrain, while in a low- to medium relief terrain, errors are smaller (Falorni et al., 2005). Gonçalves (2005) found that, globally, mean square errors are generally small (e.g. 4 or 5 m) but that local systematic errors occur in forested areas. The SRTM signal was partially or fully reflected by tree canopies (NASA, 2005; Gonçalves, 2005), giving a false (high) elevation in these areas.

3.1.5 2005 high resolution photogrammetrically derived DEM

A photogrammetric survey of the Mt Eccles Lava Flow region was flown by AEROmetrex on 22nd April 2005 using a LMK 2000 camera with Kodak InfraRed 2443 film, and focal length of 153 mm. Frame dimensions were 230 mm x 230 mm, scanned at 15 μm. Each run was flown east-west approximately 1,400 m above ground. The side and forward overlap was 30% x 60%. The pixel size of the photography was 0.15 m. The digital elevation data were supplied on a 5 m x 5 m grid, split into five files. Lake Condah and part of Condah Swamp are covered by two of the supplied DEM files. Vertical accuracy is 98% confidence 0.4 m accuracy with 5% out of accuracy (error margin), which can be achieved in flat barren areas without vegetation; 68% confidence with 0.2 m accuracy with 30% error margin, applying mostly in broken terrain and vegetated areas. Spot point accuracy is 0.3 m in clear conditions. Precious control referral points were surveyed on the ground before the flight, using a differential GPS receiver, to an accuracy of 0.02 – 0.03 m in the vertical. The survey utilised Vicmap Position-GPSnet™, a network of Continuously Operating Reference Stations (CORS) GPS infrastructure that provides high accuracy and homogeneous location information state-wide (http://www.nre.vic.gov.au/land/lcnlc2.nsf/alltitle/professions-geodesy-gpsnet). AEROmetrex used a survey mark at Hamilton to reference the Lake Condah survey. The elevation of this survey mark was determined to be accurate using GPSnet™.

3.1.6 Comparison of survey data

Ruge (2004, p. 20) recognised that the elevations on the 1980 SR&WSC and the 1989 Vicmap sheet were inconsistent; the Lake Condah floor elevations are 1.0 – 1.9 m lower on the Vicmap sheet compared to the SR&WSC plan.

A comparison of the 1980 SR&WSC Plan and the 2005 DEM revealed that the SR&WSC Plan was consistently 0.3 – 0.5 m lower across the floor of the Lake. The comparison was made by generating transects from the DEM along the same bearings as four of the transects on the SR&WSC Plan (Figure 13). The transects were 1,000 – 1,300 m long, and comprised 49 – 69 spot heights on the SR&WSC Plan and 1,025 points on the DEM. The SR&WSC Plan lacks spatial reference information, so the pegs could be located on the DEM only approximately, on the basis of comparing topographic landmarks; this led to some features not lining-up exactly. Despite this problem, the four transects showed a reasonably consistent pattern of differences in elevation across the lake floor (Figure 14). The most northern transect (near the offtake weir) showed the poorest fit. There are a number of possible reasons for this: the eastern part of the transect was disturbed between the surveys due to construction of the offtake weir and drain; the western part of the transect, in the vicinity of the drain is on private land, which may have been disturbed, and the most western part of the transect traversed a slope, so that a small locational error would create a relatively large elevation error. The most southern transect showed a reasonably consistent elevation difference except for the deepest section of the lake bed, where the difference in elevation was only around 0.1 m; the reason for this is unclear.

A comparison of the SRTM and the 2005 Photogrammetric DEM revealed that the SRTM was usually higher than the 2005 DEM, but the difference was highly variable, especially for the higher elevations (Figure 15). Some of the differences may be due to slight differences in the projections, such that the transects do not exactly overlay. Comparing only lake or swamp floor data, the mean difference was the SRTM elevation 2.3 m higher than the 2005 DEM elevation. This offset in absolute elevation and the degree of variability are not inconsistent with experience reported in the literature and by other SRTM users.

The SRTM is not the preferred DEM, but it does provide data to allow the area of interest to be extended further north into the Condah Swamp. Thus, the SRTM data were corrected by 2.3 m and patched onto the northern extent of the 2005 Photogrammetric DEM to extend the mapped area to the 60 m contour on Condah Swamp. Note that the purpose of this exercise was to calculate the volume and surface area of Condah Swamp; the area beyond the 2005 DEM extent and mapped by the SRTM is not depicted in the illustrations in this report due to its unreliable accuracy. The 1:5000 Vicmap Lake Condah Mapsheet was not used other than to locate sinkholes. The relative levels provided by Coutts et al. (1979) were used to help estimate previous Lake Condah water levels.

The 2005 Photogrammetric DEM is the preferred source of survey data for this study. The density of points, the vertical accuracy, spatially referenced data, and accurate ground control survey makes it superior to the other surveys. With respect to the accuracy of the elevations relative to AHD, AEROmetrex have previously thoroughly investigated this issue in response to inquiries by Dr Mark Lethbridge (School of Geography, Population and Environmental Management, Flinders University). The result of that review was that AEROmetrex are very confident that the 2005 DEM is accurate to AHD (Will James-Martin, AEROmetrex, pers. comm., 27th September, 2006).

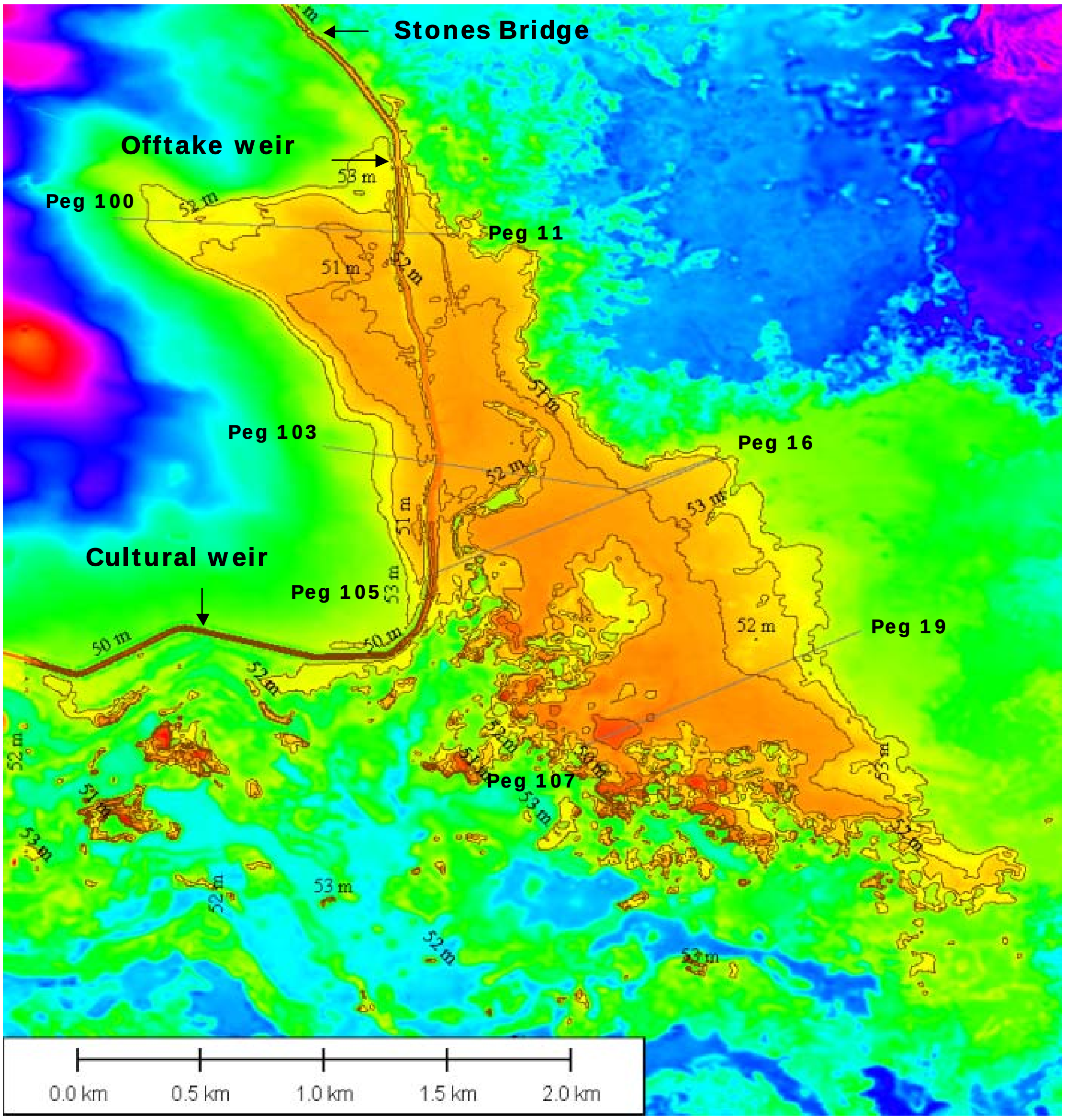


Figure 13. Lake Condah showing 1 m contours from 50 – 53 m derived from 2005 DEM. The four labelled lines are transects used to compare elevations between the 1980 SR&WSC Plan and the 2005 DEM. Peg numbers from 1980 SR&WSC Plan. North is vertical. Colour shading represents elevation gradient.

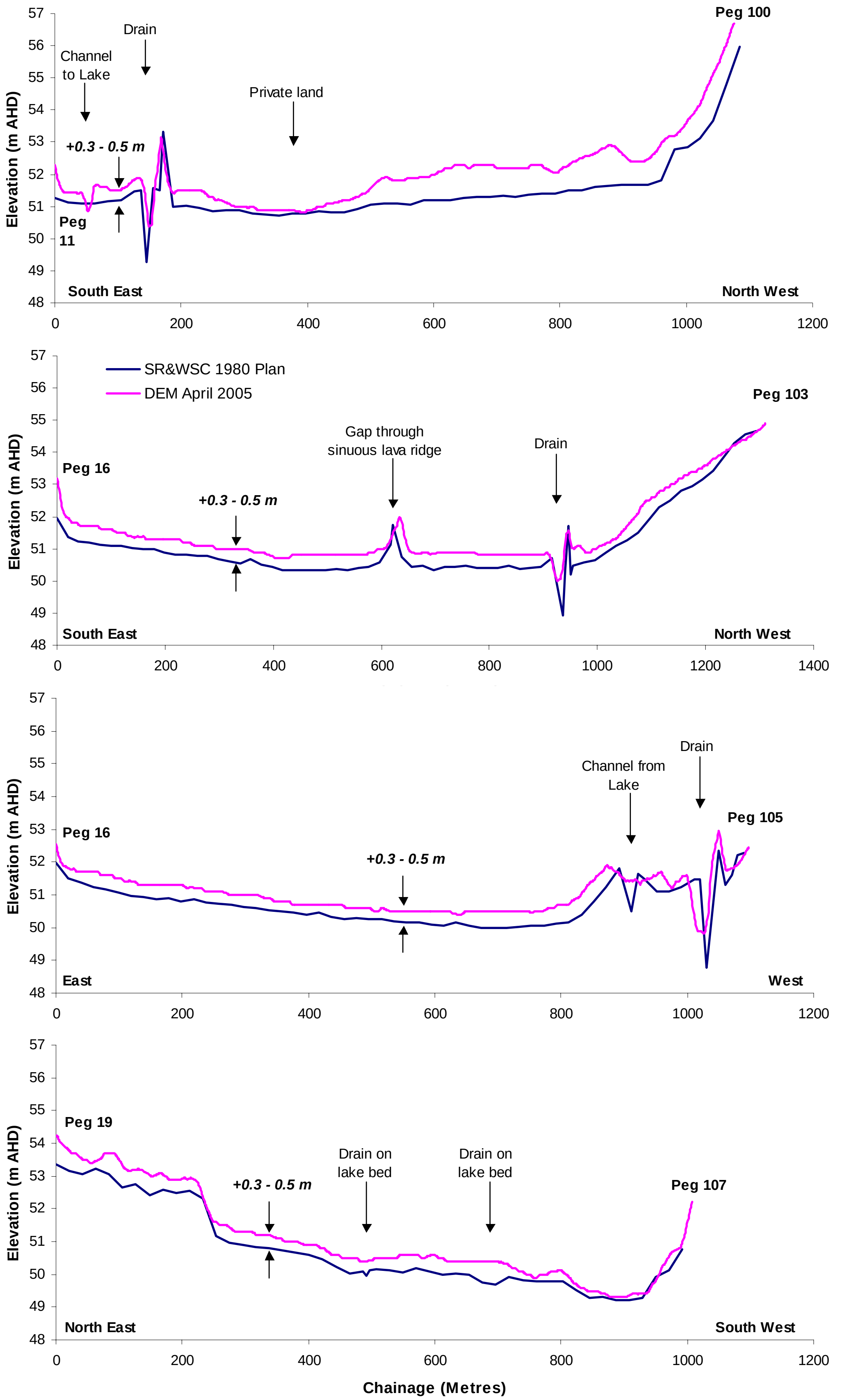


Figure 14. Comparison of elevations for three transects across Lake Condah for 1980 SR&WSC Plan and 2006 Photogrammetric DEM. View is looking downstream, most northern transect on top. Peg numbers from 1980 SR&WSC Plan.

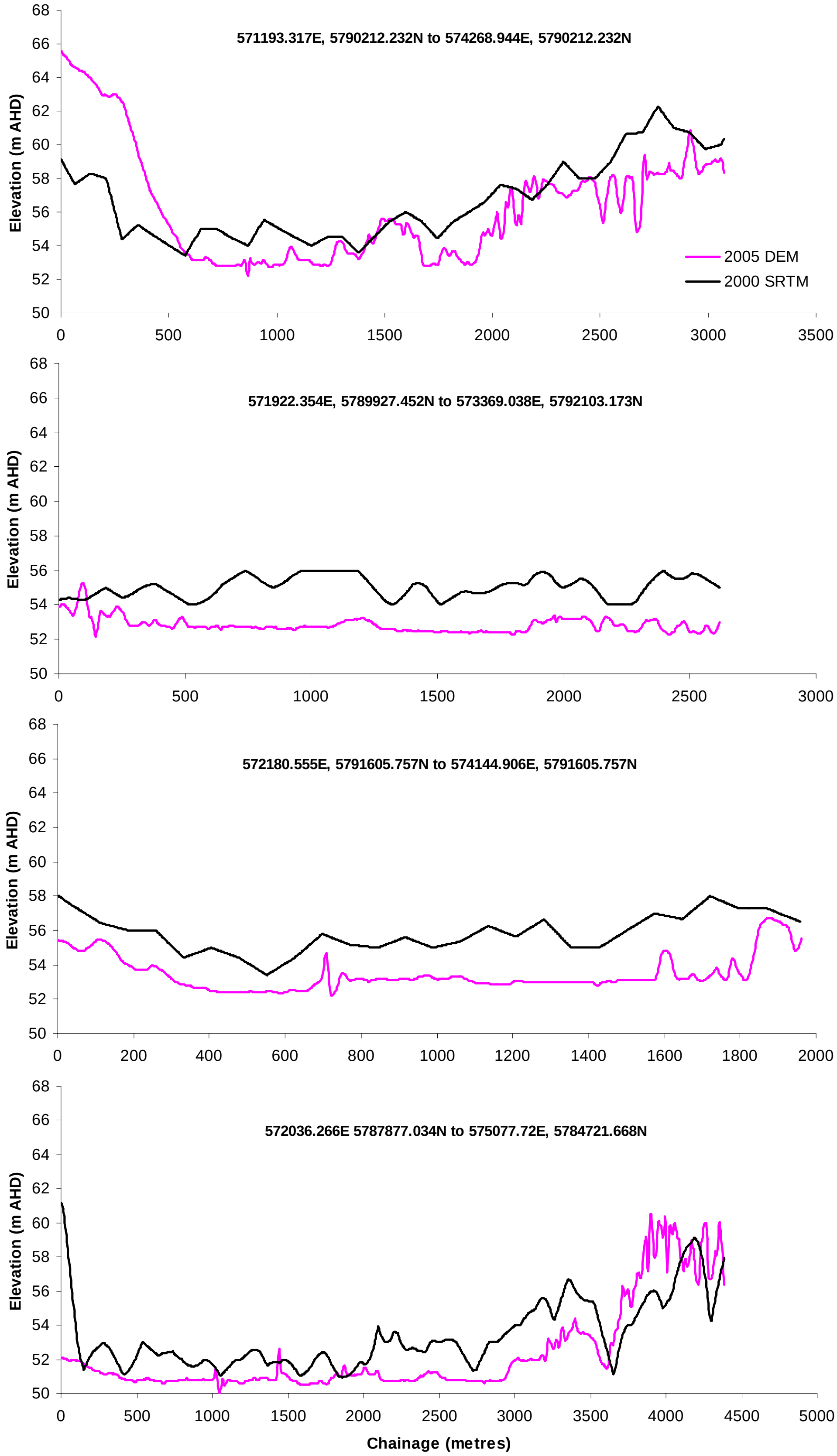


Figure 15. Comparison of elevations for four transects across Condah Swamp and Lake Condah for 2006 Photogrammetric DEM and SRTM. View left to right is West to East, most northern transect on top. Transects are straight lines between given Eastings and Northings.

The disadvantage in adopting the 2005 DEM survey levels is that the 1980 SR&WSC Plan has been exclusively used for Lake Condah management and planning up to this point. As noted by Ruge (2004):

- It was the datum used for the Condah Swamp drainage system including the Main Drain;
- It was the datum used for drainage of the Lake;
- Permanent markers adjacent to the Lake use this datum (although they appear to have been interfered with);
- It was the datum used to build the Diversion Weir and channel at the north end of the Lake; and
- It is consistent with previous attempts to restore water to the Lake.

Thus, reporting results based on the 2005 DEM can create problems when reference is made to, or comparisons are made with, earlier studies. To overcome this problem, in this report, when referring to survey data based on the1980 SR&WSC Plan, the original and an adjusted value are both given. The adjustment made here was to add 0.4 m to the SR&WSC levels. This correction for AHD is only accurate to ±0.1 m at best.

3.2 Lake Condah – Condah Swamp Levels

3.2.1 Lake Condah

Contours were generated for Lake Condah from the 2005 DEM for a range of elevations (Figure 16). The Lake has four main sections, each representing a waterbody that under certain water level conditions can be disconnected from the others. Part of Morton's property (private land) comprises the northwest corner of the Lake bed. Most of the fishtrap systems are located on the southwestern margins of the Lake.

There is very little water in the Lake at 50.5 m AHD (Figure 17); at 51.0 m most of the flat low-lying parts of the bed are covered by shallow water; at 52 m most of the lake area is inundated with higher levels increasing depth but not generating large increases in surface area (Figure 17).

3.2.2 Condah Swamp

Condah Swamp is located upstream of Lake Condah. As indicated on Figure 17, parts of the southern section of the Swamp are potentially inundated at levels above 52 m AHD. Looking at the southern section of Condah Swamp (limit of DEM) in more detail (Figure 18), it is clear that parts of the Swamp are low-lying, and it is all below 53 m AHD. Gibbons and Downes (1964) cited local landholders reporting that the surface level in the centre of the main Condah Swamp lowered by one metre since draining (in 1954).

Unexpectedly, the more northerly sections (most upstream) are the lowest in elevation, which highlights the flatness of this landscape feature. Although parts of Condah Swamp are lower in elevation than 52 m, this does not necessarily mean that water levels above 52 m in Lake Condah will cause inundation in Condah Swamp – if water is contained within the Condah Drain, then the Swamp will not be flooded. To investigate this, transects were run across Condah Swamp at the lowest points in the landscape (Figure 19). These cross-sections indicated that the Condah Drain has a distinct levee, although its height is variable (Figure 20). The cross-sections indicate that the levees protect the Swamp against inundation for levels below 52.28 m AHD. Although the cross-sections were intentionally located at points where the levee elevation was low, it is possible that lower breakout points exist. If Lake Condah is managed in the future at a level of 52.4 m, and flooding of Condah Swamp is considered undesirable, the levee along Condah Drain will require upgrading in places to seal the breakout points.

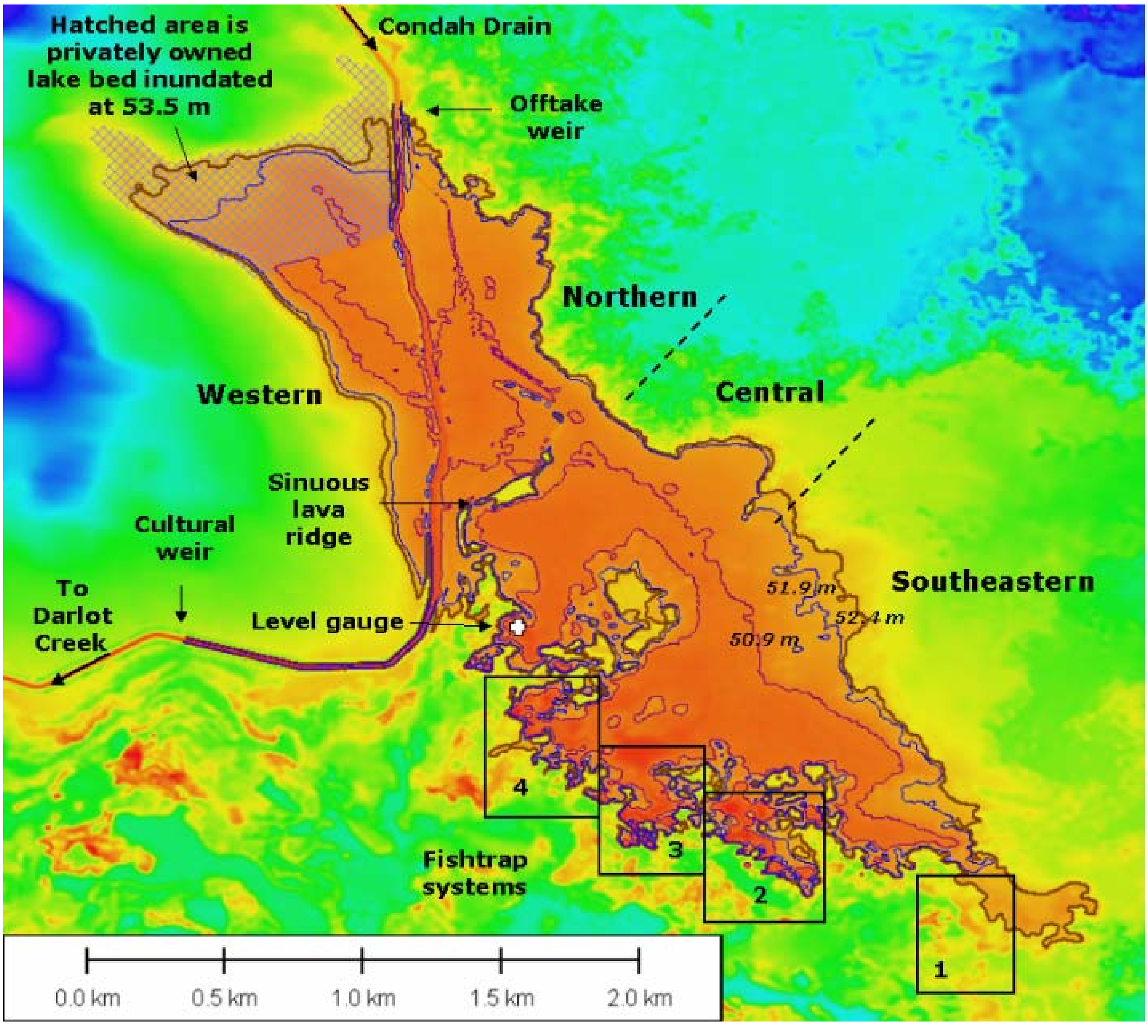


Figure 16. Lake Condah showing 50.9 m, 51.9 m and 52.4 m contours, and main features of the Lake. In this report, the Lake was divided into four main sections. The fishtrap systems indicated are those defined by Coutts et al. (1978), but structures also exist in other locations. North is vertical. Colour shading represents elevation gradient.

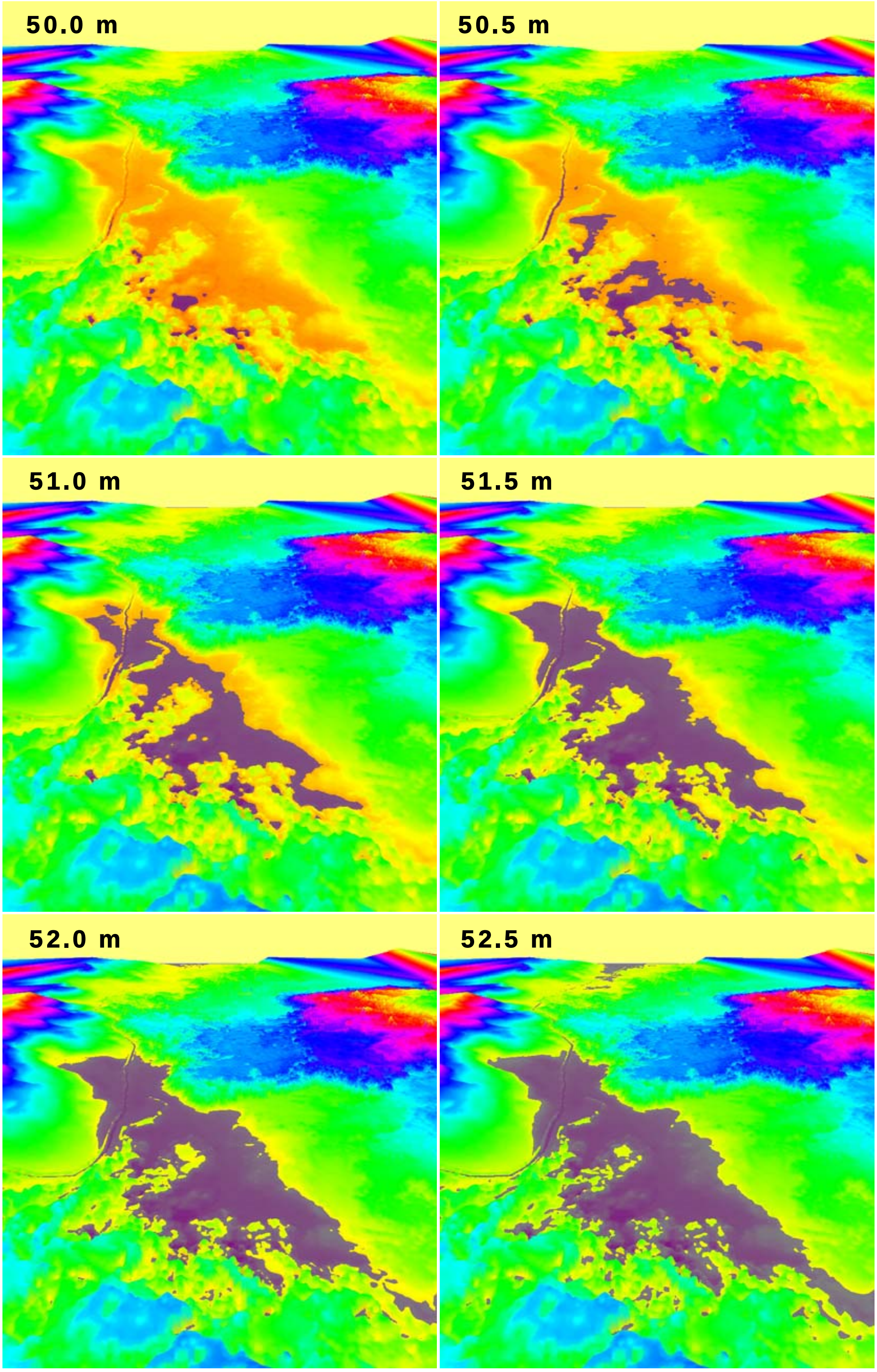


Figure 17. 3-D view of Lake Condah and southern section of Condah Swamp, showing land inundated at 50 m to 52.5 m elevations. View is to the North. Vertical exaggeration is x10. Colour shading represents elevation gradient. Views extend to the most northern extent of the 2005 DEM coverage. Northeast and northwest corners have no elevation data.

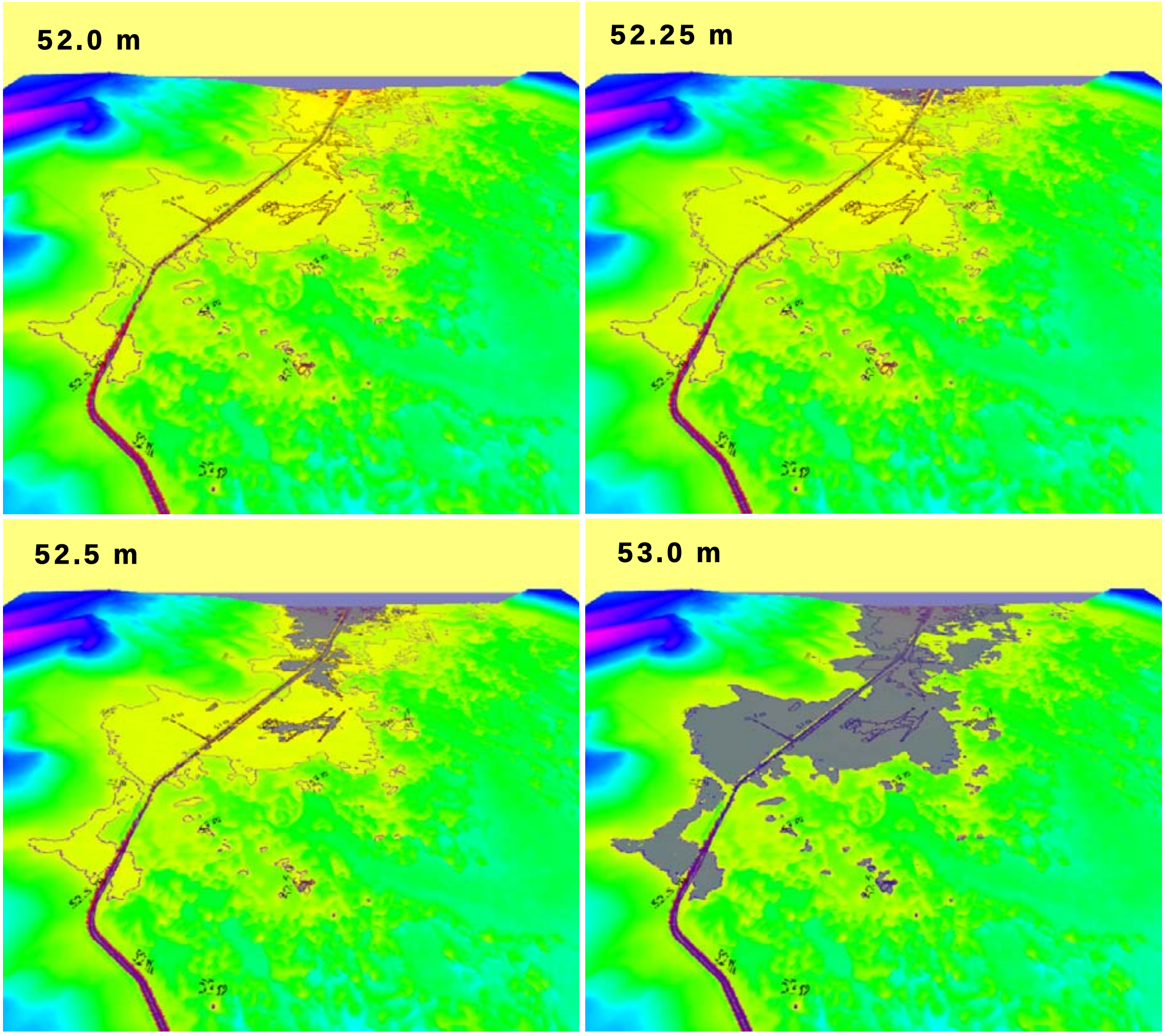


Figure 18. 3-D views of southern section of Condah Swamp, showing land inundated at 52 m to 53 m elevation. View is to North. Vertical exaggeration is x10. Colour shading represents elevation gradient. Northeast and northwest corners have no elevation data.

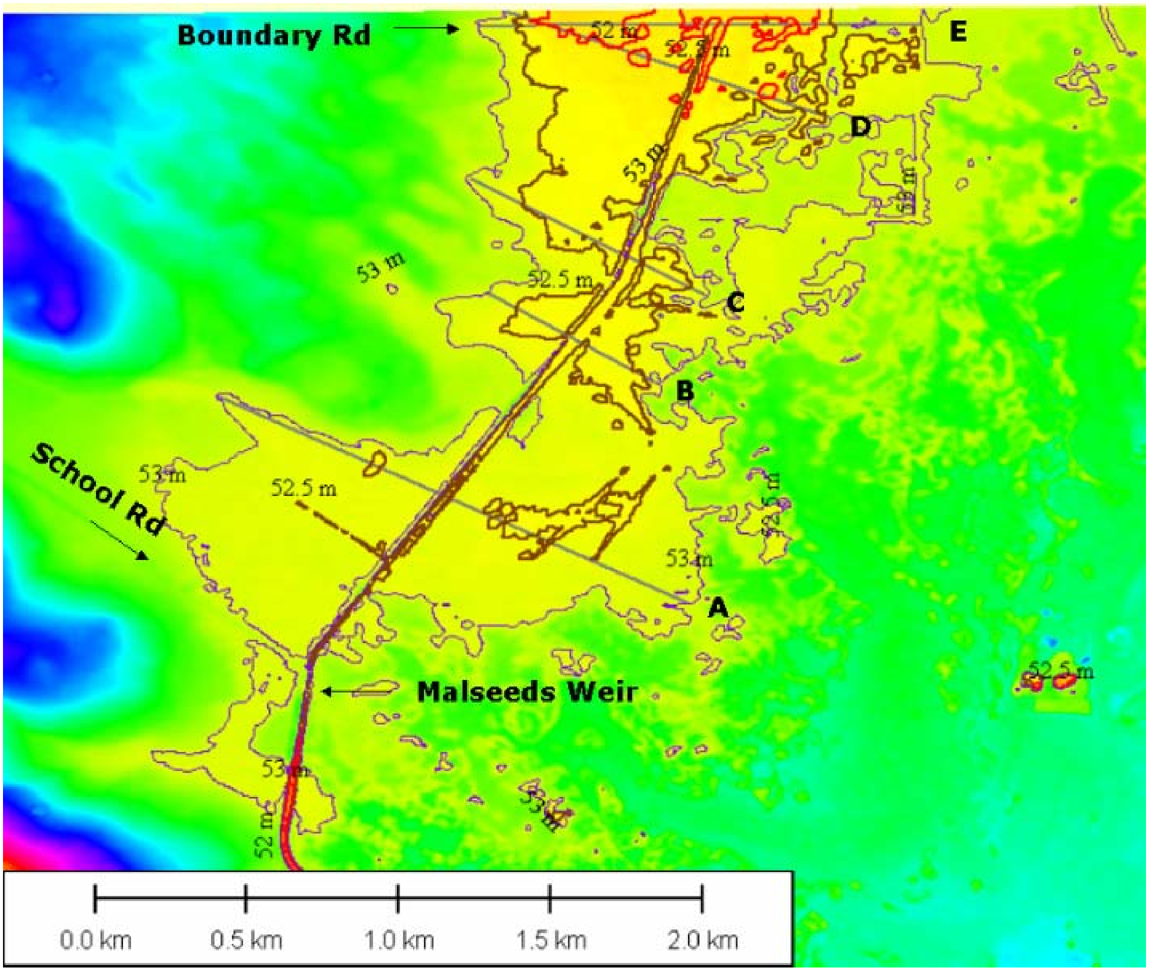


Figure 19. Southern section of Condah Swamp, showing 52 m (red), 52.5 m (brown) and 53 m (purple) contours derived from 2005 DEM. The five labelled lines are transects used to determine the drain overtopping elevations. North is vertical. Colour shading represents elevation gradient. Northern extent of map is limit of DEM data.

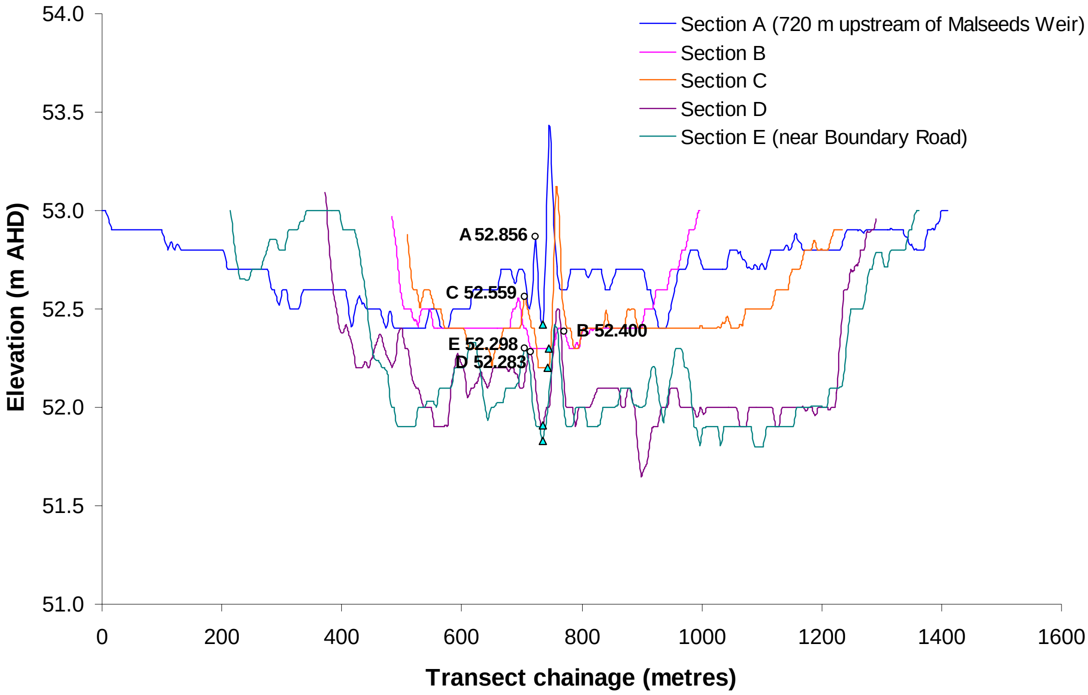


Figure 20. Cross-sections across the southern area of Condah Swamp. Sampled at points where drain levee was lowest. View is left to right looking downstream. Labelled points indicate possible levee overtopping levels. Blue triangles are lowest point in drain (water surface). Derived from 2005 DEM.

3.3 North-South transects through Lake Condah

3.3.1 Lake Condah bed

Four North-South trending transects were run along paths that approximately followed the deepest parts of the main sections of the Lake, in order to indicate the variation in bed levels (Figure 21). In general, the deepest parts of the Lake are found on the western side of the Central and Southeastern sections of the Lake (Figure 22). Most of the Northern and all of the Western sections of the Lake are higher than 50.6 m AHD. At a water level of 50.9 m AHD, most of the inundated areas in these sections are <0.3 m deep. At 50.9 m AHD, the Central and Southeastern sections contain significant areas of water 0.5 m and deeper.

3.3.2 Condah Drain

Transects were run along the Western and Eastern banks of the Condah Drain, as it passes through Lake Condah (Figure 21). The transects followed the highest points of the spoil banks/levees flanking the Drain. These banks have many breaches (low points) along their lengths. Both banks allow good connection with the Lake at a level of 50.9 m, and the Eastern bank allows a connection at 50.6 m (Figure 23).

One possible way of holding water in Lake Condah would be to build levee banks along the Eastern side of the Condah Drain and around any gaps between the Lake and the Drain, and improve the performance of the existing Offtake Weir. Ruge (2004, p. 33) reported that the Water Restoration Sub-Committee, at its meeting on 3rd June 2004, considered and rejected this option as “unsatisfactory and compromising the Lake”. This is a reasonable assessment, as this approach would require a bank around 1,800 m long and up to 2 m high in order to isolate the Lake from the drain at the target winter level of 52.4 m AHD (Figure 23).

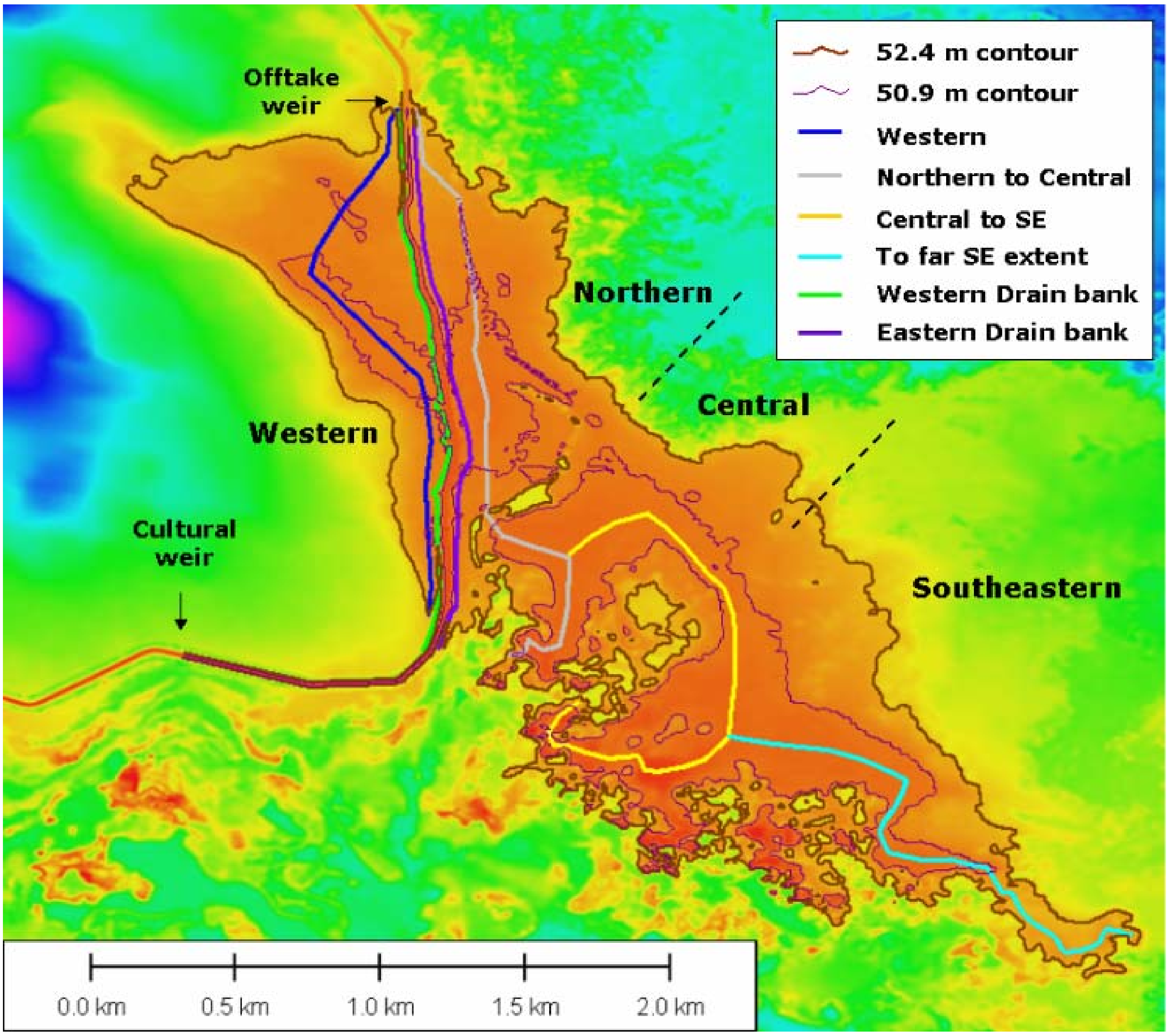


Figure 21. Lake Condah showing location of transects along the bed of the main sections of the Lake and along the banktops of the Condah Drain. North is vertical. Colour shading represents elevation gradient.

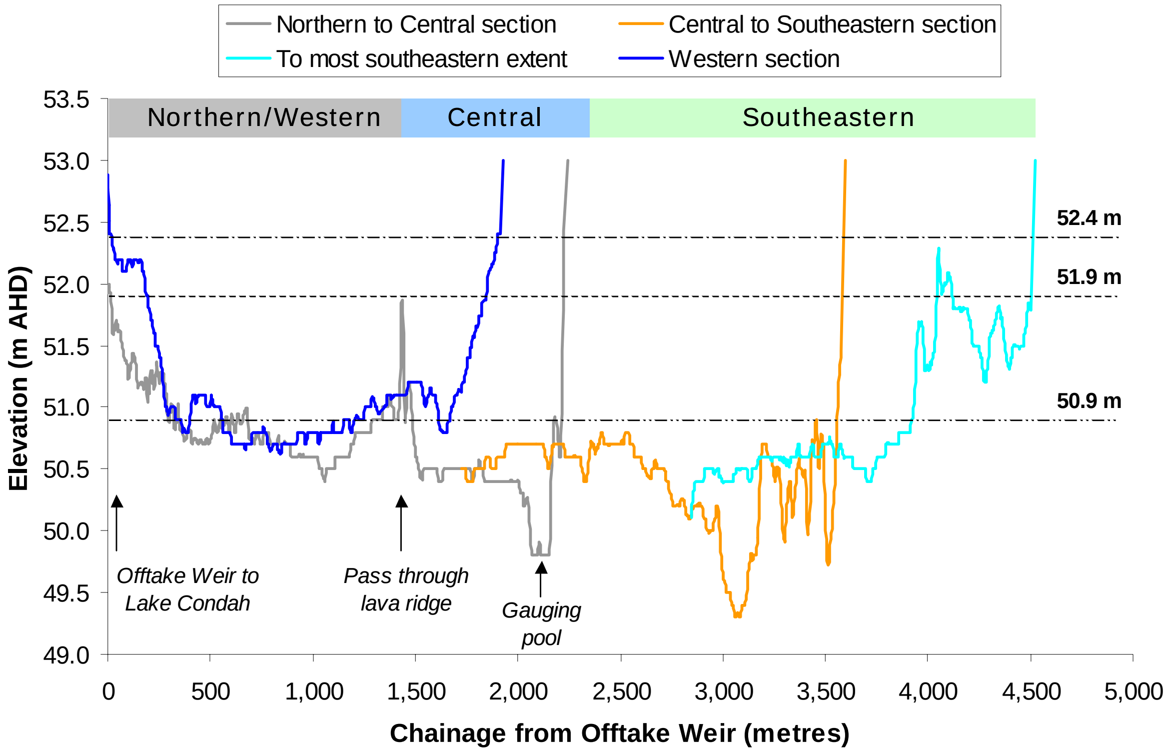


Figure 22. Lake Condah bed profiles through three main sections of the Lake. Three water levels that have previously been suggested as suitable for rehabilitation of the Lake are also shown. Derived from 2005 DEM.

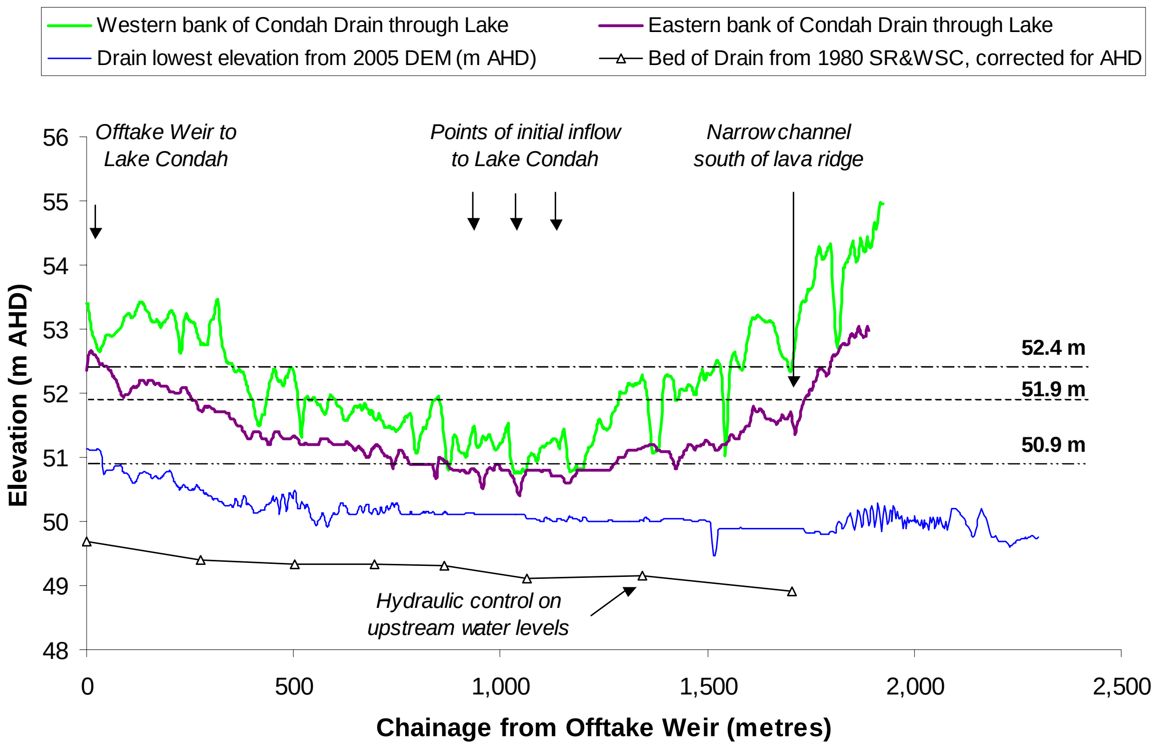


Figure 23. Profiles along the banks, surface and bed of the Condah Drain through Lake Condah. Bank and drain surface levels derived from 2005 DEM, bed levels from 1980 SR&WSC Plan, with 0.4 m added to adjust to the 2005 DEM datum. Above 50.9 m, water can flow freely from the Drain to the western and eastern sections of the Lake.

3.4 Lake Condah sill levels

3.4.1 Internal Lake sills

The four main sections of Lake Condah are separated by sills (Table 7, Figure 24). The first section of the Lake to receive water is the Northern section, followed by the Western section, with spill occurring through a low point in the bank of the Drain (Figure 25). The main sections of the Lake contain other internal sills that control water distribution within these sections (Figure 24, Table 8). Technically, it is possible for water to spill from Condah Drain into the Northern and Western sections of the Lake while the Central and Southeastern sections stay dry. However, this does not occur under the current arrangement, because at relatively low discharges in Condah Drain the diversion channel transfers water from the Offtake Weir through the Northern section and into the Central section of the Lake. The diversion channel spills back into the Northern section of the Lake at 50.91 m AHD, so all the main sections of the Lake are connected at this level.

Table 7.
Levels of main sills dividing the main sections of Lake Condah.
Source: 2005 DEM.

Sill	Sill level (m AHD)
Drain to Western	50.85
Drain to Northern	50.60
Northern to Central	50.91
Central to Southeastern	50.75

Table 8.
Levels of internal sills to various parts of Lake Condah.
Source: 2005 DEM.

Sill	Sill level (m AHD)
Lower to upper part of Western section	51.10
Pool where gauge is located	50.40
First sinkhole west of pool where gauge is located	50.80
Second and third sinkhole west of pool where gauge is located	51.60, 51.76
Mapped sinkholes in Southeastern section	50.80, 51.00
Depression on NW corner of Southeastern section	50.75
Depression on S side of Southeastern section	51.60
Depression on SE side of Southeastern section	50.74
To far SE extent of Lake	52.00
Flat area on southern side of Drain between Lake Condah and site of cultural weir	52.87

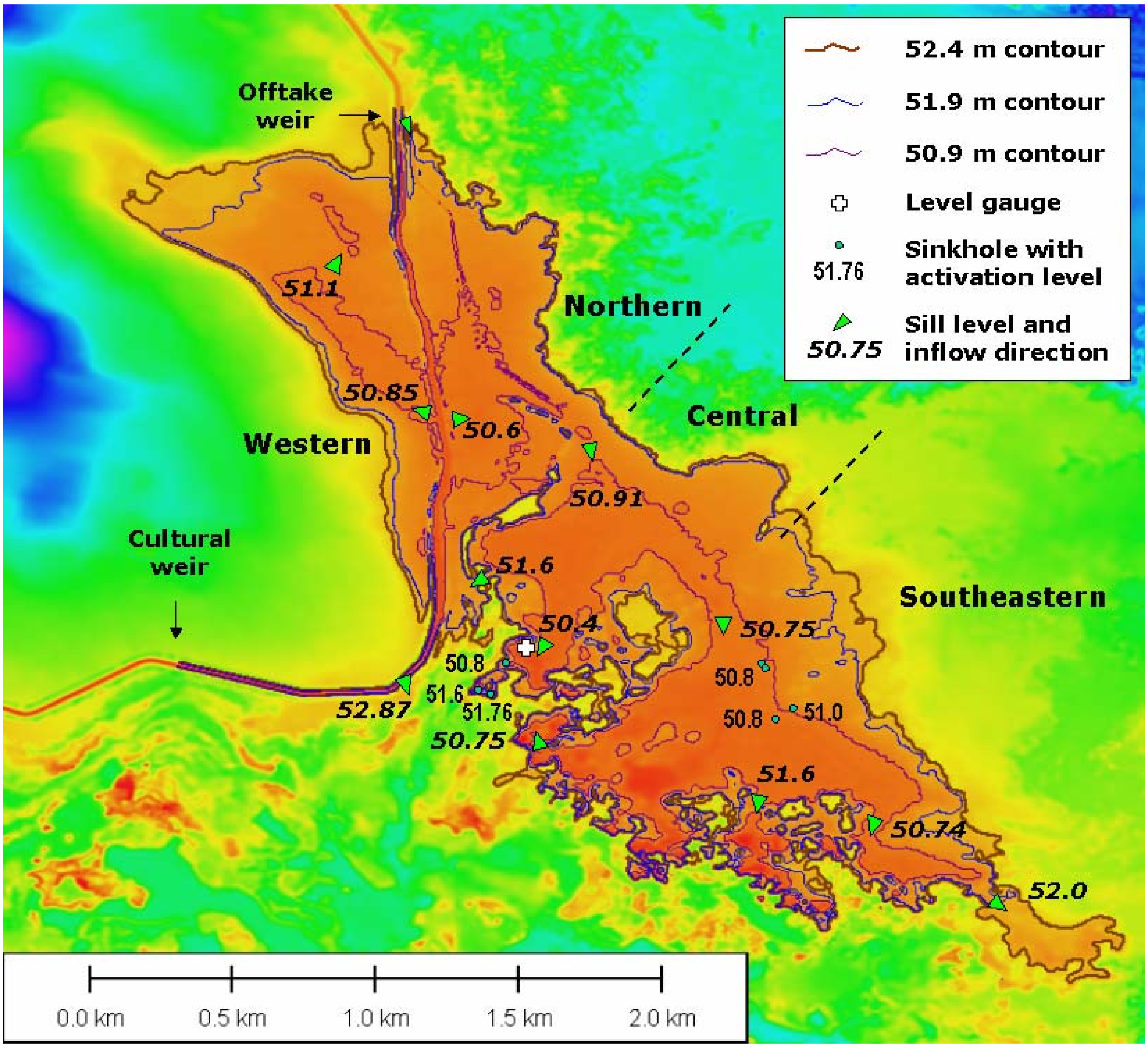


Figure 24. Lake Condah showing sills on bed to various parts of the Lake, and sinkholes with lake levels at which they become inundated. Sill levels from 2005 DEM. Sinkhole locations as identified on 1:5000 Vicmap Lake Condah Plan. North is vertical. Colour shading represents elevation gradient.

3.4.2 Drainage of Lake Condah to Condah Drain

In association with deepening of the Condah Drain through Lake Condah to Darlot Creek in 1954, several channels were cut into the lake bed to assist with draining (Ruge, 2004, p. 13). Ruge (2004, p. 34) referred to the lake bed being "*artificially drained to a height of 50.5 AHD (1980 SR&WSC Contour Map datum)*, and that (p. 22) "*There are at least five areas on the Lake where it was drained to an approximate 50.5 AHD level or less, in1954 and reinforced in 1990*". The 50.5 m elevation referred to by Ruge (2004) is equivalent to 50.9 m AHD on the 2005 DEM. The 2005 DEM indicates that the Northern section of the Lake will drain to 50.6 m AHD, and the Central and Southeastern sections will drain to 50.91 m AHD. However, note that Central and Southeastern sections will pond a considerable extent of water at 50.9 m (Figure 24).

Figure 25. Low point in Condah Drain bank allowing spill into the western and northern sections of Lake Condah. View to west. Photo: C. Gippel, 19/07/2006.

One of the Lake drainage channels passes on a Northeast to Southwest bearing through a narrow gap in the sinuous lava ridge, joining the Central section of the Lake to the flat on the eastern bank of the Drain, where it starts to bear to the southwest (Figure 26). This drain was obviously one of the five areas referred to above by Ruge (2004), as one of the photographs in Ruge (2004, p. 37) is captioned "*The East-West drain joining the Main Drain. This drain empties the southern end of the Lake to a height of 50.5 AHD, utilising a gap in the Lava ridge*". This reference to an elevation of 50.5 m derives from a single point in one of the transects across the Lake on the 1980 SR&WSC Plan (Peg 16 to Peg 105). The point is annotated "Bed of Drain". The problem with inferring that this height is the sill level of the drainage channel is that the Peg 16 to Peg 105 transect follows a straight line from the far eastern shore of the Lake to the western bank of the Condah Drain, and the surveyor was not necessarily intending for this transect to pass through the sill of this drain (i.e. the highest point of the bed of the drainage channel between the Lake and the Main Drain. Indeed, it would have been coincidental if it did. A transect and cross-sections along the drainage channel taken from the 2005 DEM (Figure 27, Figure 28) reveals that in fact, the SR&WSC transect more likely passed through the point of lowest elevation on the bed of the channel. The 2005 DEM suggests that this level is 51.0 m, which is slightly higher than that measured by the 1980 SR&WSC survey, but within the expected levels of accuracy. The 2005 DEM transect reveals that the sill level of this drainage channel is currently 51.6 m AHD (Figure 27). So, the Central section of the Lake ultimately drains around the eastern side of the lava ridge, not through this gap in the ridge. It is possible that the drainage channel was once deeper than 51.6 m, but with time it has filled with sediment and become less effective.

Figure 26. Lake drainage channel passing on a northeast to southwest bearing through a narrow gap in the sinuous lava ridge. View to southwest from Lake to Condah Drain. Photo: C. Gippel, 19/07/2006.

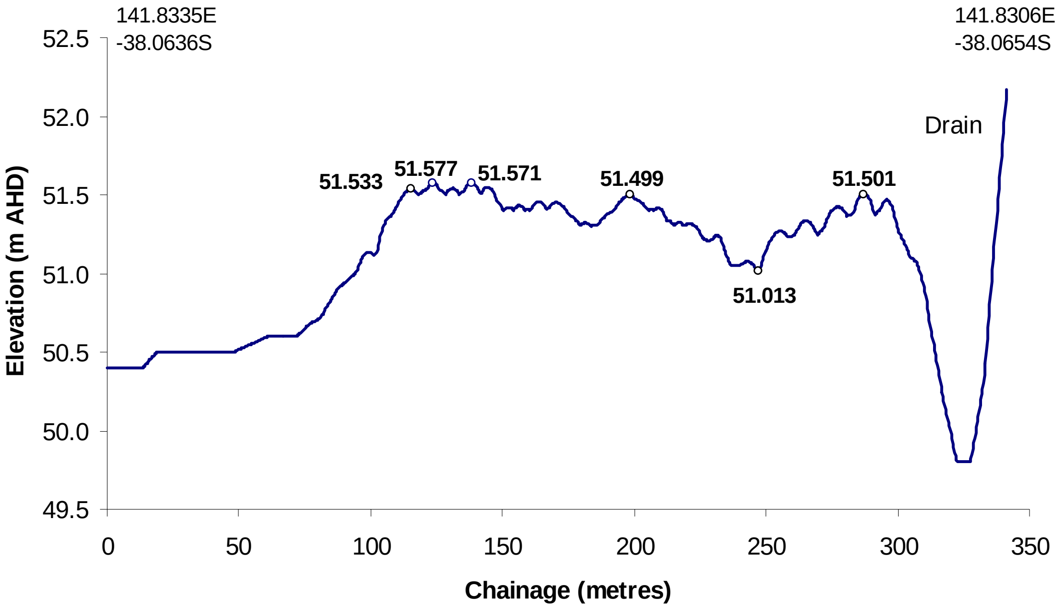


Figure 27. Long profile of drainage channel from Central section of Lake Condah to Main Drain. Derived from 2005 DEM. The SR&WSC Plan gives a single spot height of the bed of the drain at 50.5 m, which corresponds with the location of the low point (51.013 m) on the 2005 DEM.

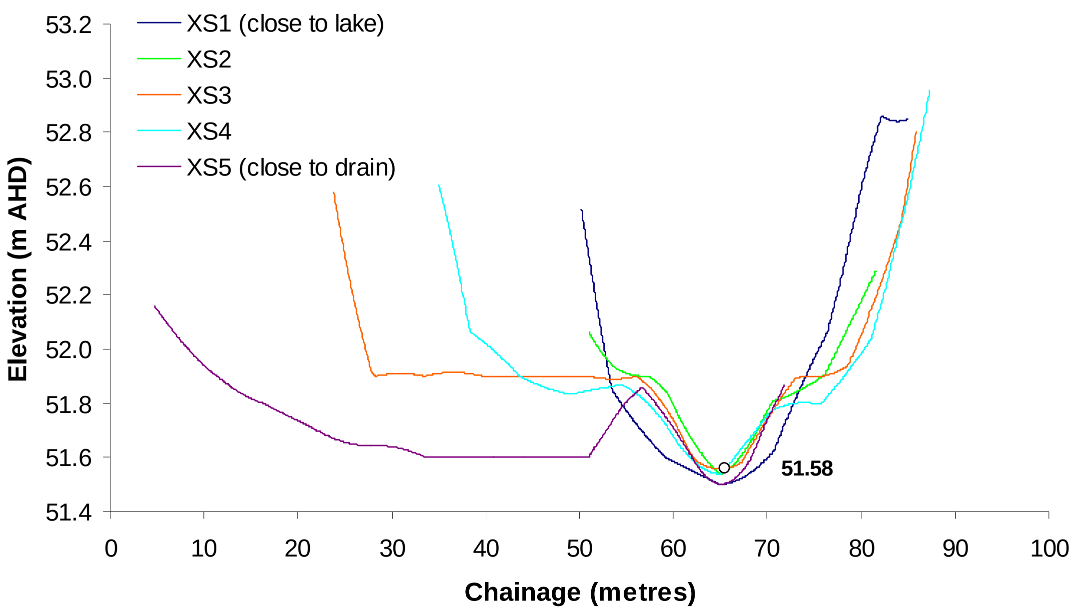


Figure 28. Cross-sections of drainage channel from Central section of Lake Condah to Main Drain. Derived from 2005 DEM.

3.5 Condah Drain flow rate and Lake Condah inundation levels

3.5.1 Recorded Lake levels

Lake water levels were recorded from 16/02/1988 to 10/03/1993 (Gauge No. 237600) (Figure 29). These data (Figure 30) were supplied by Thiess Services. The Victorian Water Resources Data Warehouse (http://www.vicwaterdata.net/vicwaterdata/) indicates that the gauge is levelled relative to an AHD benchmark established on a rock on the left side at the end of the walkway. RWC (1989) published data for the first year of observations. These values generally correspond with those supplied by Thiess, except for the early part of the inundation event in August 1989, and the slightly different gauge zero. The gauge zero is set at 49.1 m, but this simply corresponds to the bottom of the gauge well – the pool itself is deeper than this. Neville Carracher (Thiess Services, Hamilton, pers. comm., 25th Sep 2006) is of the opinion that the datum used for the gauge most likely corresponds to that used for the 1980 SR&WSC Plan.

There is a strong relationship between discharge at Myamyn and Lake Condah water levels (Figure 30). Care is required in interpreting this relationship because the hydraulics of the inflows to Lake Condah from Condah Drain were altered when a weir was constructed at the northern end of the Lake, some time in 1990, in order to divert flows from Condah Drain into Lake Condah (Ruge, 2004, p. 15) (Figure 31). A Rural Water Commission Memo from Neville Carracher (Hamilton Office, now Thiess Services) to John Oates, dated 18/08/1992 indicated that head and tail gauges were installed on the weir on 15/11/1990. The memo reported 21 individual readings (spaced approximately monthly) of gauge height and discharge to Lake Condah between commissioning of the gauges and August 1992

Figure 29. Gauge No. 237600 located on deep pool in the central section of Lake Condah. View to south. Photo: C. Gippel, 19/07/2006.

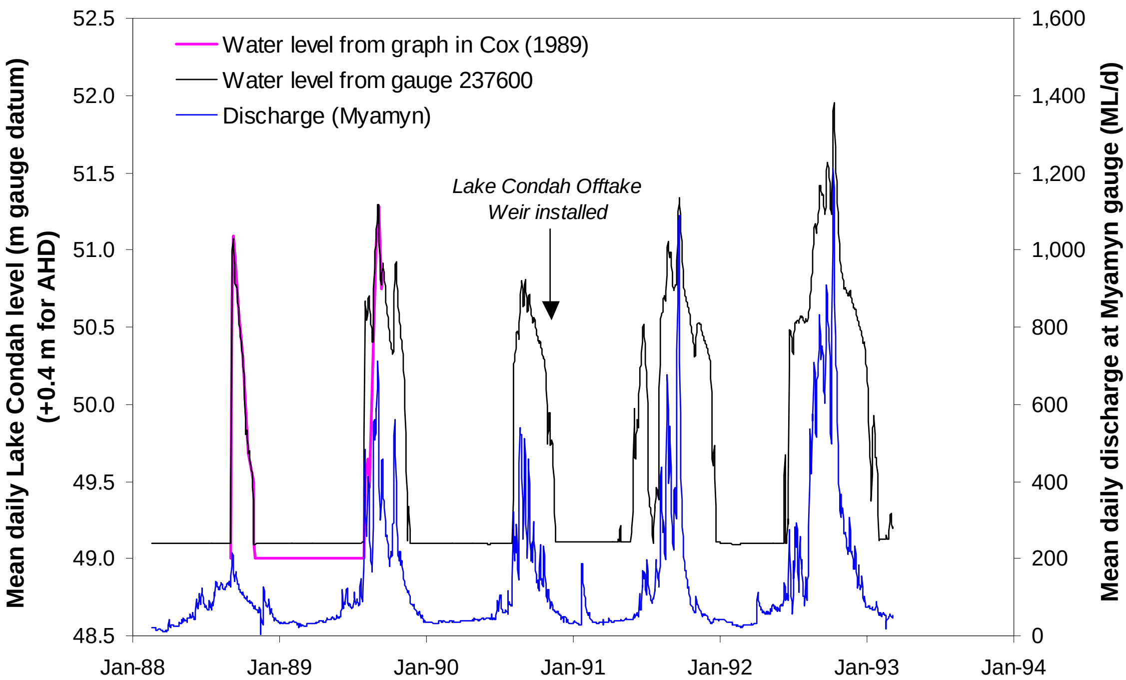


Figure 30. Time series of observed Lake Condah water levels and discharge at Myamyn for the same period. Cox (1989) refers to RWC (1989), a Rural Water Commission Memo by Cox.

Figure 31. Weir constructed at the northern end of Lake Condah, some time in 1990, in order to divert flows from Condah Drain into Lake Condah. Flow is right to left. Photo: C. Gippel, 19/07/2006.

Ruge (2004, p. 15) reported that the first trial flooding of Lake Condah by diverting water from the weir took place beginning on 01/11/1990. Ruge (2004, p. 15) also reported that the trial was a failure, with the Lake level falling rapidly. This outcome was explained alternatively by vandalism of the weir and the weir being ineffective. Examination of the Myamyn discharge records (Figure 30) reveals that on 01/11/1990 the discharge was 119 ML/d and falling rapidly; on 15/11/1990 when the first gauging was made, the flow in the Drain was down to 66 ML/d and by 22 November it was down to 60 ML/d (this was the tail of the recession of the winter/spring flood event that peaked at 540 ML/d on 23/08/1990). The gauging data from the diversion offtake indicates that the offtake was designed to operate when Condah Drain flows exceeded a threshold discharge of around 80 ML/d (Figure 32). Given that the flows in the Drain had fallen to the threshold level by 06/11/1990, it is not surprising that this trial watering of Lake Condah failed to inundate and maintain water in the Lake. The next opportunity for the weir to divert flows to the Lake was during a small event in the Condah Drain that peaked at 187 ML/d on 28/01/1991. This event exceeded the threshold for diversion, but it had no effect on levels in Lake Condah (Figure 30). Thus, it would appear that the weir was not functional at that time. Apparently the weir had been repaired/modified by May 1991, because at that time a flow of only 40 ML/d in Condah Drain caused Lake Condah to rise in level (Figure 30, Figure 32). Based on these observations, the Lake Condah inflow hydraulics can be split into the pre-diversion weir period (pre-April 1991) and the post-diversion weir period (post-April 1991).

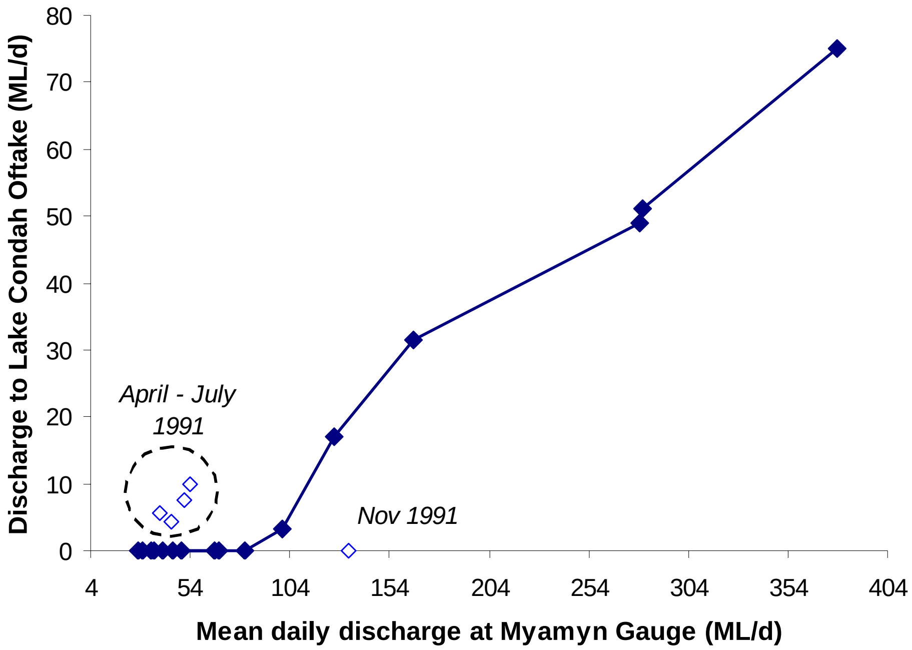


Figure 32. Gauged discharge to Lake Condah through diversion weir and discharge at Myamyn on the same day. Gaugings made monthly from November 1990 to August 1992. Outlying points are identified by open symbols.

Although there is scatter between the Myamyn discharge and Lake Condah level data (Figure 33), relationships (one for the pre- and one for the post-diversion weir periods) can be described between the maximum Lake level for any particular discharge at Myamyn gauge on the previous day (the 1-day lag allows for travel time and lake filling, and results in reduced scatter in the relationships). These relationships represent times when the Lake and the Condah Drain through the Lake were well connected, so they effectively describe the hydraulic relationship (i.e. rating curve) between discharge and water level in the Drain. The highest discharge associated with gauge zero (49.1 m gauge datum) in the pre-diversion weir period was 187 ML/d (on 28/01/1991, when the weir existed but was apparently not functional); this may represent a threshold discharge that has to be exceeded for flows to reach the gauge pool in the Central part of the Lake via overtopping of the Drain. After the diversion weir became operational this threshold dropped to 113 ML/d, although the diversion channel received flows when Condah Drain was as low as 40 ML/d (these flows apparently did not reach the gauge pool, or were insufficient to raise the pool level above the bottom of the gauge well).

The Condah Drain flow threshold for inflows to reach the Central part of Lake Condah (where the gauge is located) clearly fell after the diversion weir became functional (Figure 34). The 1988 data indicate a lower inundation threshold than applied during 1989 and 1991. Either the physical conditions were actually different (i.e. the sill was lower in 1988) or something changed in 1989 with the Lake gauging or Myamyn flow gauging procedure (i.e. either Lake levels were previously overestimated, or Myamyn flows were previously underestimated). This inconsistency cannot be resolved here, but in this report, the Myamyn flows and Lake levels recorded in 1988 are viewed with caution.

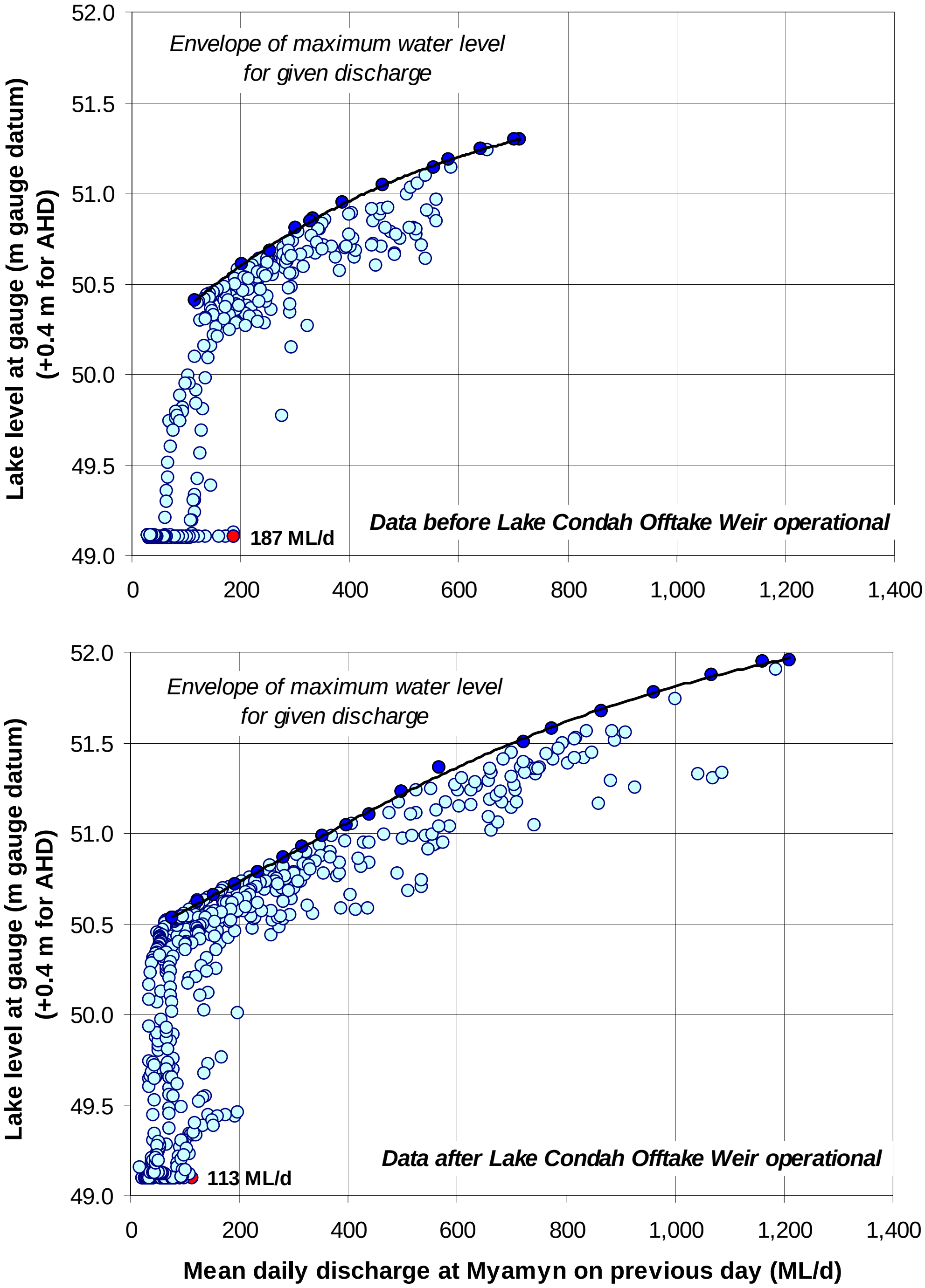


Figure 33. Relationship between observed Lake Condah water levels and discharge at Myamyn, for the pre- and post-diversion weir periods.

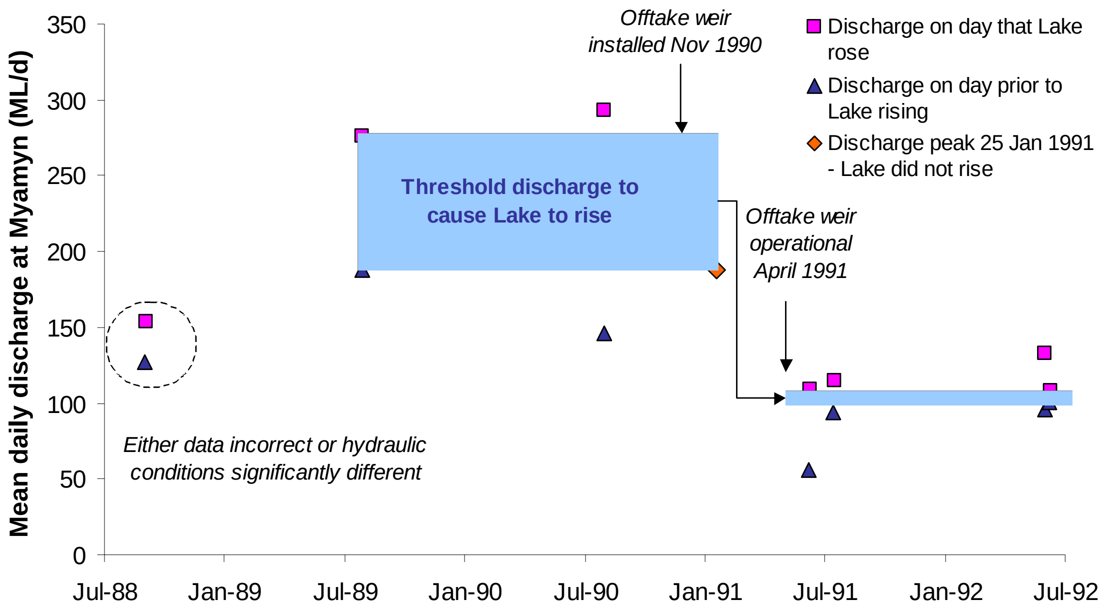


Figure 34. Discharge at Myamyn the day before and the day of initiation of water level rises from gauge zero for the five Lake Condah inundation events over the period 1988 to 1992.

When the diversion weir was installed, a shallow channel was excavated from the offtake to the eastern side of the sinuous lava ridge to direct water to the Central part of the Lake (where the gauge is located) (Figure 35). This channel has a low levee on either side, constructed from the spoil. The height of this levee was measured from the 2005 DEM to be at 50.9 - 51.0 m AHD elevation. Thus, it would be technically possible for water to flow from the diversion weir, through the channel in the Northern section of the Lake to the Central section of the Lake, with the Northern section of the Lake remaining dry. When water levels at the Lake gauge pool exceeded 50.9 m AHD (the height of the levee on the diversion channel), water would spill back into the Northern part of the Lake, and if Condah Drain was at a level lower than this, water would flow west across the Northern part of the Lake and return to the Drain. If Condah Drain level was high and rising, then the Lake would also rise at the same level, because the sills would be overcome and the Drain and the Lake would be perfectly connected hydraulically. Interestingly, the Northern Lake levels associated with these Drain discharge thresholds were 50.9 m AHD (50.6 m gauge datum) for both periods (Figure 33). This corresponds with the level of the sill between the Drain and the Central section of the Lake where the gauge pool is located. In the pre-diversion weir case, the Drain and Lake would be connected at 187 ML/d, and in the post-diversion weir case, at 113 ML/d in the Drain, the Central section of the Lake would be spilling back into the Northern section of the Lake and then draining back to the Condah Drain. It would be expected that the pre-diversion weir and post-diversion weir rating curves between Condah Drain discharge and Lake Condah water level (Figure 33) are the same for discharges above around 200 ML/d. In fact, this is not the case. The reason for this inconsistency is unclear.

Figure 35. Channel excavated from the offtake weir to the eastern side of the sinuous lava ridge to direct water to the central part of the Lake. View to south from near the offtake weir. Photo: C. Gippel, 19/07/2006.

3.5.2 Simple hydraulic model of Condah Drain through Lake Condah

In order to predict lake levels under the current hydraulic conditions, it is necessary to model the hydraulics of Condah Drain through Lake Condah, i.e. develop a rating relationship between discharge and water surface elevation in the Drain. Such a relationship can be used to predict the threshold flow required to overtop the sill between the Drain and the Lake, and thus initiate inundation; the relationship can also be used to predict Lake level as a function of discharge in the Drain. A relationship is also required for the Drain under simulated future conditions, after a weir is constructed, so that future Lake levels can be predicted as a function of flows in the Drain. Such rating relationships were derived for the pre-diversion weir and post-diversion weir periods using empirical Lake water level and Myamyn flow data (Figure 33) - an alternative way of deriving a rating curve is to model the hydraulics of the Drain itself.

The 1980 SR&WSC Plan included several spot heights for the bed of Condah Drain. A transect along the Drain taken from the 2005 DEM provided a water surface profile, although the levels to be quite variable, probably due to macrophytes (Figure 36). The mean slope of the bed of the Drain from downstream of the Offtake Weir through Lake Condah was determined to be 0.00031. The bed slope and the slope of the water surface were judged to be the same.

Six cross-section transects of Condah Drain were derived from the 2005 DEM (Figure 37, Figure 38). The location of the transects corresponded to points where the bed invert levels were provided on the 1980 SR&WSC Plan, except for cross-section E (Figure 39), the bed level of which was interpolated between that of cross-section D and F (Figure 37). The transect data from the DEM suggested a significantly higher bed level than indicated on the 1980 SR&WSC Plan, even after adjusting the 1980 SR&WSC Plan bed invert levels by +0.4 m to correspond with the 2005 DEM datum. This is probabaly due to macrophytes in the bed giving false high elevations on the DEM. To overcome this problem, the bed of each transect was adjusted by inserting the invert levels from the 1980 SR&WSC Plan (Figure 38). In each case, the bed was 5 m wide and about 1 m deeper than indicated on the DEM.

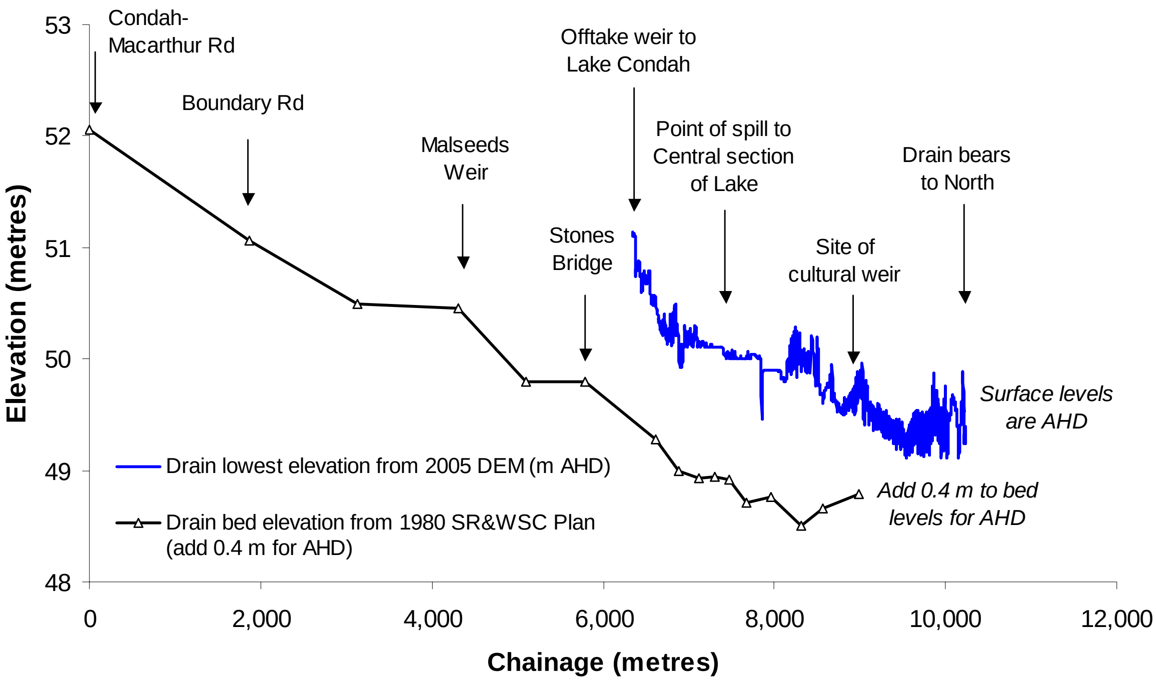


Figure 36. Long profile of Condah Drain from the southern section of Condah Swamp, through Lake Condah to where the Drain bears to the North. Bed elevations from 1980 SR&WSC Plan and elevations from 2005 DEM indicate the water surface, with macrophytes probably explaining the variations in level. Note that the 1980 SR&WSC Plan is apparently based on a datum 0.4 m lower than that of the 2005 DEM.

For each cross-section, a relationship between water surface elevation and discharge was determined using the Manning equation. For each cross-section the cross-sectional area and hydraulic radius were determined for 0.1 m elevation increments. A slope value of 0.00031 was used for all elevations. A variable Mannings n was used, ranging from 0.08 to 0.06 for 0 - 1 m depth (affected by macrophytes), 0.06 to 0.04 for 1 - 2 m depth, 0.04 - 0.035 for 2 - 3 m depth and 0.035 - 0.033 for depths 3 - 4 m and 0.033 - 0.029 for depths 4.0 - 5.5 m. (the same Mannings n values were used for each cross-section). These values of Mannings n were selected from the range of typical values given in Chow (1959). The constricted shape of cross-sections D and E strongly suggested that the channel in this area would act as the hydraulic control on inflows to the Lake, i.e. a backwater effect would be created from this area upstream. This was confirmed by the hydraulic analysis (Figure 40). The water heights at cross-section E were always higher than at cross-section C (Figure 40). Assuming a water surface slope of 0.00031, the levels for cross-section E were adjusted to predict elevation of the water surface at the Lake inflow point across a range of discharge (Figure 40).

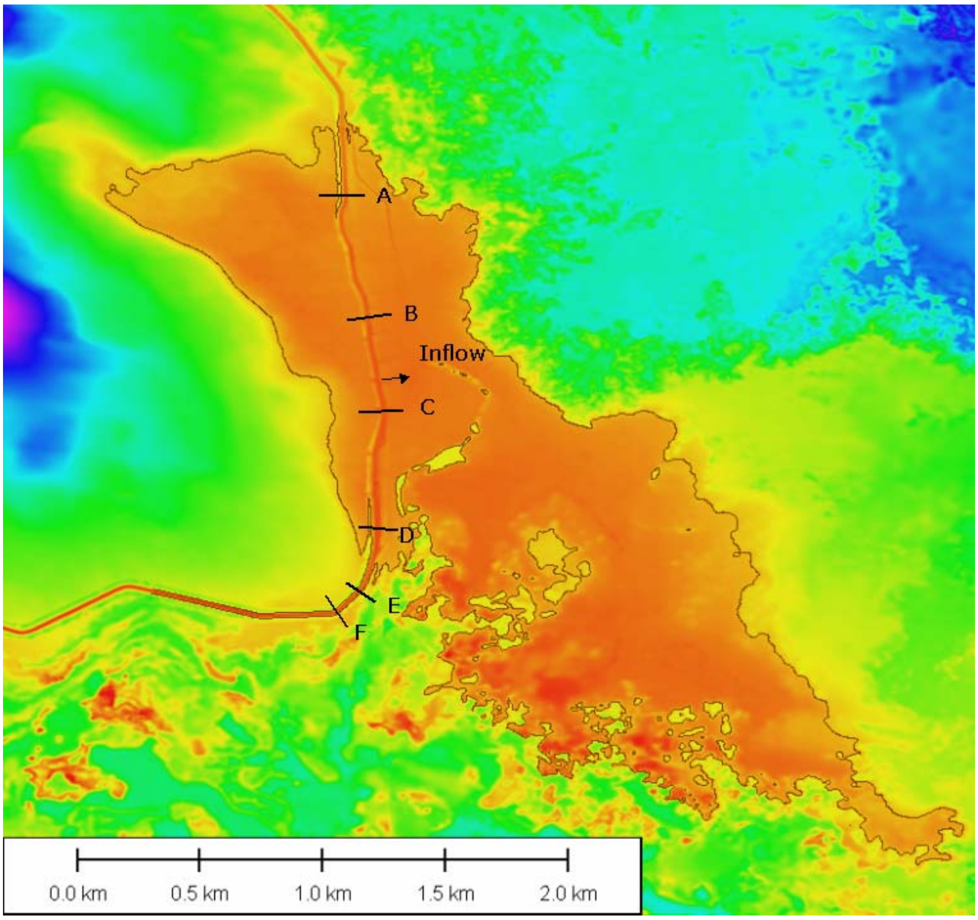


Figure 37. Location of cross-section transects on Condah Drain through Lake Condah.

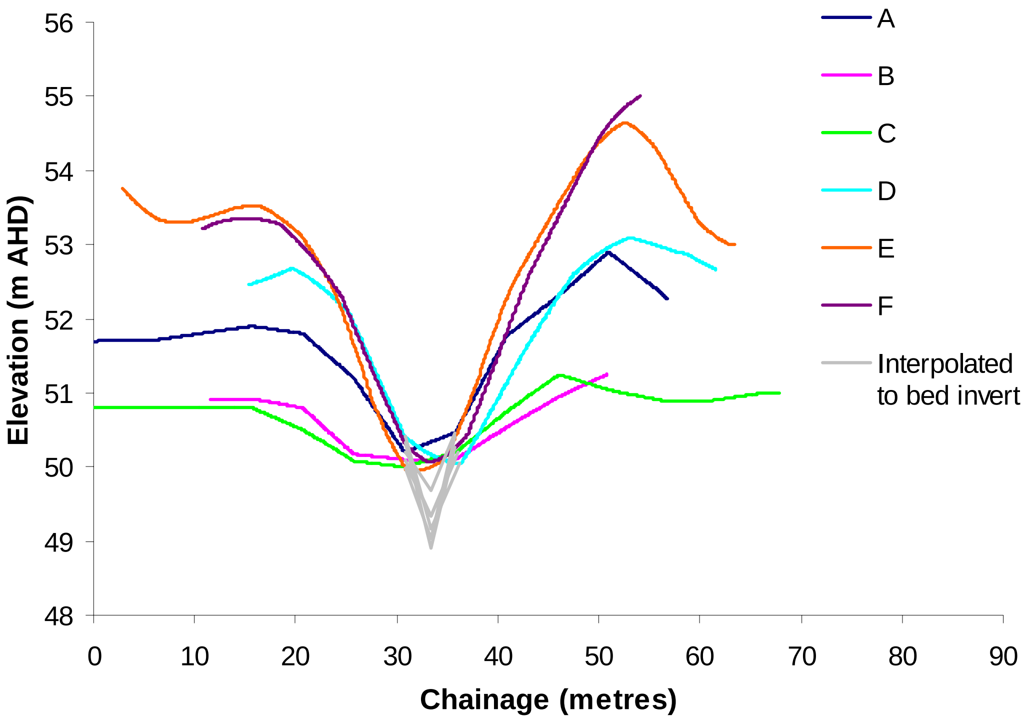


Figure 38. Cross-section profiles of Condah Drain through Lake Condah. Bed invert levels taken from 1980 SR&WSC Plan, adjusted by +0.4 m to give AHD. View is downstream.

Figure 39. Condah Drain in the vicinity of cross-section E. View to southwest. Photo: C. Gippel, 19/07/2006.

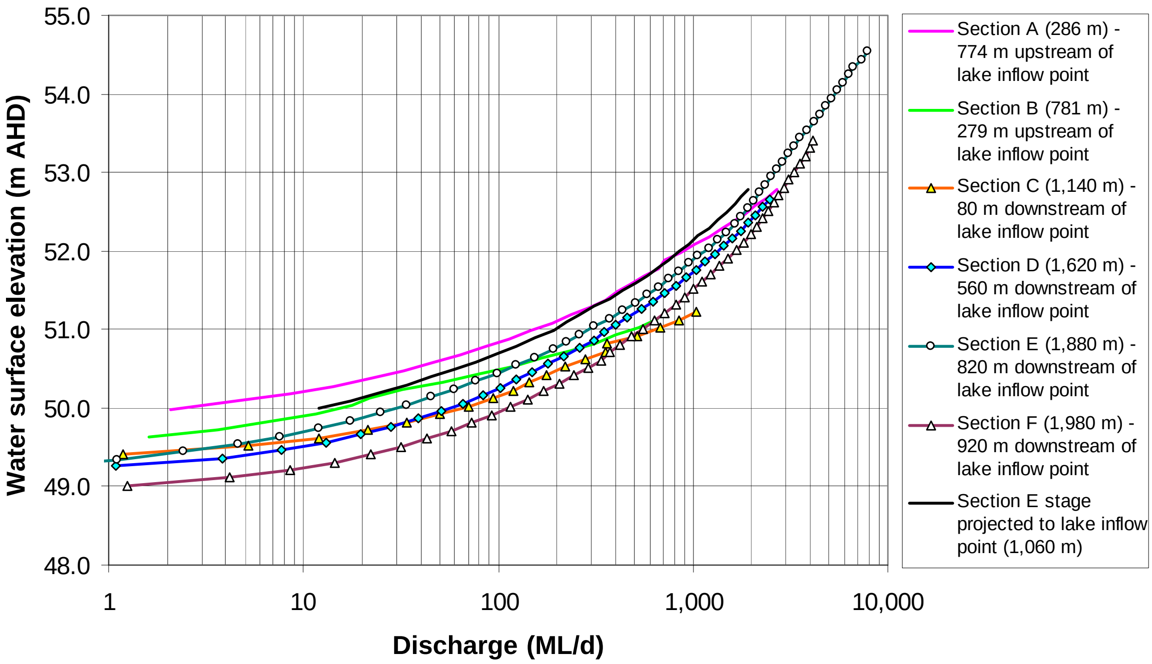


Figure 40. Modelled relationships between stage height and discharge for five cross-sections on Condah Drain as it passes through Lake Condah.

The hydraulic model for cross-section E was calibrated (by adjusting the Mannings n values) to fit the relationship derived from the empirical Lake Condah level and Myamyn discharge data (Figure 41). For the latter relationships (the derivation of which is depicted in Figure 33) the levels were adjusted upwards by 0.4 m to correct for AHD, and the discharge was adjusted upwards to account for the additional catchment area between Myamyn and Lake Condah. This was done using the relationship of Alexander (1971):

$$Q_Y = Q_X*(A_Y/A_X)^{0.7}$$

where,

Q_Y = flow at Lake Condah

Q_x = flow at Myamyn gauge

A_Y = catchment area at Lake Condah (measured at 630 km^2)

A_x = catchment area at Myamyn (measured at 585 km^2)

By way of confirmation, the daily flows for the period 1988 to 1992 predicted for Condah Drain at Myamyn and Lake Condah by a rainfall-runoff model developed for this project (detailed elsewhere in this report) were compared. The relationship was close to linear, with a coefficient virtually identical to that predicted by the equation of Alexander (1971).

As it was possible to get the two models to fit (Figure 41) using reasonable values of Mannings n, it can assumed that the curve is a reasonable representation of the relationship between flows in Condah Drain and the elevation of water in the Drain (and Lake Condah, when the level exceeds 51 m AHD). The 0.1 m difference between the pre-diversion weir and post-diversion weir curves (Figure 41) is reasonable for elevations less than around 51 m (the sill beyond which all parts of the Lake are connected), but not for elevations above 51 m. The reason for the difference is unclear and cannot be resolved here.

The current sill between the Northern section and the Central section of Lake Condah is 50.91 m. The hydraulic model-derived rating curve (Figure 41) indicates that the gauge pool will receive inflows from spill over the banks of Condah Drain when flow reaches about 150 - 190 ML/d at Lake Condah. Under 1991 - 1992 conditions, the Offtake Weir diverted water to the diversion channel at discharges lower than this, around 110 ML/d in Condah Drain at Lake Condah. This discharge resulted in a level of 50.9 m AHD (50.6 m AHD gauge datum) in the gauge pool. The diversion channel is currently overgrown with macrophytes, especially close to the Offtake Weir (Figure 35), so the threshold discharge for achieving inundation of the Lake to 50.9 m and above appears to be higher than 110 ML/d.

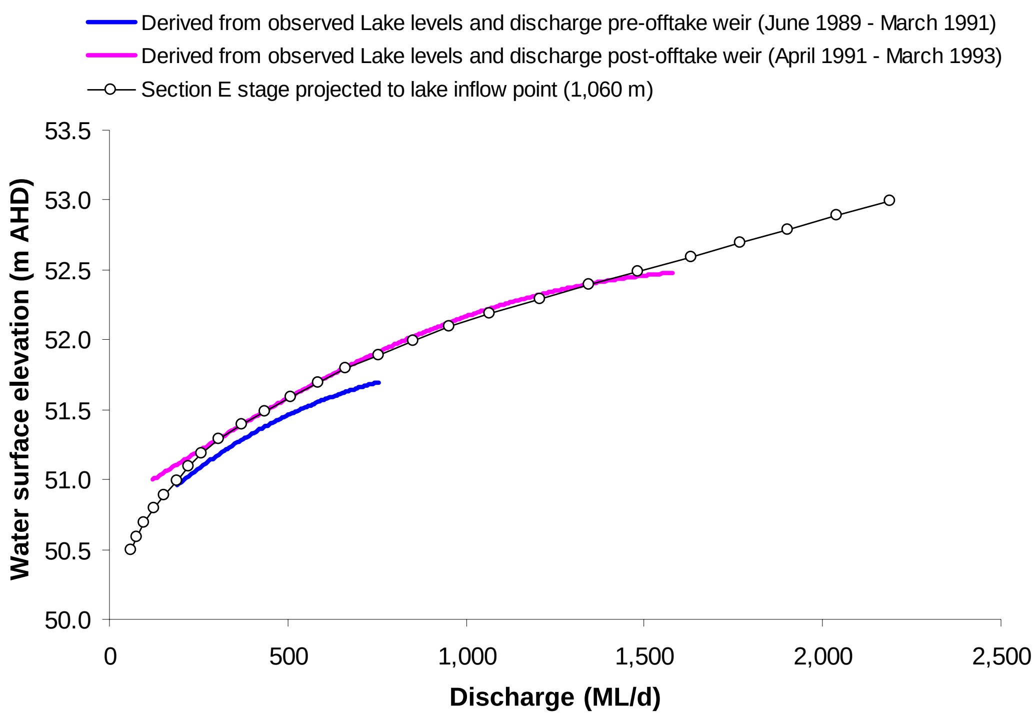


Figure 41. Relationship between stage height and discharge for Condah Drain, as predicted by observed Lake Condah levels and discharge at Myamyn gauge (these curves adjusted for additional catchment area between Myamyn and Lake Condah), and a simple hydraulic model of Condah Drain based on the Manning equation.

The hydraulic model depicted in Figure 41 was extended to the full range of modelled elevation, when water overtopped the cross-section at an estimated discharge of at 7,918 ML/d (Figure 42). The rainfall-runoff model developed for the Lake Condah catchment for this project (detailed elsewhere in this report) predicted that the March 1946 flood peaked at 9,874 ML/d. The field surveys of Coutts et al. (1978), plus field observations of debris suggests that the 1946 flood peaked at 55 m AHD (perhaps up to 0.5 m higher). Using 55 m AHD as the extreme high value, the rating curve was extended to cover the full range of discharge likely to be experienced through Condah Drain at Lake Condah (Figure 42). The relationships depicted in Figure 41 and Figure 42 were used to calibrate a full HEC-RAS model for Lake Condah (detailed elsewhere in this report).

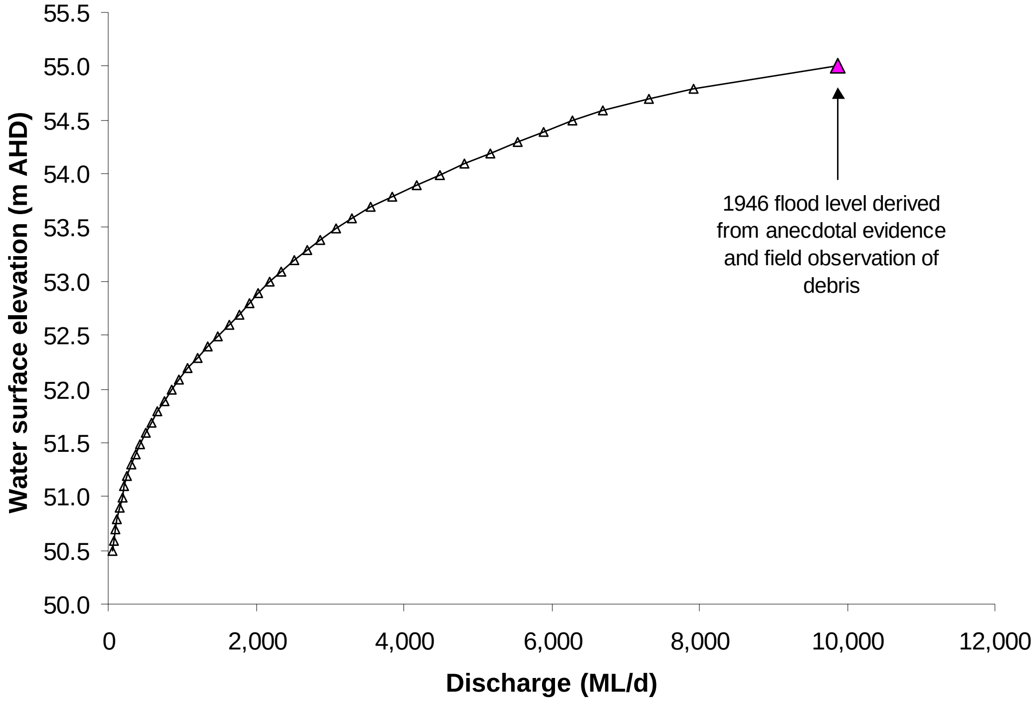


Figure 42. Modelled relationship between stage height and discharge for Condah Drain at Lake Condah. This relationship based on a simple Manning equation model for the presumed point of hydraulic control on Condah Drain, calibrated to fit the empirical water level data from Lake Condah.

3.6 Observed Lake Condah inundation patterns

3.6.1 Field inspection July 2006

During the field inspection of the Lake on 19th July 2006, standing water was present in the Northern section of the Lake – the water was in equilibrium with the elevation of the water surface in Condah Drain. Based on comparison with the contours, it is estimated that the level was around 50.9 m (Figure 43). The connection between the Northern and Central sections of the Lake was not investigated in detail, but it was apparent that the water level in the Central section of the Lake was lower than that in the Northern and Western sections of the Lake, so these sections were either hydraulically disconnected, or the connection was weak. Based on comparison with the DEM, it was estimated that the water level in the Central section was around 50.5 m (Figure 43).

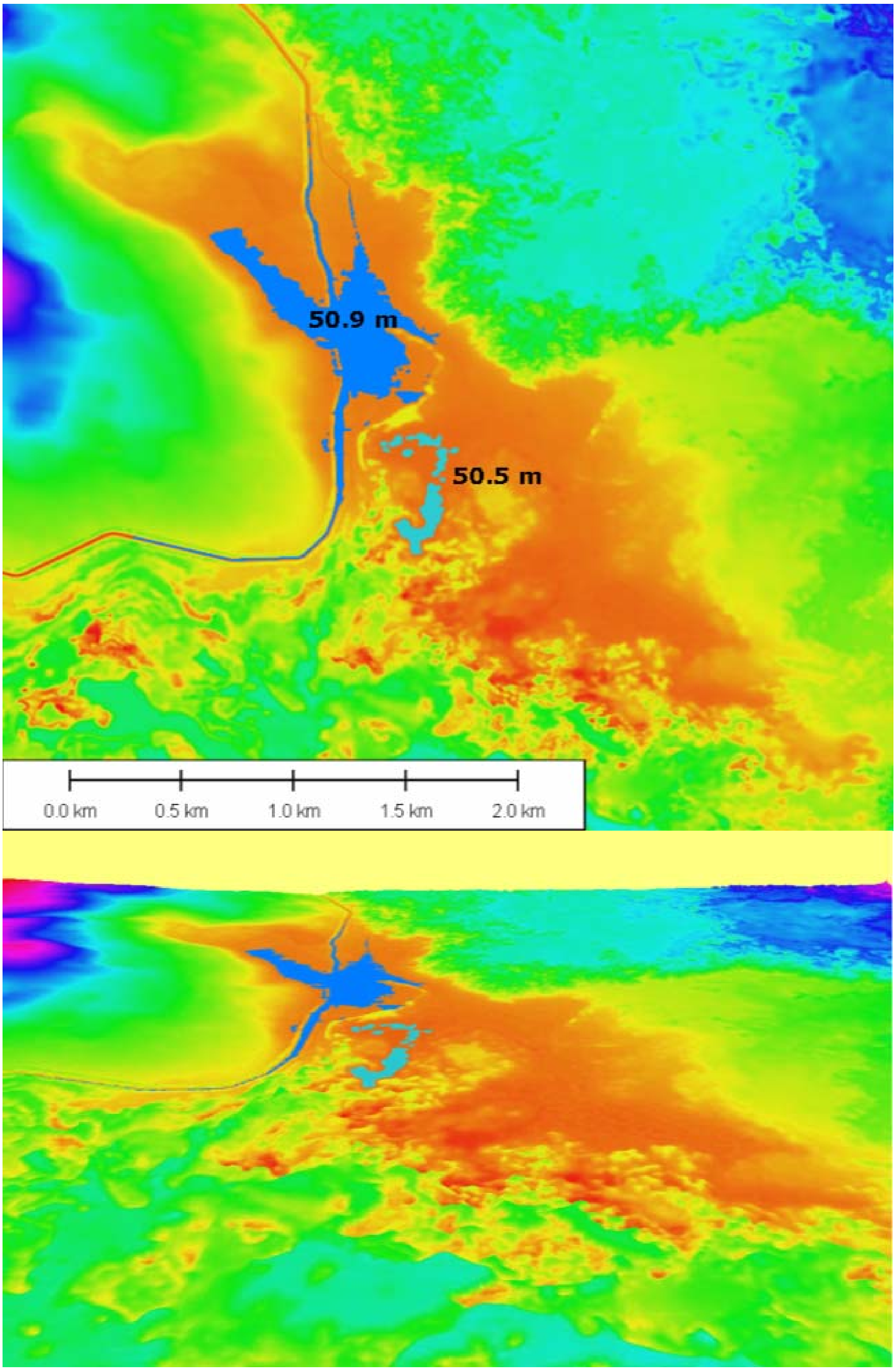


Figure 43. Plan and 3-D views of Lake Condah showing inundated area on day of field inspection, 19th July 2006. The wet Northern and Central sections of the Lake were apparently at different levels. North is vertical. Colour shading represents elevation gradient.

3.6.2 Available aerial photographs

Ruge (2004) included two oblique aerial photographs of Lake Condah, with approximate dates. The 2005 DEM was used to interpret the water levels apparent in these photographs. In the photograph dated some time in 2001, the main sections of the Lake are at different levels (Figure 44). The July 2004 photograph was taken at a higher lake level, when all the main sections of the Lake were connected (Figure 45). This height was interpreted from the DEM to be 51.25 m AHD. It was possible to almost exactly reproduce the image of the Lake in the photograph by mapping the Lake using Global Mapper, projecting the image to a 3-D view, and then rotating and stretching the image (Figure 45). Ruge (2004) suggested that for the July 2004 image, the approximate water depth was 1 m immediately north of the sinuous lava ridge and 1.3 m south of the ridge. These depths would appear to be over-estimated, because at 51.25 m the water depths in these areas are actually around 0.5 m and 0.9 m.

The 1947 Department of Lands and Survey aerial photomontage reproduced in Ruge (2004, p. 9) shows Lake Condah fully inundated (Figure 46). The pattern of inundation was interpreted from the DEM to correspond with 52 m.

Figure 44. Aerial photograph taken in 2001 (date unknown) showing Lake water at three different levels. Levels determined from comparison with 2005 DEM. Photograph taken from Ruge (2004, p. 42), credited to Glenelg Hopkins CMA. The Northern and Western sections are hydraulically connected to the Drain, while the rest of the Lake is disconnected.

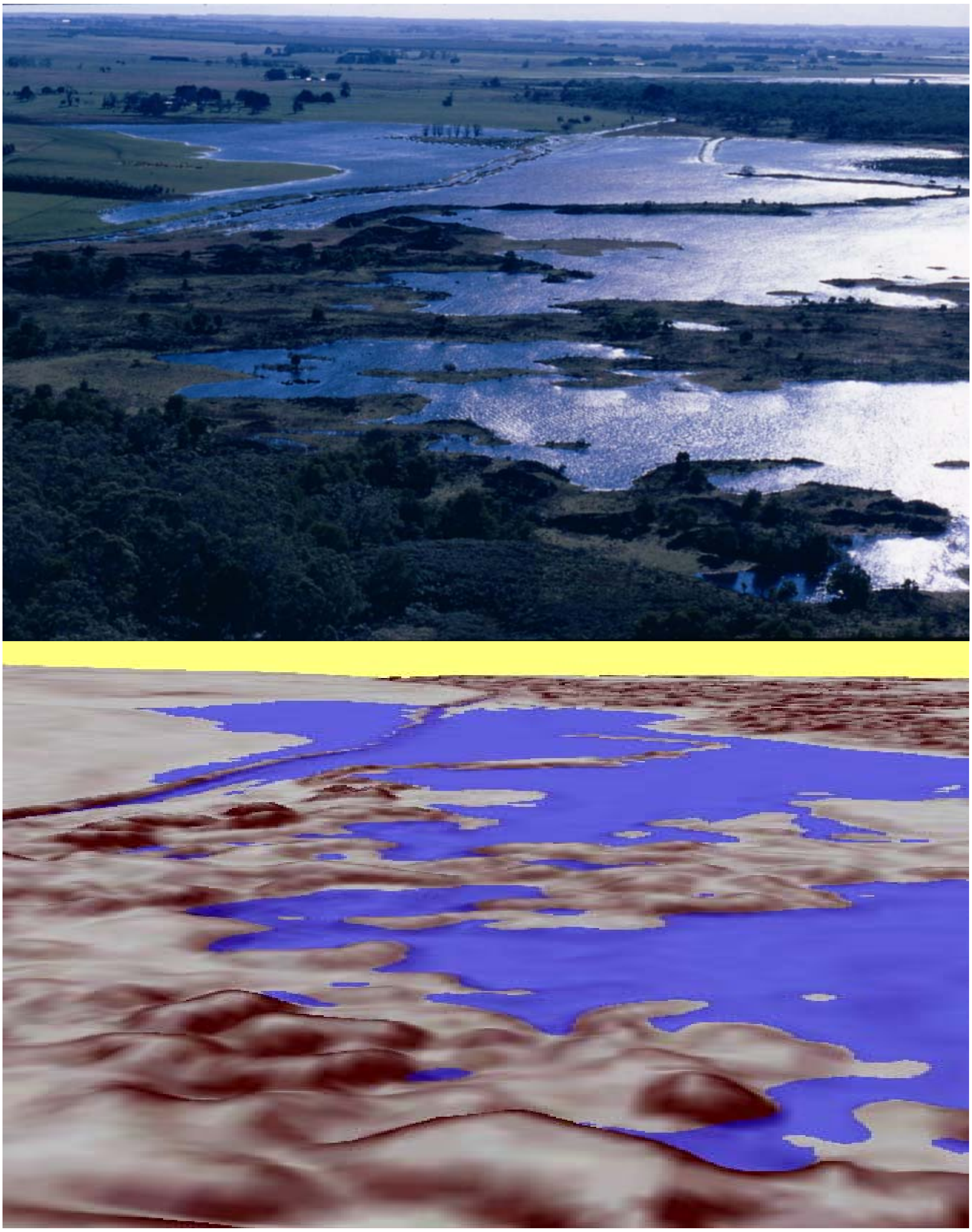


Figure 45. 3-D view of Lake Condah showing inundated area at 51.25 m as predicted by the 2005 DEM, compared to aerial photograph taken in July 2004. Note that parts of Condah Swamp (right distant view in photograph) are inundated. Photograph taken from Ruge (2004, p. 54), credited to Dept of Environment and Heritage.

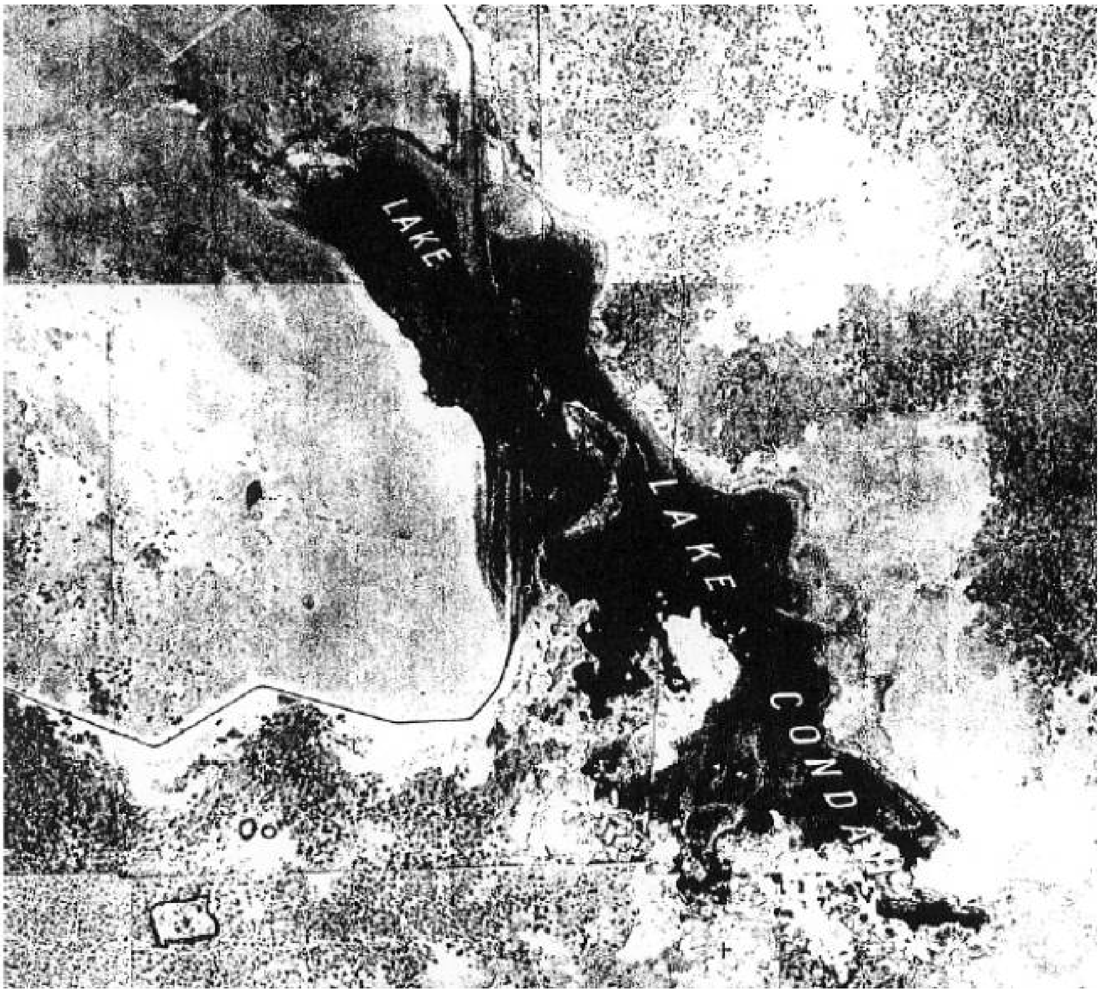


Figure 46. 1947 aerial photomontage of Lake Condah. Water level interpreted from DEM to be 52 m. Source: taken from Ruge (2004, p. 9). Original map marked as Department of Lands and Survey 1947, dated 4/11/1953. Obtained from the archives of Glenelg Hopkins Catchment Management Authority.

3.6.3 Anecdotal reports of Lake levels

Ruge (2004, p. 10) cited a quote from the late Mr. W.R. Malseed which was originally reported in the VFGA Submission on Lake Condah (1978): "There was permanent water in the northern end of Lake Condah to a depth of approximately 18" in depth over the period from 1933 until major draining operations in 1954". This suggests that the Northern section of the Lake was at a level of around 50.9 – 51.0 m AHD for this time. Interestingly, this corresponds with the level of the sill between the Northern and Central sections of the Lake (Figure 24), so the Central and Southeastern sections of the Lake could have been at a lower level.

Coutts et al. (1978) reported that in times of flood, water rarely covered more than about 20% of the lake floor, with water depths rarely exceeding 1 m. However, prior to the deepening of the Drain in 1954, the Lake was subject to more extensive flooding. Coutts et al. (1978), citing Hand (1973), reported that the highest known flood level occurred in 1942. This is certainly an error, as 1942 was an unexceptional rainfall year. The highest flood occurred in March 1946. According to Hand (1973), this event created water depths exceeding 3 m. Large floods in 1943 and 1949 reportedly filled the Lake to depths of about 2 m. If the general level of the Lake floor is taken to be 50.5 m AHD (Figure 22) then 2 m depth equates to a level of 52.5 m AHD and 3 m depth to 53.5 m AHD.

Coutts et al. (1978, their Fig 19) produced a diagrammatic sketch of flow levels in Lake Condah for fishtrap Systems 1, 2 and 3 (located on the south western part of the Lake). The levels are relative to an arbitrary datum, with the bed of Lake Condah appearing to correspond to a level of 6 - 8 m on Fig 17 and Fig 19 in Coutts et al. (1978). The bed levels of the deepest sinkholes appear (on their Fig 19) to correspond to the level of 6 m. The depth of the sinkholes cannot be read accurately from the 2005 DEM, however, the sketch of System 1 in Coutts et al. (1978, their Fig 17) can be correlated with the DEM. On this map, the 8 m contour correlates well with 51.5 m AHD. Fig 17 in Coutts et al. (1978) marks the sills of various stone channels and their elevations are given in their Fig 19. Comparing the levels of six of these sills with their elevation on the 2005 DEM (as best could be determined) suggested that 8 m in Coutts et al. (1978) corresponded with 51.0 – 51.5 m AHD. Thus, for the purposes of this report, 8 m in Coutts et al. (1978) is equivalent to 51.5 m AHD.

Coutts et al. (1978) Fig 19 indicates the minimal level of lichen growing on the rocks at 11 m or 54.5 m AHD. The lowest level of lichens indicates the normal flood limit, suggesting that, historically, Lake Condah was inundated to this level reasonably frequently. Certainly, the sills of the fishtrap channel structures surveyed by Coutts et al. (1978) are at or below this level, being 52.5 – 54.5 m in System 1, 50.5 m to 52.0 m in System 2 and 50.5 m to 51.5 m in System 3. The 1946 flood debris limit was at 12 m, or 55.5 m AHD. This is 2 m higher than the minimum level estimated above from the descriptions of Hand (1973). On the day of field inspection for this study (19th July 2006), 1946 flood debris (remains of a bridge) was observed perched on a stone fence, above the area of the flat land to south of Condah Drain, just after it emerges from the Lake proper (Figure 47). The debris was judged by eye to be around 2.5 m higher than the flat land below, the elevation of which is known to be 52.5 m. This estimate puts the 1946 flood elevation at 55.0 m, which is in reasonable agreement with the estimate based on the data of Coutts et al. (1978). For this study, a level of 55 m AHD is assumed for the 1946 flood.

Figure 47. Flood debris (remains of a bridge) from 1946 event perched on a stone fence, above the area of the flat land to south of Condah Drain. View to northest. Photo: C. Gippel, 19/07/2006.

3.6.4 Summary of observed Lake inundation patterns

The available observations suggest that Lake Condah is fully connected above 51 m. When the Lake level falls to around 51 m the Central and Southeastern sections become independent, and their levels can fall below that of the Northern and Western sections. The highest flood in memory occurred in 1946 before the Condah Drain was deepened. This flood reached a level of 55.0 – 55.5 m AHD in Lake Condah. It appears that the floods frequently reached a level of 54.5 m prior to deepening of the Drain in 1954.

3.7 Lake Condah and Condah Swamp capacity and surface area relationships

3.7.1 Procedure

One of the main aims of this project is to model the time series of water levels in Lake Condah under a range of possible future scenarios. As well as requiring knowledge inflows, outflows, net evapotranspiration and hydraulics of the Condah Drain and Lake (i.e. sills that determine when the Lake inundates) it is necessary to predict the Lake volume (capacity) and surface area across the range of expected water levels. The Lake capacity is used to determine volume of water required to fill it, and the surface area is used to estimate the evaporation component. This project is also interested in reconstructing pre-European Lake hydrology, when Lake Condah levels may have been higher (as the Drain was not in place) and connected with Condah Swamp. Thus, the capacity and surface areas were calculated for:

- Lake Condah from the downstream drainage divide near the cultural weir to the upstream topographic divide between Lake Condah and Condah Swamp at Stones Bridge
- Condah Swamp from Stones Bridge upstream to the 56 m contour.
- Lake Condah and Condah Swamp combined

The 2005 DEM was used to generate capacity tables for Lake Condah. Condah Swamp capacity tables were based on a combination of the 2005 DEM data and height adjusted SRTM data. The volume and surface area data were generated by Global Mapper using the following procedure:

1. Generate a contour at 56 m and manually mask off the boundary around the contiguous Lake/Swamp contour (i.e. eliminating low lying areas not directly connected to the Lake/Swamp).
2. Calculate the volume and surface area at this elevation.
3. Step down 0.1 m in elevation and draw a contour within the previously bounded area, checking that the contour is contiguous. If contiguous, calculate the volume and surface area. If some disconnected areas have appeared, redefine the boundary of the contiguous area and then calculate the volume and surface area.
4. Step down 0.1 m and repeat the procedure, until reaching the lowest elevation (48.1 m for Lake Condah and 50 m for Condah Swamp). This procedure involved 79 elevation steps.

The procedure was undertaken separately for Lake Condah and Condah Swamp and the results combined. The reason for calculating area and volume only for the contiguous Lake/Swamp was to eliminate any surrounding low-lying areas that are never connected to the surface water of Lake Condah/Condah Swamp, and to simulate the volume of surface water inflow that would be required to progressively fill the Lake.

3.7.2 Capacity and surface area relationships

The capacity and surface area relationships for Condah Swamp and Lake Condah are provided in Figure 48 and Figure 49. Compared to Lake Condah, Condah Swamp has a much larger ultimate capacity. At high levels Lake Condah can hold nearly 20,000 ML, but at the suggested winter target managed elevation of 52.4 m, 2 - 4 days of typical peak winter flow in Condah Drain would be sufficient to fill the Lake.

The Lake was divided at the sill between the northern and central-southeastern sections and the capacity determined for these two sections for levels below the sill (Figure 50). This shows that the northern section of the Lake has a low capacity; at 51 m AHD it holds only 77.5 ML and has a surface area of 35.3 ha.

The Lake Condah volume and surface area estimates made by SR&WSC (1980) compare quite well with those made here using the 2005 DEM (Table 9). The latter are more accurate, because the earlier SR&WSC survey had far less surveyed points, and the contours were generalised.

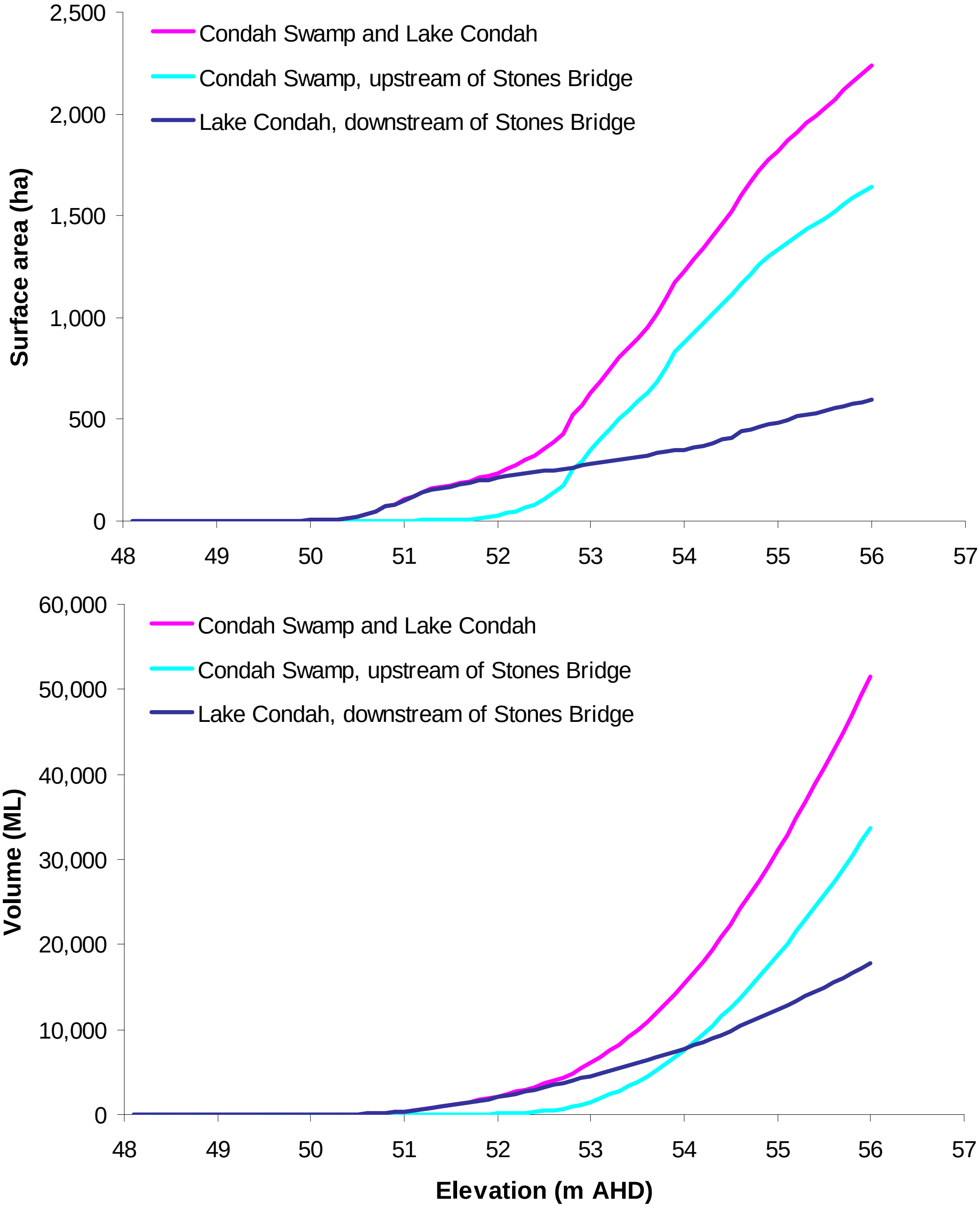


Figure 48. Volume-elevation and surface area-elevation relationships for Lake Condah and Condah Swamp across the full range of elevations considered.

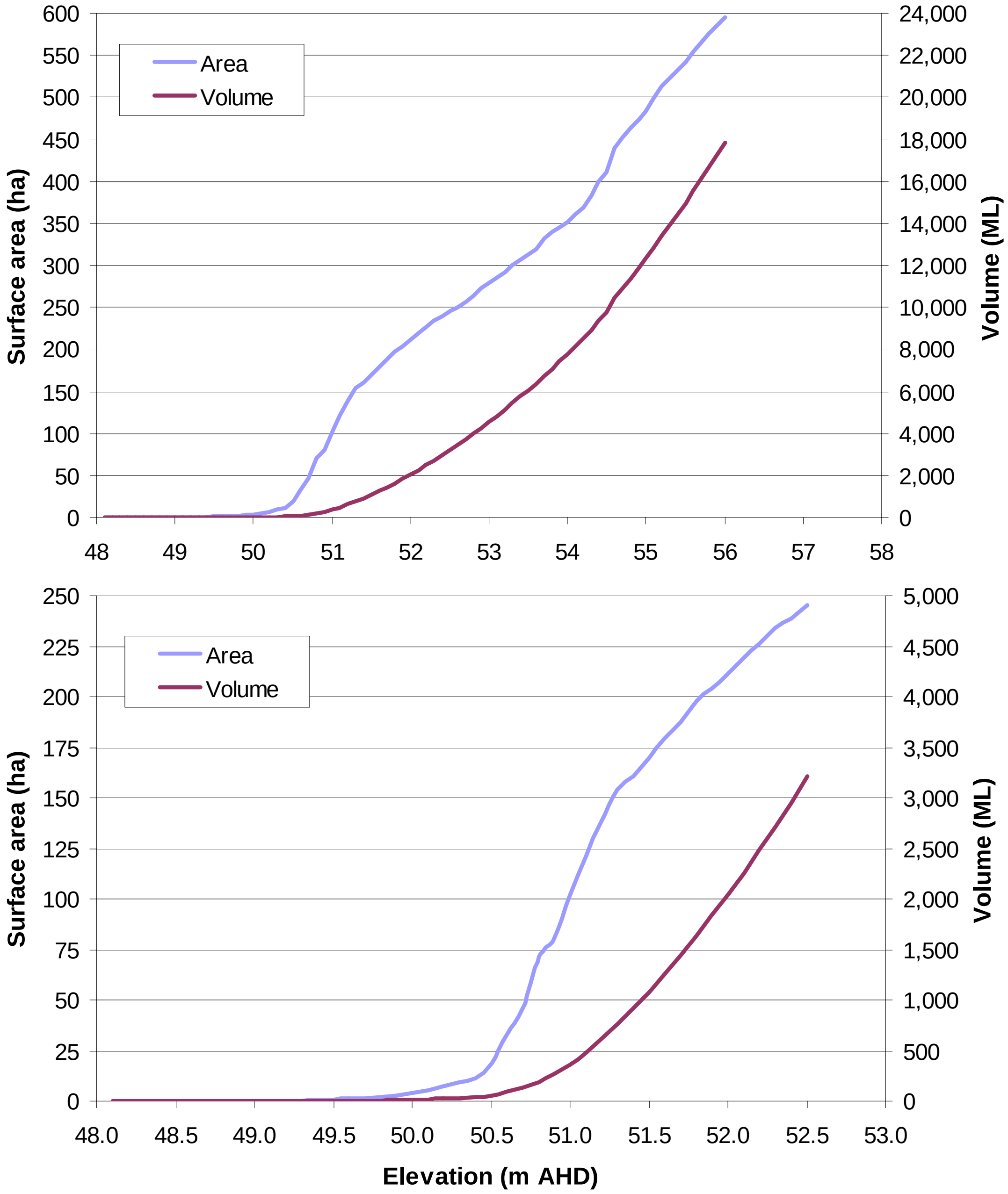


Figure 49. Volume-elevation and surface area-elevation relationships for Lake Condah across the elevation range 48 - 56 m (top) and, in more detail, the elevation range 48.0 - 52.5 m (lower).

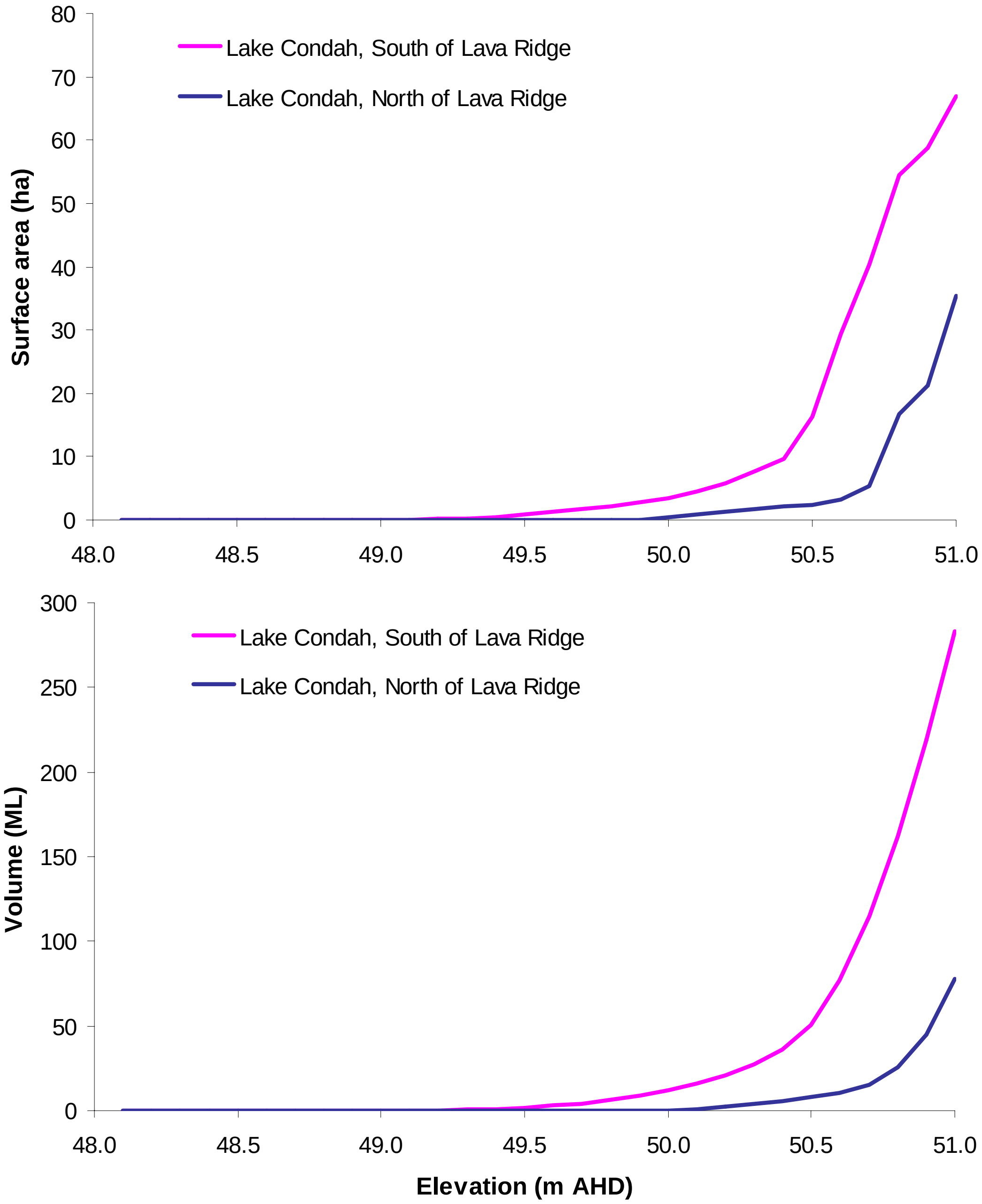


Figure 50. Volume-elevation and surface area-elevation relationships for Lake Condah, divided at the sill on the eastern side of the lava ridge, for elevations below the sill level.

Table 9.
Comparison of capacity and surface area estimates made by SR&WSC (1980) and using the 2005 DEM. Note: the correction to the SR&WSC (1980) levels to AHD is approximate (±0.1 m).

Elevation (metres)		Surface area (ha)		Capacity (ML)	
SR&WSC (1980) datum	AHD datum	SR&WSC (1980)	2005 DEM	SR&WSC (1980)	2005 DEM
49.5	49.9	0	2.9	0	8.7
50.0	50.4	9.3	11.6	18.1	41.5
50.5	50.9	84.8	80.1	253.4	263.3
51.0	51.4	165.8	160.8	880.0	914.6
51.5	51.9	211.8	204.2	1,824.0	1,835.0

3.8 Lake Condah natural rate of seepage

3.8.1 Previous estimates of Lake seepage rate

The apparently rapid rate of seepage of the Lake has long been a major concern for those interested in rehabilitating the Lake's hydrology, because of fears that:

- the Condah Drain inflows may be insufficient to sustain the Lake's level and,
- the water that leaks from the Lake will be effectively lost from Darlot Creek, depriving the Creek of water that would otherwise have flowed there.

SR&WSC (1980) reported observations of a pool in the southwestern part of the Lake, made in November 1979 by a Commission geologist. The pool (possibly the pool where the gauge was later to be installed) (Figure 29) had no external drainage (apart from sub-surface). Based on an assessment of the fall in water level from the presumed winter peak (from trash lines), and accounting for rainfall and evaporation, it was concluded that the rate of fall due to seepage was 1.2 metres over 4 months. This equates to approximately 10 mm per day. Based on a survey of the Lake's capacity, SR&WSC (1980) estimated that this rate of loss equated to 529 ML per month, or approximately 17 ML/day.

Ruge (2004, p. 28) wrote "*We know historically that the Lake did have permanent but fluctuating water levels all year round, therefore it can be presumed (but remains unproven) that the seepage rates used of 529 ML/month are excessive. Modelling indicates that with lesser seepage rates, together with some flood flows, water coverage can be maintained all year*". The lesser seepage rates referred to above by Ruge (2004) were 50% and 75% of the rate suggested by SR&WSC (1980).

3.8.2 Calculated seepage rates for the 1988 – 1992 gauged period

The five years of recorded data from 1988 – 1992 suggest that Lake Condah water level falls rapidly after the event that caused the rise has ceased (Figure 30). These data can be used to estimate seepage rates, but it is not a trivial exercise. The main problem is determining the elevation below which Lake Condah becomes disconnected from Condah Drain; at this point the Drain no longer maintains the level of the Lake. Once this is determined, the rate of fall can be calculated, making the necessary adjustments for rainfall and evaporation. Lake capacity relationships (Figure 50) allow the rate of fall to be expressed in volume lost per time interval.

For the period when the Lake level was gauged, the water surface elevation of Condah Drain at Lake Condah was estimated using the rating relationship developed in this project (Figure 41). Comparison of the modelled Drain water level and Lake water level showed a close correspondence, with a lag of one or two days in Lake level (Figure 51). A threshold level could be determined at around 50.6 m (51.0 m AHD); above this the Drain and Lake levels were closely related, and below this they diverged, with the Lake falling more rapidly, and lower, than the Drain. Data were then extracted from the four recession limbs (1988 data were ignored, as the flow records are regarded as unreliable) (Figure 52). In determining the rates of fall (Table 10), the periods of heavy local rainfall that caused the Lake to temporarily rise were ignored.

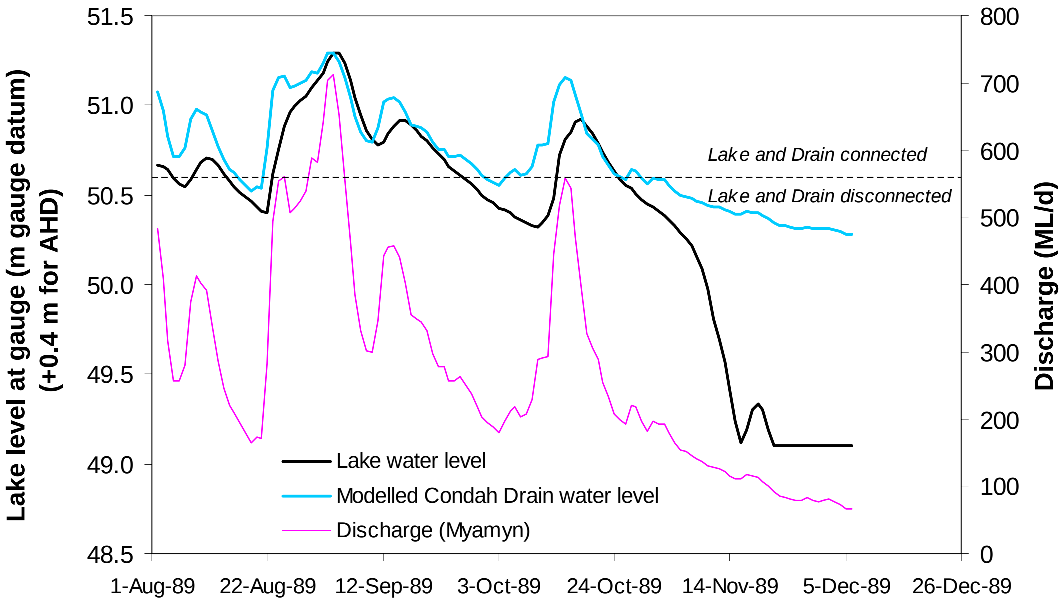


Figure 51. Lake Condah water levels for the 1989 flood event period, showing correspondence of Lake and Drain levels for elevations above 50.6 m (51.0 m AHD).

Analysis of the recession limbs depicted in Figure 52 revealed that there were two basic types of water level recession: rapid and slower (Table 10). The slower rates of water level fall occurred over the first 0.4 m, from the sill level at 51 m AHD down to around 50.6 m AHD. Below 51 m AHD the Lake separates at the sill between the northern and central sections. At a level of around 50.4 m, the rate of fall accelerated considerably. This level corresponds to the level when the gauge pool becomes isolated. At this level the rest of the Lake is virtually dry and does not supply the gauge pool with inflows. The gauge pool is probably a sinkhole, so water seeps away at a rapid rate.

The evapotranspiration rate is far too low to be an important factor explaining the drop in water level. Likewise, when the Lake level rose, the volume of rainfall on the Lake bed surface was insufficient to account for the water level rise. It is likely that when significant local rain occurs, the adjacent Stony Rises contributes a significant volume of water to Lake Condah through springs.

The observed Lake recessions reveal that the SR&WSC (1980) estimate of rate of seepage was in fact an underestimate, not an overestimate, as thought by Ruge (2004). A problem with the previous estimate of seepage rate is that it was based on a description of the fall in Lake level over the entire 4-month long recession period, when in fact, for much of this time the Lake would have been connected to the Drain, and falling and rising with the Drain water surface level. So, when connected to the Drain, the Lake is probably leaking water to the subsurface, but the rate cannot be determined because any water lost from the Lake is being replaced from the Drain.

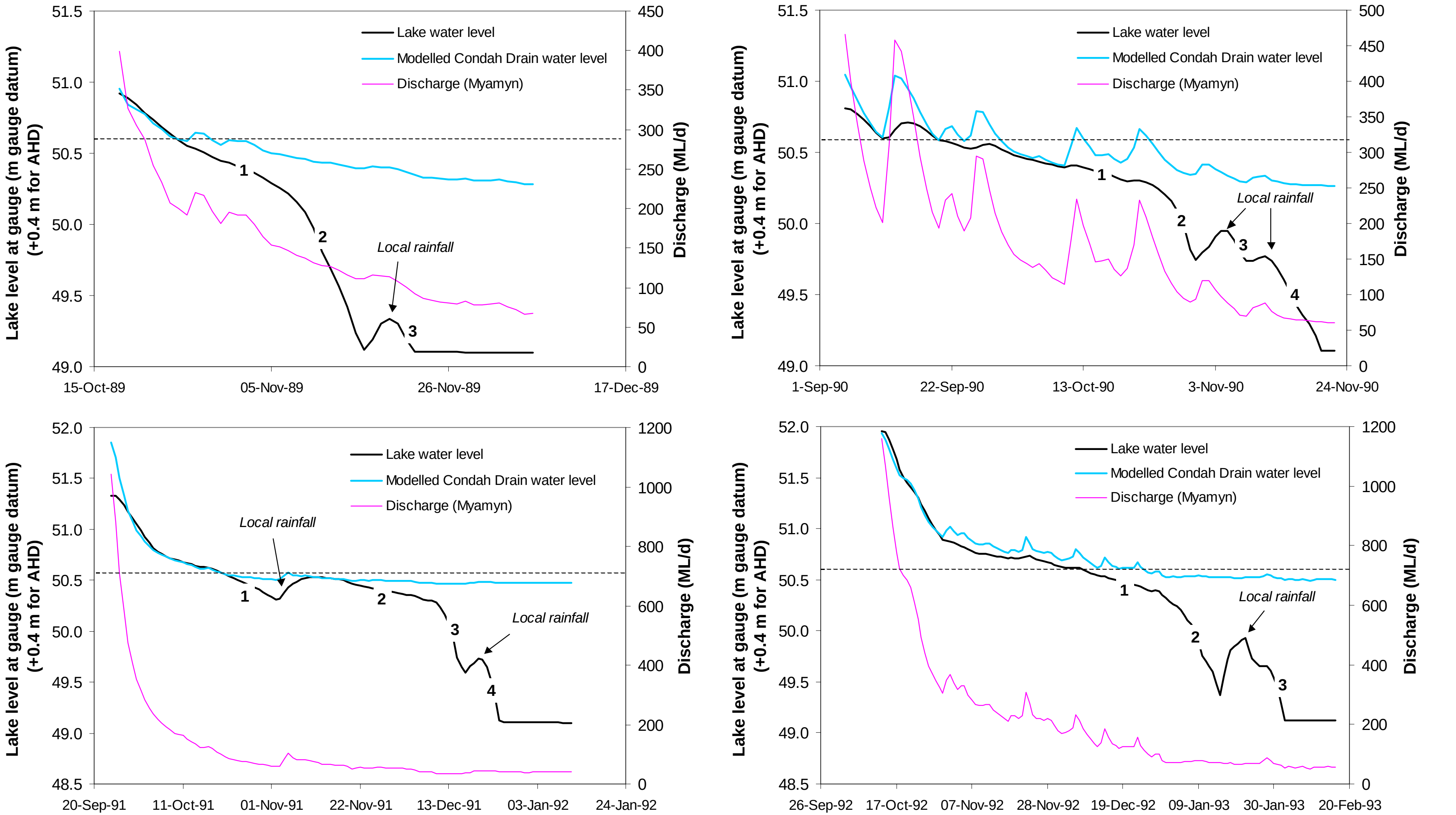


Figure 52. Lake Condah water level recession limbs, 1989 - 1992. Each graph has a 3-week period between tick marks.

Table 10.
Rate of losses from Lake Condah during recession limbs. The gauge pool is fully isolated from the Lake at 50.4 m AHD. Two recessions (1990 #2 and 1991 #3 began at 50.6 m but quickly fell to 50.4 m, so were mostly within the gauge pool. ET is evapotranspiration, estimated as DataDrill ET_O factored to simulate open water conditions.

Year	Recession limb No.	Start level m AHD	Mean water level fall mm/d	Mean lake volume loss ML/d	Mean ET loss mm/d	Mean rainfall gain mm/d
1989	1	51.0	29	14.9	3.9	2.5
1989	2 gauge pool	50.4	143	5.3	3.9	1.3
1989	3 gauge pool	49.7	101	1.4	8.0	0.0
1990	1	50.9	12	6.4	2.9	1.7
1990	2 gauge pool	50.6	83	12.5	5.8	0.5
1990	3 gauge pool	50.3	70	4.6	6.6	0.4
1990	4 gauge pool	50.1	79	2.0	5.3	0.1
1991	1	51.0	21	11.7	4.0	0.2
1991	2	50.9	9	4.5	4.8	0.6
1991	3 gauge pool	50.6	106	12.9	4.5	2.2
1991	4 gauge pool	50.1	102	2.5	4.8	0.2
1992	1	51.0	10	5.8	4.2	1.6
1992	2	50.8	62	8.4	6.3	0.2
1992	3 gauge pool	50.1	106	2.4	9.2	0.4

There are two alternative explanations for the observed pattern of recession:

1. When the level of the Condah Drain falls below the central Lake Condah sill level (50.9 – 51.0 m) water seeps from the Lake through one or more main points (sinkholes) near and in the gauge pool. The level of the water table must be lower than the Lake to allow the flow to pass down though the sinkholes. The rate of fall is controlled by the hydraulic capacity of the sinkholes – limited to about 15 ML/d when the head difference is at its greatest. The Lake drains to these points; when only the gauge pool remains, the water level falls very rapidly (a function of the bathymetry), even though the rate of water loss through the sinkhole in the gauge pool has declined to about 2 – 5 ML/d.
2. When the level of the Condah Drain falls below the central Lake Condah sill level (50.9 – 51.0 m) control of the Lake level passes to the water table. From that point on, the rate of Lake level decline (and rise after significant local rainfall) is determined by the level of the local water table. This assumes a strong connection between the Lake and the water table, through sinkholes and the rocky edge of the Lake. If this is the

case, then the water table must have a particular two-phase pattern of fall, initially falling at 10 – 30 mm/day, and then increasing to 80 – 150 mm/day (quoted rates are for fall uninterrupted by rainfall events).

3.9 Summary

A comparison of the 1980 SR&WSC Plan and the 2005 DEM revealed that the SR&WSC Plan was consistently 0.3 – 0.5 m lower across the floor of the Lake. The 2005 Photogrammetric DEM is the preferred source of survey data for this study. The density of points, the vertical accuracy, spatially referenced data, and accurate ground control survey makes it superior to the other surveys. The disadvantage in adopting the 2005 DEM survey levels is that the 1980 SR&WSC Plan has been exclusively used for Lake Condah management and planning up to this point.

Parts of Condah Swamp are low-lying, and it is all below 53 m AHD. Unexpectedly, the more northerly sections (most upstream) are the lowest in elevation, which highlights the flatness of this landscape feature. Although parts of Condah Swamp are lower in elevation than 52 m, this does not necessarily mean that water levels above 52 m in Lake Condah will cause inundation in Condah Swamp – if water is contained within the Condah Drain, then the Swamp will not be flooded. Cross-sections indicate that the levees protect the Swamp against inundation for levels below 52.28 m AHD.

In general, the deepest parts of Lake Condah are found on the western side of the Central and Southeastern sections of the Lake. Most of the Northern and all of the Western sections of the Lake are higher than 50.6 m AHD. At a water level of 50.9 m AHD, most of the inundated areas in these sections are <0.3 m deep. At 50.9 m AHD, the Central and Southeastern sections contain significant areas of water 0.5 m and deeper. The four main sections of Lake Condah are separated by sills. The main sections of the Lake contain other internal sills that control water distribution within these sections.

The available observations suggest that Lake Condah is fully connected above 51 m. When the Lake level falls to around 51 m the Central and Southeastern sections become independent, and their levels can fall below that of the Northern and Western sections. The highest flood in memory occurred in 1946 before the Condah Drain was deepened. This flood reached a level of 55.0 – 55.5 m AHD in Lake Condah. It appears that the floods frequently reached a level of 54.5 m prior to deepening of the Drain in 1954.

The Lake Condah volume and surface area estimates made by SR&WSC in 1980 compare quite well with those made in this report using the 2005 DEM. The latter are more accurate, because the earlier SR&WSC survey had far less surveyed points, and the contours were generalised.

Lake Condah water levels were recorded from 16/02/1988 to 10/03/1993. There is a strong relationship between discharge at Myamyn and Lake Condah water levels. A hydraulic relationship (i.e. rating curve) was established between discharge and water level in the Drain. The five years of recorded data suggest that Lake Condah water level falls rapidly after the event that caused the rise has ceased.

There were two basic types of water level recession: rapid and slower. The slower rates of water level fall occurred over the first 0.4 m, from the sill level at 51 m AHD down to around 50.6 m AHD. Below 51 m AHD the Lake separates at the sill between the northern and central sections. At a level of around 50.4 m, the rate of fall accelerated considerably. This level corresponds to the level when the gauge pool becomes isolated. At this level the rest of the Lake is virtually dry and does not supply the gauge pool with inflows. The gauge pool is probably a sinkhole, so water seeps away at a rapid rate. The evapotranspiration rate is far too low to be an important factor explaining the drop in water level. Likewise, when the Lake level rose, the volume of rainfall on the Lake bed surface was insufficient to account for the water level rise. It is likely that when significant local rain occurs, the adjacent Stony Rises contributes a significant volume of water to Lake Condah through springs.

A problem with the previous estimate of seepage rate is that it was based on a description of the fall in Lake level over the entire 4-month long recession period, when in fact, for much of this time the Lake would have been connected to the Drain, and falling and rising with the Drain water surface level. So, when connected to the Drain, the Lake is probably leaking water to the subsurface, but the rate cannot be determined because any water lost from the Lake is being replaced from the Drain.

4 Pre-European Lake Condah Hydrology Review

4.1 Literature review

4.1.1 Formation of Lake Condah

Context et al. (1993) provided a good summary of knowledge of the geology and geomorphology of the Lake Condah area, principally based on the work of Boutakoff (1963) and Head et al. (1991). Neville Rosengren [one of the authors of Context et al. (1993)] supported this review with fieldwork. The results of this work are summarised and interpreted below.

The Darlot Creek valley was grossly impacted by lava flows from the Mt Eccles volcanic complex (8 km east of Lake Condah), with the most recent activity thought to have occurred 20,000 to 30,000 years before present (Context et al., 1993, p. 14). The Tyrendarra lava flow formed a broad sheet towards the south west, filling the low lying areas. As the flow cooled and stopped, a "jumbled and confused" rocky surface was created (Context et al., 1993, p. 29). The flow blocked the valley, forming an uneven surface along the edges where it butted against the western side of the valley. Instead of flowing directly to the sea, Darlot Creek now backed-up behind the lava, forming a lake, or series of lakes. The main upper lake could have been the early form of Condah Swamp, with Lake Condah at that time being a (possibly) dry depression downstream. The capacity of the original lake system is unknown, but it is possible that it was large enough to contain all of the inflow of the upstream catchment. The lava would have been permeable, so water would have leaked from the lake system, forming a system of groundwater fed streams or springs downstream of the lakes. These streams would probably have flowed permanently, and have had relatively constant flow levels.

Over time, sediment and organic matter delivered from the catchment above the lake system would have resulted in sediment deposition in the bed of the lake, shallowing it, reducing its capacity, and increasing the frequency that water spilled to areas downstream. The most upstream lake would have filled with sediment at a faster rate than any depressions or lakes downstream, as the water spilling, or leaking through the sub-surface, to the areas below would be lower in sediment concentration (most of the sediment having already settled in the upstream system). As the upper lake lost capacity, its efficiency as sediment traps would decline, so more sediment would be delivered downstream, increasing the rate of sediment deposition on the bed of the downstream lake system. This hypothesised scenario could help explain why the basal sediments in Lake Condah are around 8,000 years old, while those in Condah Swamp are over 27,000 years old (Head et al., 1991).

4.1.2 Lake Condah at the time of European settlement

There is uncertainty in the literature about whether, prior to European occupation, Lake Condah was connected by a channel to Condah Swamp, or under what circumstances Lake Condah overflowed to the area downstream. There is also uncertainty regarding the permanence of Lake Condah and the normal winter water level.

SR&WSC (1980) referred to a 1973 Land Conservation Council report which concluded that Lake Condah was never a permanent wetland due to the porous substratum allowing the Lake to drain. A. Ingram's January 1883 sketch of the Lake Condah Aboriginal Fishery (Figure 53) is annotated to read "*Southwestern point of Lake Condah dry in summer time, 3 to 4 feet of water during floods*". This description suggests that the Lake had seasonally variable water levels.

A report by Hand (1973), who consulted to the Shire for the Condah Drainage Scheme, surmised that prior to European settlement, Lake Condah was hydrologically independent of Condah Swamp, relying on its own small local catchment area, and also that there was no drainage channel connecting Condah Swamp to Darlot Creek. The first drains were probably cut before 1875 (Massola, 1970, as cited in Coutts et al., 1978, p. 6) and Hand (1973) proposed that this was the first time that Lake Condah was connected to the Condah Swamp catchment. In contrast, Neville Rosengren's interpretation is that as Condah Swamp and other swamps and lakes filled with sediment (in geological history), they would have overflowed around the edge of the lava flow, and Darlot Creek would have established a new course on the western edge (Context et al., 1993, p. 34).

Ruge (2004, p. 10) quoted the first written description of Lake Condah, which occurred in the Portland Mercury on 11th January 1843. Mr. Edgar of Second River (later named Heywood) and his two companions reported: "*a splendid fresh water lake … about a mile and a half long and three quarters of a mile wide, and contains almost every variety of fish in abundance, with swans, ducks &c. It is of considerable depth, and receives a river about fifty yards broad; one side is bold and rocky and contains a number of small coves into one of which a beautiful stream empties itself, and the other side is a gently sloping shore surrounded by a fine tract of country*." The report of the Lake receiving a river 50 m wide indicates a strong link between Lake Condah and Condah Swamp.

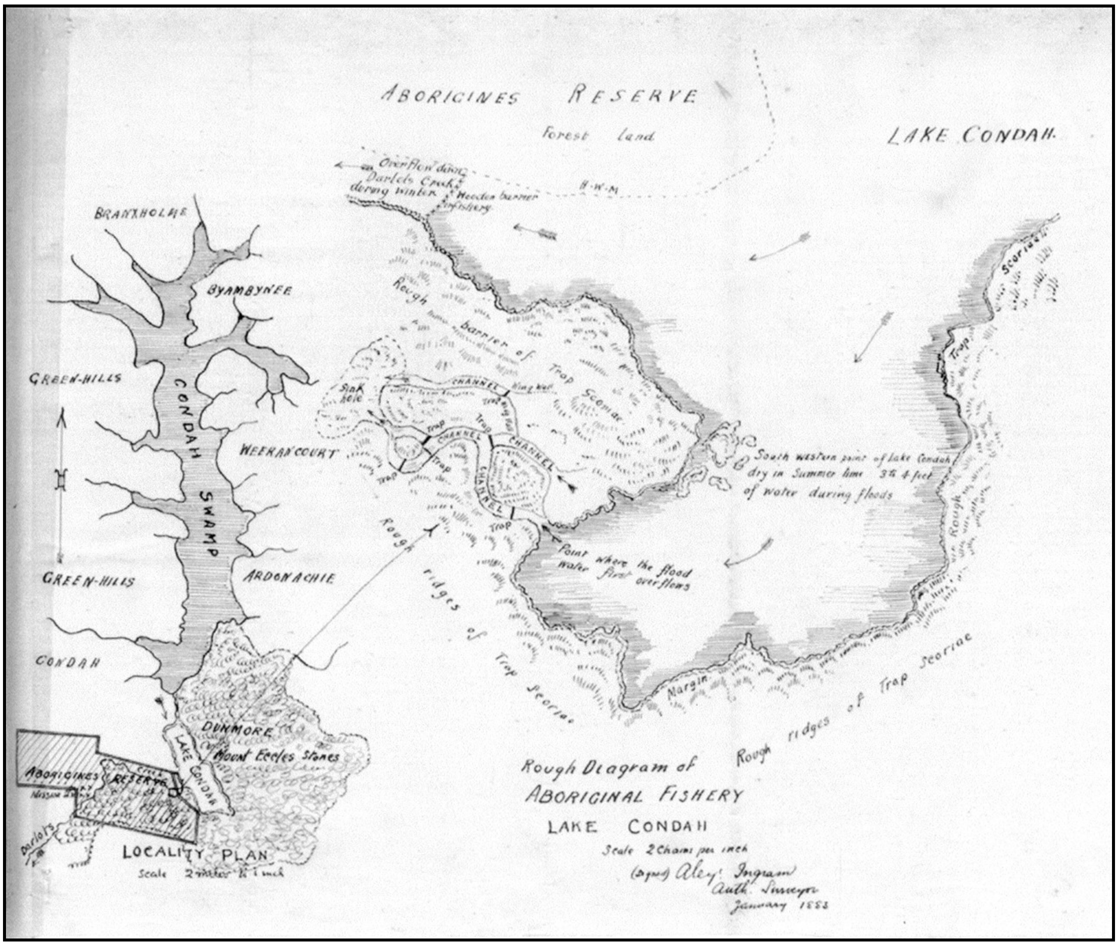


Figure 53. Surveyor A. Ingram's January 1883 sketch of Condah Swamp, Lake Condah and diagram of a section of Fishtrap area No. 6, showing channels and fishtraps. Source: taken from Ruge (2004) who acknowledged the South Australian Museum.

Coutts et al. (1978) assumed that there was no distinct channel linking Lake Condah to Darlot Creek downstream. However, a sketch of the Darlot Creek drainage system made on the basis of information in the diary of William Learmonth (Figure 54) shows Darlot Creek originating from Lake Condah. This sketch pre-dates any drainage works, so the existence of a channel following the edge of the lava downstream of Lake Condah suggests that a natural channel existed at that time. The locality plan of A. Ingram's January 1883 sketch of the Lake Condah Aboriginal Fishery (Figure 53) suggests that a channel existed both upstream and downstream of Lake Condah. The sketch is annotated, and for the outflow reads "*Overflow down Darlots Creek during winter*". The sketch also shows a "*Wooden barrier in fishery*" which could also be described as a weir, and appears to be in a similar location to the remains of the "cultural weir" that can be observed today. A. Ingram's map is highly distorted in scale and there are uncertainties in matching it to a contour map of the Lake based on the DEM (Figure 55). So, although there are doubts about the comparison, the "H.W.M." (high water mark) drawn on the map could be interpreted to coincide with the 54.5 m AHD contour on the DEM (Figure 55), which corresponds with the normal high water level of 54.5 m AHD deduced from the data of Coutts et al. (1987). Possibly contradicting this is Ingram's annotation that the southwestern part of the Lake held 3 – 4 feet (1.0 – 1.2 m) of water during floods. The bed of the Lake in the southwestern area is around 50.5 m, which equates to a winter level of only 51.5 - 51.7 m AHD.

Figure 54. Sketch of drainage of Darlot Creek and Fitzroy River as interpreted from the diary of William Learmonth by his grandson Noel in Learmonth (1934, p. 234) *The Portland Bay Settlement*. The diary would date from the mid-1800s.

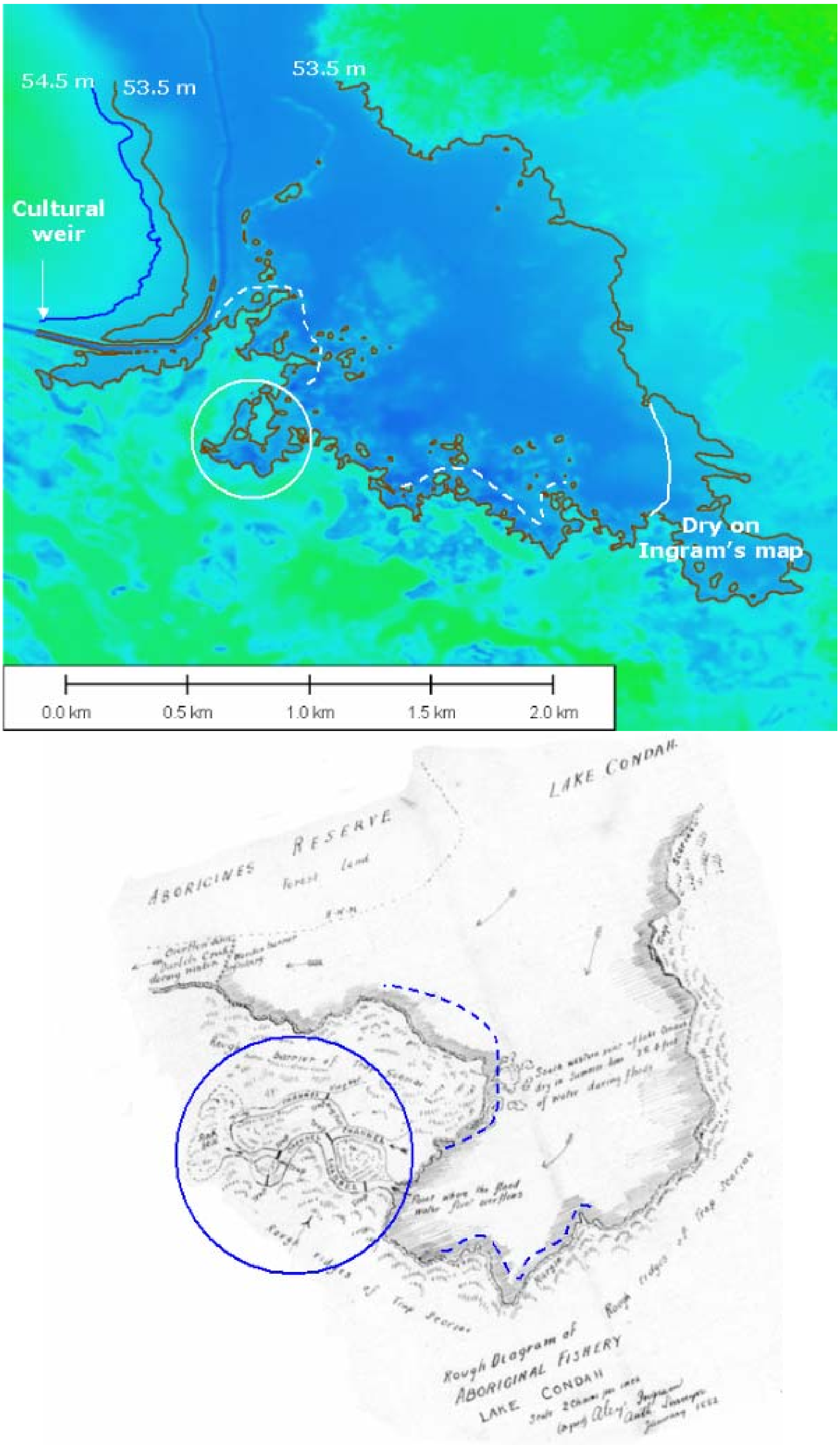


Figure 55. Surveyor A. Ingram's January 1883 sketch of Lake Condah detail (rotated), with interpretation of the map based on the 2005 DEM (oriented North). Dashed lines indicate the same areas on both maps.

If, in its pre-European condition, water levels in Lake Condah remained relatively constant at a particular level, for example, 54.5 m AHD [i.e. Ingram's "high water mark" or the level of the highest structure mapped by Coutts et al. (1978)], then the profile of the Lake's bank would show evidence of a distinct notch or benched area along the former shoreline (formed by wave action). This would only be apparent on the western shore, because the eastern and southern shores are formed in rock. The DEM does not show any consistent evidence of an erosional feature at a particular level on the western shore of the Lake. This is strong evidence of a historically variable lake level.

The evidence presented above suggests that Lake Condah was hydrologically and hydraulically connected to Condah Swamp upstream and Darlot Creek downstream. The channels would probably have been relatively shallow, as they would have flowed only at times when the waterbodies were full and inflows exceeded losses. The magnitude of flood flows through them would have been attenuated by the storage available in Condah Swamp and Lake Condah. The seasonal nature of overflows from Lake Condah to Darlot Creek, and the seasonal nature of Lake water levels, suggests that in summer, the losses from the Lake exceeded the inflows.

4.2 Pre-Condah Drain sills from the 2005 DEM

4.2.1 Lake Condah to Darlot Creek

The available evidence suggests that Lake Condah seasonally filled to a level of around 54.5 m AHD, and may have reached 55.0 - 55.5 m AHD in the peak of the 1946 flood. Discounting the Condah Drain, the level of the current "sill" between Lake Condah and Darlot Creek is 55.3 m. This sill is located at the topographic divide on the bend in the Drain, about 80 m downstream of the site of the cultural weir (Figure 56). Under the scenario of no Condah Drain, and no channel at the topographic divide, under high inflow conditions Lake Condah would potentially fill to 55.3 m, creating a vast lake that would link up with Condah Swamp (Figure 57, Figure 58). Condah Swamp would be around 3 m deep, and Lake Condah would be around 5 m deep. The simulation generated in Figure 58 gives an idea of how Lake Condah-Condah Swamp would have appeared during the flood of 1946.

Figure 56. Condah Drain in vicinity of cultural weir. Bank on southern side of Condah Drain (centre of view), Condah Drain on right, and former channel on left. View to west, looking downstream. For cross-section, see Figure 62. Photo: C. Gippel, 19/07/2006.

The 55.3 m AHD contour indicates two main natural flow paths potentially linking Lake Condah with Darlot Creek (Figure 59, Figure 60). Profiles were traced through these flow paths on the DEM (Figure 61). The flow path on the southern side of the current Condah Drain is visible today as a roughly defined channel (Figure 56). It is at its highest level near the site of the cultural weir, so if this channel once continued through to Darlot Creek, then it must have diverted north around the topographic divide. One past this point, there is an area with a sill of 54.8 – 54.9 m elevation to overcome, and once past this point there are no barriers to flow reaching Darlot Creek. An alternative flow path exists south of the Drain through the lava.

The first constriction is a pass about 10 m wide with a sill of 54.9 m AHD. The next constriction is a pass with two 8 - 10 m wide openings, one at 55.2 m and one at 55.1 m AHD. This is the highest sill that has to be overcome for flow to reach Darlot Creek.

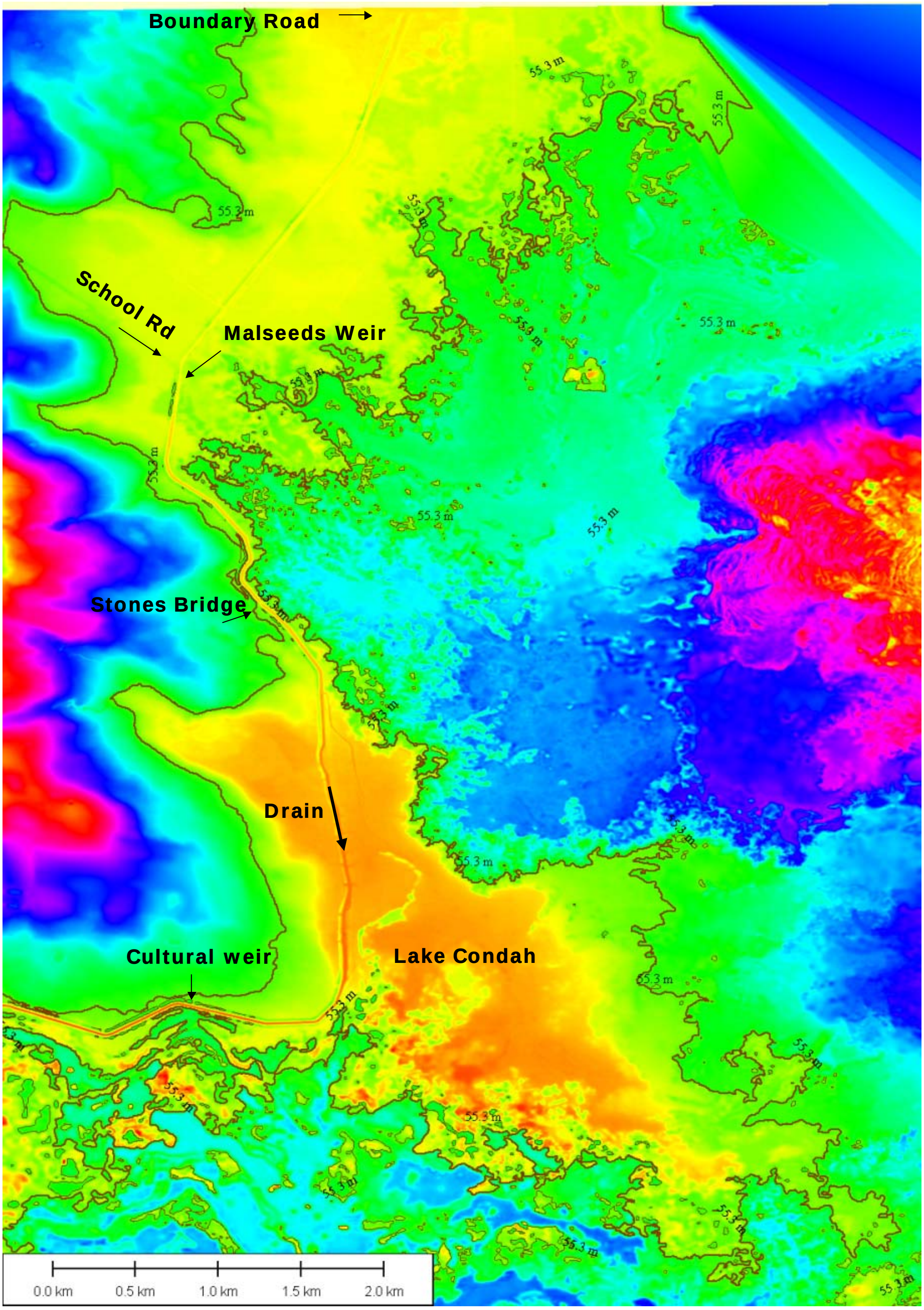


Figure 57. Lake Condah and southern section of Condah Swamp, showing 55.3 m contour derived from 2005 DEM (bold contour line encloses Lake and Swamp). North is vertical. Colour shading represents elevation gradient. Northeast corner has no elevation data.

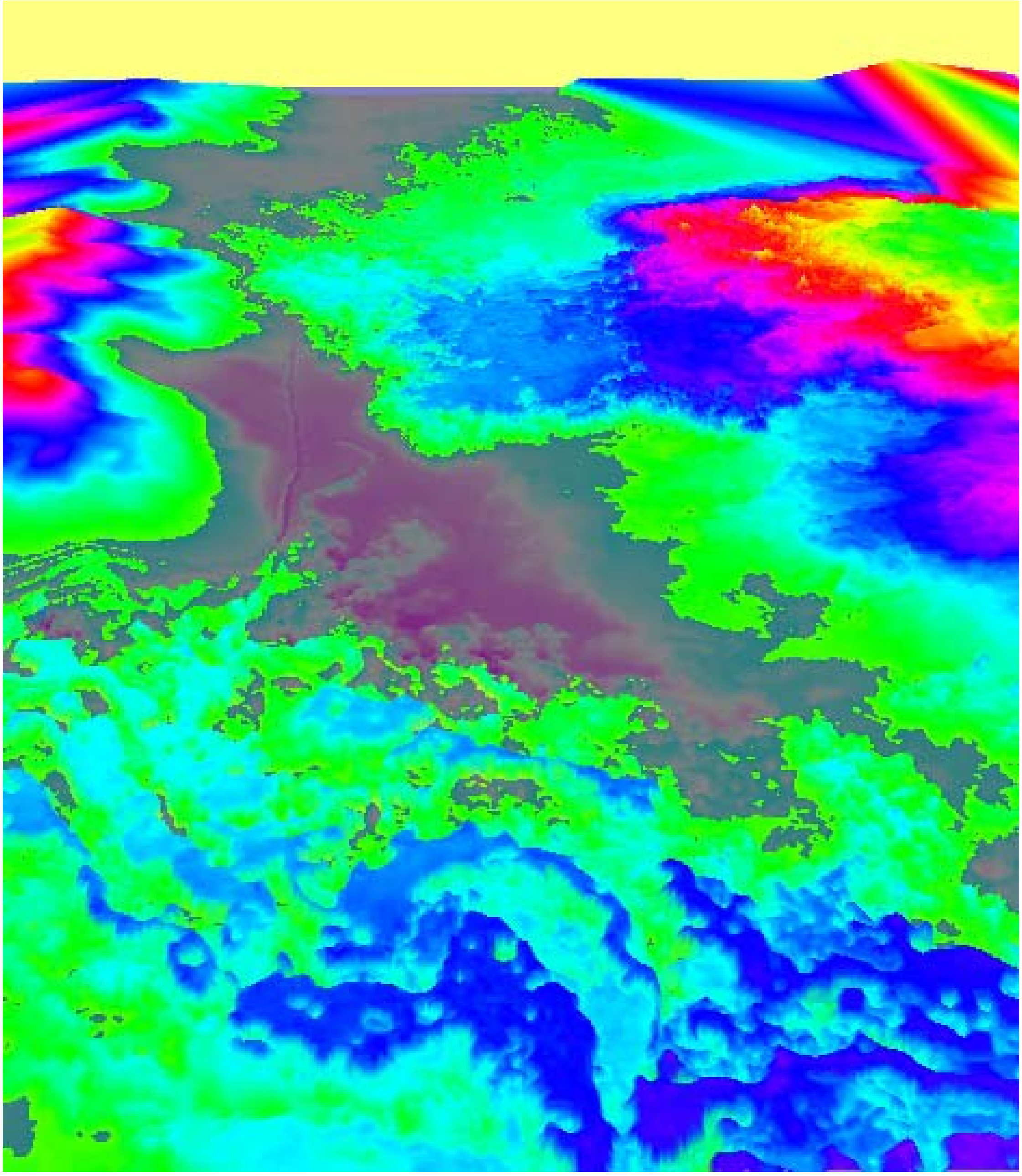


Figure 58. 3-D view of Lake Condah and southern section of Condah Swamp, showing land inundated at 55.3 m elevation. View is North. Vertical exaggeration is x10. Colour shading represents elevation gradient. Northeast and northwest corners have no elevation data.

A weir associated with the Aboriginal fishery once existed just upstream of the topographic divide. A transect through this point suggests that in order to retain water in Lake Condah at 54.5 m AHD, the weir might have been about 0.5 m high and about 30 – 40 m long (Figure 62). At this level the flow path though the lava would not be connected downstream. If the weir was higher than 54.5 m, it would not have been difficult to block off the narrow passes through the lava to prevent flow escaping via that route. It may be worthwhile investigating these locations for evidence of former structures. The bank that runs alongside the southern bank of the Drain is well treed and does not have the same appearance of the spoil heap on the right bank (Figure 56). This bank may be older spoil from the initial channelisation efforts. The natural channel that runs parallel to the Drain may have served a function related to the fishery.

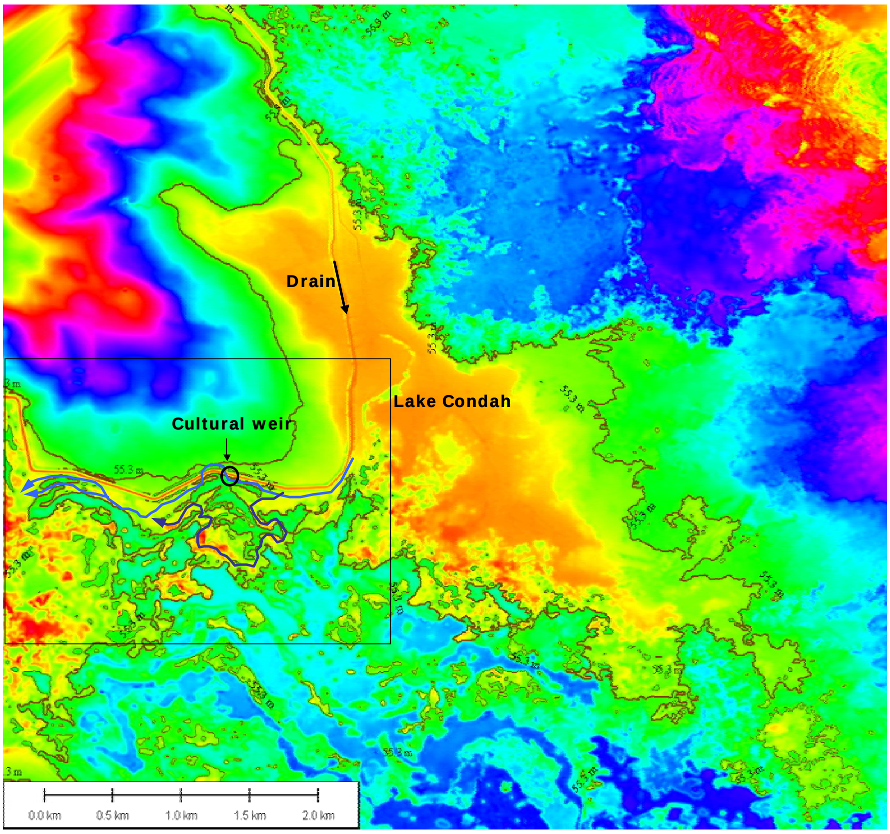


Figure 59. Lake Condah, showing 55.3 m contour. Possible historical Lake outflow paths at 55.3 m are indicated. North is vertical. Colour shading represents elevation gradient.

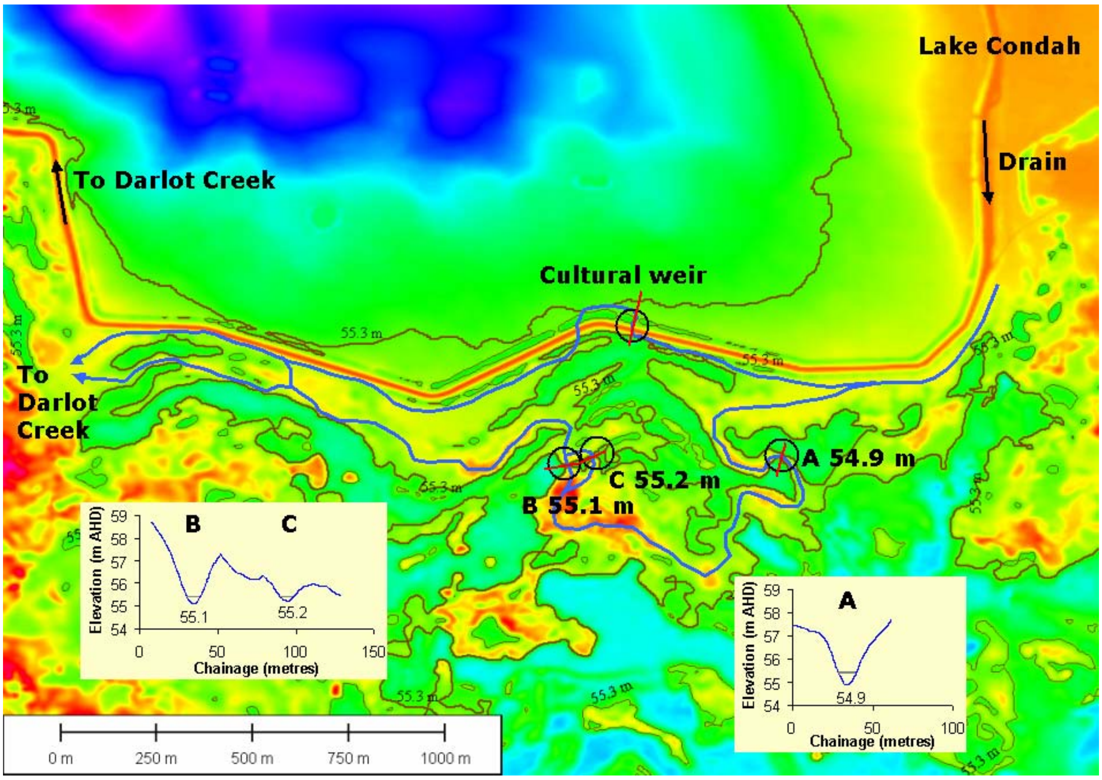


Figure 60. Detail of Lake Condah likely historical outflow paths at 55.3 m. Cross-sections show morphology of points of constriction in path through lava, with 55.3 m level shown. Red lines indicate transects. North is vertical. Colour shading represents elevation gradient.

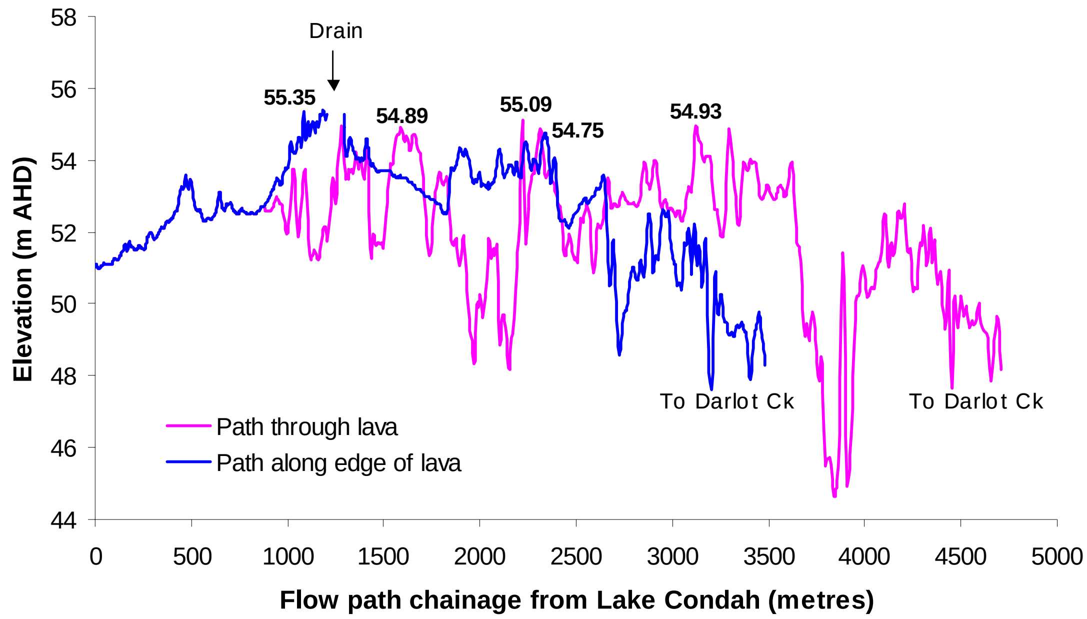


Figure 61. Long profiles of two most likely historical outflow paths from Lake Condah to Darlot Creek at 55.3 m. Area near Drain is disturbed and may not represent elevations prior to construction of the Drain. Levels through Drain omitted from profile.

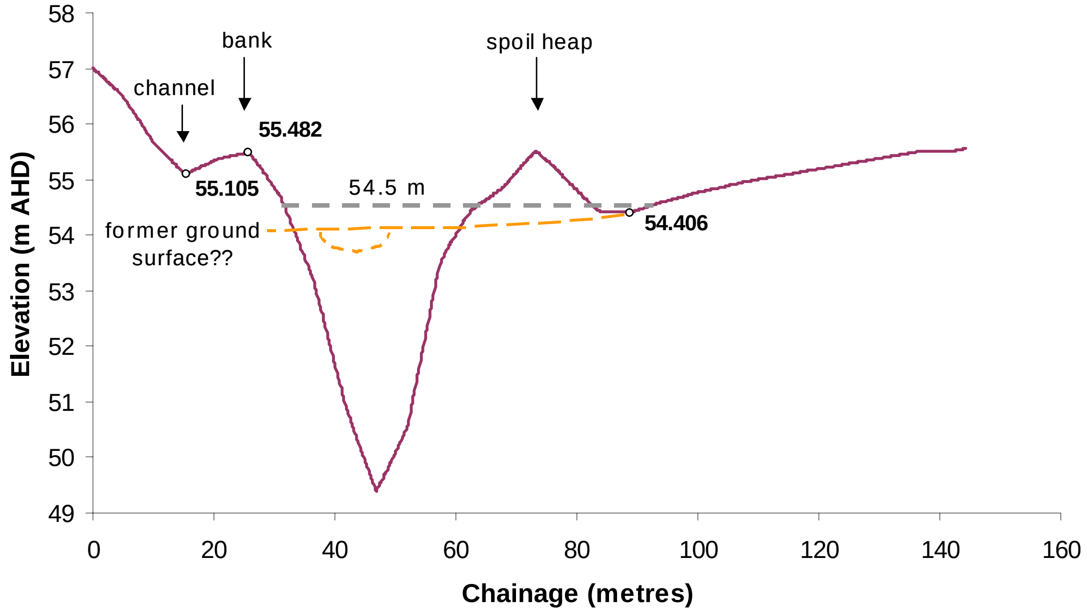


Figure 62. Cross-section at site of cultural weir. View is looking downstream. Grey dashed line indicates the likely former winter level at 54.5 m AHD, and the profile of a weir required to hold water at this level. The bank on the left may have been constructed (or enhanced) as part of the weir configuration. The spoil heap dates from when the drain was excavated (completed in 1954).

4.2.2 Condah Drain to Lake Condah

The topographic divide between Condah Swamp and Lake Condah exists at the point 35 – 40 m upstream of Stones Bridge, where a small tongue of lava pushed up against the western valley slope (Figure 63 and Figure 64). Discounting the Drain, the sill level is 55.6 m AHD. Cross-sections reveal that the area is highly disturbed by dredging the drain, and it is difficult to distinguish what the original ground surface might have been (Figure 65). However, it is quite possible that the original topographic divide was close to 55.6 m, which would make it a metre or so higher than the downstream sill between Lake Condah and Darlot Creek (Figure 62). Given this height difference, it is highly likely that a head-cut would have worked upstream from Lake Condah to Condah Swamp, forming a defined channel through the topographic divide to link the two water bodies. The channel would probably not have been deeper than 1.0 – 1.5 m, with a width of 50 m being feasible [in agreement with the description of Mr Edgar in his 1843 quote in the Portland Mercury (Ruge, 2004, p. 10)]. Once the channel had formed, Condah Swamp and Lake Condah would probably have been a single connected water body at the winter level of 54.5 m AHD (the level being controlled at the outlet of Lake Condah). Of course, this scenario depends on sufficient water being available to fill the two waterbodies to this level. At 54.5 m AHD Condah swamp has a volume of 12,549 ML, and Lake Condah 9,761 ML - a combined volume of 22,310 ML. This volume of inflows was probably achieved in most winters.

4.3 Summary

The evidence suggests that under pre-European settlement conditions Lake Condah was hydrologically and hydraulically connected to Condah Swamp upstream and Darlot Creek downstream. The channels would probably have been relatively shallow, as they would have flowed only at times when the waterbodies were full and inflows exceeded losses. The magnitude of flood flows through them would have been attenuated by the storage available in Condah Swamp and Lake Condah. The seasonal nature of overflows from Lake Condah to Darlot Creek, and the seasonal nature of Lake water levels, suggests that in summer, the losses from the Lake exceeded the inflows.

The available evidence suggests that Lake Condah seasonally filled to a level of around 54.5 m AHD, and may have reached 55.0 - 55.5 m AHD in the peak of the 1946 flood. A weir associated with the Aboriginal fishery once existed just upstream of the topographic divide on Darlot Creek downstream of Lake Condah. A transect through this point suggests that in order to retain water in Lake Condah at 54.5 m AHD, the weir might have been about 0.5 m high and about 30 – 40 m long. At this level the flow path though the lava to the south would not be connected downstream. If the weir was higher than 54.5 m, it would not have been difficult to block off the narrow passes through the lava to prevent flow escaping via that route. In most winters it is likely that Lake Condah and Condah Swamp were a contiguous lake.

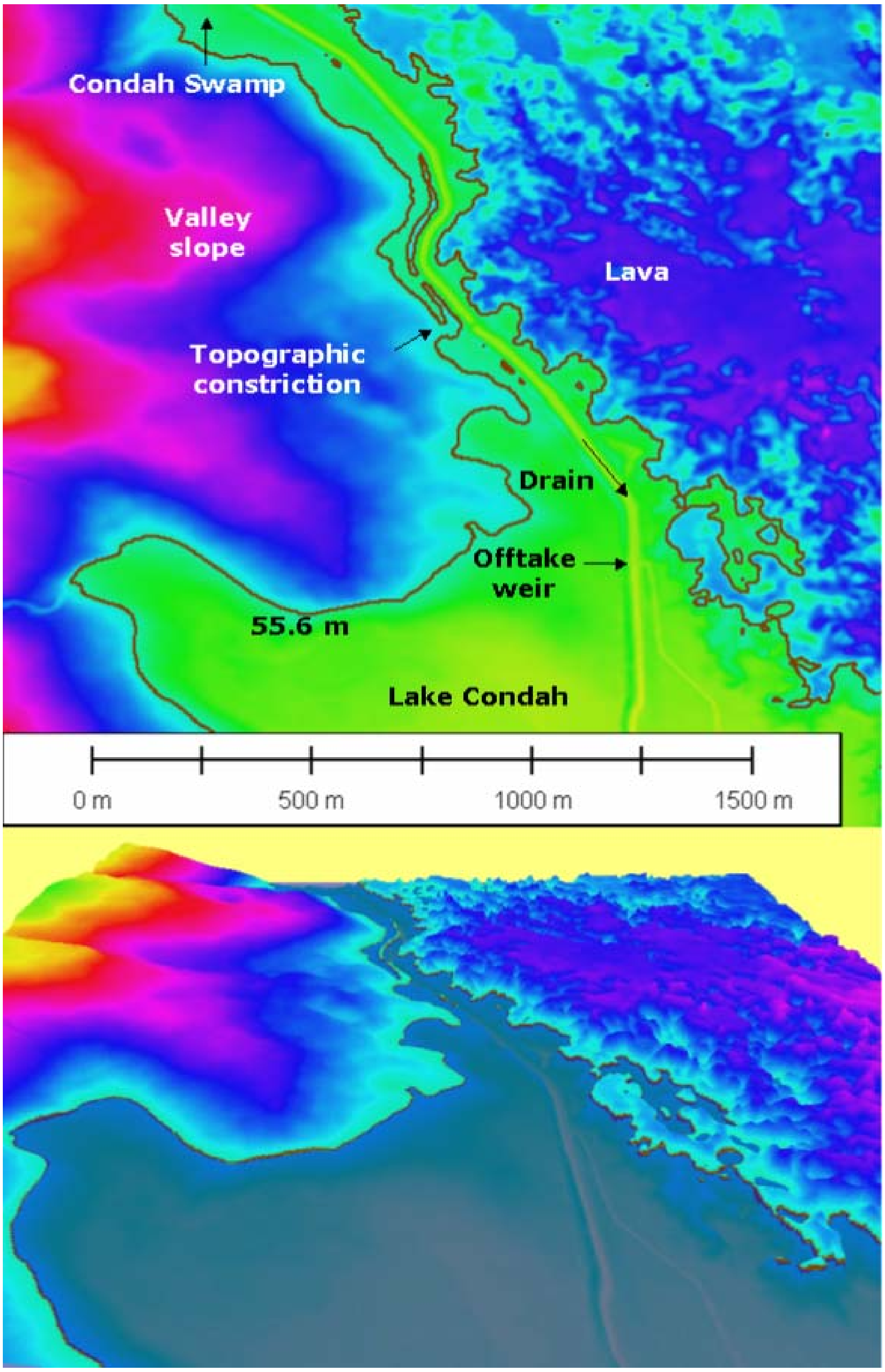


Figure 63. Plan and 3-D view of area between Lake Condah and Condah Swamp. Contour line and water level is 55.6 m AHD. Derived from 2005 DEM. View is North. Vertical exaggeration is x10. Colour shading represents elevation gradient.

Figure 64. Condah Drain looking upstream from Stones Bridge. For cross-section, see Figure 65. Photo: C. Gippel, 19/07/2006.

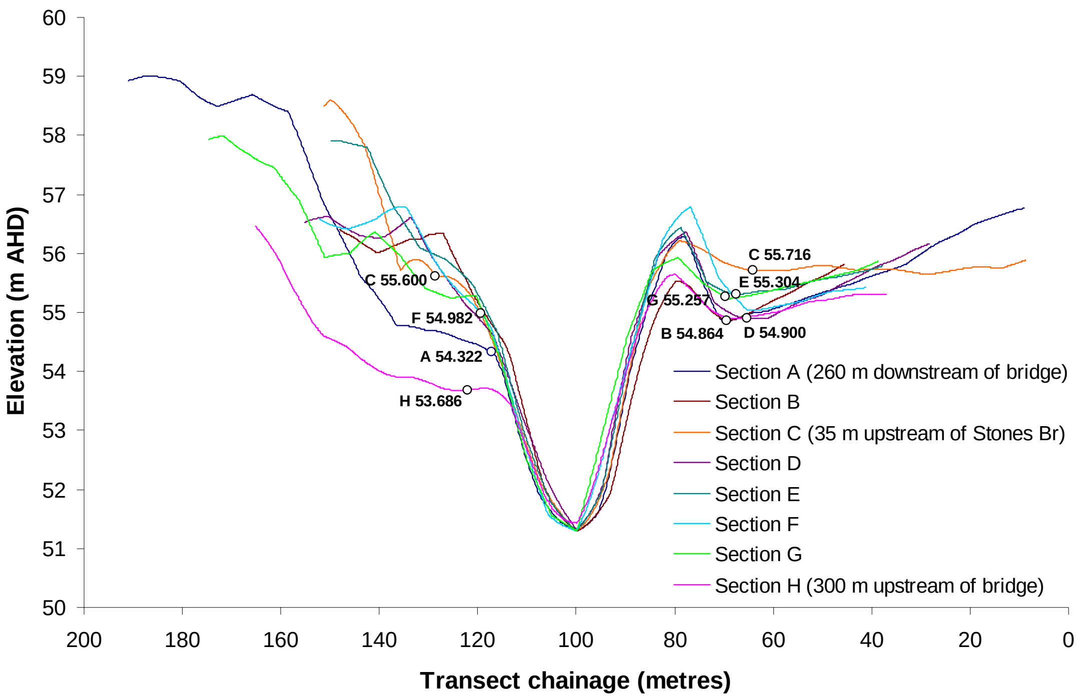


Figure 65. Cross-sections between Lake Condah and Condah Swamp. Sampled at constricted points between Lake Condah and 300 m upstream of Stones Bridge. View is left to right looking downstream, with edge of lava flow on left (East). Labelled points indicate possible sill levels between Condah Swamp and Lake Condah immediately after they were formed by the lava flow blocking the Darlot Creek valley. Derived from 2005 DEM.

5 Darlot Creek Catchment Surface Water Hydrology

5.1 Understanding Darlot Creek stream hydrology based on gauged data

5.1.1 Available data

The longest running streamflow gauge on Darlot Creek is at Homerton Bridge, with shorter records at Myamyn and Lake Condah Bridge (Table 11, Figure 66). The Homerton Bridge time series had 318 missing values that were infilled by interpolation. This presented no problem as the missing values comprised scattered periods of a few days that occurred at times when flows were either stable or changing only slowly. Water levels in Lake Condah were gauged for 5 years between 1988 and 1993 (Table 11). Monthly water quality data are available for the gauge at Homerton Bridge from 1975 to 1998; the parameter of interest for this study is electrical conductivity, as it can indicate the relative contribution of groundwater to the flow (Table 11). Two other gauges listed in the Victorian Water Resources Data Warehouse (237201 – Darlot Creek @ Homerton and 237801 – Darlot Creek @ Condah Mission) appear to refer to climate stations, although no data are available from the Warehouse for these sites. Gauge 237204 has only 2 years of data, and only one year of overlap with the gauge at Homerton Bridge, so these data were not analysed.

Table 11.
Gauging stations used in this study, showing data availability. EC is electrical conductivity.

SINO	Name	Catchment area (km^2)	Variable	Start	End
237205	Darlot Ck @ Homerton Bridge	741#	Discharge (daily)	12/01/1963	Present
237205	Darlot Ck @ Homerton Bridge	741#	EC (monthly)	04/11/1975	03/11/1998
237204	Darlot Ck @ Lake Condah Bridge	607	Discharge (daily)	04/06/1961	02/01/1964
237209	Darlot Ck @ Myamyn	585†	Discharge (daily)	16/10/1987	11/03/1993‡
237600	Lake Condah @ Lake Condah	630¥	Water level (daily)	16/02/1988	10/03/1993

\# This area is given as 760 km^2 in the Victorian Water Resources Data Warehouse, but was measured in this study to be 741 km^2.

† This area is given as 600 km^2 in the Victorian Water Resources Data Warehouse, but was measured in this study to be 585 km^2.

‡ The Myamyn gauge was re-commissioned on 16/03/2006 and data were available up to 10/07/2006. Data from 16/03/2006 to 08/05/2006 is quality coded "Rating extrapolated due to insufficient gaugings (Unreliable data)"

¥ Measured in this study as the total catchment area of Lake Condah.

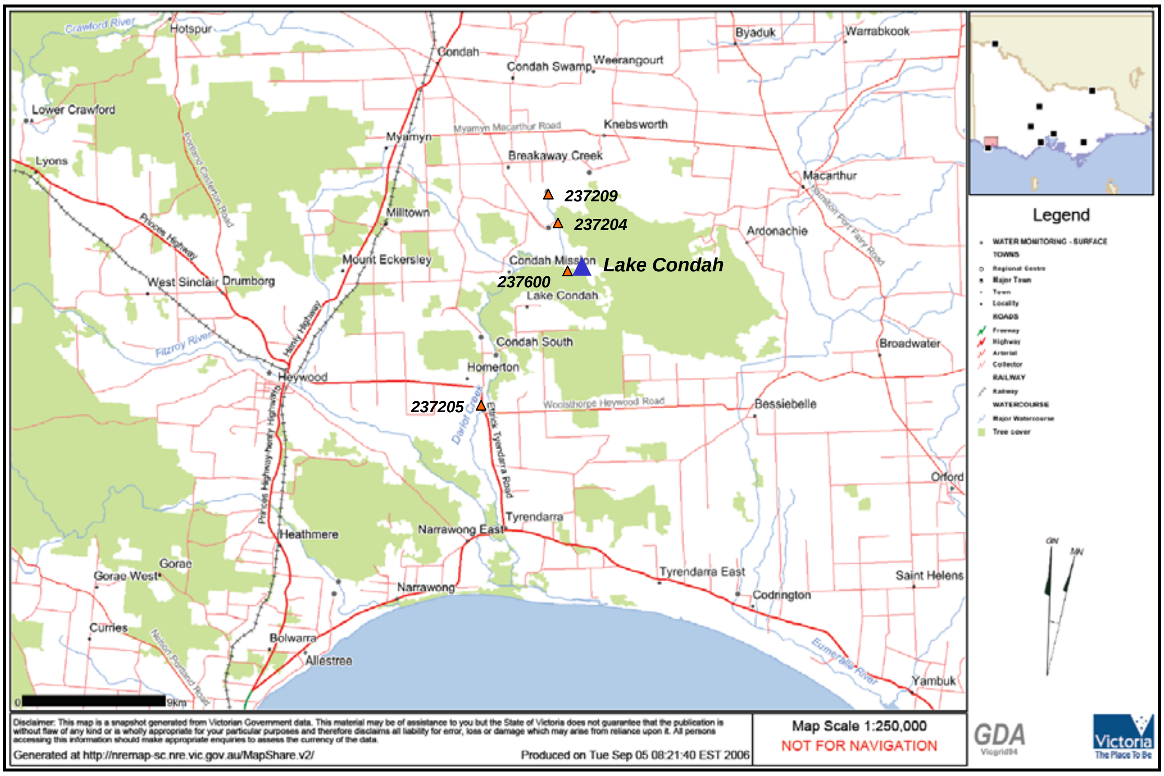


Figure 66. Locations of stream and Lake level gauges in the Darlot Creek catchment.

5.1.2 General flow statistics

A total of 42 years of data for Homerton Bridge gauge revealed that the average annual discharge of Darlot Creek was 61.5 GL (Table 12). The Creek never ceased to flow, but flow did get as low as 5 ML/d. The 5-year period in common with the Myamyn gauge was generally wetter (higher average and higher minimum), but the maximum flow was considerably lower (Table 12). A comparison of flows at Myamyn and Homerton (23.6 river kilometres apart) for identical periods shows that very low flows at Myamyn does not mean similarly low flows at Homerton Bridge, indicating considerable boosting of low flows between these stations (Table 12). The ratio of the increase in minimum flow, maximum flow, and average flow between these stations and the increase in catchment area between these stations exceeds 1. This means that the area of catchment between Myamyn and Homerton Bridge is an area of high water yield compared to the catchment upstream. This is unusual – yield of water normally decreases in the downstream direction.

The flow statistics indicate that there is a relatively high yielding source of water between Myamyn and Homerton Bridge. Wittlebury Creek is the only major tributary entering between these stations. The catchment area downstream of Myamyn to Homerton is 156 km^2; of this 77 km^2 lies to the west of Darlot Creek - geomorphologically and geologicially this area is similar to the Condah Drain catchment upstream of Myamyn, with developed soils on Newer Volcanics. The eastern portion of 79 km^2 lies in the geologically distinct Stony Rises and Tertiary limestone. If the area to the west has the same specific yield as the catchment above Myamyn, this means that for the period 1988 – 1992 it contributed an average of 6,781 ML/yr, leaving 12,887 ML/yr contributed from the eastern side of Darlot Creek. This equates to a high specific yield of 163.1 ML/km^2/yr for this area.

It appears that the largest source of the water to Darlot Creek downstream of Myamyn is groundwater flow emerging from the Stony Rises basalt/Tertiary limestone located to the east, south and southwest of Lake Condah. The reason why this geology would be relatively high yielding is that when it rains, water rapidly enters subsurface through fractures and sinkholes, thereby minimizing evaporative losses. The water then flows to downstream areas, emerging through springs.

Table 12.
General flow statistics for Homerton Bridge and Myamyn gauges.

Statistic	Homerton Bridge 1/01/64 - 31/12/05	Homerton Bridge 1/01/88 - 31/12/92	Myamyn 1/01/88 - 31/12/92
Minimum (ML/d)	5.0	32.5	2.4
Maximum (ML/d)	3,102	1,680	1,211
Daily average (ML/d)	168.4	191.3	130.3
Average of annual discharge (ML/yr)	61,492	69,883	50,215
Average of annual specific yield (ML/km^2/yr and mm)	83.1	94.3	85.8
Standard deviation (ML/d)	238	237	171
Cv	1.414	1.241	1.312
Skewness	4.161	2.696	2.796
AutoCorr	0.983	0.988	0.987
Sample size (Days [yrs])	15,341 [42]	1,827 [5]	1,827 [5]

5.1.3 Flows contributed to Darlot Creek between Myamyn and Homerton

Flows at Homerton Bridge and Myamyn overlap for the period 16/10/1987 to 11/03/1993. For most of this period, Lake Condah water level data are also available (gauge 237600). Also, at that time the Rural Water Corporation was undertaking a groundwater monitoring project at a number of bores and sinkholes located 3.5 to 5.0 km south west of Lake Condah. These bores and sinkholes were all located in the Tertiary limestones and marls, south of and topographically lower than the Basaltic Stony Rises (because the lava overlies the limestone). There is likely to be a strong hydraulic connection between the two geological units (Foley, 1993). Also, over this period, monthly electrical conductivity data are available for Darlot Creek at Homerton Bridge.

Flows at Myamyn and Homerton Bridge are clearly related (Figure 67). The average travel time between the stations (to the nearest day) was judged to be around 1 day, which equates to a mean downstream velocity of 0.3 m/s. Thus, when comparing the flows between these stations the Homerton Bridge flows were lagged one day. The percentage of flow at Homerton Bridge that represented recharge between Myamyn and Homerton Bridge showed a high degree of variability for individual days (Figure 67). This would be expected given that the lag of one day is fairly coarse, and the calculation is for mean daily flow. Despite the scatter, there was a very distinct pattern in the data (Figure 67). Just after the peak of the Winter flood period (when the major rains had ceased), during the Spring/Summer recession limb, the percentage contribution of flow downstream of Myamyn increased steadily with time from around 10% of Homerton flows to around 45% - 50% of flows (Figure 67) [compare with Hall (1991) who assumed a constant value of 35%]. This increase typically occurred over a period of around 3 – 4 months, from Sep/Oct to Dec/Feb. After that, the contribution from the catchment downstream of Myamyn began to decline, at a rate similar to the Spring increase, so that by June/July the percentage contribution was back down to around 10 - 20% (Figure 67). During the main flood periods, the percentage contribution was erratic (possibly because the lag time was variable, and sometimes shorter than one day), with most values falling between 10% and 50% (Figure 67).

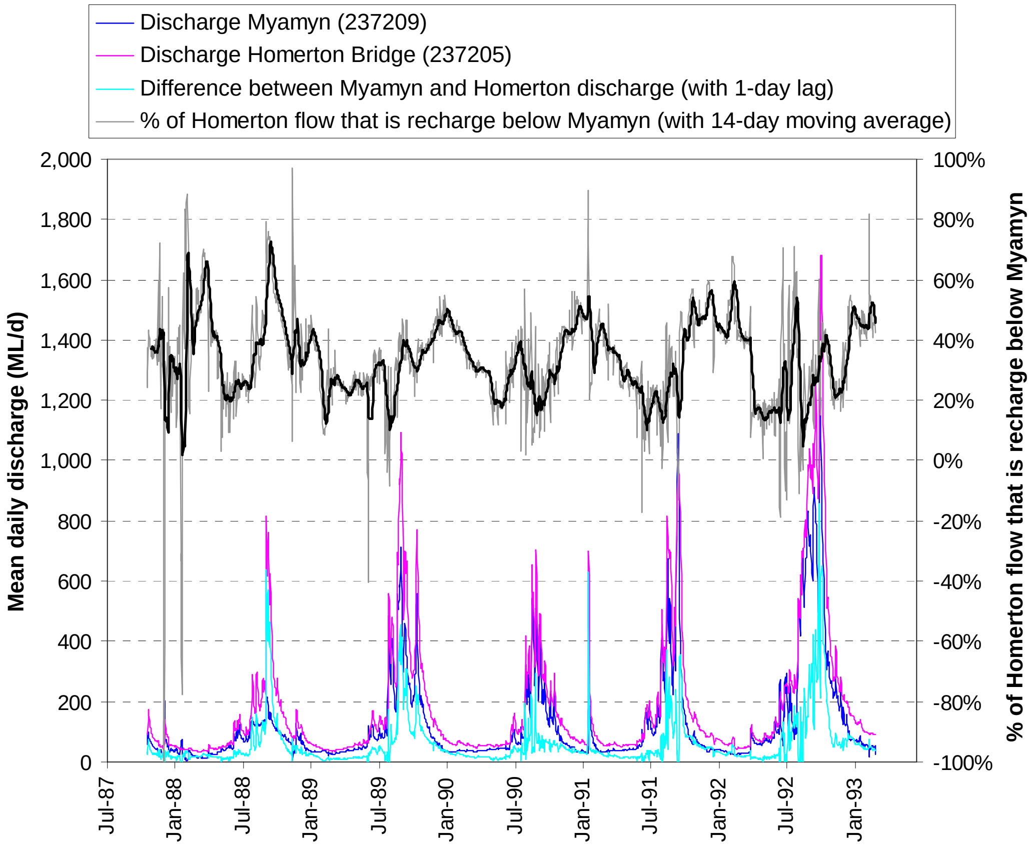


Figure 67. Time series of relationship between flows at Myamyn (upstream of Lake Condah) and Homerton Bridge (downstream of Lake Condah).

The time series of the percentage of flow at Homerton Bridge that represented recharge between Myamyn and Homerton Bridge was inversely correlated with the pattern of fluctuation in electrical conductivity (EC) of Darlot Creek water (Figure 68). The EC of the water in Darlot Creek is naturally quite high due to the nature of the geology. Fresh water input during Winter flood events diluted the stream water to around 900 – 1,200 µS/cm. During the Spring/Summer recession limb when the relative contributions from the Stony Rises downstream of Myamyn area were at their highest, the EC remained relatively steady at around 1,200 – 1,600 µS/cm. This suggests that the groundwater being contributed at that time was similar in composition to the winter stormwater. In other words, it was a similar mix of freshwater from the rainfall and higher salinity groundwater – suggesting that the bulk of the water was rainfall that had directly entered the basalt and flowed relatively rapidly downstream to Darlot Creek through the fractures. Lake Condah would also have acted as a storage of relatively fresh water to supply Darlot Creek, either through direct return flow to Condah Drain or via subterranean pathways. By February, the bulk of the fresher groundwater supply from the Stony Rises appears to have become exhausted, and flows from above Myamyn became relatively more important for maintenance of flows at Homerton. At this time EC began to rise rapidly as the baseflow became dominated by longer-residence time groundwater. By the time the Winter rains began in June/July, EC had reached a peak of 2,500 µS/cm (Figure 68).

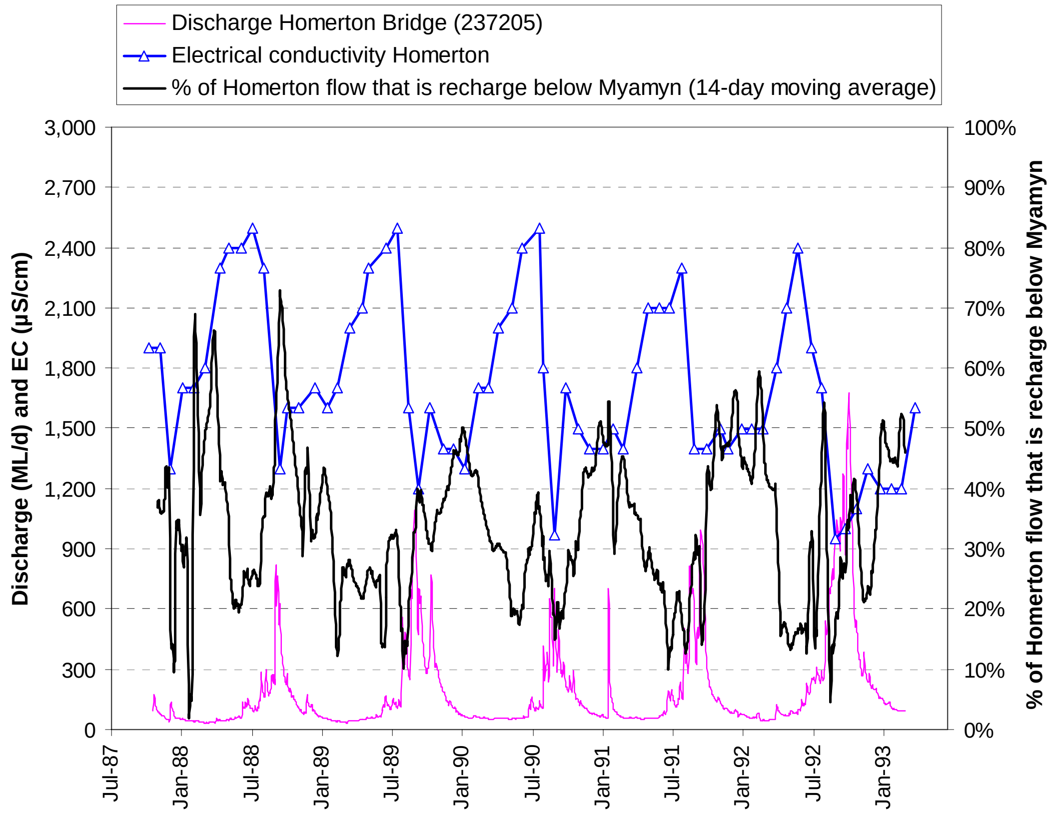


Figure 68. Time series of relationship between flows at Myamyn (upstream of Lake Condah) and Homerton Bridge (downstream of Lake Condah) compared with electrical conductivity.

The pattern of Lake Condah water level was only partly related to the pattern of EC and the pattern of percentage of flow at Homerton Bridge that represented recharge between Myamyn and Homerton Bridge (Figure 69). Lake Condah had run dry before the major groundwater contributions to Darlot Creek were exhausted. However, examination of the levels in sinkhole No. S1-2 revealed that water levels declined at around the same time that Darlot Creek EC began to rise and the Stony Rises groundwater contribution became exhausted (Figure 69). Thus, it would appear that in Winter a large reservoir of water accumulated in the Stony Rises around Lake Condah and to the Southwest. This reservoir includes Lake Condah, but the bulk of the supply would be subterranean.

The volume of water contributed to Darlot Creek between Myamyn and Homerton during the first three months of the recessions of 1988 to 1992 were calculated and found to be far greater than the volume of water that was stored and released from Lake Condah during those recessions (Table 13). The percentage of the flow contribution that could be attributed to water stored in Lake Condah varied from 4% to 14%. The catchment area of the land to the western side of Lake Condah between Myamyn and Homerton would have contributed about 30% of the inflows. The Stony Rises area (including Lake Condah) would have contributed about 70% of the inflows to Darlot Creek between Myamyn and Homerton.

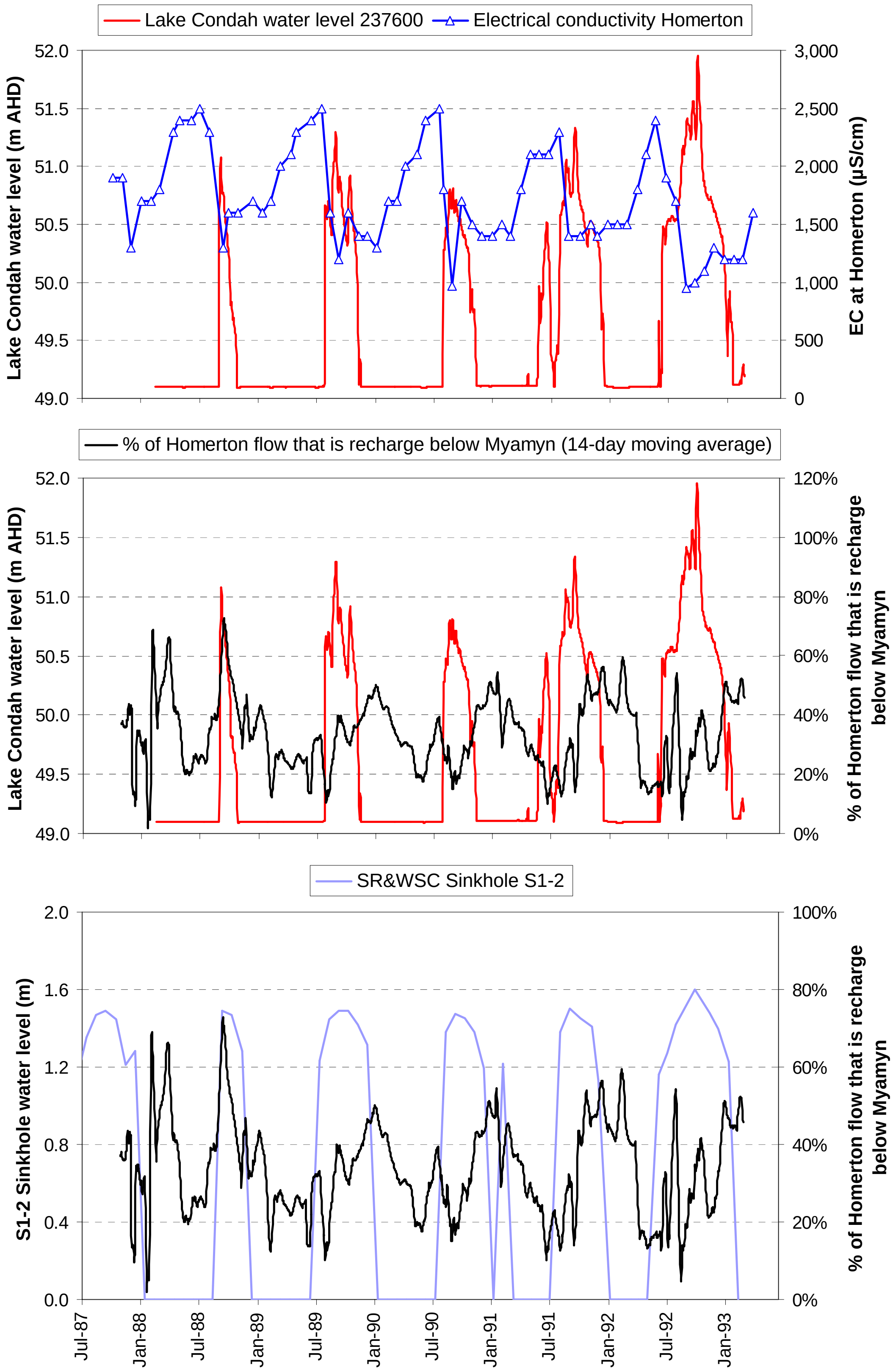


Figure 69. Time series of relationship between Lake Condah water level, Darlot Creek electrical conductivity, recharge between Myamyn (upstream of Lake Condah) and Homerton Bridge (downstream of Lake Condah) and water level in Sinkhole S1-2, located 3.5 - 5 km SW of Lake Condah.

Table 13.
Volume of water contributed to Darlot Creek between Myamyn and Homerton during 3-months of Spring recession periods from 1988 to 1992, compared to volume stored in Lake Condah in those years.

Recession period	Volume contributed Myamyn to Homerton (ML)	Peak level Lake Condah (m AHD)	Lake Condah peak capacity (ML)
07/09/88 to 07/12/88	11,194	51.1	477
16/10/89 to 16/01/80	6,591	51.3	757
14/09/90 to 14/12/90	4,825	50.8	188
25/09/91 to 25/12/91	8,168	51.3	757
13/10/92 to 13/01/93	13,579	51.95	1,940

5.2 Estimated losses from diversions from the Drain upstream of Lake Condah

A review of the licenced diversions and stock and domestic water use revealed a complex situation. The licenced volumes are nominal values and may not reflect the actual water use. The stock and domestic use is poorly known. In this study, an estimate of the potential diversions upstream of Lake Condah was made on the basis of a simple water balance. The assumptions made for the water balance were as follows:

i. The average annual diversions are equal to the total annual licenced allocation.
ii. The area under irrigation is 62 ha.
iii. The evapotranspiration rate of the Condah Swamp vegetation under flood irrigation is equal to reference crop potential evapotranspiration, ET_O.
iv. In the model, the actual losses were calculated as Net ET (rainfall – ET) on the assumption that the rain falling on the flooded surface is a direct contribution to the flow in the Drain that would not have otherwise occurred. Thus, the estimated net losses are lower than the estimated diversions.
v. The irrigation season extends from mid-December to April inclusive.
vi. When irrigation is applied to dry soil there are initial losses to the voids (air spaces). Some of the water that becomes stored in the soil will drain back to the Drain when the water level is lowered, and some will be lost to evapotranspiration at the end of the irrigation season. The loss was roughly estimated on the basis of water infiltrating to 1 m depth, and the peaty soil having a porosity of 0.6 when inundation begins. Initial losses were distributed evenly from mid-December to mid-January. The percentage initial loss returned to the Drain was adjusted as a model calibration factor to achieve the licenced volume. The return flow was distributed evenly over May. The calibrated percentage returned was 39%.
vii. Stock and domestic use was estimated to be 8 ML/yr per property, and it was assumed that there were twice as many users that do not require a licence as those that do. This calculation gave a daily total loss of 0.53 ML.

A simple water model was developed on the basis of these assumptions and run for the 115-year modelling period from 1890 to 2004. As stated above, the model was calibrated to give a long-term average annual diversion loss equal to the licenced allocation of 531 ML. The mean annual Net loss (i.e. assuming that rainfall on the flooded pasture returned water to the Drain flow) was 424 ML. The mean annual loss from stock and domestic was 192 ML. An example of the modelled potential losses from diversions upstream of Lake Condah is provided in Figure 70. Note that these are potential diversions – the actual diversions cannot be predicted, as they depend on factors that cannot be readily modelled.

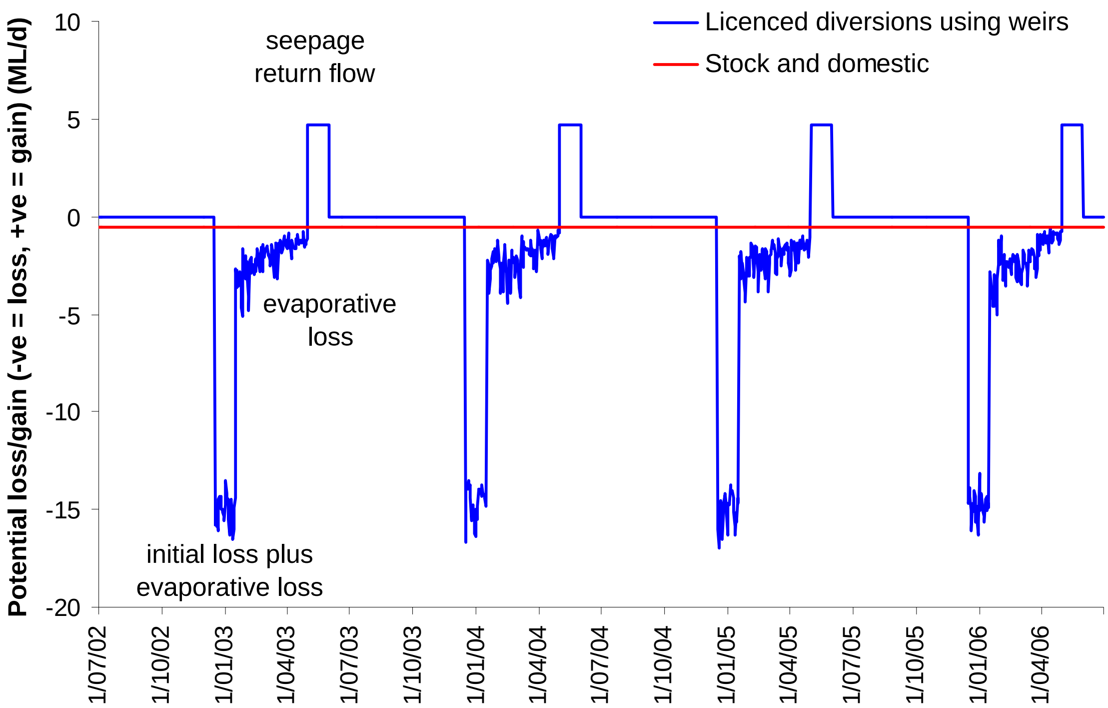


Figure 70. Example period of modelled potential losses from diversions upstream of Lake Condah.

5.3 Modelled impacts of farm dams

The impact of farm dams on streamflows was modelled using the Tool for Estimating Dam Impacts (TEDI) (SKM, 2002). The TEDI model removes the impacts of farm dams from a monthly flow series with the effects of licenced diversions already removed (i.e. added to the gauged flow record). The time series of predicted daily potential losses due to diversions was added to the gauged 5-year daily flow file for Myamyn (1988 – 1992) to produce a time series of flows as if there were no diversions; this series was aggregated to a monthly flow series. The TEDI model was run for this time series to produce a 5-year monthly time series of flows at Myamyn for no diversions and no farm dams. The monthly farm dam impacts (difference between input and output files) were disaggregated to a daily series (assuming even distribution within months); this series was then added to the daily "no diversions" series to produce a daily "no diversions and no farm dams" time series. This was the time series used to calibrate the rainfall-runoff model [Note: the rainfall-runoff model simulates the natural process of conversion of rainfall to runoff; it does not model farm dam impacts or diversions, which is why these effects had to be removed before undertaking the rainfall-runoff modelling].

The TEDI procedure involves measuring farm dam numbers, farm dam surface area, and farm dam catchment area. For the Lake Condah catchment this was done by sampling four 5 x 5 km cells (representative of the overall catchment). In each cell, every farm dam was measured from aerial photographs. A total of 87 farm dams were sampled. The measurements were for surface area and area draining to the dam. The catchment area was defined by interpretation of contours. The dam surface area was converted to volume using the relationship of Good and McMurray (1997). The relationship between dam volume and catchment area was within the normal range reported in SKM (2002). Parameter values for the demand functions were selected on the basis of advice provided in SKM (2002). Natural flows were estimated using the iterative solution option.

For flows higher than 100 ML/d, both diversions and farm dams had a relatively minor impact (Figure 71). The impacts of diversions and farm dams are greatest in summer and autumn, when demands are highest and when stream flows are lowest. Thus for flow of around 80 ML/d and lower, farm dams and diversions have lowered the discharge by around 5 – 10 ML/d, with the diversions accounting for around 2 – 3 ML/d of this (Figure 71).

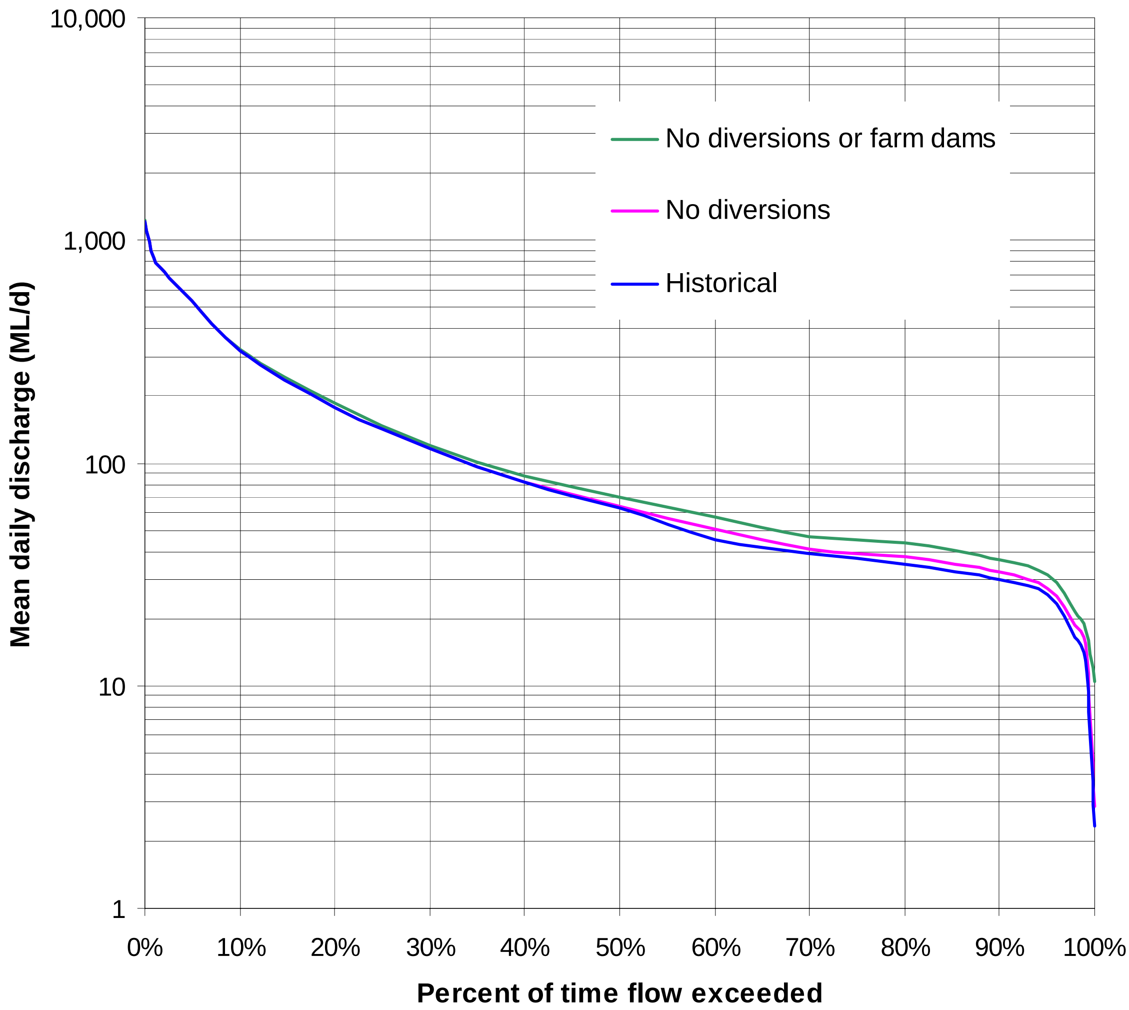


Figure 71. Flow duration curves for Myamyn daily data 1988 to 1992, historical gauged flows, flows with diversions removed, and flows with diversions and farm dam impacts removed.

5.4 Rainfall-runoff model

5.4.1 Brief literature review of impact of vegetation cover on catchment evapotranspiration and runoff

5.4.1.1 Relationships of Zhang et al. for forest and grass

It is well established in the scientific literature that, all things being equal, forests increase catchment evapotranspiration compared to grassed catchments (Calder, 1998; Zhang et al., 1999; Best et al., 2003). The key processes that control evapotranspiration include rainfall interception, net radiation, advection, turbulent transport, leaf area, and plant available water capacity. The relative importance of these factors varies depending on climate, soil, and vegetation conditions.

Evapotranspiration is an important component of the hydrological cycle and the physics of the process is well understood (Zhang et al., 1999). For wet canopies, the rate of evaporation of intercepted rainfall can be a significant component of the catchment water balance. Plant available water capacity may have a significant impact on evapotranspiration under dry conditions. Trees generally have much larger available water capacity than herbaceous plants. As a result, trees are able to maintain a relatively constant evapotranspiration rate over time, even when soil moisture in the upper part of the soil is limited. Trees generally have deeper root systems than grasses. This allows trees greater access to water stored in the soil and bedrock, which allows trees to transpire during dry periods when shallow-rooted plants have closed their stomata and reduced their evapotranspiration rate. Trees have a greater capacity to access water and thus can transpire more (Zhang et al., 1999). Forests and plantations have a higher Leaf Area Index on average than grasslands and crops. This means that they have more leaf area to capture rainfall during rainfall events, and a greater leaf area for transpiration losses. Both of these features mean that forests evapotranspire more water than grasses.

A compilation of data from over 250 catchments worldwide by Zhang et al (1999) showed that for a given vegetation cover, there is a good relationship between long-term average evapotranspiration and rainfall. The model of Zhang et al. (1999) is a good fit to the empirical data (Figure 72):

$$\frac{E}{P} = \frac{1+\omega\frac{E_z}{P}}{1+\omega\frac{E_z}{P}+\left(\frac{E_z}{P}\right)^{-1}} \qquad 1$$

where,

E = Predicted actual evapotranspiration

P = Precipitation

ω = Plant available water coefficient; ω should range between 0.5 (short grass) and 2 (forest)

E_z = Empirical parameter; best fit for a large data set was 1,410 (mm/year) for trees and 1,100 (mm/year) for grass

Similar relationships were derived by Holmes and Sinclair (1986) for 19 Victorian catchments. The relationship of Zhang et al. (1999) (Eq. 1) suggests that for a mean annual rainfall of 700 mm, a difference of approximately 130 mm in annual evapotranspiration can be expected between forested and grassed catchments (for comparison, Lake Condah catchment has an average annual rainfall of 705 mm).

The scatter in the data plotted in Figure 72 is explained by different species of tree and variations in forest age and, for managed forests, variations in stocking rates. Another source of scatter is variation between catchments with respect to summer or winter dominance of rainfall (Hairsine and van Dirjk, 2006). Water demand is lower in winter and therefore water use will be lower where most rainfall falls during colder periods (Keating et al., 2002). The Lake Condah catchment has a winter rainfall dominant climate, so with respect to water use it should be compared with the lower water using catchments plotted in Figure 72.

The Lake Condah catchment does not fit the predictive relationship of Zhang et al (1999). It is mainly under grass, yet its runoff is not much higher than predicted for a forested catchment of this size. However, examination of the data plotted in Figure 72 reveals many other cases of catchments under grass or crops in the annual rainfall range 500 – 800 mm having annual evaporation similar to forested catchments. One possible explanation for this is that the generalized curves of Zhang et al. (1999) do not take into account the variation in potential evapotranspiration from place to place (the curves reflect the combination of catchments considered).

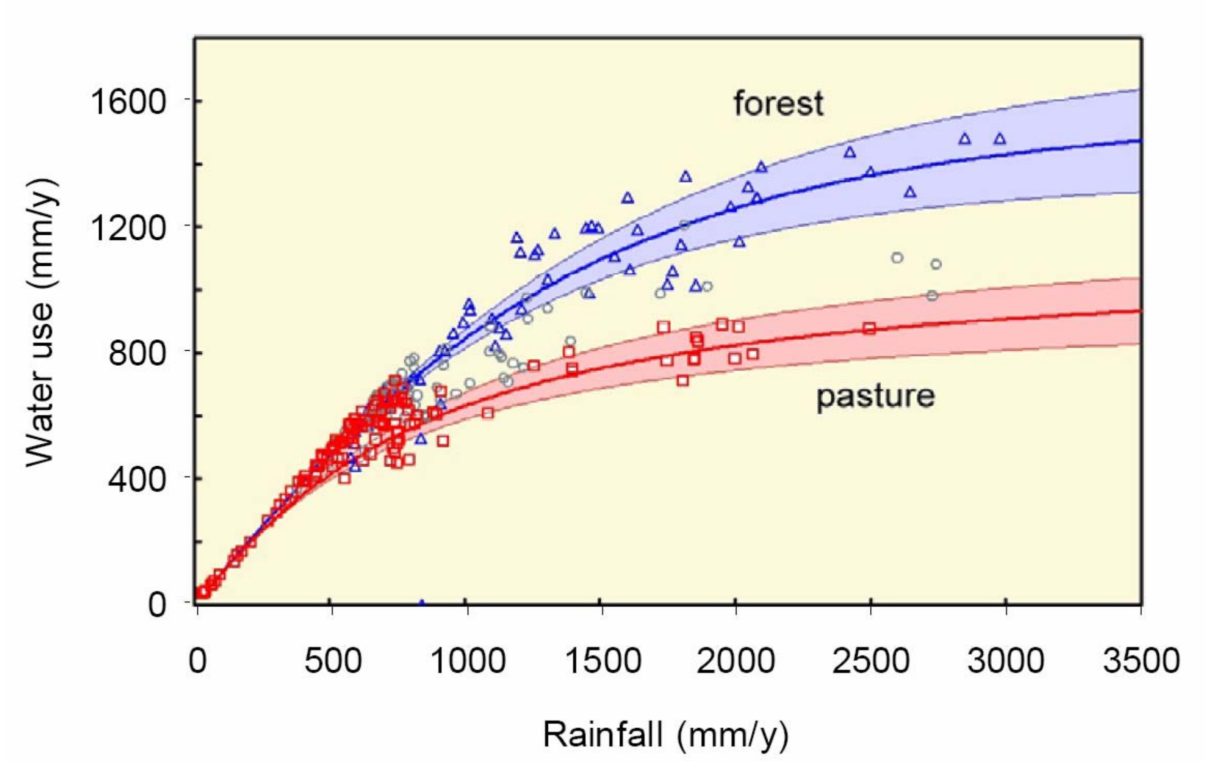


Figure 72. Relationship between annual evapotranspiration (denoted as water use on this graph) and rainfall for predominantly forest (blue) and pasture (red) catchments (grey dots represent catchments that have a mix). Plotted data represent over 250 catchment-scale measurements from around the world. Source: Figure taken from Hairsine and van Dijk (2006), plotted from data originally published by Zhang et al. (1999).

A later equation by Zhang et al. (2004) allowed for variation in potential evapotranspiration:

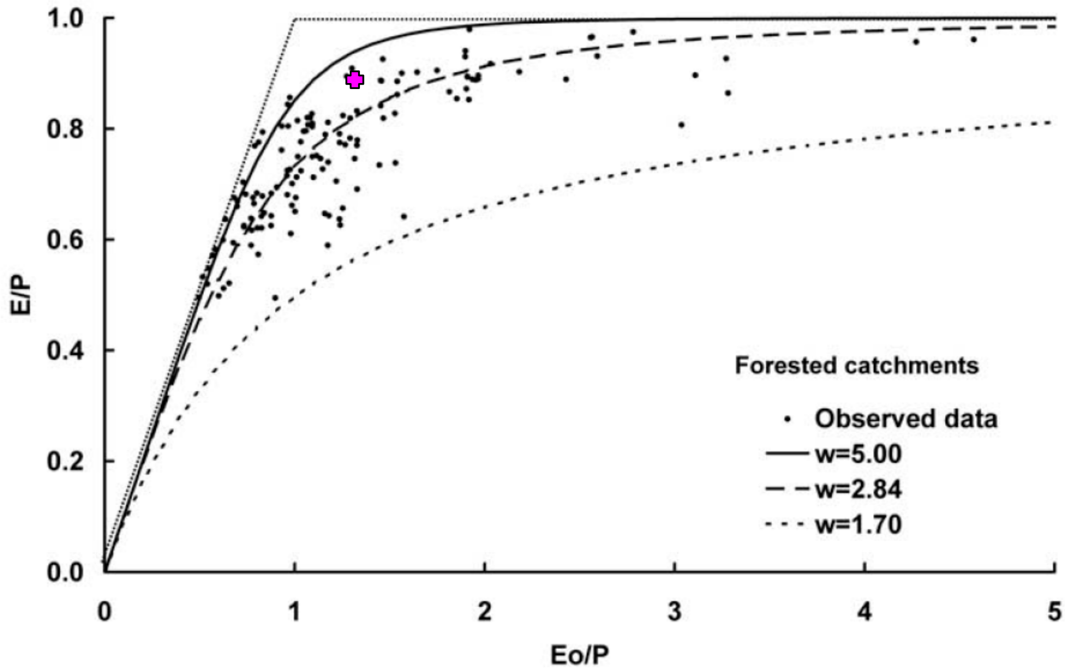
$$\frac{E}{P} = 1 + \frac{E_O}{P} - \left[1 + \left(\frac{E_O}{P}\right)^w\right]^{1/w} \qquad 2$$

where,

E_O = Potential evapotranspiration (also denoted as ET_O in this report)

w = Empirical catchment parameter; best fit for a large data set was 2.84 for forest and 2.55 for grass (Figure 73).

The study of Zhang et al. (2004) collated data from 331 Australian and 162 international catchments, representing a range of climates and catchment areas. The Australian data were for stations with at least 10 years, and in most cases 20 years, of unimpaired (i.e. unregulated) flow data. The forested catchments had over 75% tree cover and the grassed catchments had over 75% grass cover. According to Eq. 2, when evapotranspiration is restricted by potential evapotranspiration, the differences between vegetation types is much smaller than predicted by Eq. 1.



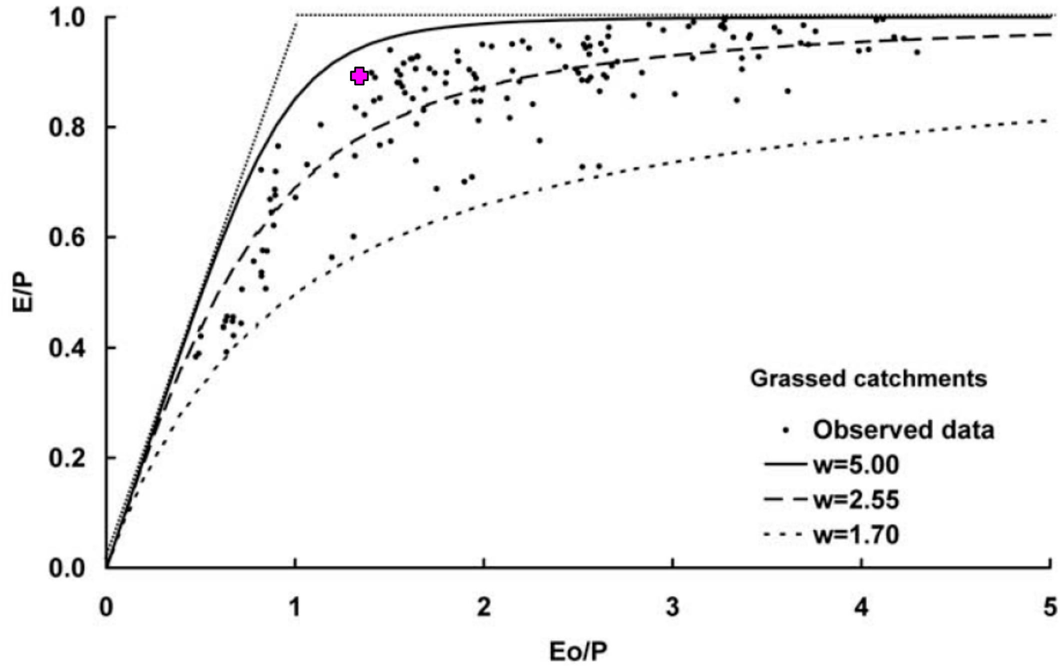


Figure 73. Scatterplot of observed evapotranspiration ratio (E/P) against index of dryness (E_0/P) from Zhang et al. (2004). Each point represents one catchment (top forested, bottom grassed), with evapotranspiration taken as the difference between precipitation and runoff. Lines are the relationships represented by Eq. 2 with different values of *w* parameter. Overlaid pink points represent observed E/P and E_0/P values for Lake Condah catchment.

Comparing the relationship between evapotranspiration ratio (E/P) and index of dryness (E_0/P) for Lake Condah catchment with the data for many catchments compiled by Zhang et al. (2004), it is apparent that Lake Condah (which is 80% grassed) fits within the range of values observed elsewhere for grassed catchments, but it also fits within the range of values for catchments that are at least 75% forested (Figure 73). This highlights the degree of variation in the hydrological behaviour of individual catchments. The best fit catchment parameters of Zhang et al. (2004) (Eq. 2) do not apply to the Lake Condah catchment, over-predicting observed runoff (Table 12). For the Zhang et al. (2004) (Eq. 2) model to describe the Lake Condah catchment, then the empirical catchment parameter w would be greater than 2.55 and less than 5. Catchment parameters $w = 4.03$ for forest and $w = 3.62$ for grass (and assuming that the mixed vegetation catchment parameter lies mid-way between these two) fit the Lake Condah catchment data. These parameters were derived by simply factoring the best fit forest and grass empirical catchment parameters derived by Zhang et al. (2004) by 1.42 (this factor was derived by trial and error application of Eq. 2 to fit the 1988 – 1992 mean rainfall and runoff for Lake Condah catchment, assuming the current landuse mix). These parameters predict that Lake Condah catchment under mean annual rainfall of 705 mm fully grassed would have runoff of 81 mm, and fully forested would have runoff of 65 mm. Thus, a (hypothetical) full conversion from grass to forest in this catchment would produce a 20% reduction in runoff.

5.4.1.2 Factors mitigating against realising of the maximum predicted hydrological effect of converting pasture to forest

The basic relationships of Zhang et al. (2001) and Zhang et al. (2004) (Eq's 1 and 2) are based on catchments that are either nearly all forest or nearly all grass. Land use change studies typically apply the appropriate equation to the proportion of the catchment to be converted from pasture to forest or vice-versa. Factors that mitigate against the maximum effect being realised in practice are percent of area planted, planting position, variation in stand age and site productivity (Vertessy, 2001; Vertessy, 2004; Hairsine and van Dijk, 2006).

The classic forest hydrology literature suggests that the magnitude of the catchment runoff effect is linearly proportional to the percent of catchment cleared (e.g. Bosh and Hewlett, 1982). So, for example, if 50% of a catchment was planted, then the effect on runoff would be expected to be half that for a fully planted catchment. However, this relationship may be non-linear, and there may be a threshold percent cover below which it is difficult to observe a change in evapotranspiration, and hence runoff. According to Vertessy et al. (2002), planting a catchment with forest to <20% of the total area will generate little impact on runoff, especially if the plantation is staged to produce a multiple-age forest (Keenan et al, 2004; Vertessy, 2004). Bureau of Rural Sciences (2003) noted that while there is strong scientific evidence that the magnitude of catchment response is proportional to the percentage of the catchment planted, this relationship is less certain where only small proportions of catchments are planted. Bureau of Rural Sciences (2003) reconfirmed that in catchments under 1,000 ha, where less than 20% is planted to forest plantations and there is no rainfall gradient within that area, it is difficult to measure a statistically significant effect on catchment yield. The percentage of Darlot Creek catchment under forest in 1990 was around 15%, and by 2030 this could double to over 30% (SKM, 2005b). Thus, the percentage of this catchment under forest should be sufficient to produce a measurable response in catchment yield.

As discussed in the preceding sub-section, planting position is important, with the further away from the stream the plantation is located, the lower will be the impact on the stream hydrology (O'Loughlin and Nambiar, 2001). Vertessy et al. (2002) cited a modelling study where a catchment was progressively planted from the top of the catchment to the bottom, and vice-versa. The results indicated that planting the lower 30% of the catchment had a much greater impact on runoff reduction than planting the upper 30% of the catchment. The reason for this is that the lower valleys are the prime runoff producing areas (convex topography), and the trees grow better there (Vertessy et al., 2002).

In most situations, the full hydrological impact of plantations is felt after a period of 8-15 years after planting. Hence a mixed-age stand of plantings will reduce the maximum hydrological impact at any particular time (Vertessy et al., 2002). If plantation growth rates are retarded for some reason, then the impact on runoff will be less than the maximum possible. Similarly, if the growth rates are above average, this might lead to larger than expected reductions in runoff (Vertessy et al., 2002).

Commercial plantings aiming to maximize productivity will tend to prefer areas with fertile, deep soils with good water holding capacity, and extended accessible areas with low slope (Hairsine and van Dijk, 2006). This suggests that commercial forestry would prefer areas where the impacts on water yield would tend to be higher than the catchment average. The

Draft Victorian Code of Forest Practices for Timber Production (DSE, 2006) does not specify maintenance of hydrological buffers for protecting the main runoff producing zones of a catchment. However, the Code does specify that buffers and/or filter strips be maintained in order to protect "water quality and river health", so the main runoff generating areas would be at least partially maintained as grass. Thus, modelled predictions of the impact of changed land use on runoff should be normally regarded as maximum possible impact.

5.4.1.3 Approach to estimating impacts of changed land cover on stream flow

The impact of tree plantations on water use and other environmental values in agricultural landscapes has been a topic of public debate in Australia in recent years. This has arisen from the expected increase in plantation establishment, coincident with publication and interpretation of various scientific articles discussing potential effects of such expansion on water run-off and stream flows (CSIRO, 2004). In October 2003 a group of Australia's leading scientists and government agencies met to clarify key scientific issues on the impact of forest plantations on catchment water yield where there have recently been conflicting or contrasting views (Bureau of Rural Sciences, 2003). The clarifying statement recommended an approach to modelling the water yield impacts of plantations across large catchments with variable characteristics. This approach involved first dividing the catchment into small spatial units, calculating the mean annual water yield impact for each of these units using established relationships (e.g. Zhang et al. 2001, Eq. 1), then re-aggregating the small units to give the total impact for the entire catchment. Of course, the only reason for subdividing the catchment would be if rainfall and evaporation, or percentage area planted, varied significantly across the area of interest. Thus, the conventional approach is to apply a rainfall-runoff model to the problem, with parameters selected to suit the local conditions (local details such as soil type and tree type can be considered) and calibration performed where data are available. The rainfall-runoff model is then re-run for various future scenarios of percentage forest area, and in some cases for forest age scenarios, to predict the daily or monthly stream flow over the period for which rainfall data are available.

Bureau of Rural Sciences (2003) recognised that the location and planting design of trees may increase or decrease water yield in catchments. O'Loughlin and Nambiar (2001) described the concept of the *hydrologically effective area* in a catchment. According to this concept, some parts of catchments may become hydrologically isolated from discharge areas or streams when upper parts of hillslopes dry out, and there is no downslope water movement from these areas. As the convergent slopes remain wetter than the others, they are more effective in maintaining streamflow during dry periods. Aryal et al. (2003) detailed the concept of effective catchment areas and provided a method for calculating their location and extent. Converting the vegetation on a convergent hillside, from pasture to forest for example, has a more significant effect on baseflow than a similar change on other hillslope shapes. This effect is compounded by forests being able to draw more water from convergent slopes, compared with the drier parallel or divergent slopes. The net result is that planting forest vegetation on convergent parts of a catchment, usually located close to drainage lines, will maximise the impact of the planting on reducing baseflows. Conversely, protection of the hydrologically effective zones (by not altering the land cover in these zones) means that changes in land cover in upslope areas will have little or no impact on streamflow. In an application of the methodology of Aryal et al. (2003) to a catchment on the Fleurieu Peninsula, South Australia, Gippel (2005c) demonstrated that the percentage of the total catchment area planted to forest is not inherently relevant to the protection of summer baseflows, provided appropriately wide grass streamside buffers are maintained.

The conventional approach to predicting impacts of changed land cover on runoff using established relationships (such as Eq. 1 and Eq. 2) does not take account of hydrological buffers, because the empirical studies that produced the calibration data for the models did not consider this variable [i.e. the catchments investigated by Zhang et al. (2001, 2004) were assumed to be almost entirely forested or entirely under pasture]. Also, rainfall-runoff models do not simulate the concept of dynamic hydrologically effective hillslope lengths (Aryal et al., 2003). In reality, forest practice codes require various buffers and setbacks. If buffers are left as pasture, they will produce more runoff than if the buffer area was planted.

Very few studies that have made predictions of the likely impacts of converting pasture to plantation forests have used the methodology of Aryal et al. (2003). Although the methodology was devised by leading hydrologists and is published in what many would regard as the leading international hydrology journal, we are aware of only one subsequent application of the model to a real-world situation – Gippel (2005c). A possible explanation for this is the higher data demands and greater complexity of modelling required by the Aryal et al. (2003) approach. Certainly, application of this methodology is well beyond the resource limitations of the Lake Condah study. The alternative is to assume that the Lake Condah catchment has hydrological properties similar to those studied elsewhere and apply a general relationship, as recommended by Bureau of Rural Sciences (2003). The results obtained from this approach hinge on the particular "established relationship" that is adopted to describe the relationship between vegetation type and hydrological response. For a given change in the percentage planted to various land use types, the magnitude of the predicted impact is purely a function of the adopted relationship. As explained previously, the Zhang et al. (1999, 2001) relationship (Eq. 1) is of doubtful relevance to Lake Condah catchment, being unreliable for areas with annual rainfall less than around 800 mm and with relatively low potential evapotranspiration.

The Zhang et al. (2004) equation with catchment parameters $w = 4.03$ for forest, $w = 3.62$ for grass, $w = 3.83$ and $w = 3.55$ for bare land predicts the current runoff from Lake Condah catchment to be 79 mm for annual rainfall of 705 mm. Using these same parameters, for the WatLUC Bas case land use change scenario (increase in percentage forest of around 15% by 2030), the Zhang et al. (2004) model predicts mean annual runoff of 76 mm, which is a reduction of only 4% from the current scenario. In contrast, the SoilFlux model used in the WatLUC study (SKM, 2005b) predicted a 38% reduction in runoff in the Darlot Creek catchment for the Base case land use change scenario. Even as a maximum possible impact, this value appears high when compared with other data published in literature on this topic.

This study makes no pretence to "know" what the impact of land use change on runoff might be for the Lake Condah catchment. Predictive models suggest that the WatLUC Base case 2030 land use change scenario could result in a reduction in runoff ranging from 4% to 38%. In this study, an average 12% runoff reduction was adopted for the 2030 land use scenario. The rainfall-runoff model was calibrated to produce this degree of impact. The value of 12% reduction is not presented as the most likely eventuality should the predicted 2030 land use change take place. Rather, it is an arbitrary value that lies within the range of possibilities.

5.4.2 Background to rainfall-runoff model

Rainfall-runoff models simulate catchment runoff on the basis of rainfall and evapotranspiration data. Various models are available. The models are normally applied to catchments from 10 km^2 to 10,000 km^2 on a monthly or daily time step. The models are typically used to fill gaps and extend streamflow records, or to run scenarios with altered parameters.

WaterCress 2000 Version 1 Feb 2006 (Water - Community Resource Evaluation and Simulation System) is a water balance model for designing and testing trial layouts of water systems that can access multiple sources of water. WaterCress was developed by David Cresswell and Richard Clark and can be downloaded from the Water Select Pty Ltd website (URL: http://waterselect.com.au/index.htm). WaterCress is not a rainfall-runoff model itself. Rather, it is a model that uses numerous models to complete the tasks of estimating water availability and routing (Cresswell et al., 2001). The model is designed to explore alternative system layouts at the feasibility stages of water resource system planning. Modelling the rainfall-runoff process is a core component of WaterCress. WaterCress has a number of alternative rainfall-runoff models available within its structure. For this project the WC-1 model was used.

WC-1 is based on the typical lumped parameter Boughton model using a partial area method. The WC-1 model is a 10-parameter model using 3 storages to track interception, soil moisture and groundwater (Cresswell et al., 2001). The model was run for 115 years from 1890 to 2004 using daily potential ET_O and rainfall time series' derived from DataDrill files.

5.4.3 Rainfall-runoff modelling procedure

The WC-1 rainfall-runoff model requires input of various parameters, plus suitable rainfall and evapotranspiration time series'. The modelling procedure involved a data gathering and model calibration phase, followed by various modelling steps to produce five daily time series of 115 years duration (Figure 74). It should be noted that the calibration procedure was less than ideal, due to the very short length of gauged record available at Myamyn. The model was not calibrated to Homerton Bridge gauge data, because it appears that the Stony Rises downsteam of Lake Condah produces a particular hydrological response that may not be present, or not as marked, upstream of Lake Condah. Another issue with calibration is that predictions of diversions and farm dam impacts were not made within the rainfall-runoff model itself, so these effects had to be removed from the calibration file prior to modelling. The WC-1 model does allow for these components to be included, but in this study we preferred to utilize the widely-accepted Victorian method for assessing farm dam impacts (TEDI), and estimating diversions was a fairly straightforward, if inexact, procedure. Having only five years of data for calibration meant that it was not possible to test model performance against real data. The calibration procedure followed was to adjust the model parameters to achieve the best fit to the adjusted daily Myamyn 1988 - 1992 data, then make no further changes to the model parameters when generating other scenarios – the only different inputs were the rainfall and evaporation files (for climate change scenarios) and altered proportions of the four hydrological land use types (for land use change scenarios).

The WC-1 model structure allows a catchment to be simulated by a large number of linked nodes. The only justification for dividing the catchment into separate areas is if these areas can be assigned different hydrological properties. In the Lake Condah catchment there was insufficient information available to justify subdividing the catchment spatially. However, the catchment was divided into four virtual areas on the basis of different land cover classes: forest, mixed vegetation, grass and bare land. The areas of these land covers were varied according to the land use scenario. Each of these land covers was assigned a different set of parameter values (Table 14). These parameters were set on the basis of advice provided in the WC-1 User Manual, previous experience with the model, and trial and error adjustments made during the calibration process. Also, the relative difference between the parameters for the four land use classes were set so as to produce a 10% impact on runoff for the WatLUC 2030 Base case land use change scenario for the 1988 – 1992 calibration period. A further calibration step was to introduce a routing function to redistribute flows so that the shape and timing of the modelled hydrographs matched the observed patterns. This was a simple function available within Watercress, calibrated using a coefficient and exponent: Store (t) = 60 x Outflow $(t)^{0.75}$, where Inflow = ΔStore + Outflow. Calibration of the model was performed as a trial and error process:

1. Set model parameters according to WC-1 Manual and previous experience with the model. The proportionality between parameter values for the four land use classes was based on the relative differences that would be expected for these land use types.
2. Run the model and compare annual, monthly and daily predictions with the observed data and determine the correlation coefficient between monthly predicted and observed discharge.
3. Adjust GWN and SMD and GWR to achieve observed baseflow pattern.
4. Adjust MSM, IS, CD and PF to achieve observed peak flows and flow recessions. In adjusting these values, the logical proportionality of the values between the four land use classes was preserved.
5. Re-run the model, and compare the correlation coefficient between monthly predicted and observed discharge with that of the former model run.
6. Continue the process from Step 3 to Step 5 until the correlation coefficient between monthly predicted and observed discharge was maximized, and the predicted daily flow time series was a good representation of the observed pattern of baseflows, stormflows and recession limbs.

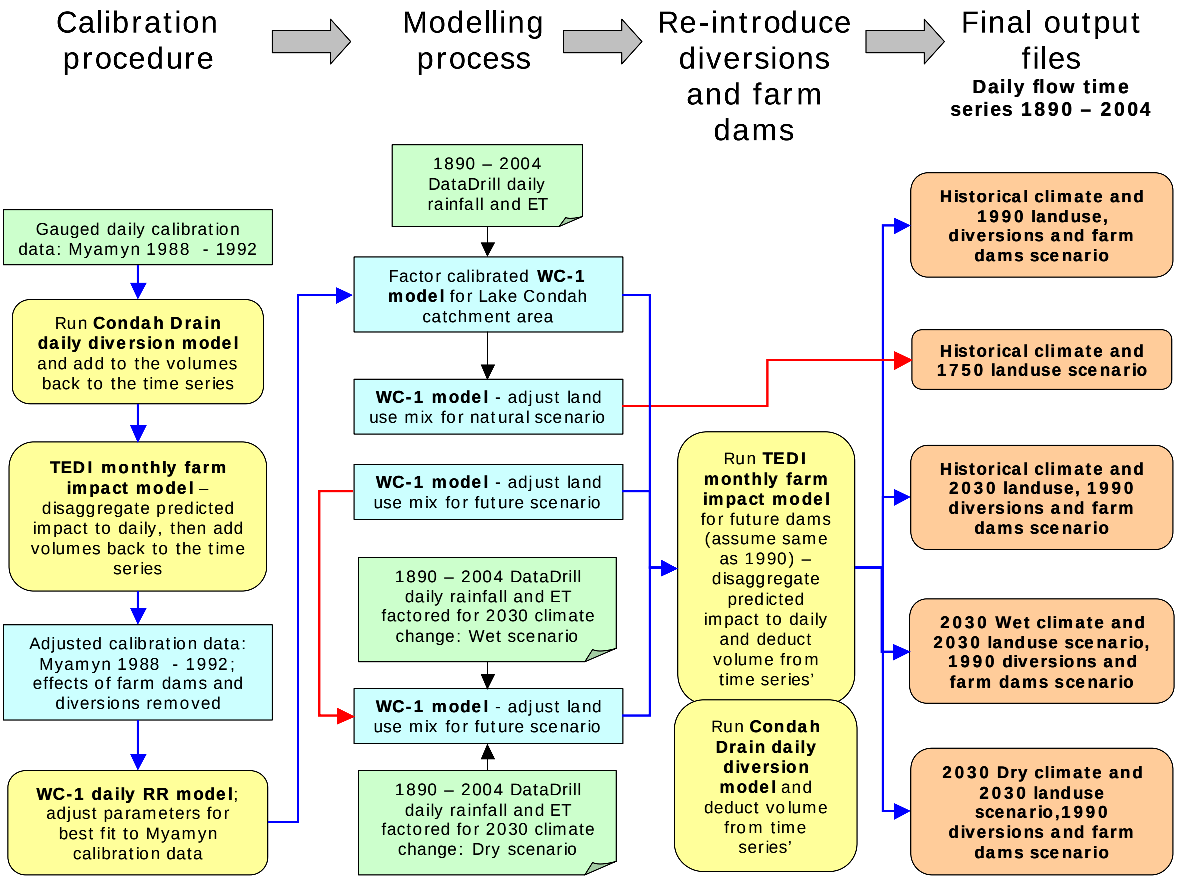


Figure 74. Depiction of the main modelling steps in deriving the required daily discharge time series' for Condah Drain at Lake Condah.

5.4.4 Model calibration results

It was possible to closely reproduce the gauged record at Myamyn (adjusted to remove effects of diversions and farm dams) using the WC-1 model. Annual discharge was closely predicted, except for 1988 (Table 15). Modelled total discharge over the period 1989 - 1992 was within 3% of the estimated historical value. Note that the model calibration intentionally produced a predicted 2030 land use change impact on runoff of around 10% (discounting 1988) (Table 15). Modelled and historical monthly total discharges were closely correlated (Figure 75, Figure 76), except for the period September to December 1988. The problem is also apparent in the plot of daily discharges, where it is clear that the only real points of poor fit are the two minor flood peaks of 1988 (Figure 77). Suspicion must fall on the gauged data in this case, because these two peaks were clearly recorded at the Homerton Bridge gauge. On that basis, it was decided to ignore the 1988 gauged data. The modelled flood peaks and recessions fitted the observed data well, with the only weakness being lower predicted baseflows in autumn (it was not possible to correct this with calibration). By normal modelling standards, the fit between observed and predicted values is very close.

Table 14.
Values of WC-1 model parameters for Lake Condah catchment simulation.

Parameter	Normal range	Bare areas (transport)	Pasture/ grass	Mixed veg.	Mature forest
Medium soil moisture (MSM)†	150-300	100	150	200	300
Interception store (IS)‡	10-25	10	14.5	20	24
Catchment distribution (CD)*	25-60	35	30	28	25
Ground Water Discharge (GWD)&	0.0010-0.0001	0.001	0.003	0.003	0.004
Soil moisture discharge (SMD)%	0.0001	0.0001	0.0003	0.0003	0.0004
Pan factor for soil (PF)¶	0.6-1.0	0.40	0.85	0.95	1.00
Fraction to groundwater loss (FGL)#	zero	zero	zero	zero	zero
Store reduction coefficient (SRC)§	0.9	0.9	0.9	0.9	0.9
Groundwater Recharge (GWR)¥	0.05-0.30	0.10	0.30	0.30	0.40
Creek Loss (CL)Ω	zero	zero	zero	zero	zero

† Represents field capacity of soil, higher for forest.

‡ Size of interception store, low for pasture and high for forest.

* Sets the range of soil moisture values about MSM. A larger value will initiate runoff earlier and more often, so higher for grass.

& Proportion of the groundwater store that discharges as baseflow to the stream. Higher than normal range in order to produce sufficient baseflow.

% As soil moisture increases there is a rise in the baseflow that occurs due to the saturation of the soil storage. Higher than normal range in order to produce sufficient baseflow.

¶ WC-1 normally uses pan evaporation as input, in which case it has to be factored downwards to simulate actual evapotranspiration (ET). Potential ET (E_O) was used as input, with scaling factors set to produce a 10% impact on runoff for the WatLUC 2030 Base case land use change scenario.

Assumes no loss of water to regional groundwater aquifer.

§ Determines the rate that water from the interception store moves to the soil store. Model relatively insensitive to this parameter.

¥ Proportion of water passing to groundwater. For this catchment high values were required in order to produce enough baseflow to fit observed data.

Ω A reduction factor used to decrease runoff. This simulates take up of water from riparian vegetation and the reduction of baseflow in summer months. Not relevant here.

Table 15.
Annual data for WC-1 calibration period for Myamyn. Note: 1988 historical data considered unreliable.

Scenario	Variable	Year					
		1988	1989	1990	1991	1992	1989-1992
	Rainfall (mm)	652	716	658	699	892	
Historical (adjusted for no diversions or farm dams)	Runoff (GL)	26.8	50.8	37.7	49.3	86.5	224.3
	Runoff (mm)	46	87	64	84	148	
	Water use (mm)	606	630	593	615	745	
Modelled historical	Runoff (GL)	41.7	52.6	38.6	41.3	84.5	217.1
	Runoff (mm)	71	90	66	71	144	
	Water use (mm)	581	626	592	628	748	
Modelled 2030 WatLUC Base case land use change scenario	Runoff (GL)	39.7	47.3	34.4	36.6	75.8	194.1
	Runoff (mm)	68	81	59	63	130	
	Water use (mm)	584	636	599	636	763	
	Reduction in runoff from historical (%)	5%	10%	11%	11%	10%	

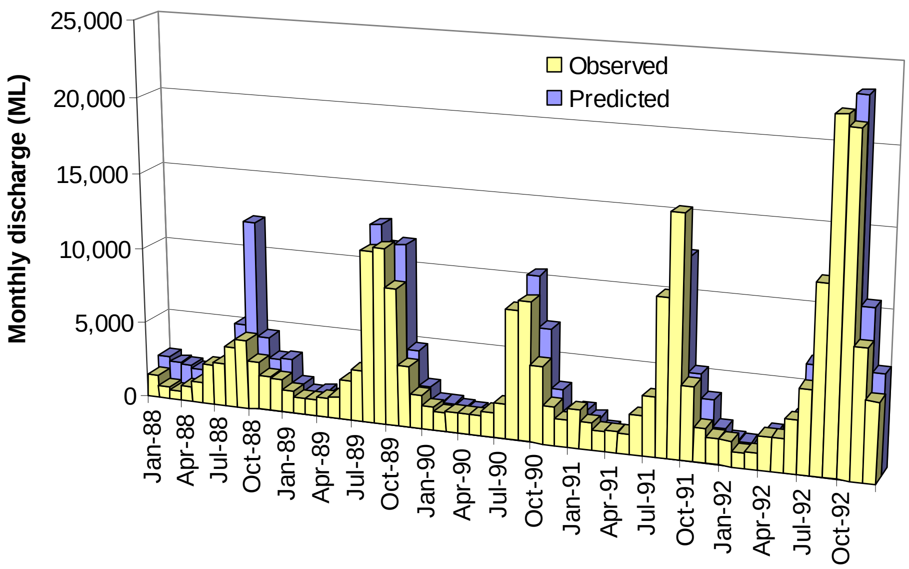


Figure 75. Time series of observed and predicted monthly discharge for Myamyn (with diversions and farm dam effects removed) over the 1988 - 1992 calibration period. Gauged discharge for winter of 1988 is suspected to be incorrect.

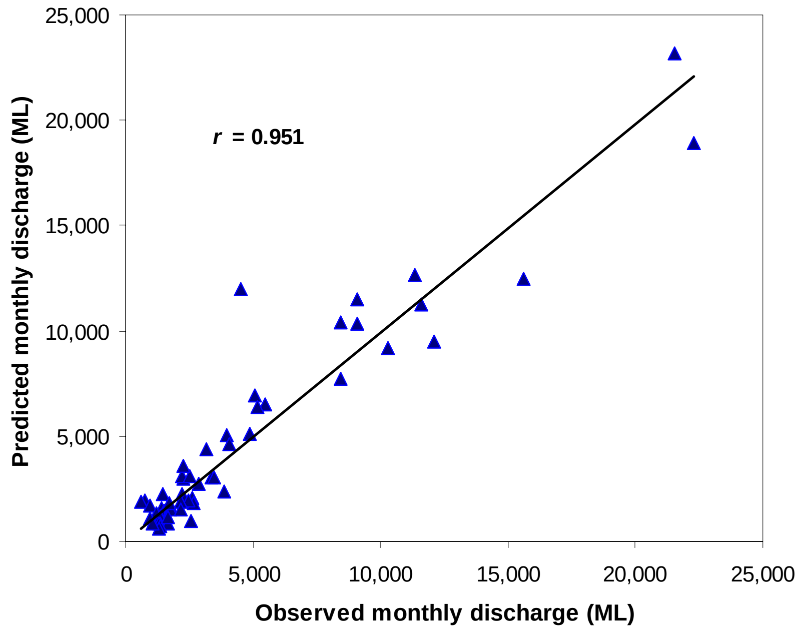


Figure 76. Scatterplot of observed and predicted monthly discharge for Myamyn (with diversions and farm dam effects removed) over the 1988 – 1992 calibration period. Outlying point at 4,500 ML observed discharge is from Sep 1988, when gauged discharge is suspected to be incorrect.

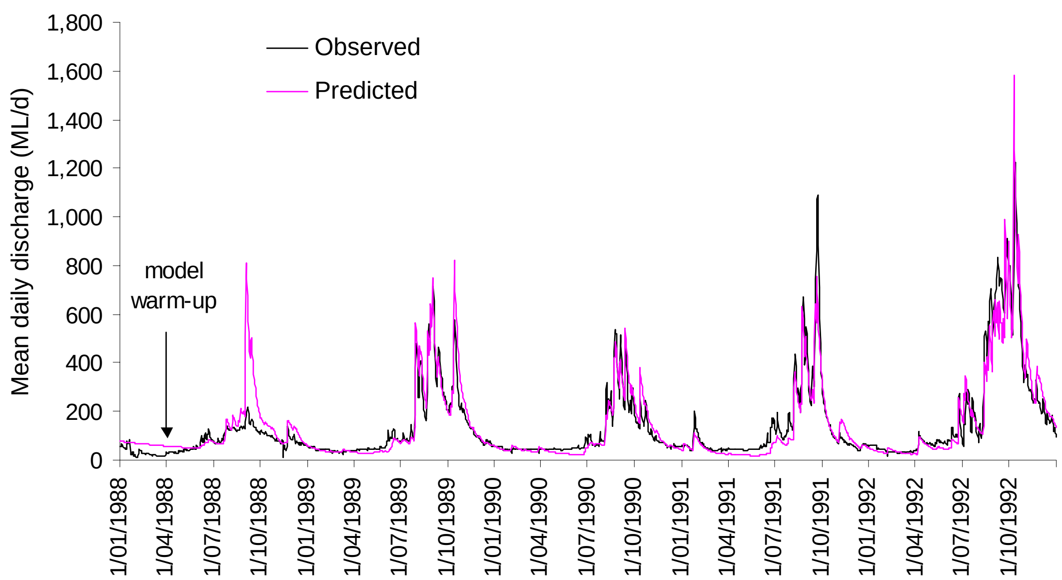


Figure 77. Observed and predicted mean daily discharge for Myamyn (with diversions and farm dam effects removed) over the model calibration period.

5.5 Predicted Condah Drain (at Lake Condah) hydrology under natural, current and future scenarios

5.5.1 Time series of flows

The 115-year time series of annual flows (Figure 78) shows a high degree of inter-annual variability. This alone suggests that with respect to maintaining managed water levels in Lake

Condah, the prospects from year-to-year will be at least partly determined by this variability. The 115-year time series of daily flows shows that winter flows regularly reach 1,000 ML/d peaks (Figure 79). The plot also shows one extraordinary feature of the time series of Darlot Creek flows. On 18th March 1946 the catchment was subjected to a flood of very high magnitude. The difference between the magnitude of this flood and the second largest is unusually large. It is important to recognize that this is an uncalibrated modelled discharge peak, and may be unreliable. Also, the model predicts mean daily discharge, so theoretically the instantaneous peak flow would have been higher than this.

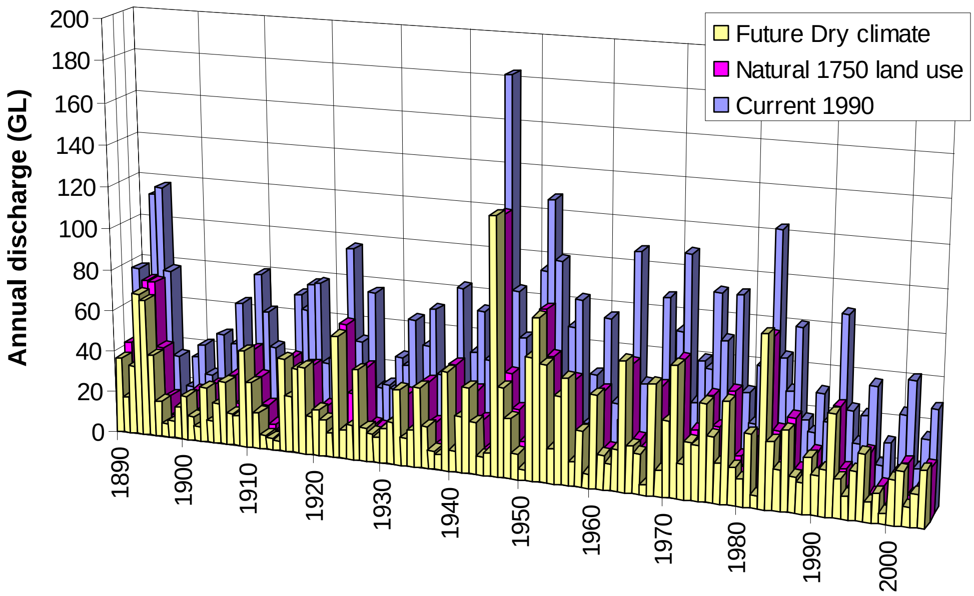


Figure 78. Predicted time series of annual discharge Lake Condah catchment under three modelled scenarios.

5.5.2 Mean annual runoff

The predicted mean annual runoff values (Figure 80) were not dissimilar to those derived from the gauged data (Table 12). The change to 2030 land use was calibrated to have a 10% impact on runoff for the 1988 – 1992 period, but for the entire data series the impact was 12%. The Natural scenario of 1750 vegetation and historical climate had 47% less runoff than under the Current scenario, but it must be remembered that the relative impact is a function of the way the model was set up and calibrated to respond to the main land use types. The 2030 Dry climate with 2030 land use scenario reduced runoff by 48%, which is virtually identical to that of the 1750 Natural land use scenario (assuming Current climate). This predicted combined impact (i.e. 38 GL/yr reduction), although high, is less severe than that predicted by SKM (2005a). The 2030 Wet climate with 2030 land use scenario produced a 7% reduction in runoff – in this case the increased water use due to land use change was offset by the increased rainfall. The 2030 Dry climate impact alone was predicted to reduce mean flows by 32%, which aligns well with the reduction of around 40% predicted by the SoilFlux model of SKM (2005a) for Darlot Creek catchment, and the reduction of 40% for the Driest scenario modelled by Jones and Durack (2005) for the wider Portland Coast catchment. The 2030 Wet climate impact alone was predicted to *increase* mean flows by 17%. This compares with a 5% *reduction* in runoff for the Wettest scenario modelled by Jones and Durack (2005) for the wider Portland Coast catchment.

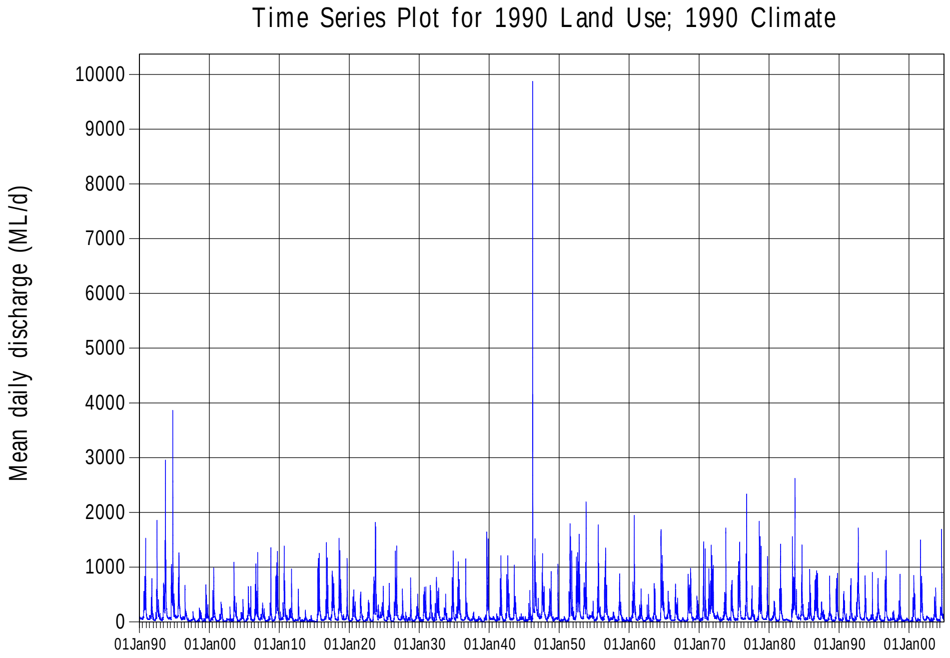


Figure 79. Predicted time series of daily discharge Lake Condah catchment under modelled "Current" scenario.

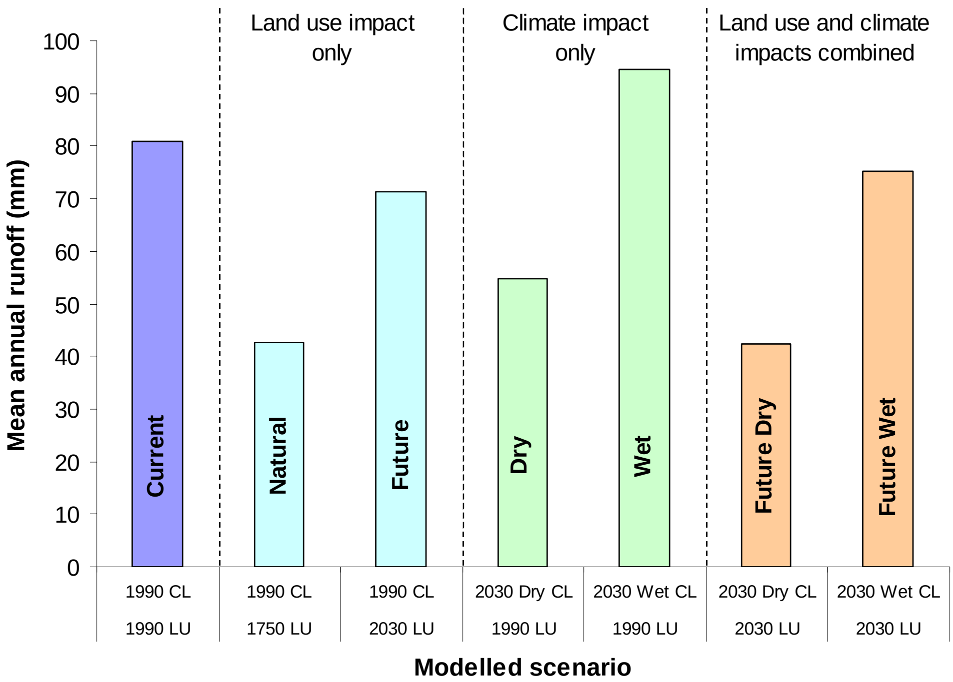


Figure 80. Predicted mean annual runoff in Lake Condah catchment under modelled scenarios for 115 year period from 1890 to 2004. Note that the degree of land use impact for the Future scenario (12% reduction) was pre-determined as part of the model set up and calibration process and is not a prediction of the most likely impact. Note that the "Climate impact only" scenarios were run solely for the purpose of comparing predicted average annual impact with other studies - they are not presented as realistic future scenarios. 1990 CL is shorthand for historical climate.

5.5.3 Flow duration

The flow duration curves reveal that the major hydrological impact is for the Future Dry climate scenario and the 1750 scenario, which reduced all flows (Figure 81). Only the Current scenario did not exhibit cease to flow.

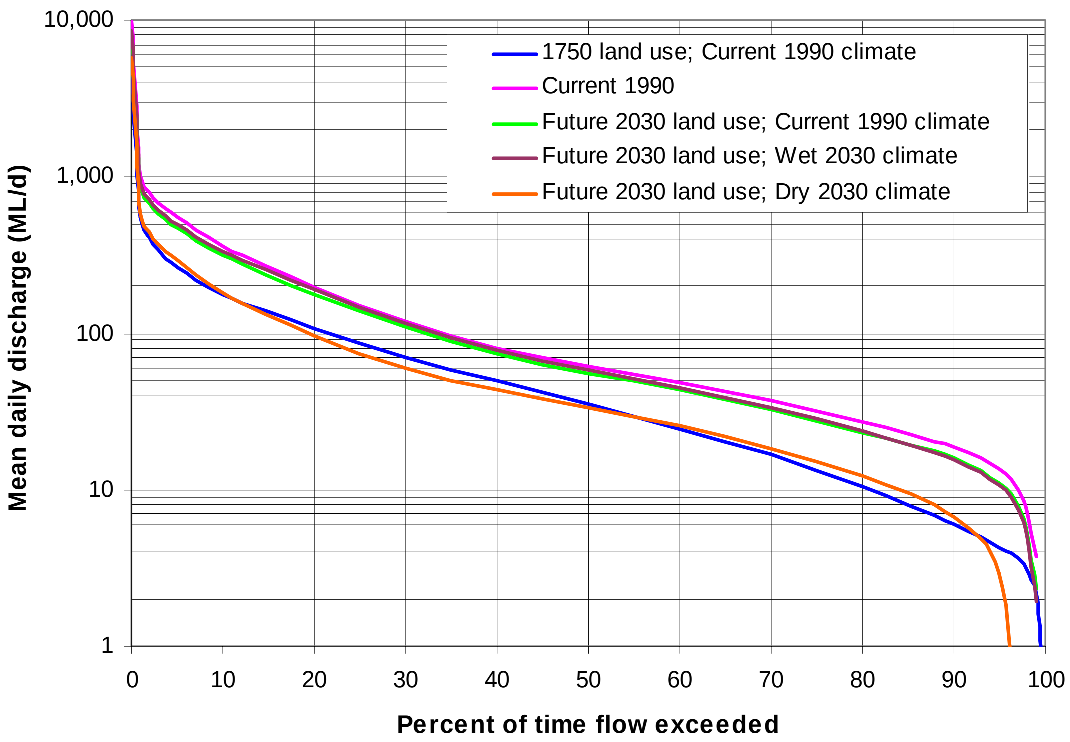


Figure 81. Flow duration curves for predicted daily flows for Lake Condah catchment under modelled scenarios.

5.5.4 Flood frequency-magnitude

Partial duration series analysis was undertaken, extracting 230 events from the time series of each scenario, with event independence defined by conditions of:

- a minimum period of 14 days between independent event peaks and
- the value between two independent events must be less than 75% of the smaller peak.

The partial duration series is preferred to the annual series for flood events with ARI<10 years (IEA, 1988). The plotting position was determined using the Cunnane formula with $\alpha = 0.4$, as recommended in Gordon et al. (2004, p. 207). It is normal engineering practice to fit a line through the plotted data and make predictions about larger magnitude, infrequent events, but this was not necessary here due to the long data series available and the low scatter in the plotting positions (Figure 82). There is always uncertainty in the plotting position assigned to the largest event. In the case of the modelled Lake Condah catchment flows this is especially the case. It is important to remember that these are modelled flood peaks, and are thus are unreliable. The model was calibrated to only 4 years of gauged data, and in that period some peaks were overestimated and some underestimated (Figure 77). So, it is likely that some of the peaks selected for this analysis were over-estimated. The predicted 18th March 1946 flood peak is much higher in magnitude than any other peak. This flood resulted from extraordinarily sustained and heavy rain during at time. The 1946 value plots as an outlier (Figure 82), for which there are two possible interpretations:

- the modelled value is an overestimate, or

- the ARI of the event is actually much higher (up to 500 years or more).

The truth is probably a mix of these two possibilities. It is not possible to make an accurate assessment of the ARI or the peak magnitude of the 1946 event, but in all probability it was an event of at least 1 in 300 years ARI with a peak magnitude of 8,000 – 10,000 ML/d. Estimates of the magnitudes of a range of ARI events were made on the basis of the partial duration series analysis (Table 16).

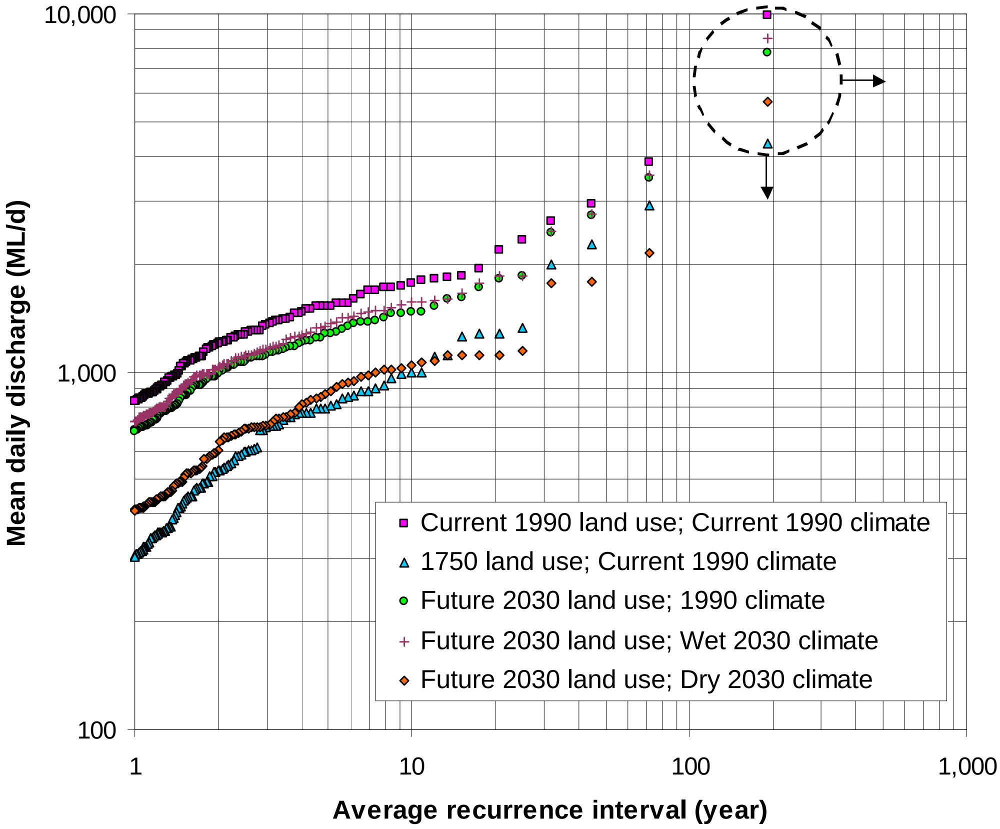


Figure 82. Partial duration flood series for predicted daily flows for Lake Condah catchment under modelled scenarios.

Table 16.
Estimated magnitudes of flood events of a range of ARIs for Condah Drain (at Lake Condah) modelled Current flows. Values interpolated between calculated ARIs and rounded to nearest 50 ML/d. Value for 100 year event extrapolated.

ARI (years)	Magnitude (ML/d)
1	850
2	1,200
5	1,550
10	1,800
50	3,150
100	4,500

The rainfall-runoff model predicted mean daily discharge. During flood events, the peak instantaneous discharge can exceed the mean daily discharge. From the perspective of predicting the highest flood level, this is the important variable. The instantaneous discharge peaks measured at Myamyn gauge over the period 1989 to 1992 were compared with the mean daily discharge. This involved 26 peaks, ranging from 235 – 1210 ML/d. The relationship was $Q_{peak} = 1.004\ Q_{mean}$ ($R^2 = 0.9998$), which means that there was very little difference between mean daily discharge and peak instantaneous discharge. Thus, it was assumed that mean daily discharge is a good representation of peak discharge for the day.

5.5.5 Low flows

Low flows were analysed by examining the distribution of flow spells for flows <0.1 ML/d (i.e. cease to flow) (Figure 83), <10 ML/d (Figure 84) and <30 ML/d (Figure 85). Flows <0.1 ML/d (i.e. cease to flow) are virtually unheard of in Darlot Creek. A few spells of cease to flow are predicted for current and future scenarios during November (Figure 83). This is an artifact of the licenced diversions model, which predicts high initial losses when the Condah Swamp is first flooded with irrigation water in November. In practice, the roster system would prevent cease to flow occurring at Lake Condah. Flows <10 ML/d are currently rare in Darlot Creek, although the accuracy of flow predictions in this range is uncertain. The Dry climate scenario produced a marked increase in the number and duration of spells <10 ML/d, and long spells of flow <10 ML/d were common in the late summer and early autumn for the 1750 scenario. Spells <30 ML/d are common under all scenarios in the summer and autumn months.

5.5.6 Comparison with Homerton Bridge gauged flows 1964 – 2004

The gauge at Homerton Bridge, downstream of Lake Condah, has data available from 1964. These data were not used to calibrate the rainfall-runoff model for Condah Drain at Lake Condah because Homerton flows are influenced by Lake Condah itself, plus baseflow from the Stony Rises. Comparison of the Homerton annual flows with the model predicted annual flows for Condah Drain at Lake Condah for the period 1964 to 2004 (Figure 86) revealed a degree of variability in the relationship, and in 9 years the annual flow at Lake Condah was slightly higher than at Homerton. This is most likely the result of model error and is unlikely to occur in reality. For the model calibration period (1988 to 1992) the modelled flows fit very well between the Myamyn and Homerton flows. The exception is 1988 – the gauged record at Myamyn for that year is circumspect. The model appears to over-predict some flood flows, which creates the higher than expected annual flows in some years. This aspect was considered less important than that of realistically characterising baseflows. Considerable effort was expended fitting the model to the baseflows at Myamyn; factoring the results to better predict Homerton flows would have compromised this important aspect of the modelled flows.

Spells analysis for flows <10 ML/d and <30 ML/d at Homerton Bridge (Figure 87) showed that these low flows are less common at Homerton than at Lake Condah (Figure 84 and Figure 85), which was expected. In reality, there is a complex relationship between low flows at Lake Condah and Homerton. At times of low flow, diversions to Condah Swamp are managed according to a set of rostering rules that allow the flows to be distributed among the licenced diverters; this prevents Darlot Creek downstream of Lake Condah being deprived of water. For this project, no attempt was made to model the detail of this process (this would be a very difficult exercise and would rely on having very accurately modelled flows into Condah Drain).

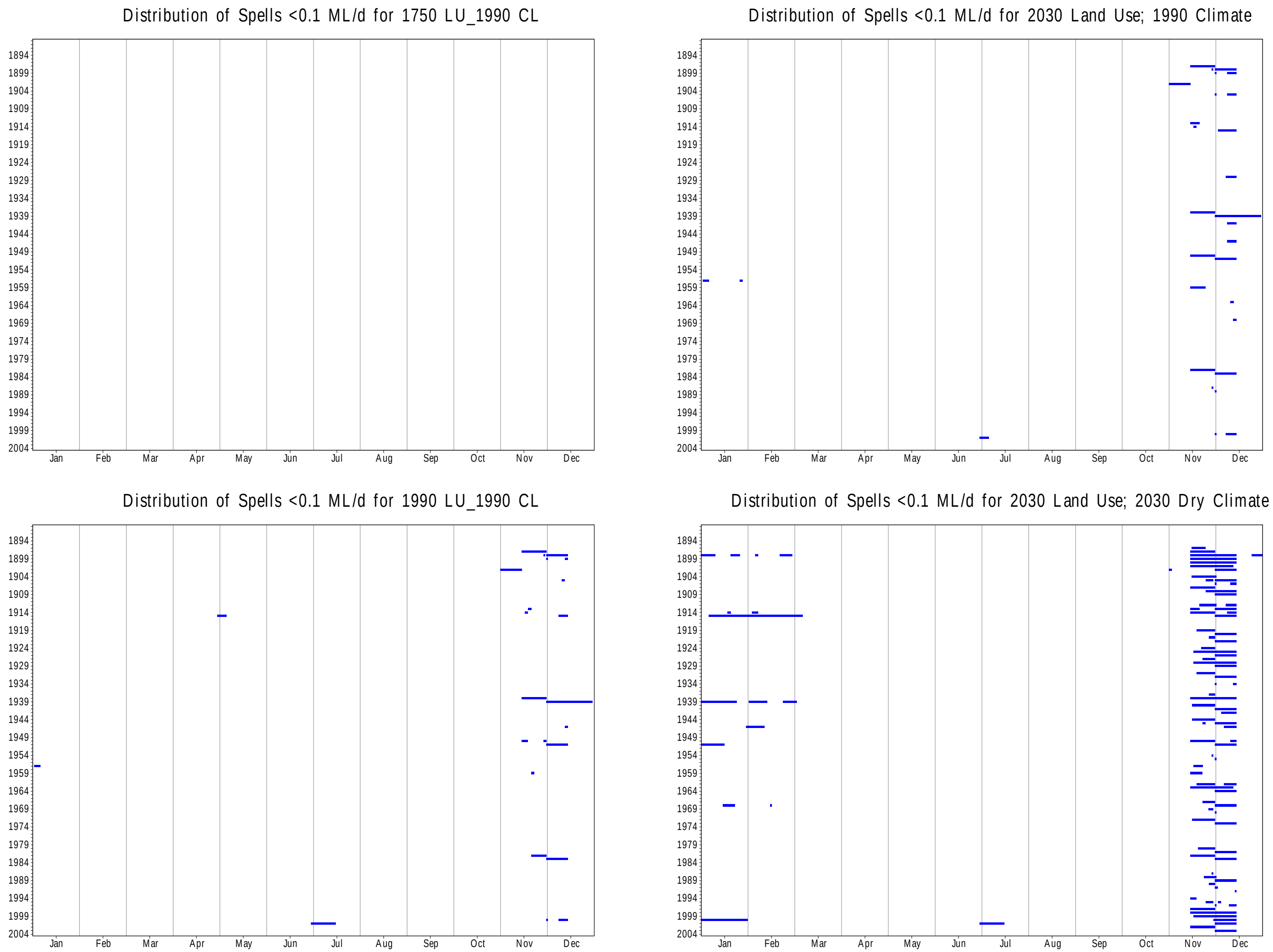


Figure 83. Distribution of spells of flows <0.1 ML/d for Lake Condah catchment under modelled scenarios.

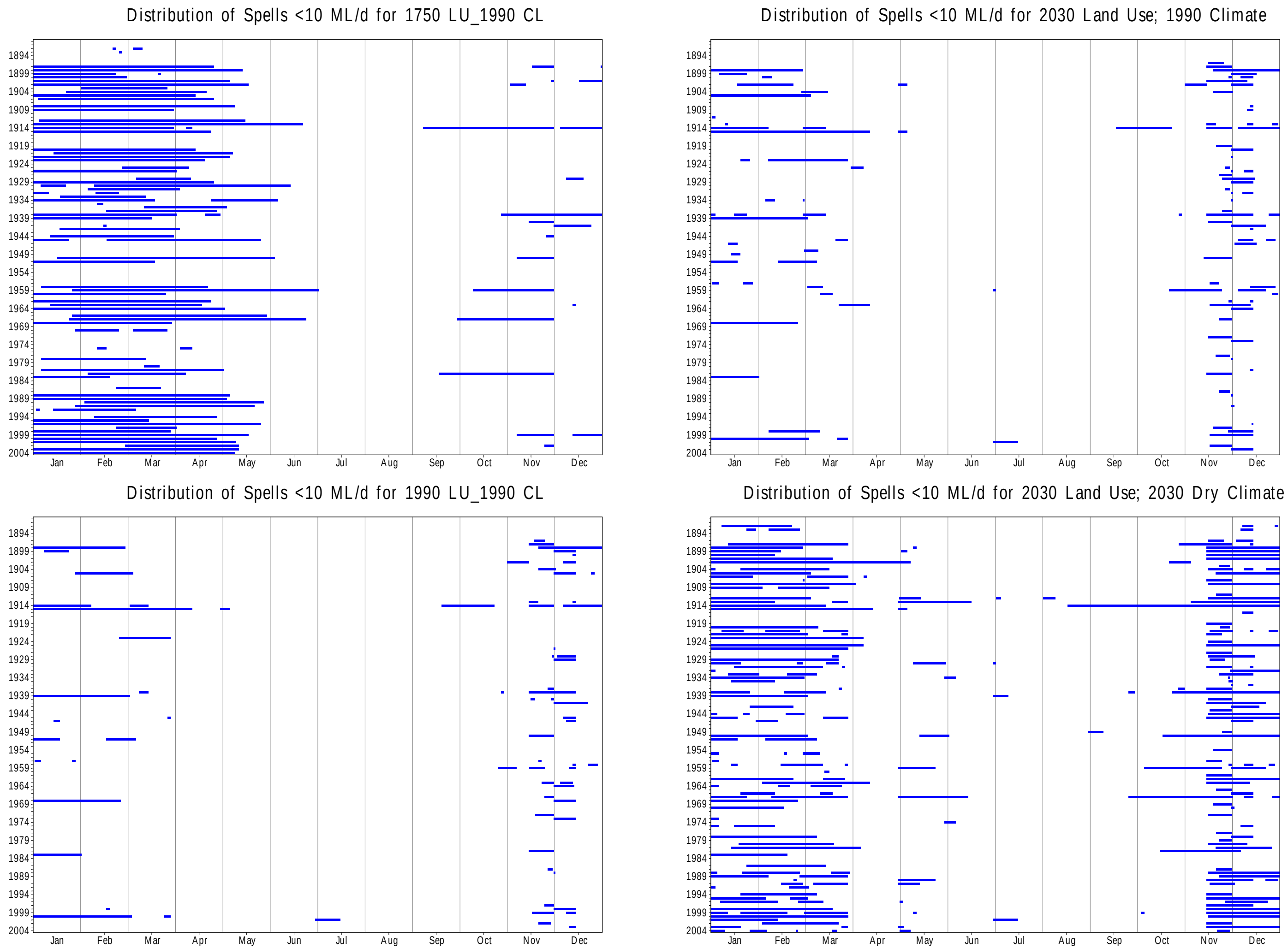


Figure 84. Distribution of spells of flows <10 ML/d for Lake Condah catchment under modelled scenarios.

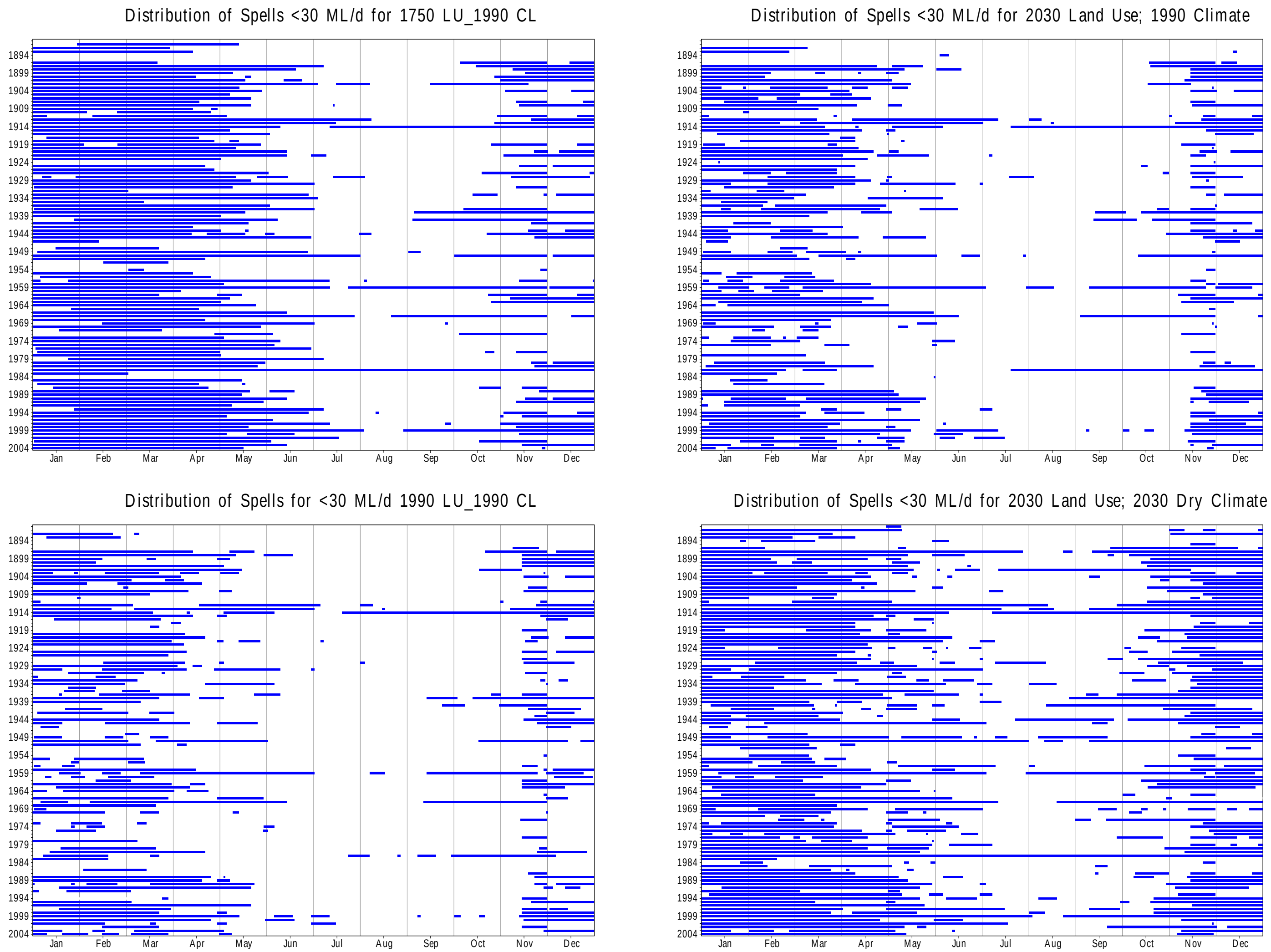


Figure 85. Distribution of spells of flows <30 ML/d for Lake Condah catchment under modelled scenarios.

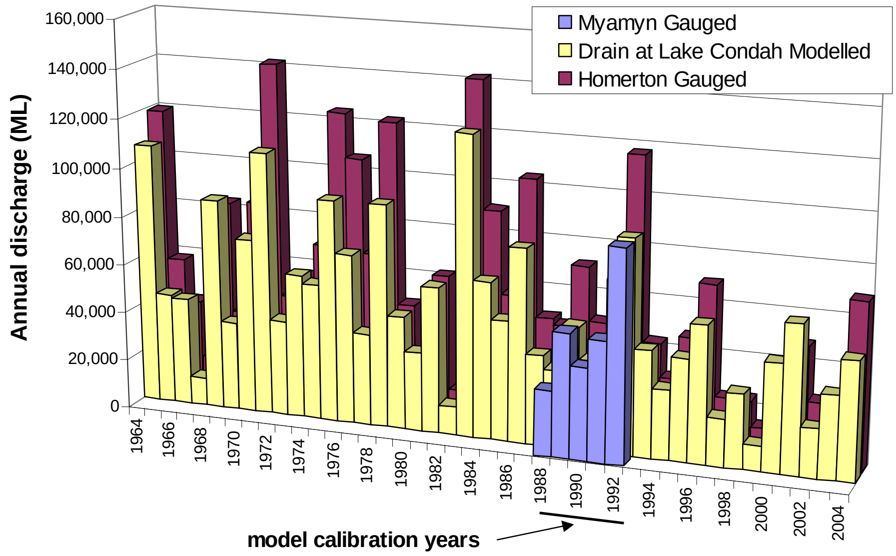


Figure 86. Annual discharge for gauged flows at Homerton Bridge and Myamyn, compared with model predicted flows for Condah Drain at Lake Condah.

5.6 Modelled potential impact of future winterfill diversions (SDL)

The method of calculating rules for Sustainable Diversion Limits (SDL) was set out in DNRE (2002). The method was devised principally for making rapid estimates of SDLs across all the unregulated catchments of Victoria. The method was not intended as a tool for actively managing winterfill diversions, but here we used the SDL derivation rules as defacto management rules. The annual volumetric limit of the SDL calculated for Darlot Creek upstream of Lake Condah was 6,257 ML (O'Brien, 2006) and the winterfill period is designated as 1 July and 31 October. The other components of the SDL, as defined in DNRE (2002) are:

- Minimum flow below which diversions should cease

  The maximum of 30% of the mean annual daily flow and the winterfill period daily median exceeded in 95% of years

- Maximum diversion rate which cannot be exceeded on any one day

  Difference between the median winterfill period flow exceeded in 50 percent of years and median winterfill period flow exceeded in 80 percent of years.

These components of the SDL for Darlot Creek catchment were calculated for the 115 year modelled time series of daily flows in Condah Drain at Lake Condah, for the Current climate and land use scenarios (Table 17), as was assumed in the SDL derivation process.

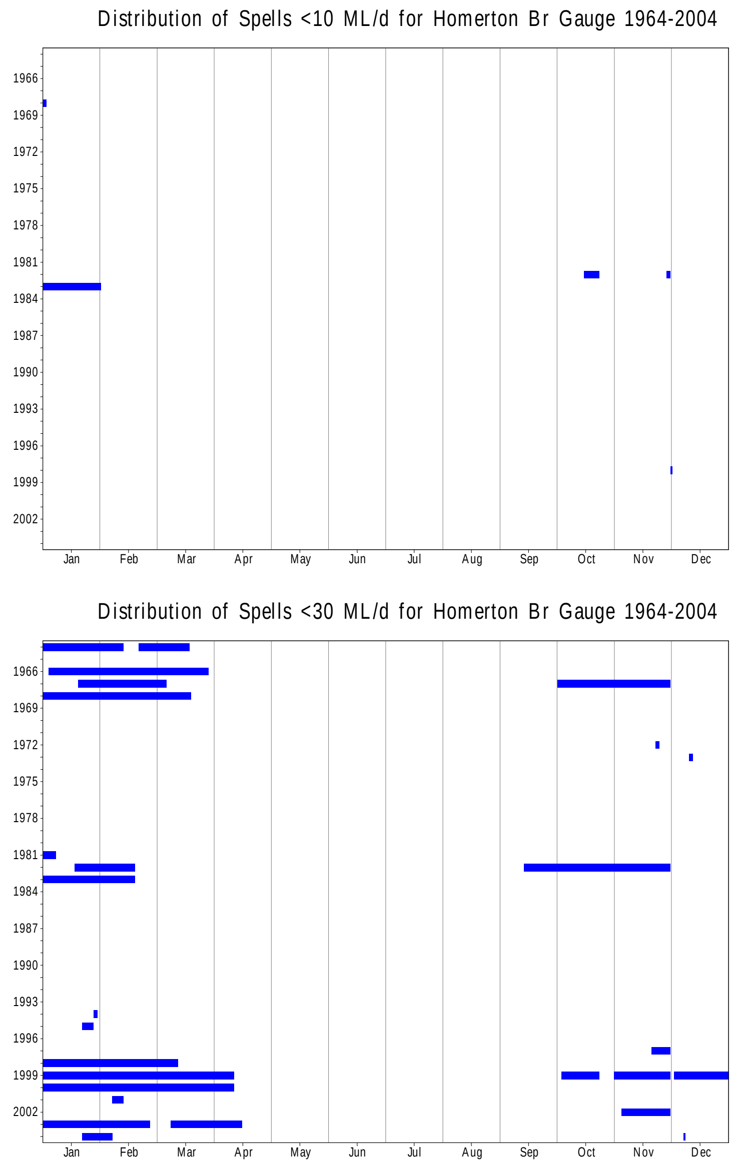


Figure 87. Distribution of spells of flows <10 ML/d and <30 ML/d for Darlot Creek at Homerton Bridge, 1964 - 2004.

Table 17.
SDL minimum flow and maximum diversion rate calculated from the 115 year modelled time series of daily flows in Condah Drain at Lake Condah, for the Current climate and land use scenarios. Bolded values are the adopted values.

Index	Value (ML/d)
Minimum flow	
30% of mean annual daily flow	**42**
Winterfill period daily median exceeded in 95% of years	41
Maximum diversion rate	
Median winterfill period flow exceeded in 50% of years	172
Median winterfill period flow exceeded in 80% of years	91
50th percentile - 80th percentile	**81**

An algorithm was devised to simulate future daily winterfill diversions, assuming that diversions were always made at the maximum allowable rate (taking notice of the minimum flow requirement); with diversions in any particular year ceasing once the annual volumentric cap was reached. The algorithm was applied to three flow scenarios: Current climate and land use, Current climate and Future 2030 land use, and Future Dry climate and Future 2030 land use.

Given the fact that flows are predicted to decline in the future, due to both land use change and climate change, the SDLs developed for Victoria in 2003 (DSE, 2003) may be too generous for some catchments, as they are based on gauged flows (i.e. Current flows). In this project we assumed that the SDLs would be fixed into the future, even though they may be revised at some stage. Thus, the same rules for winterfill extractions were applied to the Current and Future flow scenarios.

Winterfill diversion rules prevent impacts on low flows, and the upper limit on diversion rate means that the impact on flood distributions is minimal. The main impact of winterfill diversions is to reduce annual flows (Table 18) and shift the main body of the flow duration curve downwards (Figure 88, compare with Figure 81). The mean annual volume diverted was lower than the volumetric cap (6,257 ML) because in the drier years the limits on minimum flows prevented the full volume being diverted.

Table 18.
Mean annual flow in Condah Drain at Lake Condah with and without winterfill diversions, for three scenarios.

Scenario	Mean annual flow (GL)		Mean volume diverted (ML)	Mean % reduction
	No winterfill	With winterfill		
Current land use and climate	51.0	45.5	5,534	11%
Future 2030 land use and Current climate	45.0	39.5	5,450	12%
Future 2030 land use and Future 2030 Dry climate	26.7	22.5	4,252	16%

5.7 Summary

A total of 42 years of data for Homerton Bridge gauge revealed that the average annual discharge of Darlot Creek was 61.5 GL (83 mm). A comparison of flows at Myamyn and Homerton (23.6 river kilometres apart) for identical periods shows that very low flows at Myamyn does not mean similarly low flows at Homerton Bridge, indicating considerable boosting of low flows between these stations. It appears that the largest source of the water to Darlot Creek downstream of Myamyn is groundwater flow emerging from the Stony Rises basalt/Tertiary limestone located to the east, south and southwest of Lake Condah. The reason why this geology would be relatively high yielding is that when it rains, water rapidly enters subsurface through fractures and sinkholes, thereby minimizing evaporative losses. The water then flows to downstream areas, emerging through springs.

A review of the licenced diversions and stock and domestic water use revealed a complex situation. The licenced volumes are nominal values and may not reflect the actual water use. The stock and domestic use is poorly known. In this study, an estimate of the potential diversions upstream of Lake Condah was made on the basis of a simple water balance. The model was calibrated to give a long-term average annual diversion loss equal to the licenced allocation of 531 ML. The mean annual loss from stock and domestic was 192 ML. These are potential diversions – the actual diversions cannot be predicted, as they depend on factors that cannot be readily modelled.

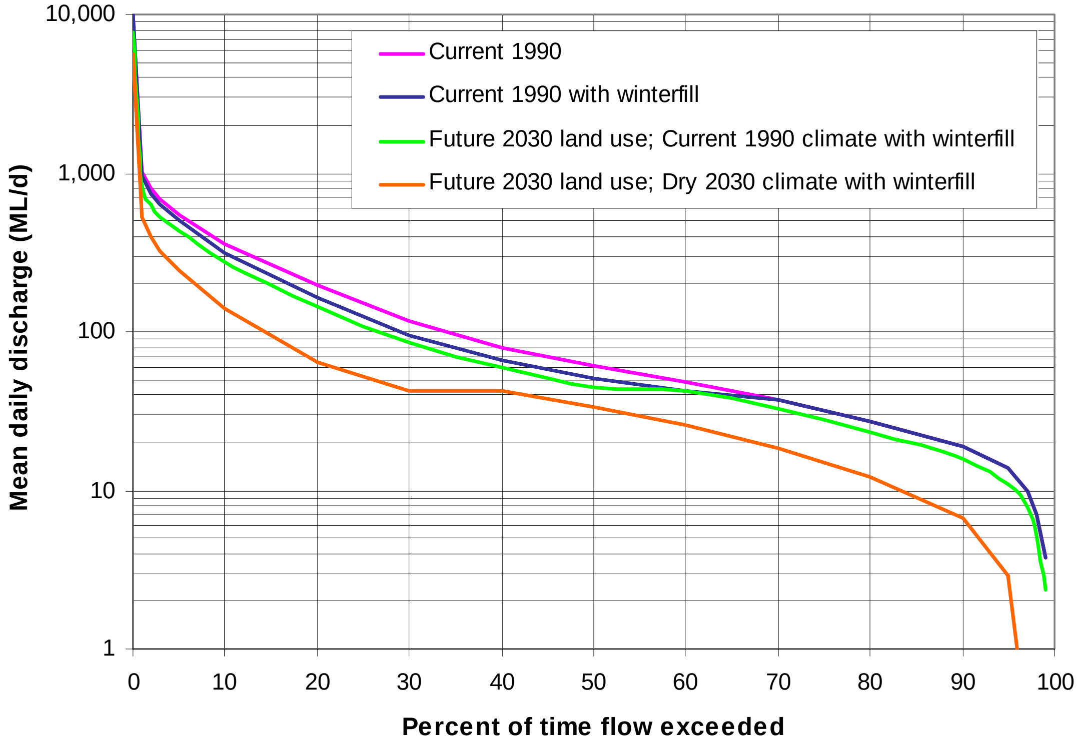


Figure 88. Flow duration curves for predicted daily flows for Lake Condah catchment under modelled scenarios with modelled winterfill diversions (at maximum allowed rate). Current (no winterfill diversions) scenario included for reference.

The impact of farm dams on streamflows was modelled using the Tool for Estimating Dam Impacts (TEDI). For flows higher than 100 ML/d, both diversions and farm dams had a relatively minor impact. The impacts of diversions and farm dams are greatest in summer and autumn, when demands are highest and when stream flows are lowest. Thus for flow of around 80 ML/d and lower, farm dams and diversions have lowered the discharge by around 5 – 10 ML/d, with the diversions accounting for around 2 – 3 ML/d of this.

This study makes no pretence to “know” what the impact of land use change on runoff might be for the Lake Condah catchment. Predictive models suggest that the WatLUC Base case 2030 land use change scenario could result in a reduction in runoff ranging from 4% to 38%. In this study, an average 12% runoff reduction was adopted for the 2030 land use scenario. The rainfall-runoff model was calibrated to produce this degree of impact. The value of 12% reduction is not presented as the most likely eventuality should the predicted 2030 land use change take place. Rather, it is an arbitrary value that lies within the range of possibilities.

For this project the WC-1 model (within WaterCress) was used to predict runoff from rainfall. WC-1 is based on the typical lumped parameter Boughton model using a partial area method. The model was run for 115 years from 1890 to 2004 using daily potential ET_O and rainfall time series’ derived from DataDrill files. The modelling procedure involved a data gathering and model calibration phase, followed by various modelling steps to produce five daily time series of 115 years duration. It should be noted that the calibration procedure was less than ideal, due to the very short length of gauged record available at Myamyn. It was possible to closely reproduce the gauged record at Myamyn (adjusted to remove effects of diversions and farm dams) using the WC-1 model. Annual discharge was closely predicted.

Flow duration curves reveal that the major hydrological impact is for the Future Dry climate scenario and the 1750 scenario, which reduced all flows. Only the Current scenario did not exhibit cease to flow.

An algorithm was devised to simulate future daily winterfill diversions, assuming that diversions were always made at the maximum allowable rate (taking notice of the minimum flow requirement), with diversions in any particular year ceasing once the SDL annual volumentric cap was reached. The algorithm was applied to three flow scenarios: Current climate and land use, Current climate and Future 2030 land use, and Future Dry climate and Future 2030 land use. Winterfill diversion rules prevent impacts on low flows, and the upper limit on diversion rate means that the impact on flood distributions is minimal. The main impact of winterfill diversions is to reduce annual flows and shift the main body of the flow duration curve downwards.

6 Hydrogeology of Lake Condah Area

6.1 Current understanding of groundwater interaction with Lake Condah

6.1.1 Introduction

A review of the current understanding of groundwater interaction around Lake Condah is limited by the relatively small amount of work done in this area. In addition there is virtually no borehole data which bears directly on Lake-groundwater interactions. The only surface-groundwater studies directly focused on the Lake-groundwater interaction were carried out by the Rural Water Commission and its pre-curser, the State Rivers and Water Supply Commission over the period from 1980 to 1993, with the monitoring of Lake levels and groundwater levels occurring between 1987 and 1993.

After recommendations were made for a comprehensive drilling and monitoring program of the Lake specifically designed to understand Lake-groundwater interactions (SR&WSC, 1980), a groundwater monitoring program was instigated in 1987 and was inexplicably situated 2.7 km to 7.5 km south of Lake Condah in Tertiary limestone (Figure 89). It was later deemed irrelevant to Lake-groundwater interactions and abandoned in early 1993.

6.1.2 SR&WSC 1980 Report

The early work on the interactions of groundwater and Lake Condah were mostly carried out by the State Rivers and Water Supply Commission (1980) following the recommendations of the Land Conservation Council (1973) for an investigation of the potential for the flooding of Lake Condah. In the LCC 1973 report, whose conclusions were quoted in SR&WSC (1980), it was observed that based on geological information, Lake Condah was never a permanent wetland:

> "*as the substratum is virtually self draining and incapable of supporting permanent storage*".

This was essentially the same conclusion drawn by Hand (1973):

> "*In spite of periodic heavy flooding this area appears unable to retain surface water due more to the nature of the surface and sub-strata than to any other discernible factors.*"

Following a request from the Fisheries and Wildlife Division in 1979, SR&WSC (1980) undertook an investigation which included advice on the hydrogeological aspects of the Lake system. It was also noted that seepage losses from the proposed pondage could occur through alienated land to the south west and this could create a number of problems in the future. Similarly, it was noted that "seepage water currently re-emerges in freehold land downstream of Lake Condah" (SR&WSC, 1980, p 8).

The recommendation from SR&WSC (1980, p 2,) was that surplus flows from the main drain be not diverted into Lake Condah.

During an earlier Lake inspection by SR&WSC, observation of flotsam on the banks suggested water levels up to 1.5 m higher in the four preceding months (July-October, 1979) than that present at the time of the visit (November 1979). This was considered as being due to flooding following heavy winter and spring rains. On the assumption that there was no surface drainage from the Lake at the time, and that evaporation over the period was 0.3 m, then 1.2 m was attributed to outseepage through the lake floor and the sides. For the purpose of water balances, seepage losses were taken as 275 mm/month, however it was suggested that the actual losses could be significantly different from this value.

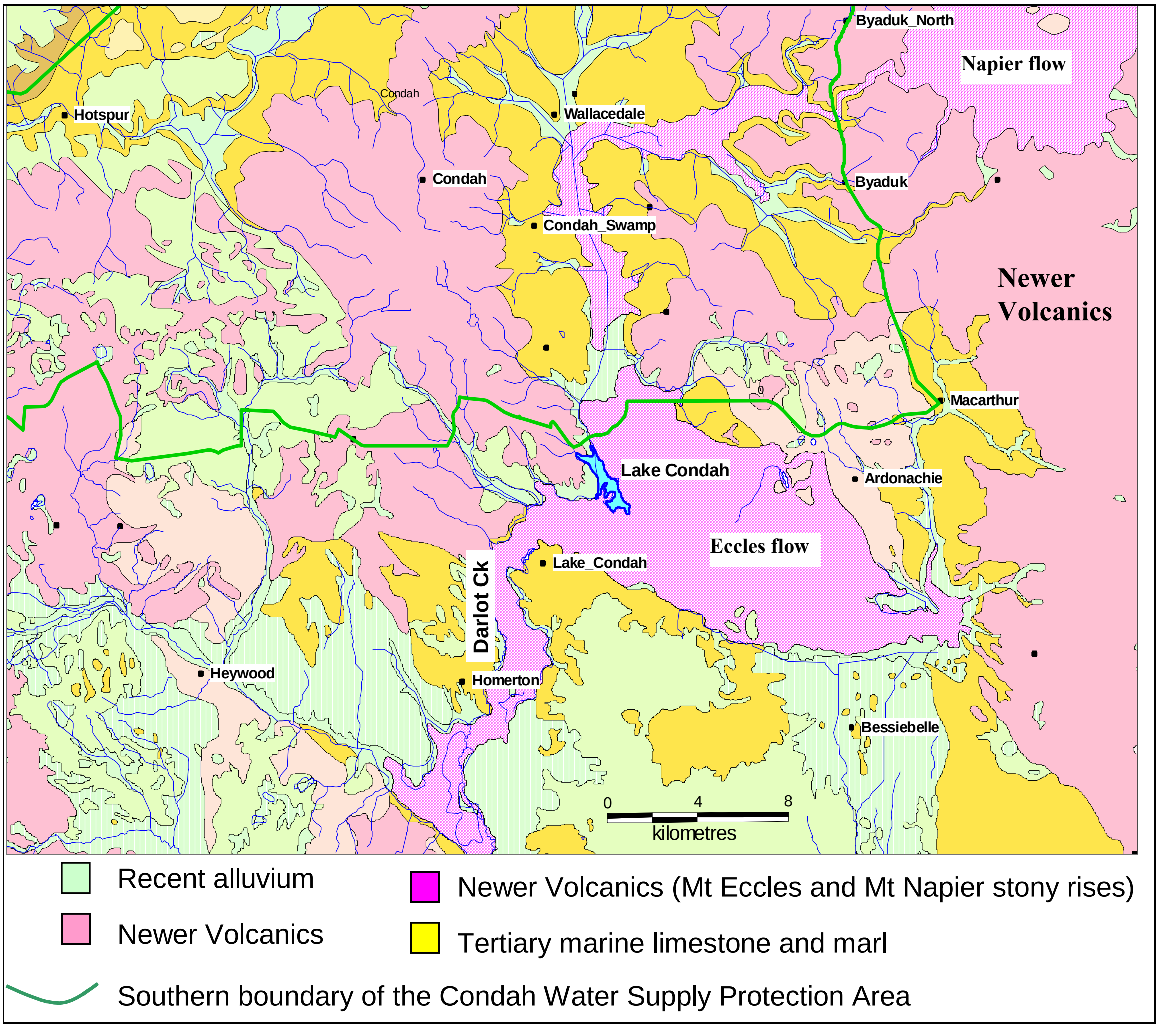


Figure 89. Geology of the Lake Condah area.

It was recognized that depressions in the lake floor were sinkholes which might have developed in either karstic (Port Campbell) limestone or stony rise basalts. These sinkholes were seen as preferential recharge zones while the alluvium forming the lake floor was not deemed to be sufficiently impermeable to prevent the losses. Comments sought from a geologist from the Department of Mines (DME) also suggested that loss via the lake alluvium would account for the majority of water loss to the groundwater system. DME also noted that an estimate of the losses would be difficult to determine and that a drilling program be undertaken. The proposed program included seven bores drilled to 10 m depth and sampled every 0.5 m. Piezometers were to be constructed in each bore (Figure 90). The SR&WSC also agreed with DME that no assessment of outseepage losses could be undertaken without a drilling program and the installation of a groundwater monitoring system. This was deemed a SR&WSC responsibility.

6.1.3 RWC Reports, 1990 and 1993

The drilling and monitoring program around the Lake deemed necessary in the 1980 report and by the DME was not proceeded with by the Rural Water Commission (RWC - successor to the SR&WSC). Instead, in order to gain an appreciation of natural trends and to gauge the impacts of filling of the Lake, an alternate monitoring program of Lake and groundwater levels was undertaken. However the six bores and three sinkholes monitored were in the Tertiary limestone 'at distances between 2.75 km and 7.5 km south west of the Lake' (RWC, 1989 p1). There is no explanation for why the original drilling program designed to measure the nature of lake-groundwater interactions and provide data needed for an improved water balance was abandoned, and instead a largely irrelevant monitoring program substituted.

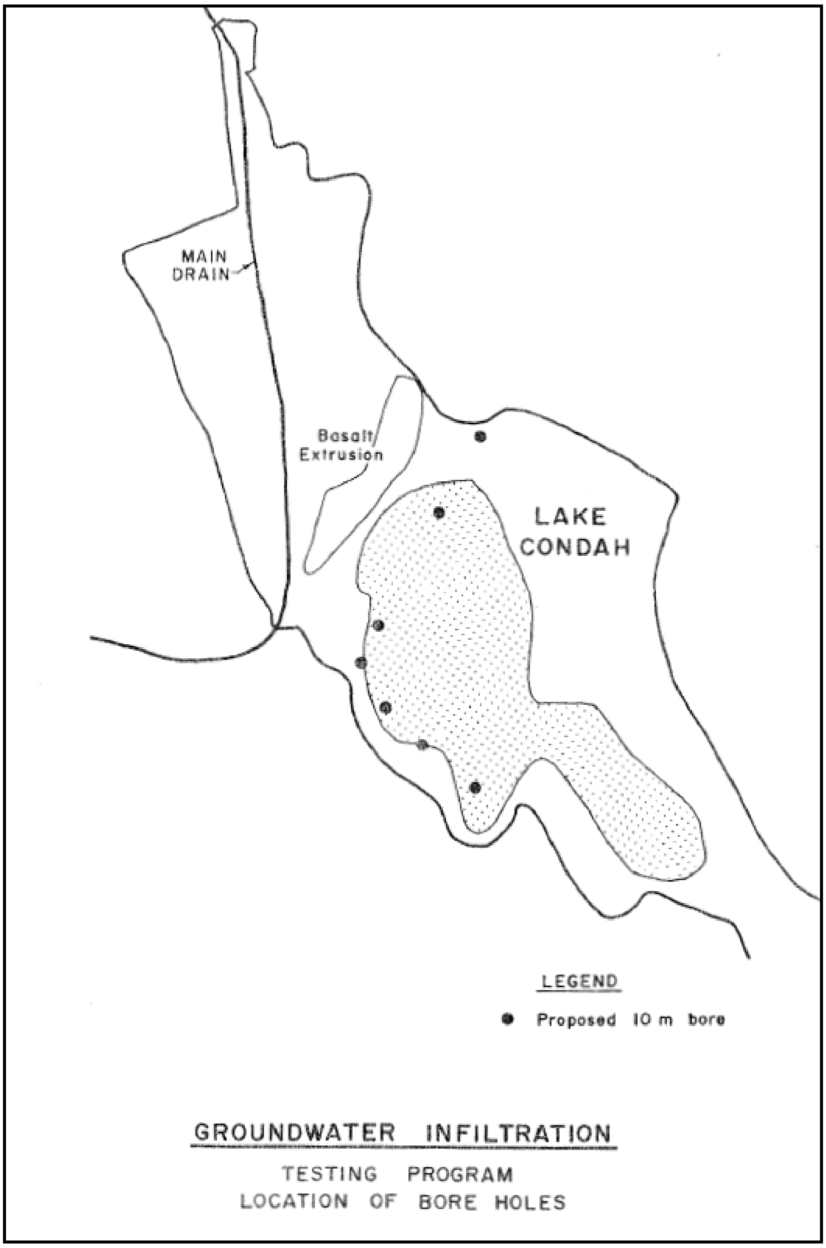


Figure 90. Proposed sites for seven shallow (10 m deep) bores around the Lake perimeter (SR&WSC, 1980).

Continuous monitoring of the Lake was carried out from February 1988 up to March 1993 and monthly water levels were measured in the 6 distant bores, BM, BI, BIA, B17, B16 and B31, and the three sink holes S1, S2 and S3 (RWC memo 2nd Feb 1990 – review of monitoring). In the 1990 report it was recommended that the monitoring be restricted to two boreholes (B1 and B1A) and the three sinkholes. It was noted that the bores and sinkholes were responding to rainfall inputs but did not respond to the flooding of Lake Condah in 1991 and 1992. The sinkholes were seen to be related to rainfall induced surface runoff while the B1 and B1A bores responded to rainfall. It was considered that the monitoring was only recording rainfall-recharge effects within the limestone and provided no information on Lake-groundwater interactions 'therefore no comment can be made on the local effects (i.e. within 1 km of the Lake) that filling of Lake Condah may have held.' (RWC memo 69/06435 - data analysis and review of monitoring 4th March 1993). It was recommended that since the monitoring of the sink holes and bores was not reflecting lake seepage, further monitoring should cease.

The relationship between the sinkhole fluctuations and the rainfall from the review of monitoring study is given in Figure 91 from RWC (1993).

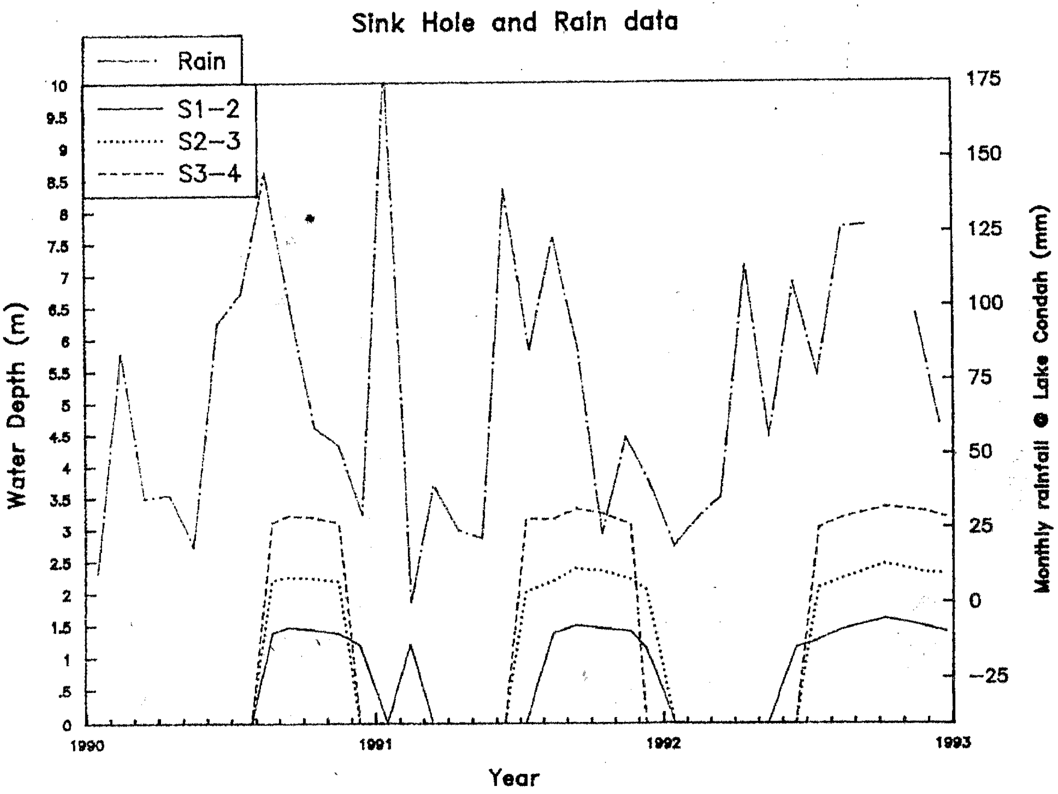


Figure 91. Precipitation and sink hole fluctuation 1990-1993 (RWC, 1993).

While it was considered by RWC (1993) that the distant limestone sinkhole and bore monitoring provided no information on Lake-groundwater relationships, an examination of the flow in Darlot Creek at Homerton (Station 237205), Lake levels at the 237600 gauging station at Lake Condah near the sinkhole in the basalt, and the three sinkholes in the limestone to the south between 1988 and 1993 show a marked sympathy of fluctuations (Figure 92). The limestone sinkholes are in turn responding in a similar manner to the groundwater in general as shown by a comparison of the water levels in the sinkhole and in two monitoring bores (B1 and B1A) also in the limestone aquifer (Figure 93).

The relationship depicted in Figure 92 suggests that the surface systems and groundwater in the unconfined limestone aquifer are strongly hydraulically connected, with the unconfined groundwater system responding not only directly to the rainfall as suggested by RWC (Figure 91) but to surface water flows, and perhaps to some extent the surface flow is impacted by groundwater levels. A similar empathy would be expected to be passed to the shallow water tables and spring flow across the region.

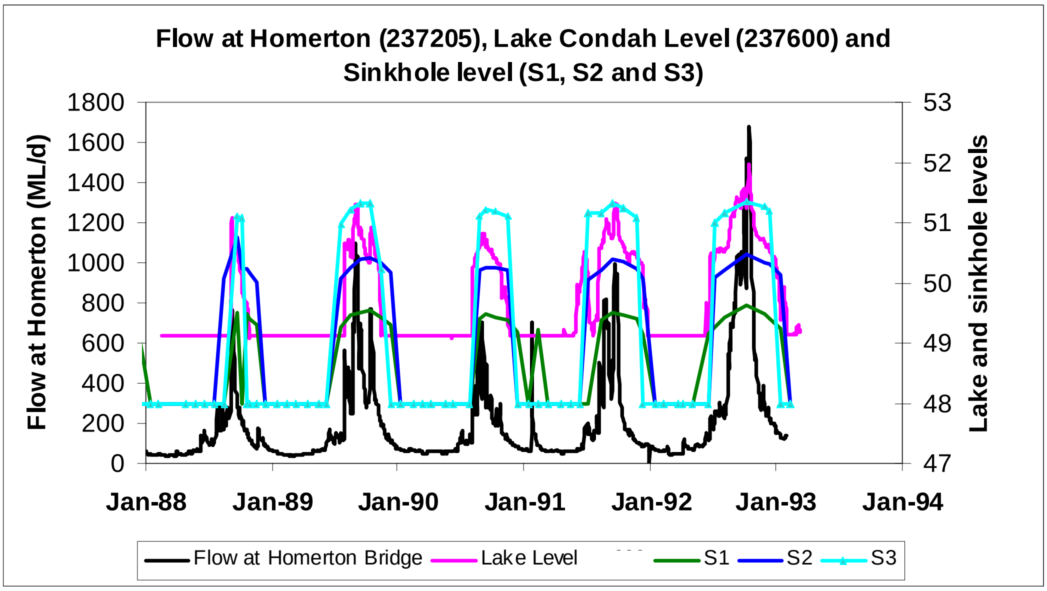


Figure 92. Superimposition of Darlot Creek flow at Homerton, Lake level at Lake Condah and the water levels measured in three limestone sinkholes (S1, S2 and S3) situated more than 2 km distant from the Lake. The sinkhole levels have been taken from a hypothetical base of 48 m in order to provide a comparison of fluctuation patterns with the Lake level and the Darlot Creek flow

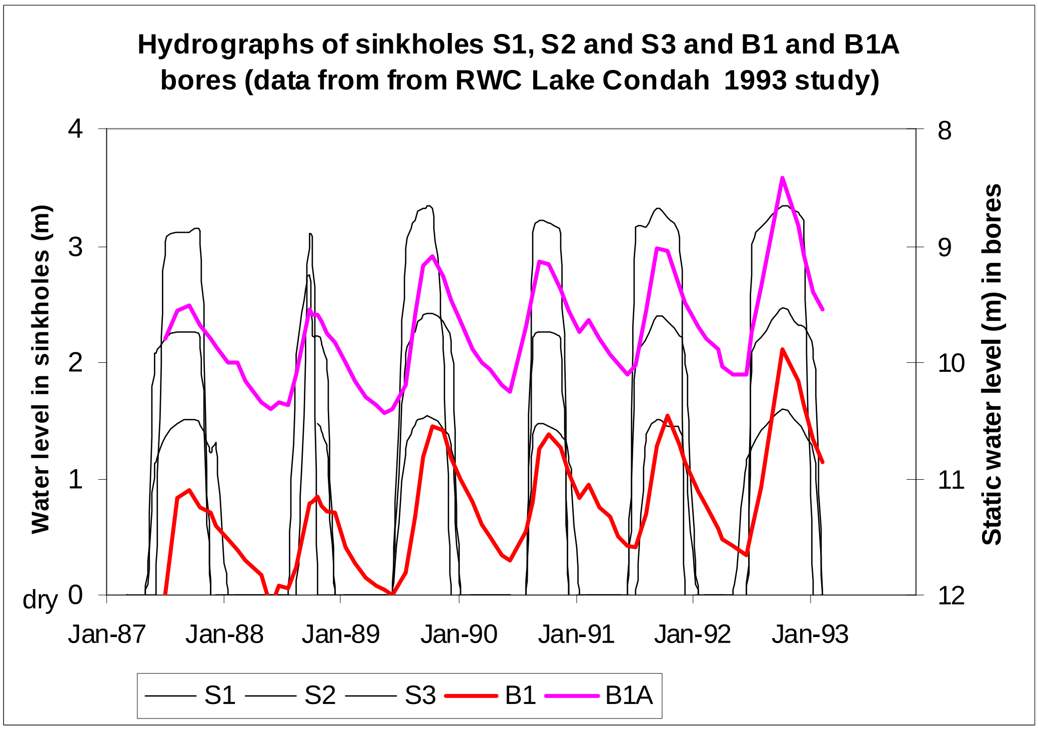


Figure 93. Comparison of fluctuation in groundwater and sinkhole level from SR&WSC & RWC monitoring situated 3.5 to 5 km southwest of Lake Condah. The groundwater shows a rapid rise similar to that in the sinkholes but a more subdued fall.

6.1.4 Coutts, Frank and Hughes (1978)

A further account of lake-groundwater behaviour comes from Coutts et al. (1978) who note that most of the perimeter of the Lake comprises steep-sided fissured basalt flows with numerous large, deep potholes which, at times of high Lake level fill with water to form pools.

Coutts et al. (1978) note that flotsam around the Lake edge indicating higher Lake levels may date back to a period of earlier flooding to depths of 2-3 m during the 1940s when the artificial outlet was not being maintained. They suggest that the Lake may have filled naturally to an overflow level equivalent to 4 m above the lake floor, a height to which the fish traps are found. They also acknowledged Hand's (1973) comment that there was no significant channel between Condah Swamp and Lake Condah and that the fractured stony rise surface would not provide run-off from the surrounding area. Therefore to explain Lake filling, Coutts et al. (1978) suggest this was done by overland flow, saturated throughflow or groundwater flow from the fissured basalt, with local rainfall deemed to be the main feeder. In this scenario, a Lake full stage was deemed to have occurred in early winter to late spring as evaporation decreased and run off increased. Their map of the traps scattered around the perimeter of the Lake shows a concentration in the far south with Systems 1 to 4 covering the area of the southern 'sinkholes' (Figure 16).

6.2 Relationship between the surface aquifers around Lake Condah and the Condah Water Supply Protection Area

6.2.1 Introduction

Lake Condah is a lake developed on the Darlot Creek drainage system (*sensu lato*) which passes southwards as a drain from the Wallacedale area through the Condah Swamp and Lake Condah after which it becomes a more natural stream passing towards Homerton (Figure 94). An early account by Hand (1973) suggested that there was little drainage connection between the Condah Swamp and Lake Condah. If this were the case, then the catchment would have been limited to that of the Breakaway Creek given the virtual absence of runoff from the stony rises basalt. However it seems unlikely that the Lake could fill regularly from local rainfall on the lake surface and the limited catchment of the Breakaway Creek, without a more significant surface water feeder. It seems more likely that there was a southern outlet from the Condah Swamp towards Lake Condah contributing to its regular filling. At the same time the distribution of drains in the lower reaches of Breakaway Creek and Whittlebury Creeks/Swamp indicates high water tables probably reflecting an underlying groundwater contribution to the surface water systems from the shallow aquifers. This is the case at Condah Swamp (see below) and likely to be the case at Lake Condah.

6.2.2 The Condah WSPA and the aquifer system in the Condah area

The shallow aquifer system beneath the Condah Water Supply Protection Area (WSPA) (Figure 95) and Lake Condah consists of a thin uppermost alluvial sequence restricted to the valley and lake floors, a series of Newer Basalts including the stony rises basalts of the Tyrendarra Flow (from Mt Eccles) and the Mt Napier Flow, and a suite of marine limestones, marls, and calcareous sands forming the Heytesbury Group. The Heytesbury Group is comprised of the Port Campbell Limestone, the Gellibrand Marl and the Clifton Formation (Figure 96). All of the above with the exception of the Clifton Formation outcrop in the WSPA and in the vicinity of Lake Condah (Figure 89).

There is a lack of specific hydrogeological data at the Lake Condah site; however the intensive hydrogeological studies of the Condah WSPA immediately to the north may be used to gain an understanding of the likely groundwater-surface water interactions in the vicinity of Lake Condah. The Condah Water Supply Protection Area (WSPA) lies immediately to the north of Lake Condah. It covers an area of about 950 sq km and includes the area of the Condah Swamp. The Condah WSPA is restricted to a single hydrogeological unit, the Clifton Formation which occurs at depth of between 70 m and 200 m within the WSPA. A Permissible Annual Volume (PAV) of 8,760 ML/yr was calculated by SKM (1998). All hydrogeological studies since then have been directed at reviewing and refining the original PAV (Macumber, 2000; Nolan-ITU, 2002; Nolan 2003; TAP, 2004; SKM, 2006).

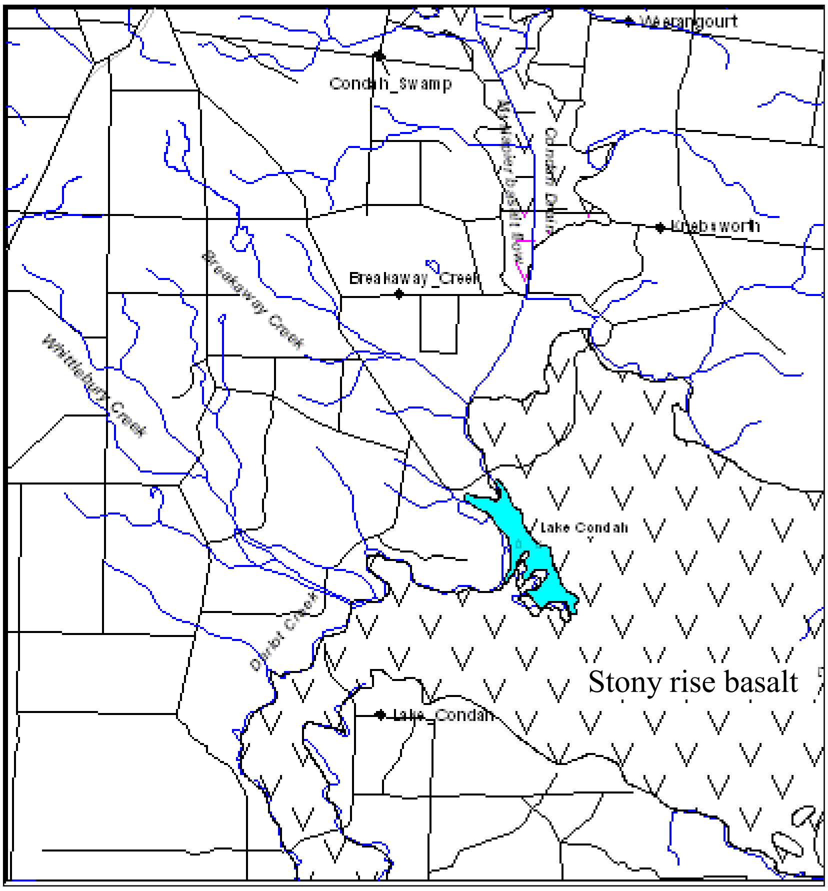


Figure 94. Stream network and Mt Eccles stony rises basalt distribution in the vicinity of Lake Condah.

6.2.3 Hydrostratigraphy

Quaternary and Recent Alluvium:

These deposits consist of sands, gravels, silts and clay that have been deposited by the Darlot Creek and its tributaries, and on the floor of Lake Condah.. The alluvial deposits are generally expected to be thin and commonly overlie Newer Volcanics or Heytesbury Group marine sequences. At Lake Condah a thin lacustrine suite overlies the stony rise basalts of the Mt Eccles flow.

Newer Volcanics:

The. Newer Volcanics form a remnant plateau between the Darlot Creek and the Crawford River. Relatively recent volcanic flows from Mt Eccles and Mt Napier have passed down the palaeovalley of the Darlot Creek which was dammed back creating the Condah Swamp and Lake Condah (Figure 89). The relatively young age of the flows has resulted in their broken blocky surface, and lava flow features such as lava blisters and lava tunnels. They form a strongly fractured hardrock aquifer and groundwater moves via fissures and fractures in the basalt. This is notably the case to the southwest of Lake Condah where the Darlot Creek goes underground and re-emerges several hundred metres further downstream. Loss into the fractured basalt aquifer is the main pathway for water loss from Lake Condah. Despite the post-European modification of the Darlot Creek, it would still be the same today, except perhaps under very high lake levels when the surface outlet via Darlot Creek is reactivated. Gill (1979) observed sub-volcanic alluvial sequence in a bore to the south of Lake Condah, however this layer was not observed in the drilling in the Condah WSPA. Any relevance to the hydrology of Lake Condah would be determined by the recommended drilling program (see below)

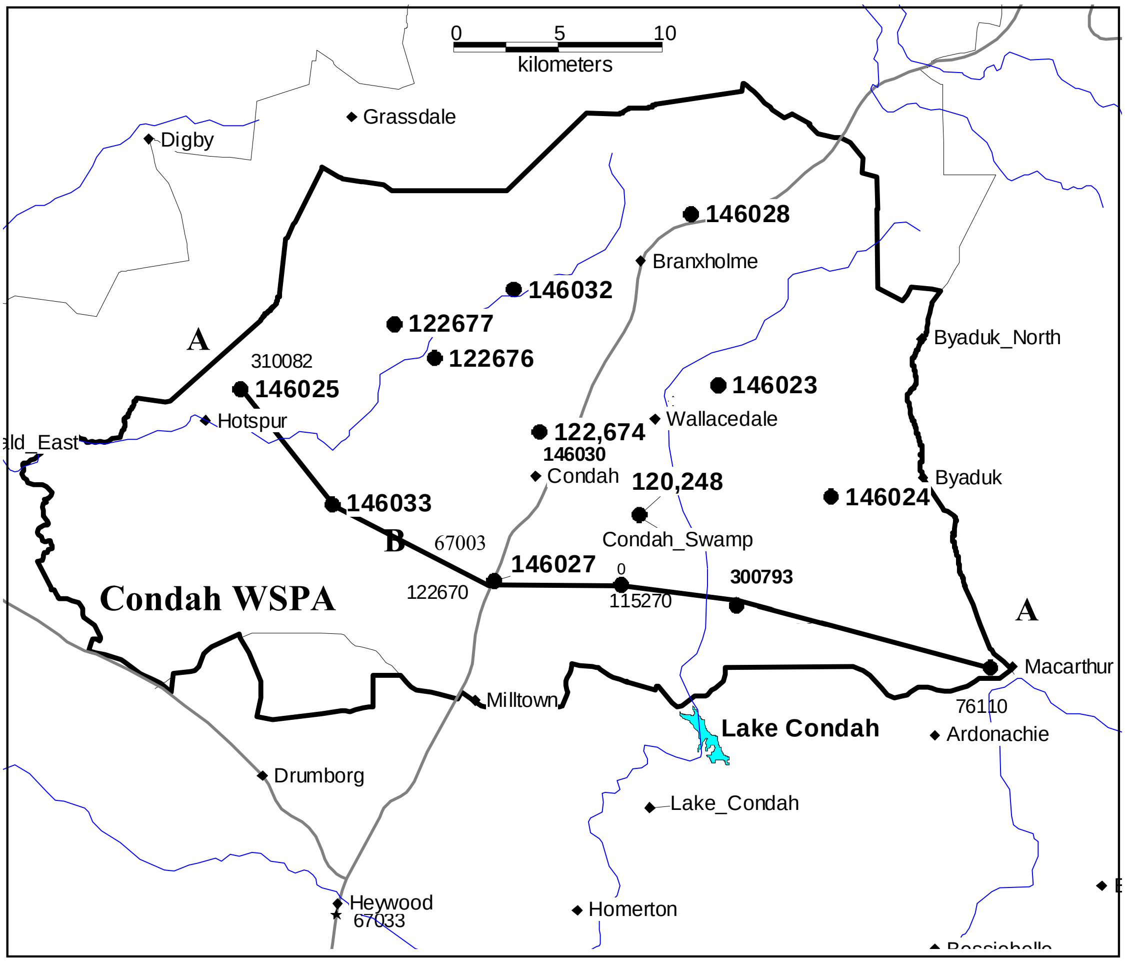


Figure 95. Position of west to east geological section line 'A-A' across the Condah WSPA to the north of Lake Condah for Figure 96. Additional monitoring bores also shown.

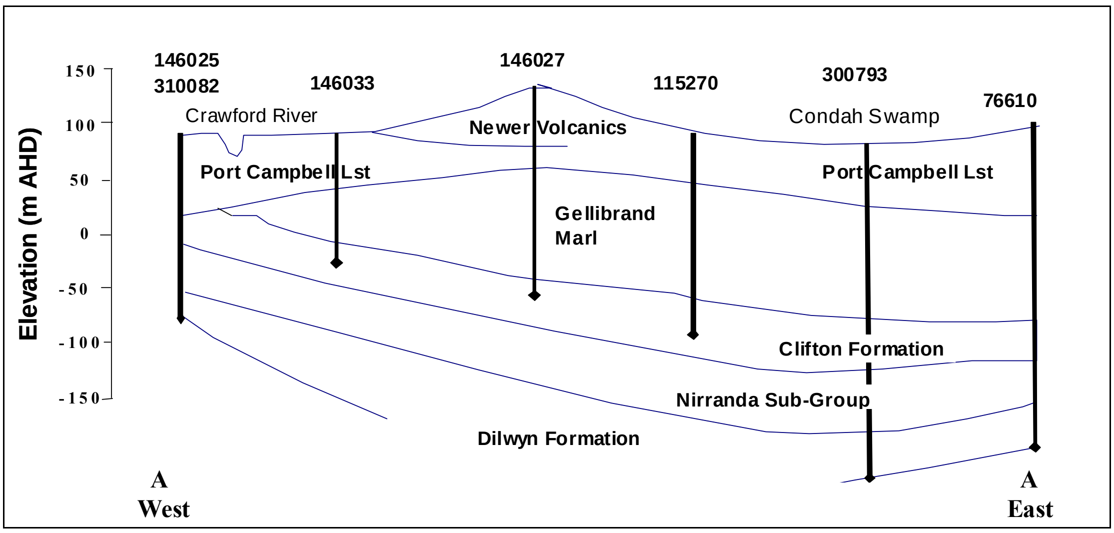


Figure 96. West to east cross section from Crawford River through Condah Swamp - location of section line is shown in Figure 95.

Heytesbury Group:

The uppermost sedimentary cycle consists of the Heytesbury Group (Figure 89 and Figure 96), which is a suite of mid-late Tertiary marine limestone and marls becoming sandier toward the basin margins near Hamilton and in the western areas of the Condah WSPA. It has three members:

- **Port Campbell Limestone**. Outcrops along the sides of the Darlot Creek where it is commonly overlain by the Newer Basalt. The limestone can be karstic or cavernous, however yields from the aquifer system are variable. Groundwater levels in sink holes were monitored during the RWC (1989 and 1993) investigations
- **Gellibrand Marl**: Forms an aquitard between the Port Campbell Limestone and the Clifton Formation. However it is not deemed to prevent throughflow of groundwater from the Clifton Formation in the vicinity of the Darlot Creek and the Condah Swamp
- **Clifton Formation**: This is the main aquifer in the Condah WSPA. The Condah WSPA deals specifically with the Clifton Formation, a littoral to shallow marine transgressive unit in the lower part of the Heytesbury Group. It is a calcareous sand aquifer underlain by the marly Narrawaturk Marl and overlain by the Gellibrand Marl. It is a semi-confined aquifer ranging in thickness from about 56 m in the north but wedging to about 6-15 m in the south. This affects the groundwater flow enhancing the development of a regional groundwater discharge area in Condah Swamp and along the Darlot Creek on passing south towards Heywood.

The underlying aquifers of the Nirranda and Wangerrip Groups are not considered to be of significance to the hydrology of Lake Condah.

There is an absence of borehole data in the immediate vicinity of Lake Condah on which to construct geological cross sections through the Lake, and instead an E-W section is taken from a line of bores situated in the southern part of the Condah WSPA (Figure 96). This section showing the geology/aquifers systems is based on an interpretation of Nolan-ITU (2002).

A more detailed west to east section through the central part of the WSPA crossing the Condah Swamp shows the relationship between the aquifers and the groundwater salinity (Figure 97 and Figure 98). The key to salinity and yield is provided in the salinity/yield matrix (Figure 99).

6.2.4 Surface - groundwater interactions in the Condah WSPA area

The understanding of surface-groundwater interactions within the regional aquifer system has come from the study of the groundwater flow system in the Condah WSPA. Groundwater monitoring bores were initially established mostly in the Clifton Formation within the Condah WSPA and these have been supplemented in recent times by additional bores in the overlying Port Campbell Limestone. The bores now form piezometer nests required to determine the extent and direction of vertical groundwater flow within the WSPA. While lying just to the south of the WSPA, generalizations about the nature of groundwater-surface water interactions are equally applicable to the situation in the vicinity of Lake Condah.

The primary groundwater study for the region was the Study of Limestone in SW Victoria (SKM, 1994). This laid the stratigraphic foundation for later hydrogeological studies. It outlined the significance of the Clifton Formation, which is the sole aquifer for the Condah WSPA. The Clifton Formation is a calcareous marine sand which occurs within a thicker marine sequence of limestone and marls making up the Heytesbury and Nirranda Groups. It is a semi-confined aquifer which does not outcrop in the Condah WSPA but instead occurs at depth of between 50 and 200 m, averaging about 35 m in thickness. The E-W southern boundary of the Condah GMA passes a little to the north of Lake Condah.

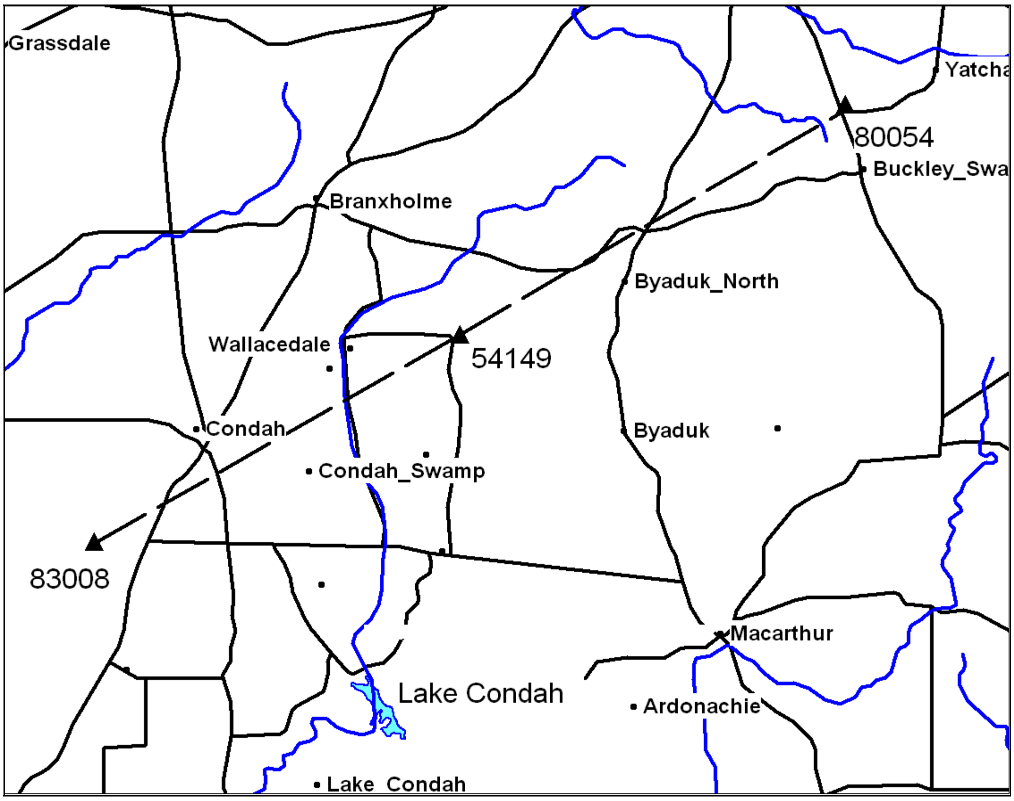


Figure 97. Location of SW-NE hydrogeological cross section for Figure 98. Taken from the 1:250,000 Hamilton hydrogeological sheet (AGSO, 1994).

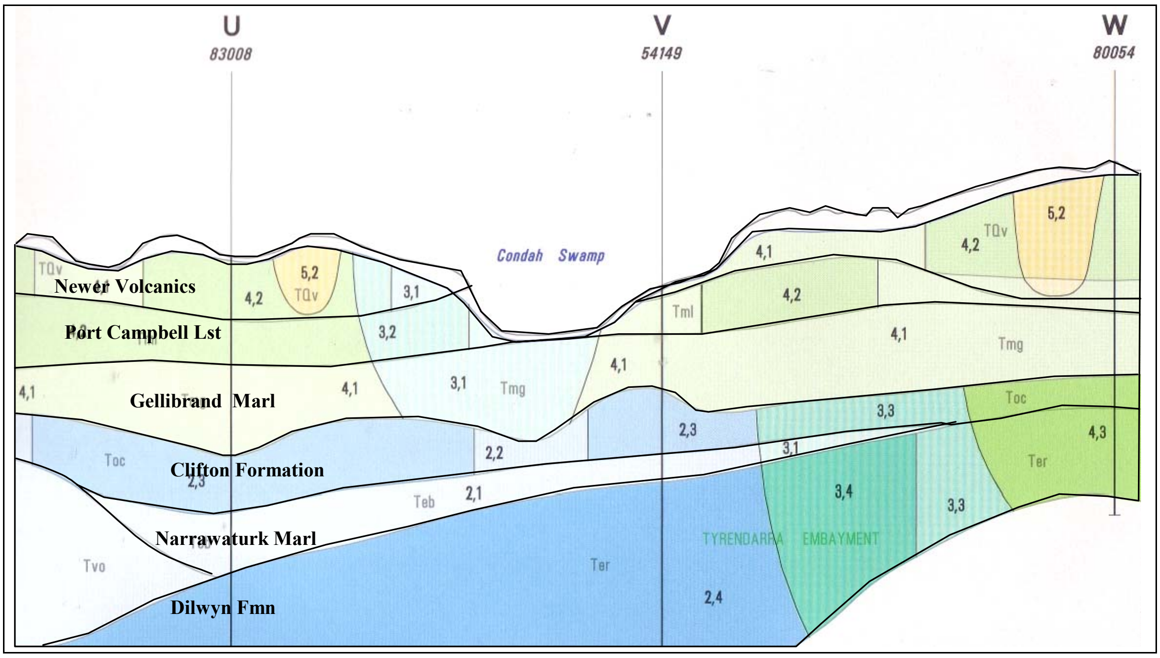


Figure 98. SW-NE hydrogeological cross section across the Condah Swamp with salinity and yield data. The section passes through Condah – locality plan shown on Figure 97 (AGSO, 1994).

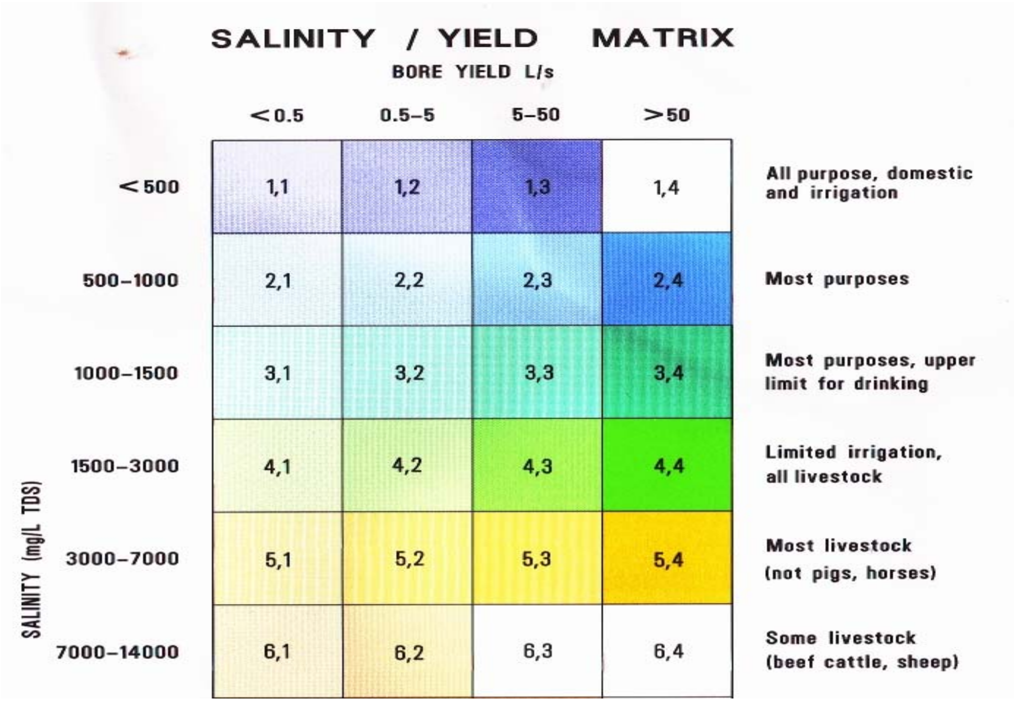


Figure 99. Salinity/yield matrix for Figure 98 (AGSO, 1994).

SKM (1998) showed that across the Condah area groundwater flow was from north to south and that groundwater discharge from the Clifton Formation may occur in the vicinity of the Condah Swamp where the Clifton Formation aquifer comes to within 50 to 100 m of the surface, and is artesian. Within the Condah Depression, groundwater levels (potentiometric surface) of the Clifton Formation are above the ground surface and flowing bores occur. The lowering of the potentiometric surface in this area suggests hydraulic connection between the Clifton Formation and the ground surface, and groundwater may be discharging upwards from the Clifton Formation by means of leakage through overlying sediments (SKM, 1998).

Macumber (2000) noted that in the case of the 120248 bore situated at a lower elevation in the depression of the Condah Swamp, the groundwater level fluctuates from about 8 m to 11 m above groundsurface. He considered that the discharge component within the WSPA could be as high as one third of the throughflow, and commented that any values obtained for cross sectional flow at the lowermost end of the WSPA will not account for groundwater discharge losses to the surface within the WSPA, especially into the Condah Swamp.

In a review of the PAV, Nolan-ITU (2002; 2003) was engaged by Southern Rural Water to prepare a groundwater report to help develop a Groundwater Management Plan for the Condah Water Supply Protection Area (Condah WSPA), formerly the Condah GMA. Two reports were prepared: an initial report (Nolan-ITU, 2002) examined the through flow calculations used to determine the PAV, and recharge to the aquifer. The second report (Nolan-ITU, 2003) examined the potential for flow from the Clifton Formation into the overlying aquifers.

The Nolan-ITU (2002) report showed that in the vicinity of the Condah Swamp, there was an upwards directed hydraulic gradient from the Clifton Formation towards the surface (Figure 100). They showed that on passing downbasin there was an increase in throughflow from the north to the centre of the Condah WSPA but this then decreased on passing further south across the WSPA. As was the case in Macumber (2000), Nolan-ITU (2001) saw the Condah Swamp as a potential discharge area for the Clifton Formation aquifer (Table 19, Table 20). However they considered that groundwater discharges from the Clifton Formation into both the overlying Port Campbell Limestone and the deeper aquifers. The gain and loss of water on crossing the Condah WSPA was also noted by SKM (2006).

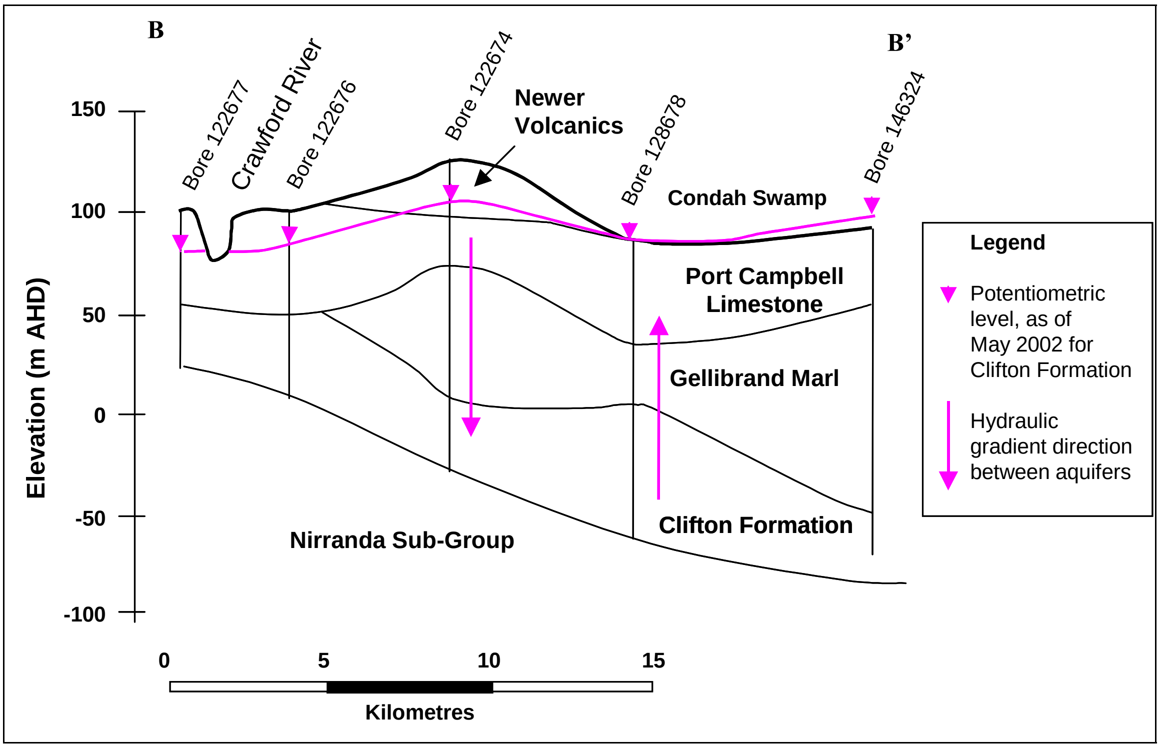


Figure 100. Vertical flow directions in southern E-W section of the Condah WSPA (Section B-B' from Nolan 2002). Note the upwards directed flow beneath Condah Swamp.

The throughflow calculations (Table 19, Table 20) show significant gains in groundwater throughflow in the Clifton Formation aquifer in the northernmost parts of the WSPA (324%) and even larger losses in the south of the Condah WSPA (89% loss). That is, the aquifer is being recharged in the north and then loses almost 90% of its flow, which contributes to surface discharge in the south.

As there is no direct outcrop of the Clifton Formation, Nolan-ITU (2002) comment that there is no direct connection between the Clifton Formation and the Crawford River or Condah Swamp. However based on hydrographs there is evidence of indirect interaction between the semi-confined Clifton Formation aquifer and overlying aquifers (and therefore, presumably the surface). Nolan-ITU (2002 p. 12) note that given that there is no monitoring of water levels or flows in the Condah Swamp area, 'it not been possible to assess whether pumping from the Clifton Formation aquifer has impacted upon water levels in the Condah Swamp'

In addition Nolan-ITU (2002) note (p. 21) that because of the lack of surface water monitoring on the Crawford River and diversion drains in the Condah Swamp, baseflows cannot be determined, and an assessment of the increased reduction to baseflow from actual and licensed usage of groundwater is not possible. Furthermore (p. 24), they observed that since there is no current surface water monitoring program and no information on ionic ratios of nearby groundwater in the WSPA, an assessment of the groundwater-surface water interactions cannot be made.

Comments on the Nolan-ITU reports were prepared by the Technical Audit Panel (TAP) established to review the groundwater Management Plans and Stream Flow Management Plans that were prepared or are being prepared across Victoria. TAP (2004) noted that while threats to sustainability due to declining groundwater levels, borehole interference, declining baseflows to streams and Condah Swamp have been identified, little assessment of the magnitude of the threats has taken place. TAP (2004) accepted that while some of the threats cannot be reliably assessed due to the absence of required data, an improved analysis could be undertaken with existing data.

Table 19.
Throughflow calculations based on Nolan (2001). Table modified from SKM (2006).

Location	Potentiometric contour * (m)	Hydraulic conductivity (m/d)	Throughflow (ML/year)	Gain/Loss %
Upstream	Between 100 m and 105 m potentiometric contours	3 18.5	885 5,456	
Midstream	Between 90 m and 95 m potentiometric contours	3 18.5	3,755 23,158	324% gain 324% gain
Downstream	80 m potentiometric contour	3 18.5	411 2,532	89% loss 89% loss

Table 20.
Throughflow recalculated by SKM (2006) using revised hydraulic conductivity. Table modified from SKM (2006).

Location	Potentiometric contour (m)	Hydraulic conductivity (m/d)	Throughflow (ML/year)	Gain/Loss %
Upstream	Between 100 and 105m potentiometric contours	2.5 3.9	737 1150	
Midstream	Between 90 and 95 m potentiometric contours	2.5 3.9	3,129 4,882	324% gain 324% gain
Downstream	80 m potentiometric contour	2.5 3.9	342 534	89% loss 89% loss

*The potentiometric surface for June 2006 differs from that of Nolan (2001) as it ignores the 122674 bore the integrity of which has been questioned.

SKM (2006), in the recent review, used data from a pumping test and information from Bennetts (2005), who suggested that local faults may have a significant role in groundwater recharge. Bennetts (2005), as quoted in SKM (2006), also indicated that the groundwater (radiocarbon dated at 20,000 years) in the Clifton Formation may be fossil and has recharged under a different climatic regime than that which exists at present. However, the date came from a single groundwater sample from bore 146023. The bore is an artesian bore in the Condah Depression and has a strong upwards directed flow component. It is possible that older groundwater from deeper aquifers may be contributing to the age. Whatever the case, groundwater dates often require considerable interpretation as a consequence of intermixing with older water, and a date from a single bore in a zone of strong vertical hydraulic gradients cannot be used in any definitive way. SKM (2006) in their conclusions echo the response of TAP (2004) above when they noted that:

> "*There is uncertainty surrounding recharge mechanisms to the Clifton Formation and their relative contribution to the water resource. There is inadequate description of the influence of groundwater gradients and aquitards on potential inter-aquifer flow. Areas of potential recharge and discharge from the Clifton Formation need to be spatially mapped across the Condah WSPA*" (Knowledge Gaps, p. 18) and that,

> "*However, the hydraulic relationship between the Clifton Formation and the Port Campbell Limestone, the Dilwyn Formation and the intervening aquitards (Gellibrand and Nullawaturk marls) is less clear. Further work is required to understand the extent of faulting and its influence on local interaction between the key hydraulic units*" (Executive Summary, p. 1).

Notwithstanding this concern, an attempt at extending the basic understanding of the significance and extent of groundwater-surface water interactions is provided in this report.

A persuasive argument for regional groundwater discharge in the Condah Swamp area, and by analogy in the Darlot Creek and Lake Condah areas, is suggested by the extensive drainage network at Lake Condah (Figure 101) and the use of drains in a number of lower tracts of creeks such as the Whittlebury and Breakaway Creeks flowing into the Darlot Creek near Lake Condah. That is, the Condah area has all the characteristics of being in a zone of regional groundwater discharge as defined in Macumber (1991). The almost 90% loss of water from the aquifer between the middle and lower parts of the Condah WSPA, detailed above (Table 19 and Table 20), provides a strong driving mechanism for this process.

6.2.5 Hydrographic Data

6.2.5.1 Regional groundwater flow system

The hydrogeological evidence for a strong groundwater influence on surface water systems is based on the presence of artesian conditions in bores in and adjacent to the larger depressions such as the Condah Swamp. That groundwater discharge occurs is also clear from the various calculations on declining groundwater throughflow on passing downbasin. The reason for the decline in throughflow is two-fold:

- thinning of the Clifton Formation aquifer on passing downbasin towards Heywood from more than 50 m to less than 15 m giving an overall 75%-80% reduction in aquifer carrying capacity from this factor alone (see below).
- loss into the overlying sediments wherever steeper upwards directed hydraulic gradients occur as is commonly the case beneath depressions.

A feature of the isopach (aquifer thickness) map for the Clifton Formation is its reduction in thickness on passing down basin (Figure 102). The flow line ‘c-c’ shows a reduction from over 55 m in the north to 15 m in the south. A consequence of this wedging of the aquifer is that there is a reduction in carrying capacity which forces water from the aquifer resulting in groundwater discharge as swamps and base flow along the Darlot Creek.

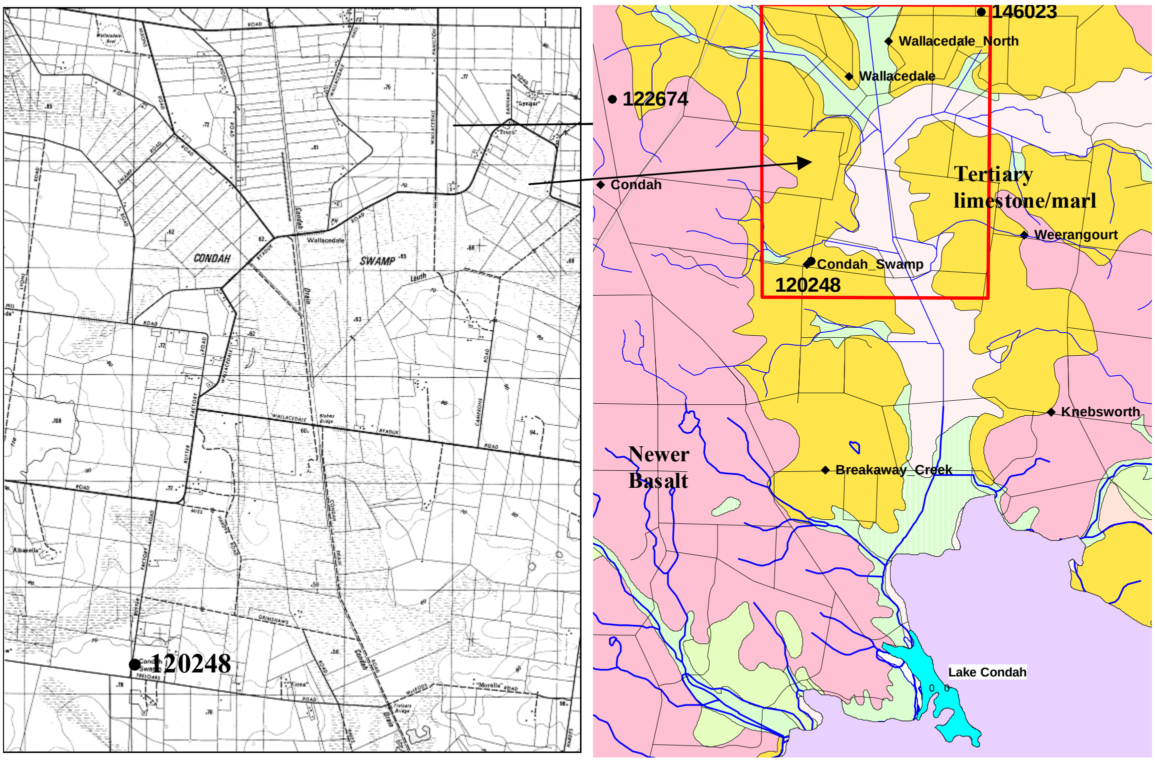


Figure 101. Road and drainage system in the vicinity of Condah Swamp and its geological setting.

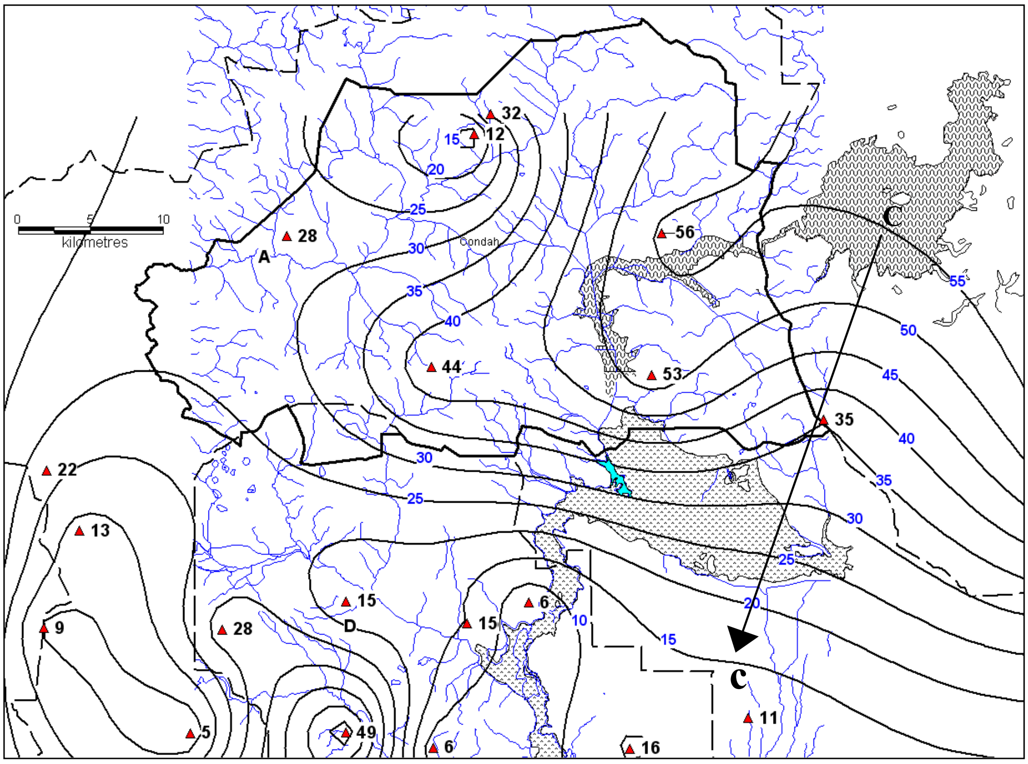


Figure 102. Isopach map of the Clifton Formation with aquifer thickness at each bore site (June 2006).

An examination of the west to east cross section through the Condah Swamp shows the potentiometric surface of the Clifton Formation aquifer and the Port Campbell Limestone aquifer relative to the groundsurface (Figure 103 and Figure 104). The section is taken through bore 120248 (screened in the Clifton Formation between 64-78 m), which forms a piezometer nest with bore 146029. The shallow 146029 bore was drilled to a depth of 32 m in the Port Campbell Limestone; although the screen depth is not stated it is probably in the interval between 22 and 32 m. Because of the relatively elevated level in the deeper bore 122674 to the northwest of 120248, its reliability was questioned by TAP (2004). Two alternative interpretations might be placed on the level, one taken from the configuration shown in the potentiometric surface for June 06 (Figure 105) without 122674, and the other using the original monitored data including 122674 (dashed line in Figure 104). The high measured level in the more recently constructed 146030 bore in the Port Campbell Limestone aquifer is not in question.

Whichever the case, the implications are the same, that in the vicinity of the Condah Swamp, there is a strong upwards hydraulic gradient from the Clifton Formation aquifer towards the shallow aquifers and the surface. While there is no data adjacent to Lake Condah, it is likely that a similar upwards directed hydraulic gradient occurs from the Clifton Formation with discharge occurring into the Darlot Creek.

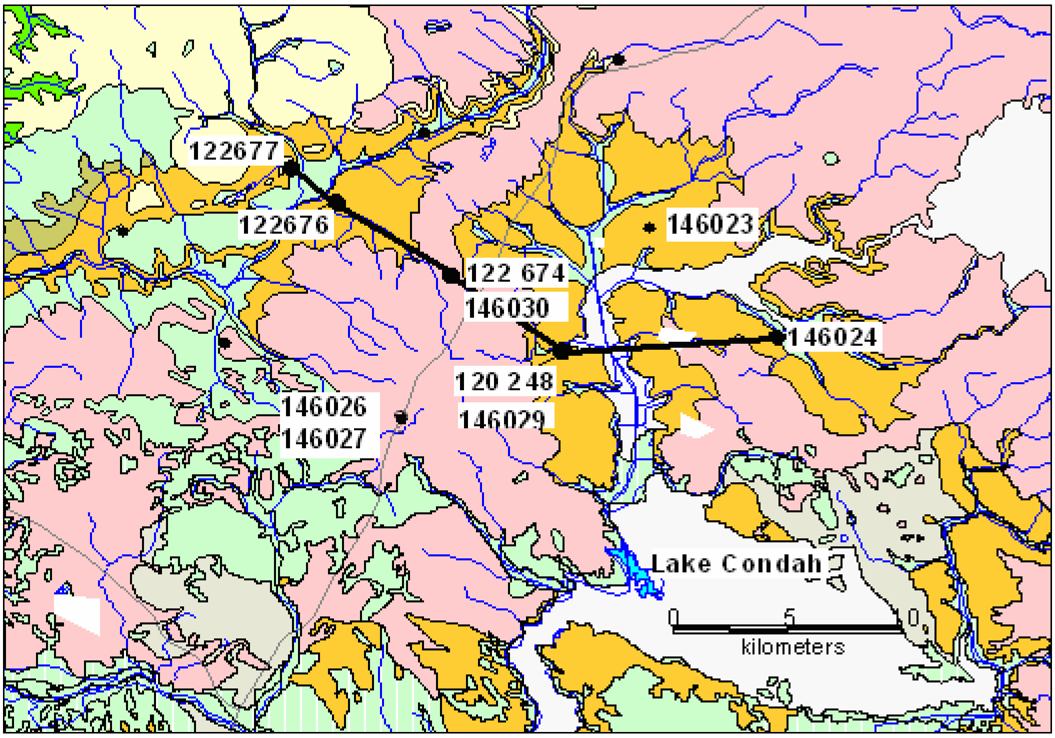


Figure 103. Geology of the Condah area with the bores and section line for Figure 104.

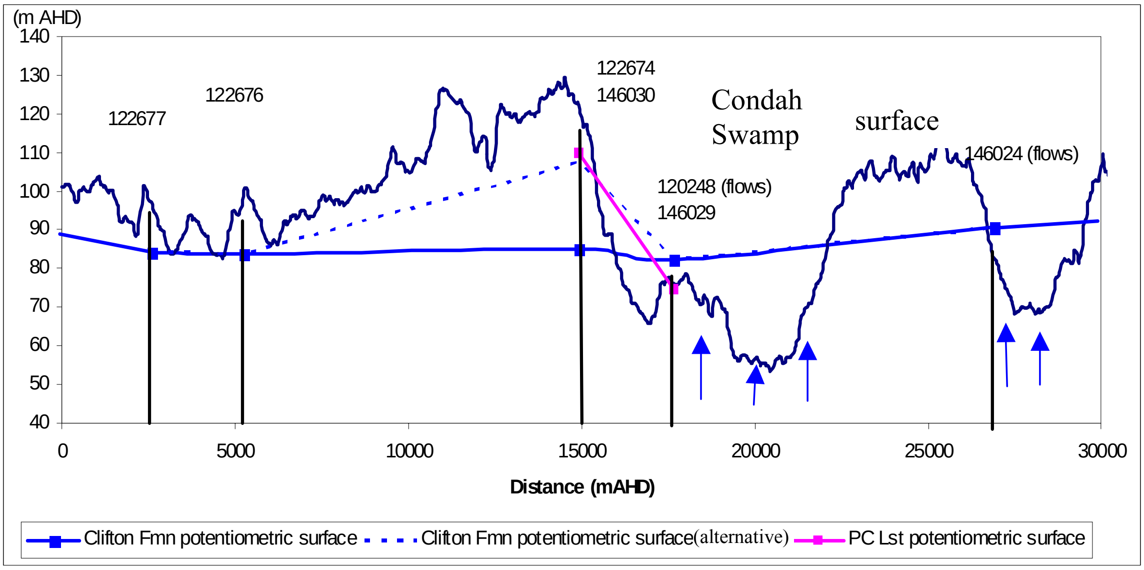


Figure 104. West to east section across Condah Swamp showing potentiometric head in the Clifton Formation with flowing bores located in the depressions. This suggests that the low areas are groundwater discharge areas for the deeper Clifton Formation aquifer. Location of section in Figure 103.

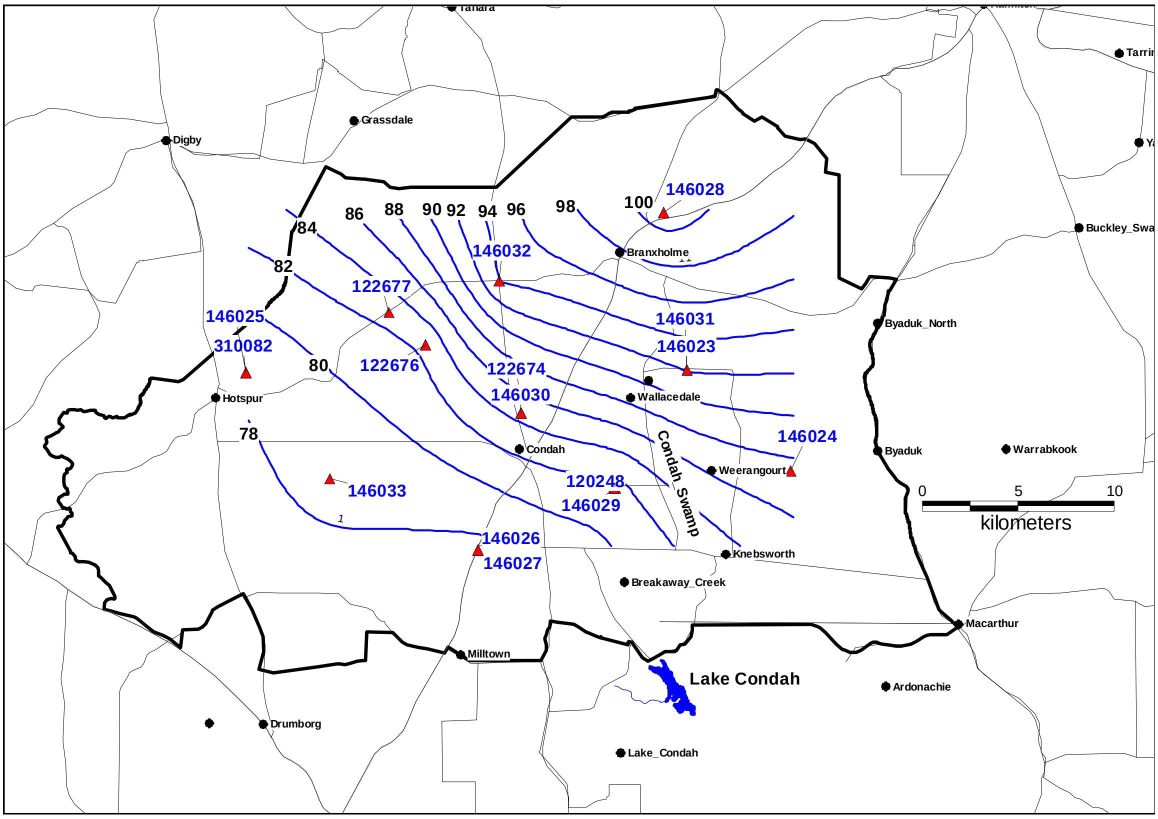


Figure 105. Potentiometric surface of the Clifton Formation aquifer (June 2006).

6.2.5.2 Local groundwater flow system from the valley side

The potentiometric level in the upper Port Campbell Limestone aquifer (pink in Figure 104) is at a relatively high elevation in bore 146030 (110 m AHD) but in bore 146029 (74.5 m) it is about 35 m lower (Figure 104). At the 146030 site groundwater recharges whichever of the alternative levels is taken, while at 146029 the upwards directed hydraulic gradients indicate groundwater discharge. At the 146029 site, groundwater levels were seasonally within 2 m of the groundsurface between 2001 and mid-2005, but fell away to be greater than 4 m depth (Figure 106).

The conceptualization of the shallow aquifer is one of a local recharge-discharge flow system, reflected in levels at the 146030 and 146029 sites (Figure 107). Groundwater outseepage would be expected in the lower areas adjacent to the 146029 bore and is likely to be accentuated beneath the Condah Swamp and by analogy, the Darlot Creek and probably Lake Condah. That is, groundwater discharges directly into the major drainage system and its feeder creeks. The discharge would be from two sources, the regional Clifton Formation aquifer (regional discharge) and the local flow system recharged on the higher basaltic and limestone areas lateral to the valleys (local discharge).

Hydrographs of the nearest monitoring bore - 120248 and 146029 – on the western edge of the Condah Swamp and to the north of Lake Condah - show that the deeper bore fluctuates strongly in response to groundwater pumping with the amplitude increasing over time, as development of the aquifer proceeds. The deeper bore has a higher potentiometric level than the shallower bore showing that there is a strong upwards hydraulic gradient between 64-78 m and 32 m (Figure 108). This relationship is also brought out in Figure 100.

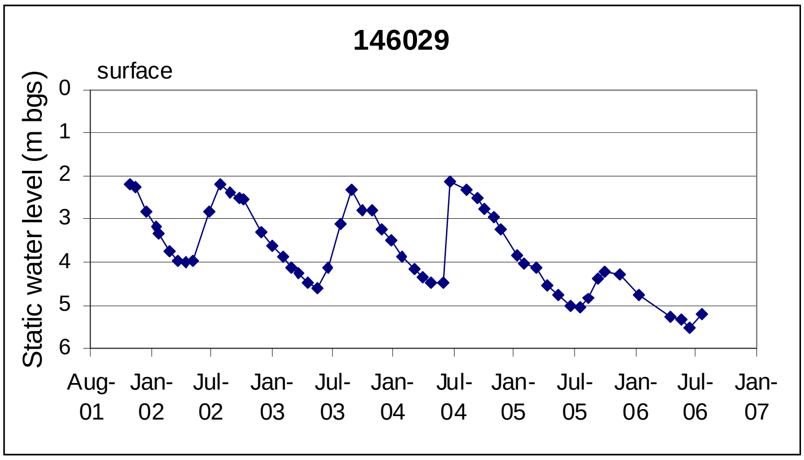


Figure 106. Groundwater level and fluctuation in the shallow Port Campbell Limestone bore 146029.

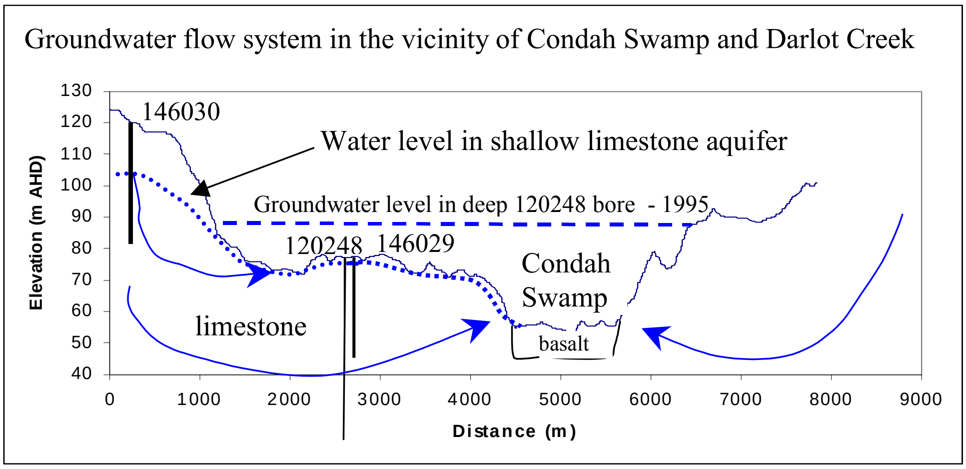


Figure 107. Groundwater flow pattern and potentiometric surface levels at Condah Swamp.

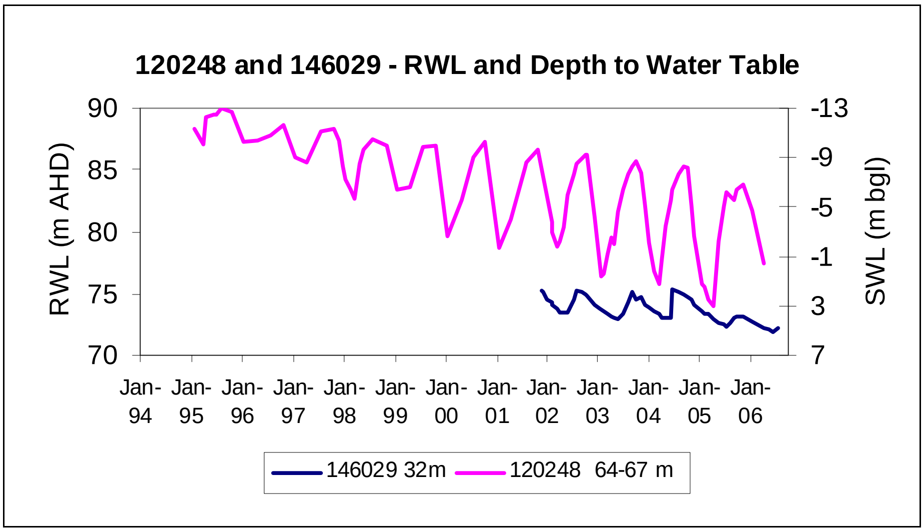


Figure 108. Hydrographs of the 120248 and 146029 bores showing water levels with respect to AHD and the ground surface (bgl). On the right hand axis the ground surface is at zero and negative values represent artesian conditions with 120248 being a flowing bore.

While the groundwater from both the deeper and shallower bores may impact directly on the surface systems at the site, both these bores are located on a higher terrace (Figure 107). The potentiometric surface of the Clifton Formation bore is significantly higher than the floor of the swamp where groundwater levels associated with the deeper aquifers are assumed to have remained strongly artesian. There are no similar borehole data available at Lake Condah, but it is likely that this will also be the situation there.

At the 120248/146029 site there is evidence in 2005 of a notable fall in the shallower groundwater level in bore 146029 with the recovery level being 2 m less than previously (Figure 106); it is possible that this is perhaps echoed by a fall in the water table. However the record is too short to be definitive, and again, the extent to which this is in response to the increased groundwater extractions (shown by the steady fall and increased amplitude of water level fluctuation in the 120248 bore - Figure 108 and Figure 109), and to what extent it is influenced by the prolonged drought, cannot be determined. However the pattern of a recent fall in shallow groundwater is repeated in the 146026 bore screened from 31 – 34 m in Newer Basalt (Figure 110). This forms a piezometer nest with the 146027 piezometer (screened at 181-191 m), which also shows the steady fall in levels since monitoring began in 2001. This nest differs from the 146029/120248 nest in that it has a strong downwards hydraulic gradient indicating recharge from the Newer Basalt towards the Clifton Formation.

6.2.6 Hydrochemical indications of groundwater contribution to Darlot Creek

Electrical conductivity (EC as µS/cm) and other chemical measurements have been taken monthly for the Darlot Creek at Homerton (Figure 89) for the period 1976 to 1998 (Figure 111). A strong indication of the groundwater contribution to the surface water systems can be gained by comparing the salinity of the groundwater and the creek. Where there is a significant contribution from groundwater the salinity is normally higher than would otherwise be the case. The salinity of the Darlot Creek (converted from measured EC µS/cm), ranges from a low of about 600 mg/L corresponding to peaks in early spring stream flow, up to about 1500 mg/L commonly occurring in winter and at times of lower stream flow in early spring. The average salinity of the Darlot Creek over the period from 1976 to 1999 was 1040 mg/L, however in the low flow period commencing with the drought in 1997, salinities did not fall below 1100 mg/L (Figure 111).

Comparison of stream salinity may be had with groundwater salinity (as mg/L) from a large number of shallow and deep bores in the vicinity of the valley of the Darlot Creek and Condah Swamp between Wallacedale and Homerton (Figure 112). The salinity of the groundwater lies mostly between 250 mg/L and 2,500 mg/L with the largest percentage of bores (57%) lying between 1,000 and 2,000 mg/L. No samples were found for the stony rise basalts, which normally contain fresher groundwater as a consequence of the direct and rapid recharge of the fractured rock aquifer. The range of salinities of Darlot Creek at Homerton Bridge, commonly being between 1,200 mg/Land 1,500 mg/L, comfortably fits the model of a stream with a significant base flow contribution both directly, and from side tributaries. This would appear to be the case with Whittlebury Creek/Swamp.

Although no direct evidence is available, it is likely that the water in the stony rises basalt aquifer is supplemented from groundwater flowing upwards from the Tertiary aquifers similar to the processes occurring at Condah Swamp (Figure 107). This may in part explain the apparent absence of fresh groundwater, which is the normal occurrence in stony rise basalts because of the rapid infiltration. Confirmation of this process and an assessment of the rate and extent of such additions can only come with the establishment of piezometer nests in the vicinity of the Lake.

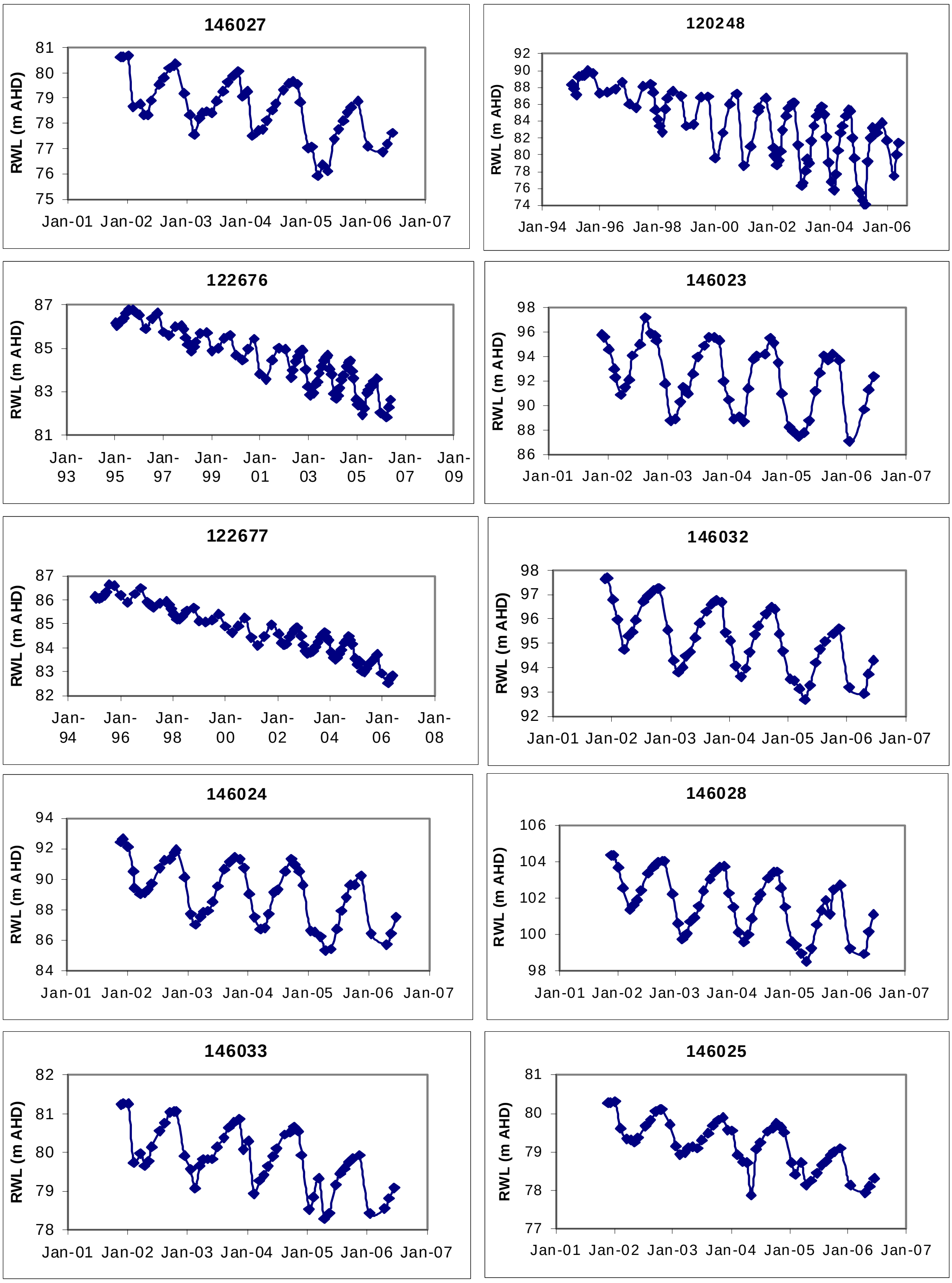


Figure 109. Hydrographs of various monitoring bores across the Condah WSPA. All show a steady decline in potentiometric head reflecting groundwater pumping and perhaps exacerbated by decreased recharge in response to the post 1996 dry years.

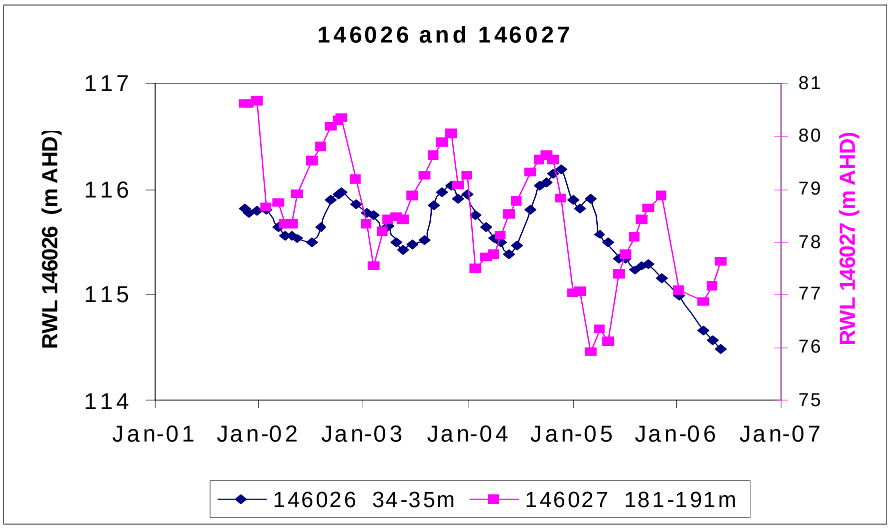


Figure 110. 146026 and 146027 piezometer nest, NW of Lake Condah. Locality given in Figure 103.

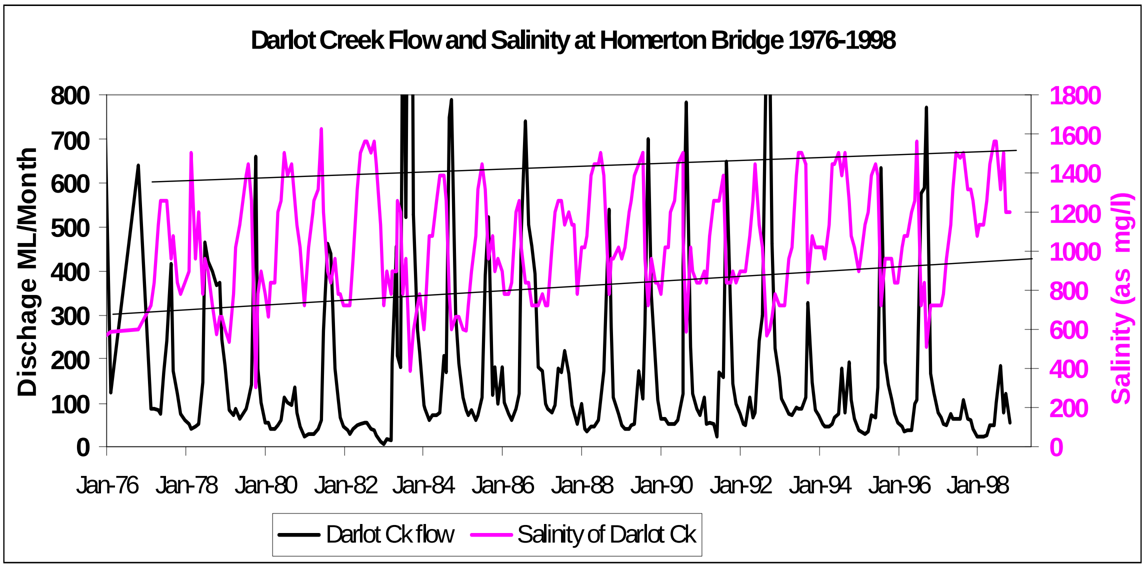


Figure 111. Salinity and flow in the Darlot Creek at Homerton Bridge.

For this review, surface water salinities were sampled at a number of points along the Darlot Creek, Condah Swamp and Deep Creek in mid July and late September 2006 (Figure 113). The values ranged mostly from 1,600 mg/L to 2,050 mg/L, but some fresher water was met in Deep Creek east of Homerton.

The range of salinities in Darlot Creek of between 1,640 mg/L and 2,040 mg/L was similar to that found in pools in southwestern Condah Swamp (1,660 mg/L to 1,740 mg/L) and that in small drainage channels on the stony rise basalt (Figure 114), which cross Coustleys Road forming the headwaters of Deep Creek (1620 mg/L to 1710 mg/L). The salinity range is higher than that recorded in Darlot Creek at Homerton between 1976 and 1998 (Figure 111) perhaps caused by a lessened surface water component as a consequence of the drier years from 1997 onwards. Whatever the case, the salinity is significantly higher than that normally expected from surface runoff alone, the affect of which was observed further south, along the Woolsthorpe-Heywood Road where Deep Creek had a low salinity of 540 mg/L in July 2006 while in September it was only 330 mg/L following heavy rains (Figure 115). By contrast, further west at the Homerton stream gauging site, the salinity of Dalton Creek was 1650 mg/L in September (Figure 113).

Perhaps the most significant feature of the recent field sampling was the similarity of the salinity of Darlot Creek, the pools in Lake Condah and the drainage channels forming the upper parts of Deep Creek, sourced in the basalts. All three are in separate hydrological systems isolated from each other. It is considered that they all strongly reflect a strong groundwater influence.

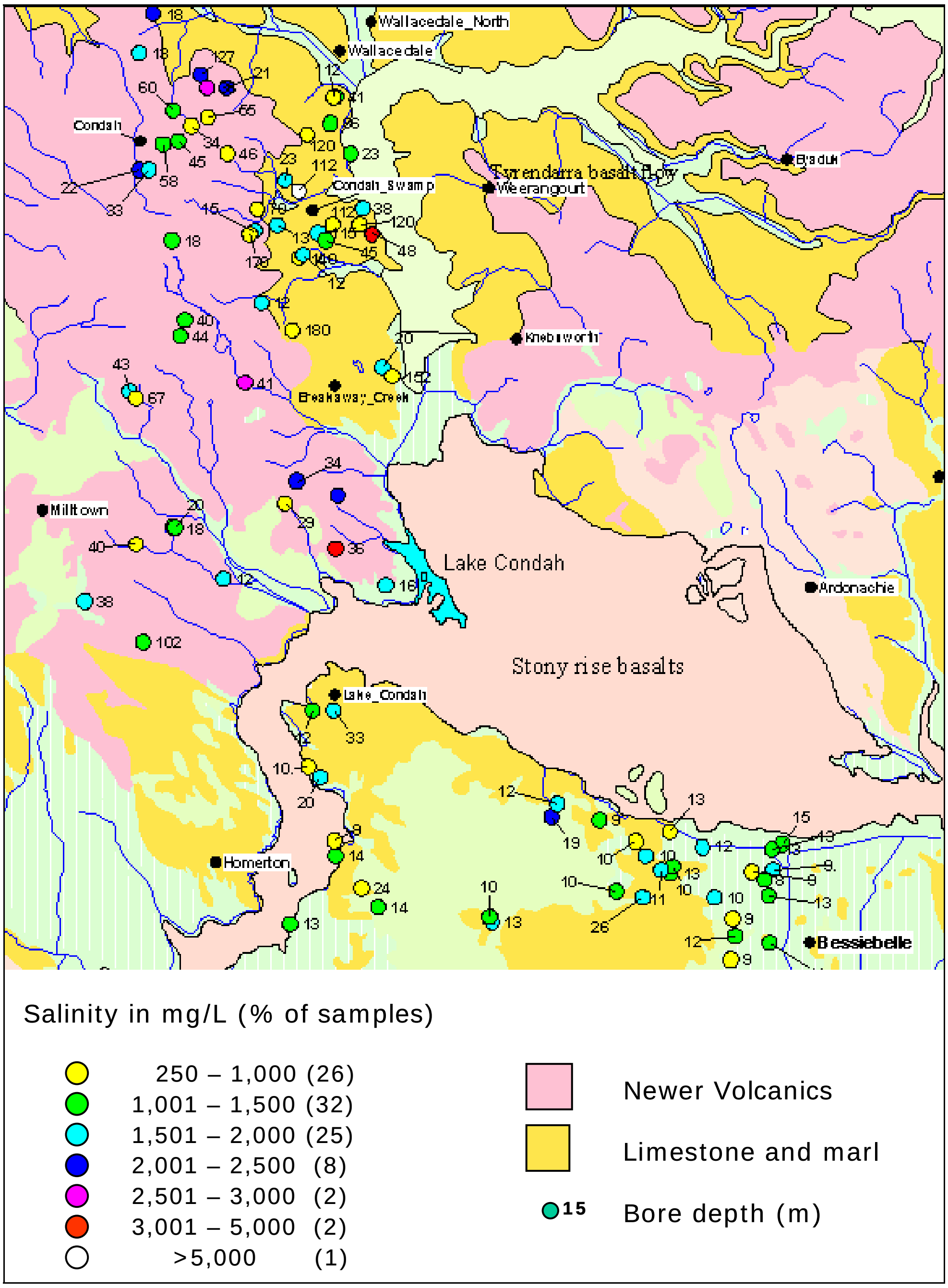


Figure 112. Geology with groundwater salinity ranges as mg/L. Percentages of samples shown in brackets.

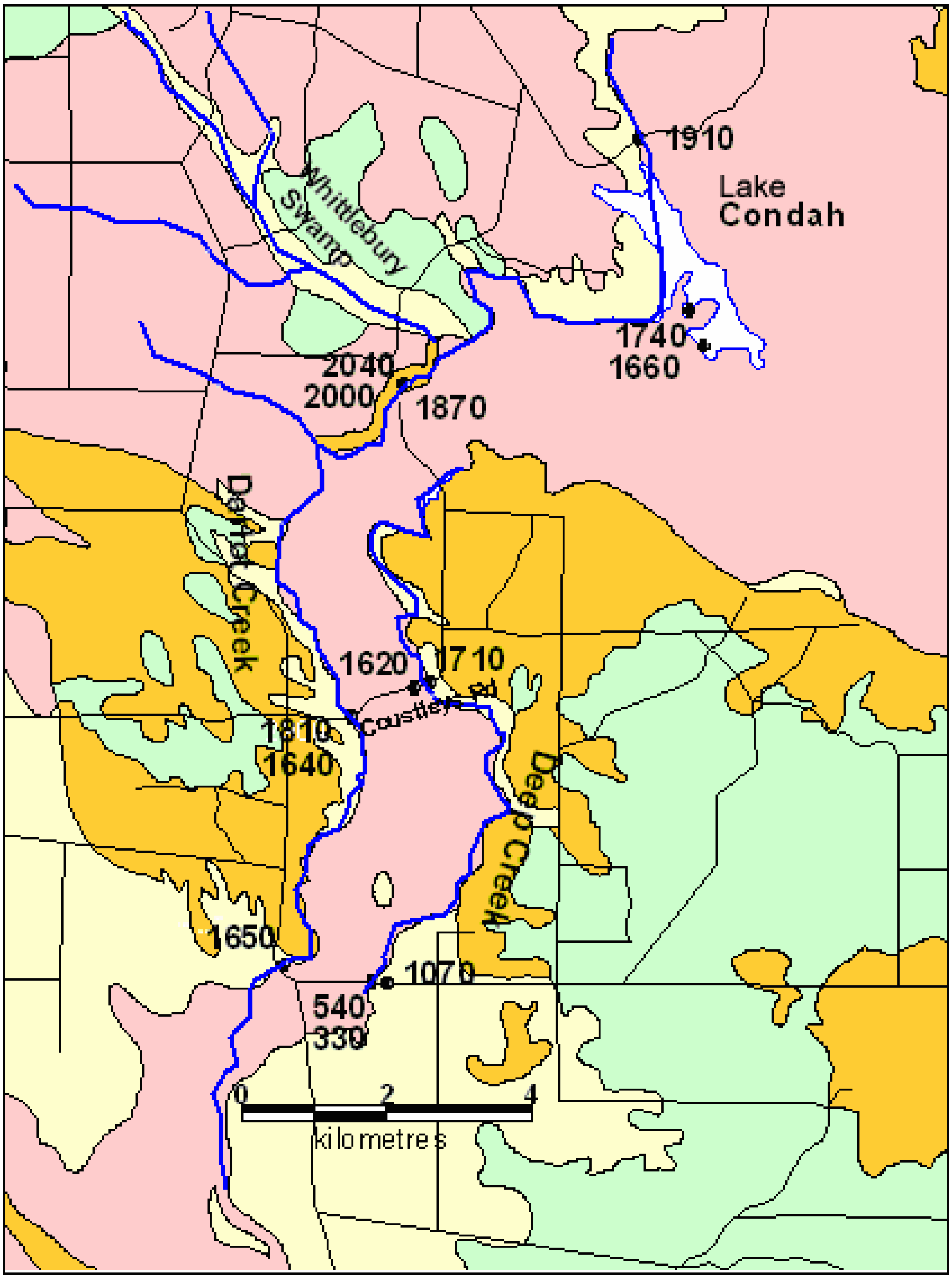


Figure 113. Surface water salinity in the vicinity of Condah Swamp, Darlot Creek and Deep Creek (July and September, 2006).

Figure 114. Drainage channel forming the upper reaches of Deep Creek at Coustleys Road. The salinity was 1600-1700 mg/L indicating a significant groundwater component. Photo: P. Macumber, July 2006.

Figure 115. Deep Creek – Woolsthorpe-Heywood Road. The salinity ranged between 330 mg/Land 540 mg/L indicating a significant rainfall/runoff component. Photo: P. Macumber, July 2006.

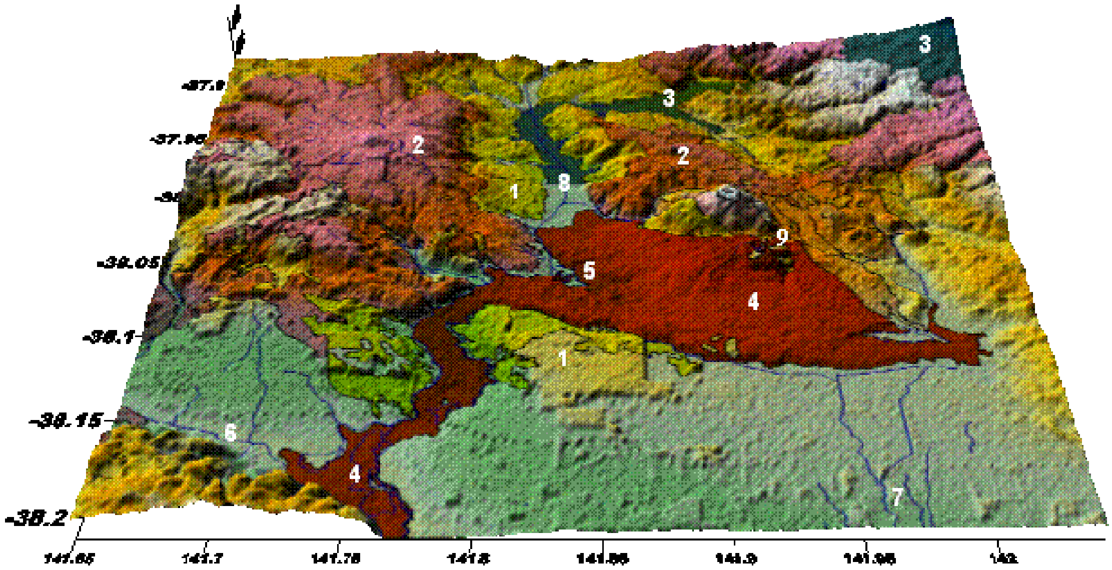
6.3 Potential for seepage from Lake Condah to increase groundwater recharge to local and regional aquifers

6.3.1 The stony rises basalt aquifer

Lake Condah was originally formed by the damming of an ancestral Darlot Creek valley by the Tyrendarra basalt flow coming from Mt Eccles and passing down the valley (Boutakoff, 1963). The Lake is enclosed on three sides by the youthful Tyrendarra stony rises flow (Figure 116).

A brief review of the character of the stony rise basalts appears in Grimes (2004). The aquifer which surrounds the Lake is strongly fissured, fractured and jointed. The lava flow originating from Mt Eccles has an extensive development of pseudo-karstic features such as lava caves and lava blisters which occur on the slopes of Mt Eccles as partially collapsed unroofed lava tunnels and lava blisters. Figure 117, taken from a tourist guide to the Mt Eccles area produced by Parks Victoria (n.d.), provides some understanding of the extent to which karstic features exist in the stony rise basalt flow in the vicinity of Mt Eccles.

According to the Coutts et al. (1977) survey, the surface outlet from the Lake to the creek is about 4 m above the lake floor. This is also indicated by the long profile from the Lake passing down the lake outlet to the west which shows a rise from the Lake (ca 50.5 mAHD) to a level of about 54 – 55 m AHD prior to dropping into the valley of Whittlebury Creek valley (Figure 118). This suggests that at least under lower flow conditions, the Whittlebury Creek rather than Lake Condah may have been the principal feeder of surface flows to the lower Darlot Creek prior to the construction of the Condah main drain. Further to the south, near the Condah Mission, the Darlot Creek passes underground into the stony rise basalt, to re-emerge as an efflux several hundred metres further downstream (Figure 118 and Figure 119).



1. Port Campbell limestone
2. Newer volcanics
3. Mt Napier Basalt flow
4. Tyrendarra (Mt Eccles) Basalt flow
5. Lake Condah
6. Fitzroy River
7. Eumarella River
8. Condah Swamp and Darlot Creek
9. Mt Eccles

Figure 116. Geology and geomorphology of the Condah area.

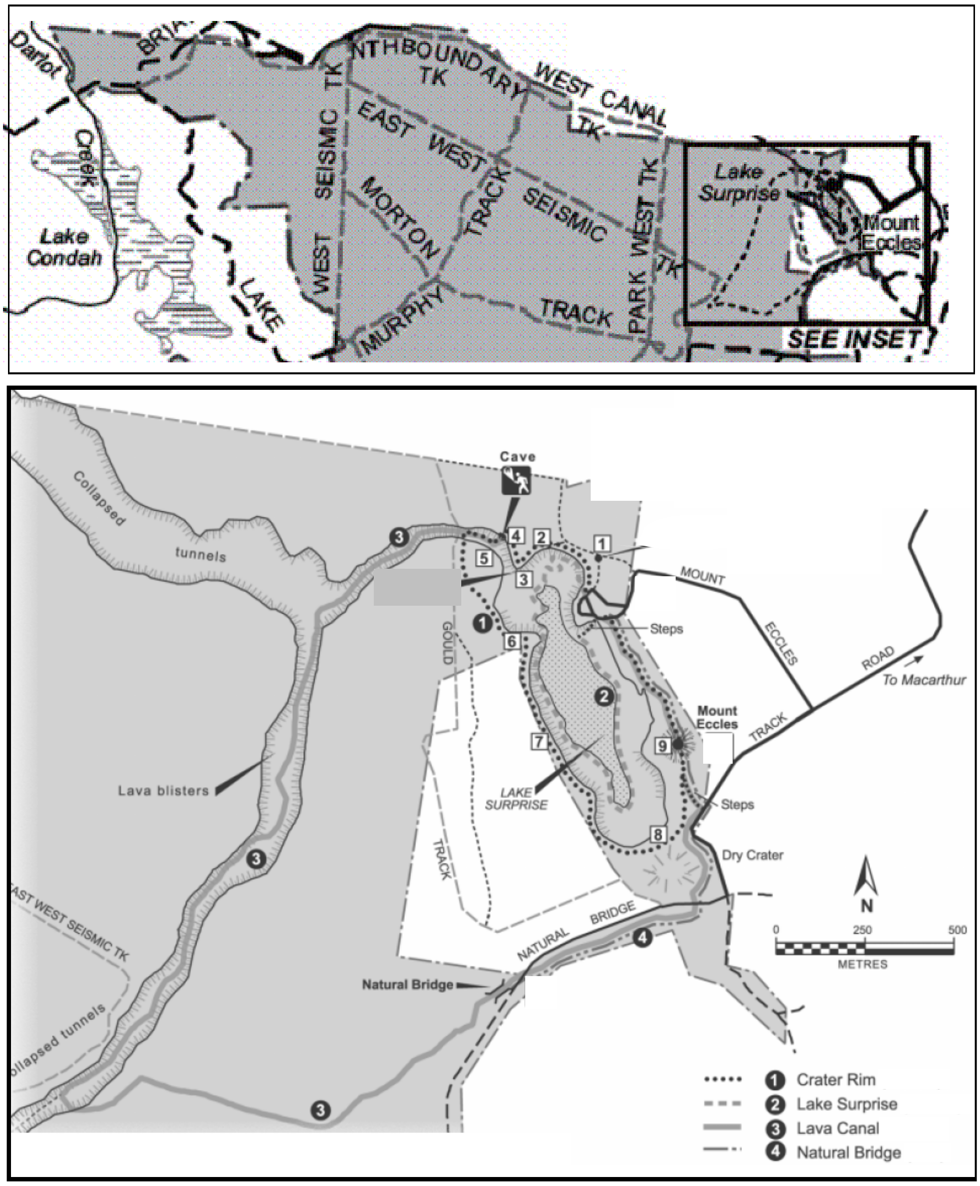


Figure 117. Distribution of pseudo-karstic features in the vicinity of Lake Eccles, modified from Parks Victoria (n.d.).

6.3.2 Loss of lake water into the stony rises basalts

The loss of the Darlot Creek into the stony rise basalt sequence is a strong pointer as to the behaviour of Lake Condah, which loses water into a number of sink-holes, referred to as 'lake-side water sinks' by Kiernan et al (2003), in the south west. While there are a number of descriptions of water being lost from the surface via the sinkholes, it seems likely that the highly fractured basalt beneath and bounding the Lake forms one large recharge zone whenever the Lake holds water.

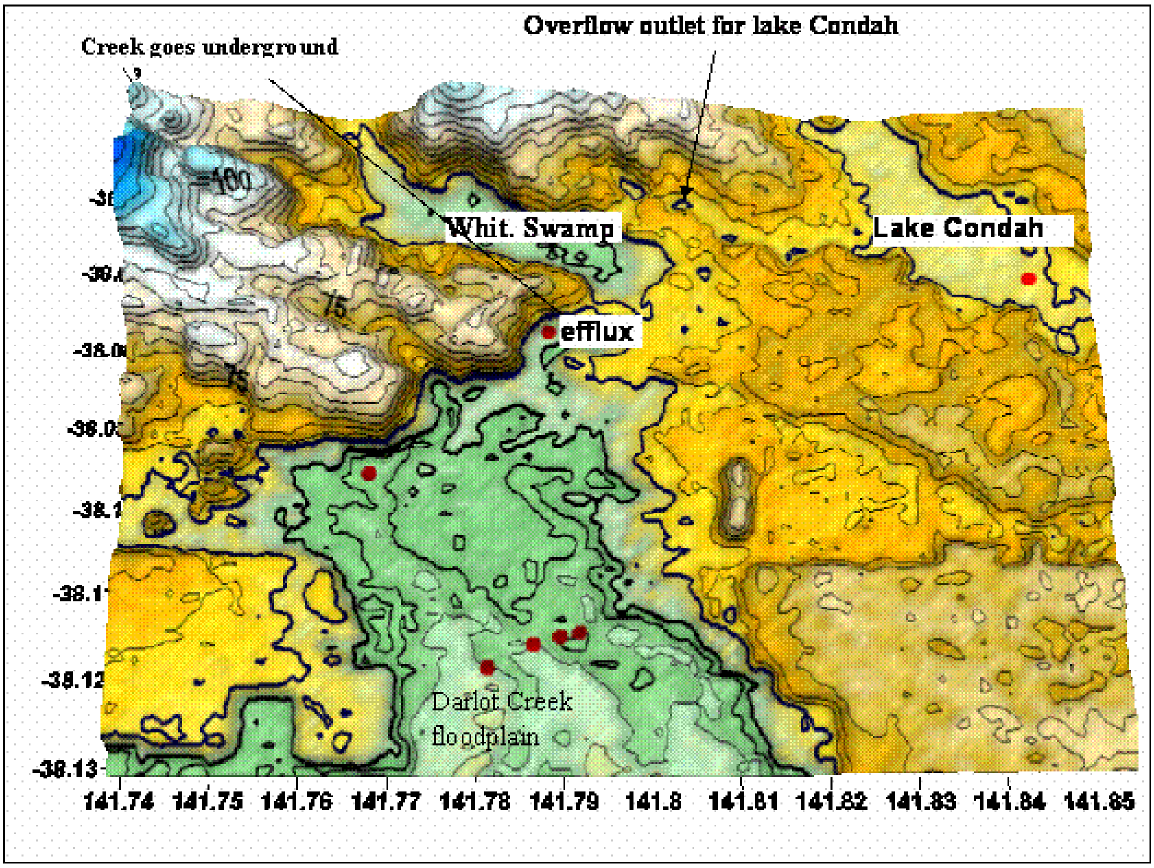


Figure 118. Relationship of Lake Condah to Whittlebury Swamp and the lower Darlot Creek flood plain. Contour Data from the SRTM.

Figure 119. Re-emergence (efflux) of Darlot Creek from beneath the basalt. Photo: P. Macumber.

The process and extent to which groundwater flow may occur in basaltic systems such as that which occurs around Lake Condah was reviewed by Kiernan et al, (2003) for Iceland and Australia. They showed that, in the case of Iceland, integrated karstic underground drainage systems develop on very young lava flows. These systems exemplify the complexity of the fissured and conduit aquifers that can develop. In such flows conventional cooling cracks are supplemented by brittle fracturing caused when the congealed lava crust is raised or lowered by hydrostatic pressures. There may develop discrete 'stacked' lava flows in which the boundaries between each flow contain significant laterally extensive voids that allow high-volume turbulent groundwater flow. There is a close similarity of features described by Kiernan et al. (2003) to the landscape in the vicinity of Mt Eccles (above) and to features occurring in the vicinity of Lake Condah.

In the case of lava tubes or tunnels, water may be stored or transmitted and may flow for some considerable distance. The fractured basaltic aquifers may produce aquifers with exceptionally high transmissivity. This is clearly shown to be the case with the loss of the Darlot Creek into the swallow hole near the Condah Mission, before it re-appears several hundred metres downstream as a resurgence (Figure 119).

Once the level of Lake Condah rises, the water encounters the highly permeable broken and fissured basalt forming the lake perimeter. It is in this setting that activation of the fish traps around the southwestern lake edge occurs (Figure 120). During times when the Lake is at a high level the lake water is lost by turbulent flow into the sinkholes. In the vicinity of the fish trap sites in the southwest [i.e. Coutts et al. (1978) sites 1-4, plus others] where the Lake loses water into sinkholes, a number of large depressions, probably formed as collapse structures, are found. In many instances these are isolated and not interconnected, yet would probably fill with water when the Lake is high due to the strong hydraulic connectivity in the groundwater system developed in the shallow fractured rock unconfined aquifer. Small natural channels are commonly modified to become fish trap sites, but such channels commonly terminate (or start) in collapse depressions. The slope of the channels is towards the Lake, and this may facilitate some return flow to the Lake as if falls, from the fractured basalt aquifer where water is stored as 'in-bank storage'.

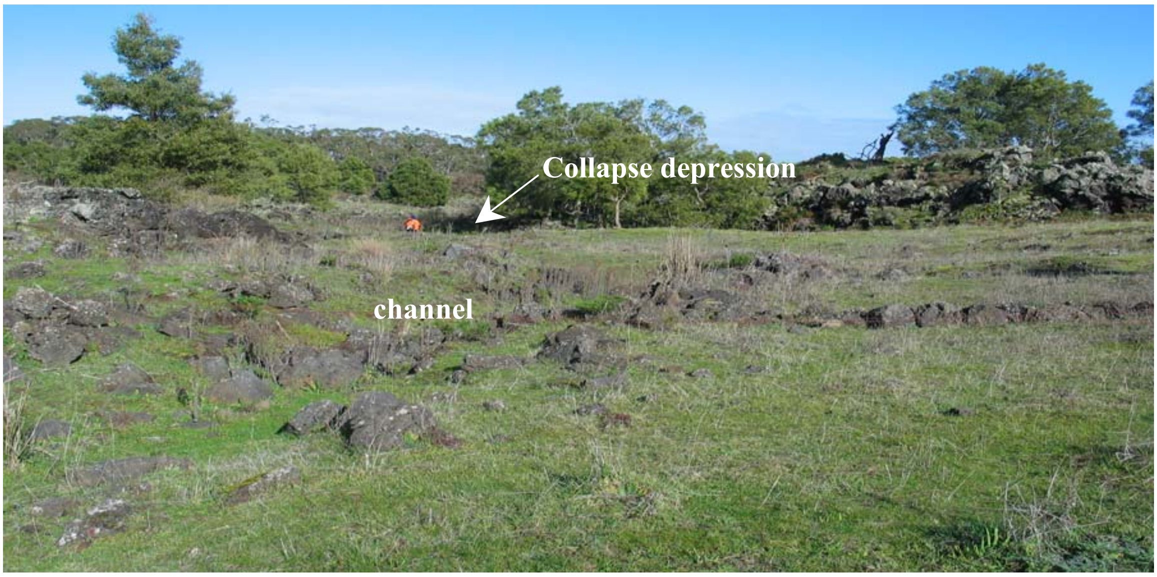


Figure 120. Shallow depression associated with eel trap structures. The depression terminates in a collapse sink (near the person in the background). A second peripheral channel runs to a depression at the base of the stony outcrop to the right, then terminates. Photo: P. Macumber, July 2006.

The observed Lake level data from 1988 – 1992, when compared with Darlot Creek discharge and groundwater level in the limestone to the southwest (Figure 92), showed the close conformity in stream flow, lake level and groundwater level fluctuations. Over this period there was a relatively rapid fall in lake level after the stream flow declined, suggesting that in this system continued stream flow is necessary to balance the evaporative and outseepage losses from the Lake. The Lake remained low (at the lowest level that the gauge could record) for a further six months over the summer/autumn period until it was again refilled from the Darlot Creek over winter and spring, commensurate with the renewed inflow from the Darlot Creek.

While rainfall and evaporation do influence lake levels, at Lake Condah the monthly range of Net evaporation (evaporation minus precipitation) is small (positive 0.177 m/month to minus 0.044 m/month) compared to that of lake level falls (seasonal drop of 1.5 to 2.0 m overall), so the seasonal climatic impact on lake level is comparatively minor.

While loss to the groundwater system into the fractured basalts forming the lake perimeter would especially be the case during periods of higher lake level, recharge is also likely to occur from the broader lake floor. The lake bed is composed of clay/silt sediments which have a low infiltration rate, but they are not impervious On the basis of the high level of the natural surface outlet (ca 54 – 55 mAHD), it is concluded that in the past, water loss from the Lake was always significant, but mostly into the stony rises basaltic aquifer around the lake perimeter with surface overflow occurring only under higher lake level conditions which permitted overtopping of the lake outlet towards Whittlebury Swamp. Given the lack of any values for the hydraulic parameters and potentiometric data for the fractured basalt aquifer, the rates of loss must be based on observed data.

The absence of any potentiometric data does not permit other than a generalized comment on the relationship between the Lake and the underlying groundwater system, However an understanding may be had from other studies on lake-groundwater interactions which commonly show a mounding of the groundwater beneath lakes, where the top of the water table equates with the level of the lake (Macumber, 1991, 2002, 2005). Turbulent flow into the sinkholes would be expected mostly during the early phase of lake filling as the groundwater mound developed.

During a brief visit to Lake Condah in mid July 2006, large areas of the lake floor had a shallow water cover. A large pool existed in the vicinity of the sink hole where the Lake gauge is located (Figure 121). A second remnant pool to the south was also inspected during the September visit. In both instances the salinity of lake edge pools was much the same, being about 1,600-1,750 mg/L (2,700 – 2,900 µS/cm). While overflows from the Creek and diversions from the upstream weir provided much of the water cover on the Lake, another possible explanation for the ongoing presence of pools is their maintenance by the high shallow groundwater table which outcrops in depressions on the lake floor. Under this scenario, the pools shrink and finally dissipate as the water table falls.

Figure 121. Ponded water at the site of one of the larger sink holes (gauge pool). The absence of any clear sign of sinkhole recharge at the time suggests that the elevation of the water table at the site may have coincided with that of the pond surface. Photo: P. Macumber, July 2006.

6.3.3 Re-emergence of recharged Lake water at the surface

Filling of the Lake causes a concomitant groundwater mounding in the underlying stony rise aquifer and around the lake perimeter. Water lost from Lake Condah is likely to move directly through the stony rise basalts towards the south west with the downbasin pathway dictated by the nature of the passages in the underlying aquifer system. The original lake overflow level along the Darlot Creek was at about 55 m AHD, and a zone representing the range of levels of the Lake from 50 mAHD to 55 mAHD is shown in Figure 122. There are likely to be many discrete preferential groundwater flow paths and an indication of potential emergence points within the fractured rock basalt landscape is provided by the plot of the yellow 50 – 55 mAHD contour zone (Figure 122).

A number of low points in the terrain are evident, especially to the south of the Darlot Creek outflow channel and to the east of Whittlebury Swamp, where areas lying within the 55 – 50 m AHD zone are scattered throughout the stony rise basalts. While much of the Lake water may re-emerge in Darlot Creek in a zone downstream from the entry of Whittlebury Swamp, the presence of a broad zone at 50 -55 mAHD lying along the southern edge of the stony rises at its boundary with the Tertiary Limestone suggests that under high lake levels this is a significant zone of high water tables and perhaps groundwater outseepage fed by Lake water passing southwest through the stony rise basalts. It covers the upper catchment of Deep Creek (Figure 123), which a little further to the south passes through culverts under Coustleys Road, and was there represented by water-filled channels in September 2006 (Figure 114, location in Figure 113). In its upper reaches, Deep Creek has the familiar salinity pattern (1,620 – 1,710 mg/L) of the lake and groundwater system (Figure 113). However, further south, where it becomes more prominent (Figure 115) prior to joining Darlot Creek, it was observed on both occasions in July and September to have gained significant fresh runoff to have a low salinity ranging from 300 mg/L to 600 mg/L (Figure 113).

Should Lake Condah be filled to a level sufficient to reactivate the south western fish trap sites, one likely consequence is the reactivation of the Deep Creek with increased flows from the upper catchment areas.

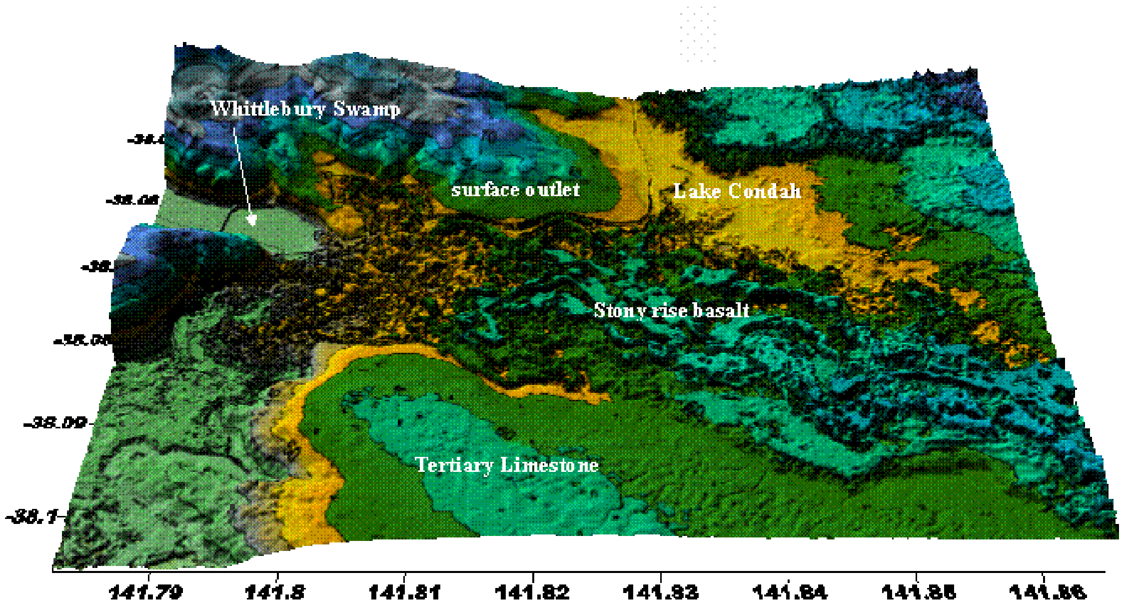


Figure 122. Lake Condah region with range of elevations from 50-55 m AHD, shown in yellow.

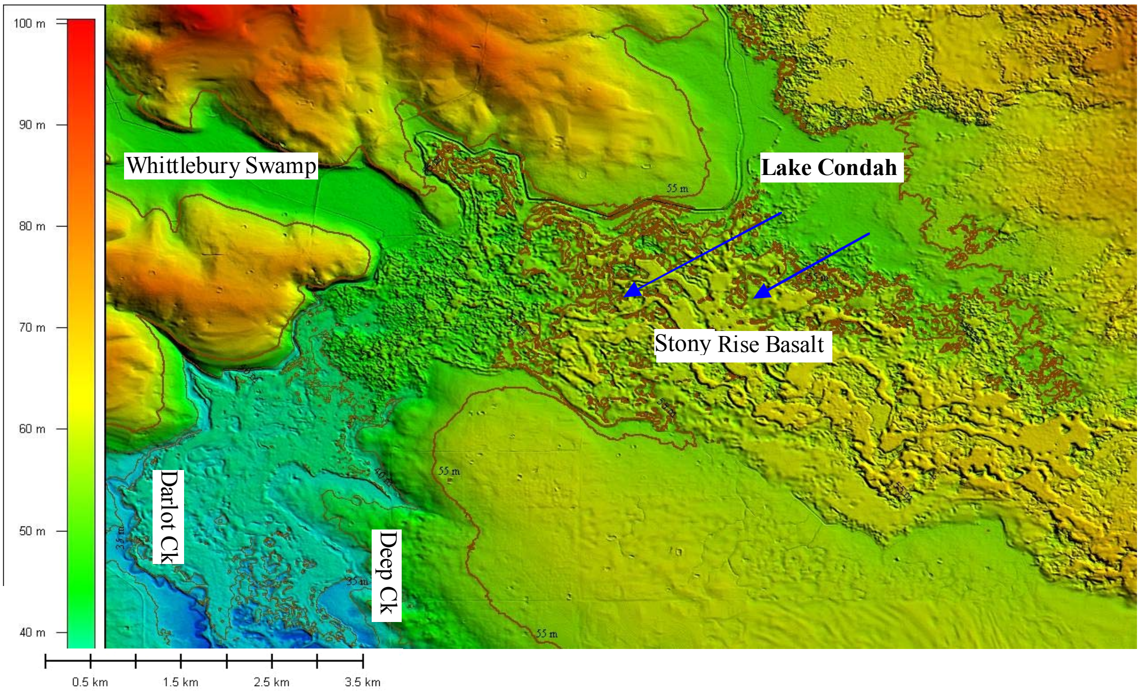


Figure 123. The Darlot Creek and Deep Creek to the southwest of Lake Condah showing likely groundwater flow path (blue arrows). Topography from 2005 DEM.

6.4 Conclusions and Recommendations

6.4.1 Conclusions - Hydrogeology

[1] It has long been recognized that there is much that is speculative about the nature of the direct lake-groundwater relationship at Lake Condah. This is especially the case with the process and rates of outseepage, and the flow path taken by the Lake water once it enters the groundwater regime dominated by the fractured rock stony rises aquifer system. As no groundwater data from the vicinity of the Lake are available, comment is limited, and is based mostly on observations from surface water systems. The current understanding of groundwater interactions with the Lake is therefore largely determined by the Lake observations from earlier periods such as that recorded in Hand (1973), and from the Lake Condah/Darlot Creek surface water monitoring, especially that between 1987 and 1993.

[2] There is an initial gain then major loss of groundwater from the regional Clifton Formation aquifer on passing southwards across the Condah WSPA with perhaps as much as 90% being lost between the central and southernmost areas. Losses are likely to be into both the underlying aquifers and into the overlying Port Campbell Limestone and then to the surface.

[3] Much of the Darlot Creek Valley including Condah Swamp and probably tributary systems such as Whittlebury Swamp lie within a zone of regional and perhaps local groundwater discharge with groundwater levels in the deeper aquifers having higher potentiometric heads than those in shallow aquifers indicating upwards flow towards the surface. Bores located within the large natural depressions are commonly artesian. This may also be the case at Lake Condah, however it requires confirmation.

[4] Some indication of likely broader processes influencing groundwater/lake/surface interactions at Lake Condah may be had from the behaviour of the regional groundwater systems in the Condah WSPA. Groundwater levels in the regional Clifton Formation aquifer are falling across the Condah WSPA in response to extractions, yet they remain artesian with respect to lower points in the landscape such as the Condah Swamp. The vertical flow pattern within the Condah WSPA is likely to carry over into the Lake Condah basin and the Darlot Creek. Groundwater levels across the WSPA continue to decline largely in response to pumping with no indication of any new equilibrium being reached.

[5] It is unlikely that there is any short-term threat to the hydrology of Lake Condah from the falling groundwater levels in the regional aquifer, but this cannot be fully assessed without deep groundwater monitoring bores in the vicinity of the Lake. Therefore, a drilling/monitoring program such as that suggested below is recommended.

[6] The loss of Lake water into lake-side sinkholes is a strong indicator of the importance of the pseudo-karst aquifer developed in the stony rises basalt. The observation that this water re-emerges to the southwest of the Lake was a concern to the SR&WSC (1980). It is likely that this is the source of Deep Creek.

[7] By comparison with outseepage, evaporation and precipitation are only very minor contributors to the Lake water balance, which is dominated by creek inflow and outflow, and outseepage to the groundwater system.

[8] The periodicity of seasonal oscillation in Darlot Creek flow and Lake Condah level on the one hand, and limestone sinkholes and bores to the south on the other, suggests a strong connection between all the surface and groundwater systems.

[9] A similarly close connection between the surface and groundwater systems is also suggested by the similarity of the salinity of distinct surface water systems such as Darlot Creek (from Myamyn to Homerton), upper Deep Creek and pools in soutwest Lake Condah. The range and level of salinities in these systems at the time of testing in July and September 2006 is not far removed from that of the groundwater systems, indicating a strong groundwater component.

[10] It has been shown across much of northern Victoria that groundwater monitoring programs are crucial in establishing the nature of lake-groundwater interactions e.g. at Lake Elizabeth, the Avoca Marshes, Lake Tutchewop, Lake Tyrrell, Cullens Lake etc. A drilling/monitoring program as proposed in SR&WSC (1980) is clearly essential to best understand the nature and process of lake-groundwater interactions. This monitoring program was also recommended by the Dept of Mines at the time. Unfortunately, the recommended program was never adopted, and instead a program of monitoring of bores and sinkholes situated 2.5 – 7 km from the Lake was inexplicably substituted. After 6 years of monitoring this program was deemed to be providing no understanding of lake-groundwater interactions and was abandoned.

6.4.2 Recommendations - Hydrogeology

[1] It is clear from the previous work of the SR&WSC (including the comment by DME), the RWC and Nolan-ITU, reviewed above, that a groundwater monitoring system is a prerequisite for any confident estimate of the nature, rate and seasonal extent of seepage loss from Lake Condah into the surrounding stony rise basalt. It is recommended that to better understand the relationship between the Lake and the groundwater system(s), a drilling/monitoring program is undertaken to:

- examine the behaviour of the Lake and groundwater systems in response to seasonal wetting and drying, and hence establish the hydraulic relationships existing between the surface and groundwater systems.
- establish the extent to which the deeper aquifers, especially the Port Campbell Limestone and perhaps Clifton Formation influence shallow groundwater levels in the vicinity of the Lake and in both the lake bed silts and the underlying basalts.
- establish several piezometers nests further downbasin from the Lake in the stony rise basalts to determine the extent and rapidity of water transference through the fractured rock aquifer away from the Lake.

[2] The groundwater monitoring program should be centred on Lake Condah, but in addition several sites should be established on the stony rise areas to the south. Bores should be constructed as piezometer nests, with a shallow and deeper bore at each site to establish the direction and extent of vertical groundwater flux as well as lateral flow parameters. At least in one case near the Lake, a piezometer nest should also include a bore into the deeper Port Campbell Limestone and the Clifton Formation aquifers.

7 Ecology of Lake Condah and Darlot Creek

7.1 Ecological values

7.1.1 Setting and issues

Most of the catchment of Lake Condah and Darlot Creek is located in the undulating weathered basalt plains of south-western Victoria in the Victorian Volcanic Plain bioregion. The Victorian Volcanic Plain stretches from Melbourne west to Portland, south to Colac and north to Beaufort (DSE, 1997). It is characterised by vast areas of grasslands, small patches of open woodland, stony rises that denote old lava flows, the low peaks of extinct volcanoes and numerous shallow lakes. The catchment is located primarily north of the Mount Eccles Lava flow. The open and fertile grassy plains were developed for pastoralism soon after settlement. There is very little public land and few significant conservation reserves.

Darlot Creek joins the Fitzroy River before discharging to Portland Bay. This final coastal section of Darlot Creek and Fitzroy River lie in the Warrnambool Plain Bioregion (DSE, 1997). This area has deep soils of volcanic origin with watercourses cutting into underlying limestone. The catchment has been substantially cleared of native vegetation for agriculture; predominantly wool-growing.

During the late 1800s the first drainage scheme was undertaken to reclaim areas of Condah Swamp for local landholders. However, the water regime of Condah Swamp remained largely intact and it was a permanent wetland with seasonally fluctuating water levels. Since the major drainage of Darlot Creek was completed in 1954, the Lake has retained little water and is now flooded only during and immediately after periods of high rainfall and river flow.

As reported by Ruge (2004, p. 10), the first written description of Lake Condah occurs in the Portland Mercury on 11th January 1843. The find was reported by Mr. Edgar of Second River (later named Heywood) and his two companions as follows:

> "…*a splendid fresh water lake … about a mile and a half long and three quarters of a mile wide, and contains almost every variety of fish in abundance, with swans, ducks &c*…"

Anecdotal reports documented by Ruge (2004, p. 10) describe the water regime of the Lake prior to drainage:

> "*There was generally permanent water over the lake area. Only during rare and very dry seasons did it go dry. This provided a habitat for regular breeding programs of the main types of wildlife, in particular birds and fish. White Ibis had extensive colonies on typical breeding rafts in the lake.*" James Vaughan, Victorian Field and Game submission on Lake Condah, 1978.

> "*There was permanent water in the northern end of Lake Condah to a depth of approximately 18 inches in depth over the period from 1933 until major drainage operations in 1954. This loss of water caused loss of reed beds and associated aquatic life, which supported large populations of many species of waterfowl. They almost blotted out the sky when they took off.*" W.R. Malseed, Victorian Field and Game submission on Lake Condah, 1978.

Most native shrub and sedge vegetation has been cleared from Lake Condah. The Lake bed has a long history of grazing (Context et al., 1993). The Lake is surrounded by cleared, grazed pasture. The landscape to the west is cleared for pasture. To the north, east and south the Lake lies close to the Mount Eccles National Park.

Mt Eccles National Park is 6,120 ha in size and is one of the most significant native vegetation remnants in the Victorian Volcanic Plains Bioregion. It lies predominantly on the Mt Eccles lava flow. In the vicinity of Lake Condah and Darlot Creek it supports wet sclerophyll vegetation, predominantly *Eucalyptus viminalis* woodland.

There is little information to describe the original habitat of Darlot Creek below Lake Condah. It is known to have flowed permanently with freshes and floods generated by overflow from Lake Condah. The creek is likely to have supported a range of semi-emergent, flow-tolerant macrophytes in the permanently flowing reaches, with dense marshy vegetation on the creek banks. The vegetation is likely to have comprised salt-tolerant species due to the salinity contributed by groundwater inflows.

In the vicinity of which is now Condah Mission, the flow in Darlot Creek passes underground into the stony rise basalt, to re-emerge as an efflux several hundred metres further downstream (Figure 118 and Figure 119). On the day of field inspection (20th July 2006), the Creek was in recession from a minor runoff event, and flow was estimated to be in excess of 30 ML/d. At this flow level, there was no surface flow in this location. The difference in elevation through this section of Creek was estimated to be in the order of 1 – 2 m. Thus, Darlot Creek has at least one natural barrier to low flow fish passage. At a certain discharge the Creek flow would exceed the rate of loss to the subsurface, and surface flow would be continuous; this discharge is not known but it would correspond to a fresh rather than a baseflow. Under conditions prior to drainage of Lake Condah (pre-1800s, and especially pre-1954), there would have been a significant barrier to fish passage at the downstream end (south west) of Lake Condah. The Lake only spilled over the natural outlet to Darlot Creek during times of high winter flow. Thus, for most species, fish passage was available only during periods of high flow, with eels possibly utilizing overland or subsurface pathways during migration periods if a surface flow path was not available at the time.

In terms of the plants and animals (fish and macroinvertebrates) becoming adapted to the last 50 years of altered hydrology, the ecosystem will have adjusted to some degree (it may still be in some sort of transition). It is likely that all or most of the components of the original system are still in existence, but in a different combination or abundance. The native species have a deal of resilience and ability to survive (although not necessarily flourish) under altered hydrological conditions.

7.1.2 Pre-1750 ecosystem – Lake Condah

The original structure of the Lake Condah ecosystem can be interpreted from remnant vegetation geomorphology, hydrology and historical records (Context et al., 1993), and from the characteristics of other wetlands of the Lake Condah land system (Gibbons and Downes, 1967).

The deepest pools would have provided permanent habitat for aquatic fauna and would have supported aquatic macrophytes. Soft-leaved semi-emergent plants such as *Myriophyllum* spp. and *Potamogeton* spp. would have provided substrates for biofilms and would have supported communities of macroinvertebrates. Beds of macrophytes would have provided habitat for fish, dabbling duck, piscivorous waterbirds and other fauna groups.

The perimeter of these pools would have been permanently waterlogged but seasonally inundated. This environment would most likely have supported dense stands of sedges, presumably species such as *Baumea* spp. and *Restio* spp. Reed beds would have provided seasonal feeding and breeding habitat for small fish and breeding habitat for waterbirds which build nest platforms on flooded reed beds.

Dense stands of *Leptospermum lanigerum* would have occupied the outer permanently waterlogged area where flooding was less frequent. Understorey species would have included *Carex gunniana, Microtis oblonga* and *Carex tasmanica*. Remnant vegetation suggests the shrubland extended north through a broad area to Darlot Swamp and surrounds. When flooded, this dense vegetation would have provided extensive breeding sites for waterbirds such as large wading birds and piscivores. The birds would have nested in the shrubs and sedges and fed on macroinvertebrates, frogs or fish in the nearby open water, sedge and mudflat areas.

At the outer perimeter of the Lake where the soil was less waterlogged, the vegetation graded the *L. lanigerum* shrubland to perennial tussock grasses. Tussock grasses may have continued as an understorey to *Eucalyptus obliqua* woodland from the lake edge to the weathered basalt plain to the west. To the north, south and east a woodland of *Eucalyptus viminalis, Acacia melanoxylon* and *Exocarpus cupressiformis* with an understorey of *Pteridium* and tussock grasses, mainly *Poa* spp. occurred on stony rises and the adjacent Mt Eccles lava flow (Context et al., 1996).

7.1.3 Extant ecosystem assets – Lake Condah

The following vegetation characterisation of Lake Condah is taken from Context et al. (1993), Carr et al. (2006) and Flora Information System records (Appendix A).

The central and deepest areas of Lake Condah are occupied by Aquatic Herbfield Complex, which is a remnant of the former permanent water habitat. The deeper areas are flooded to 1.5 m and support soft-leaved aquatic species such as *Myriophyllum* spp. and *Potamogeton* sp. The surrounding mud flats are regularly exposed and support aquatic herbs such as *Ranunculus amphitrichus, Rumex bidens, Crassula helmsii* and *Amphibromus fluitans*. Emergent aquatic plants are also present including *Scheonoplectus validus, Typha domingensis* and *Bolboschoenus medians*.

The intermittently flooded parts of the lake bed are occupied by an Amphibious Herbfield Complex. This plant community is a highly modified remnant of the former sedgelands and *Leptospermum* shrublands and has been affected by the reduction in flood duration and depth, the reduced persistence of waterlogging and the long history of grazing. The vegetation supports a high proportion (45%) of weed species. The most abundant species are the waterlogging-tolerant herbs **Potentialla anserina* and **Alopecurus geniculatus* and the grass **Poa annua*. Native amphibious plants include *Eleocharis acuta, Isolepis fluitans* and *Juncus pallidus*. When flooded the area supports the semi-emergent aquatic plant *Triglochin procera*. The presence of *Carex tasmanica*, a nationally Vulnerable plant, is evidence that this area was previously occupied by *Leptospermum lanigerum*; it is a understorey component in remnants elsewhere.

Over 100 species of waterbirds, frogs, fish and aquatic reptiles have been recorded in wetlands and watercourses throughout the district (Appendix B).

Waterbirds have been recorded in Lake Condah in 1975, 1981, 1991 and 1993 (Appendix B). When flooded the Lake supports populations of ducks such as Pacific Black Duck (*Anas superciliosa*), Grey Teal (*Anas gracilis*) and Australian Shelduck (*Tadorna tadornoides*), which feed on marcoinvertebrates. Prolonged floods (i.e. 6 months or more) are likely to support large populations of piscivorous waterbirds such as Great Cormorant (*Phalacrocorax carbo*), Little Pied Cormorant (*Phalacrocorax melanoleucos*) and White-faced Heron (*Egretta novaehollandiae*).

Small and Large waders are attracted to the shallow waters to feed on invertebrates. This includes Australian White Ibis (*Threskiornis molucca*), Straw-necked Ibis (*Threskiornis spinicollis*),Yellow-billed Spoonbill (*Platalea flavipes*), Black-fronted Dotterel (*Elseyornis melanops*), Black-winged Stilt (*Himantopus himantopus*), Banded Stilt (*Cladorhynchus leucocephalus*). Reeds and other dense fringing vegetation provide foraging habitat and shelter for Purple Swamphen (*Porphyrio porphyrio*) and Cape Barren Goose (*Cereopsis novaehollandiae*)

Seven species of frog have been observed in the region. However, only one species, the Striped Marsh Frog (*Limnodynastes peronii*) has been recorded from the Lake, in 1972 and 1993. Two other species recorded from Darlots Creek Spotted Marsh Frog (*Limnodynastes tasmaniensis*) and Common Froglet (*Crinia signifera*) may inhabit the Lake when flooded.

Yarra Pigmy Perch (*Nannoperca obscura*), Common Galaxias (*Galaxias maculatus*), Southern Pigmy Perch (*Nannoperca australis*) and the exotic species Tench (*Tinca tinca*), were recorded in Lake Condah in 1990 (Hall, 1991).

Cape Barren Goose (*Cereopsis novaehollandiae*) and Yarra Pygmy Perch (*Nannoperca obscura*) are the only fauna species of conservation significance that have been recorded in Lake Condah (Appendix B). This probably reflects of a lack of observations rather than the potential of the Lake to support threatened species, particularly when in flood. A wide variety of threatened species may be attracted to the Lake such as the nationally vulnerable Painted Snipe (*Rostratula benghalensis*), state endangered Terek Sandpiper (*Xenus cinereus*), Australasian Bittern (*Botaurus poiciloptilus*) and Freckled Duck (*Stictonetta naevosa*) and state-vulnerable Lewin's Rail (*Rallus pectoralis*) and Southern Toadlet (*Pseudophryne semimarmorata*).

The aquatic herbfield complex described by Context et al. (1993) has been equated to the Aquatic Herbland EVC (653) by Carr et al. (2006), which has endangered conservation status in the Victorian Plains Bioregion.

7.1.4 Extant Ecosystem Values – Darlot Creek

Darlot Creek below Lake Condah has long been excavated to the form of a deep trapezoidal drain. Drains have also been cut through many swamps on Darlot Creek to extend pastures for sheep and cattle grazing. Stock access to Darlot Creek is largely unrestricted. The Creek also has significant infestations of willow (*Salix fragilis* / *Salix* x *rubens*) (Ecology Australia, 2004).

Despite the disturbance, Darlot Creek retains some highly significant aquatic and riparian habitat. This is partly attributed to the permanent flow in the creek, which is derived from discharge from the Tertiary limestone aquifer underlying the weathered basalt. Since gauging began in the 1960s, the Creek has not ceased to flow at Homerton, but has fallen as low as 5 ML/d. The salinity of Darlot Creek is naturally quite high. During the Spring/Summer recession limb the EC is relatively steady at around 1,200 – 1,600 EC. This is water that is most likely to be discharging from the basalt aquifer. Freshwater input during winter storms reduces salinity to around 900 - 1,200 EC.

Darlot Creek provides permanently flowing water to a maximum depth of approximately 2 m in the pools. The width of the stream typically varies between 2 m and 8 m. The banks are fringed by tall emergent aquatics including *Typha domingensis, Schoenoplectus validus* and *Bolboschoenus medianus*. *Rumex bidens* occurs in muddy margins. Instream submerged vegetation includes *Montia australasica, Lilaeopsis polyantha, Potamogeton ochreatus, P. pectinatus, Ranunculus amphitrichus* and *Vallisneria americana*. *Potamogeton tricarinatus* occurs in swiftly flowing rocky sections.

The waterlogged riparian zone provides habitat for dense shrublands of *Leptospermum lanigerum* and swampy land provides habitat for *Gahnia clarkei*. Freshwater wetland and stream vegetation is dominated by sedges, *Triglochin procera* and *Juncus* sp. (Willis, 1964).

The Darlot Creek aquatic herbfield complex described by Context et al. (1993) has been equated to the Riparian Wetland (EVC 962) by Ecology Australia (2006), which has endangered conservation status in the Victorian Plains Bioregion.

Many species of waterbirds, frogs and fish have been recorded in or near Darlot Creek (Appendix B). Of the birds, Musk Duck (*Biziura lobata*), Baillon's Crake (*Porzana pusilla*), Whiskered Tern (*Chlidonias hybridus*), Latham's Snipe (*Gallinago hardwickii*), Wood Sandpiper (*Tringa glareola*), Brolga (*Grus rubicunda*), Royal Spoonbill (*Platalea regia*), Great Egret (*Ardea alba*), Magpie Goose (*Anseranas semipalmate*), Australasian Shoveler (*Anas rhynchotis*), and Hardhead (*Aythya australis*) have conservation significance. Also present are the listed Mountain Galaxias (*Galaxias olidus*) and Glenelg Spiny Cray (*Euastacus bispinosus*) (Appendix B). Overall, a combined total of 10 species of fish and crustacean have been recored. This includes River blackfish (*Gadopsis marmoratus*) recored as recently as 2003 (Appendix B).

7.2 Environmental water requirements

7.2.1 Previous investigation

Hall (1991) recommended a minimum environmental flow for Darlot Creek downstream of Lake Condah, on the basis of maximising fish habitat, with regard to the natural flow regime. The philosophy was that during periods when the natural flows (unregulated) are less than the recommended minimum flow, then the natural flows should prevail. Hall (1991) did not undertake any hydraulic investigations, so his recommendations were based on the natural flow pattern, and the projected diversion requirements for wetland maintenance.

Hall (1991) estimated that mean flow at Homerton gauge over the summer months was 50 ML/d. On the basis of advice from the Rural Water Commission, it was assumed that 35% of this flow was sourced from the catchment downstream of Lake Condah. Thus, it was assumed that at Lake Condah, mean daily flow in summer was 30 ML/d. This was considered to be the appropriate minimum environmental flow. Analysis of gauged flows at Myamyn revealed that the mean flow in summer was higher than the 30 ML/d assumed by Hall (1991) (Figure 124). Hydrological environmental flow methods recommend flows according to a flow index, which could be any flow index, not just the mean flow. Hall's (1991) flow recommendation better fits the 80th percentile summer flow for Myamyn, as determined from the 1987 – 1993 record (Figure 124).

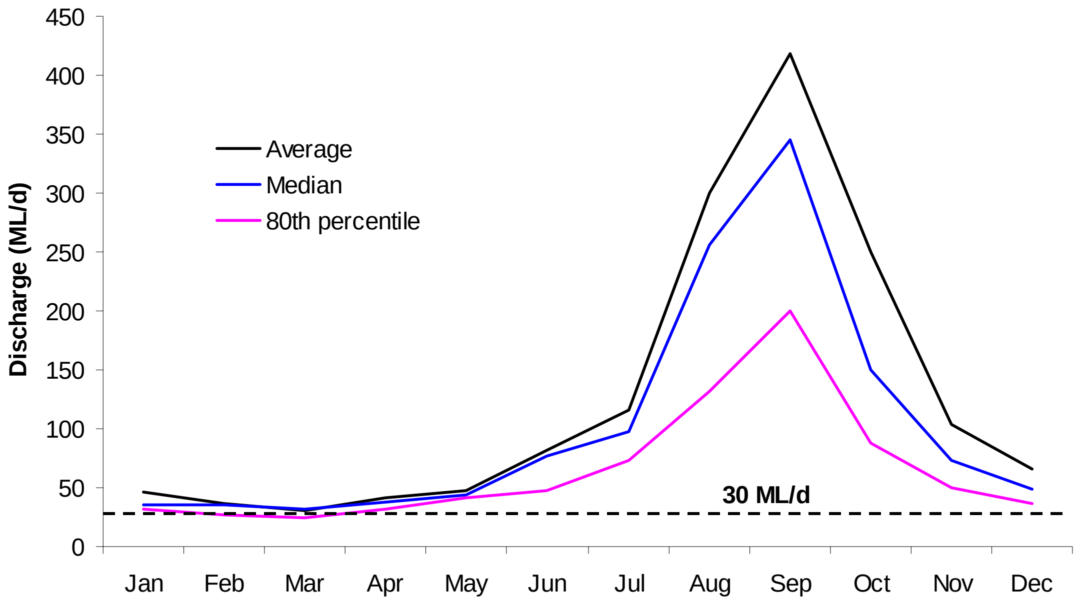


Figure 124. Flow statistics for Darlot Creek at Myamyn gauge, for gauged flows from 16 October 1987 to 11 March 1993. The value of 30 ML/d was suggested by Hall (1991) as a minimum environmental flow.

Based on available hydrological data, Hall (1991) estimated that there was suplus water in Darlot Creek to maintain a depth of at least 1 m in Lake Condah for all months except February, March and April. Hall (1991) suggested that the Lake level would fall to around 0.5 m in March, and then begin to fill again in April, although this would vary from year to year.

Hall (1991) was of the opinion that the recommended environmental flow would be unlikely to interfere with the breeding and survival of life history stages of the resident fish species. Also, it was thought unlikely that upstream migrations by short-finned eels would be severely affected by diversion of water into Lake Condah, because migrations usually coincide with higher flow months. Resident estuarine species would be unlikely to be affected as their spawning activities generally occur during periods of high flow (late spring). Hall (1991) warned of the possibility of erosion of the Condah Drain negatively impacting the resident fish and aquatic invertebrates.

7.2.2 Environmental water requirements for Lake Condah

Maintenance of Lake Condah's existing ecological values, including habitat for threatened aquatic plants and animals requires:

- permanent flooding with a median seasonal depth range of 1 m in the Aquatic Herbfield habitat;
- seasonal inundation to the greater Lake bed between August and November.

The ecological values of the Lake could be promoted by increasing the habitat for aquatic plants and animals and increasing its value as a drought-refuge and by restoring habitat for sedges on the inner lake bed and restoring habitat for *Leptospermum lanigerum* shrublands on the outer lake bed.

These objectives could be achieved by:

- maintaining a minimum depth of 1 m in 75% of years in the deepest parts of the Lake bed (equivalent to a minimum elevation of 51 mAHD, as this level connects all sections of the Lake);

- providing permanently waterlogged conditions throughout the Lake bed (equivalent to a minimum elevation of 51 mAHD, as this level connects all sections of the Lake);
- flooding the former sedge habitat to a depth of 0.25 m (shallow extent of habitat) to 1.25 m (deep extent of habitat) between July and November for a median duration of 3 months (equivalent to around 52 mAHD);
- flooding the former *Leptospermum lanigerum* habitat to a minimum depth of 0.05 m to 0.25 m for up to 3 months in 50% of years (equivalent to around 52.5 mAHD).

7.2.3 Environmental water requirements for Darlot Creek

In determining the environmental flows for Darlot Creek it is important to consider the fish community and the life history of key species, together with other organisms. These key characteristics include the life span, spawning season, incubation, duration, migration, and habitat requirements. Information on the ecological requirements of key fish species actually or likely to inhabit the Lake Condah and Darlot Creek system are provided in Appendix C.

The Short-finned Eel life cycle was described by Native Fish Australia (2006) and DSE (2004). The cycle involves the mature adults migrating from fresh water to the sea in order to spawn after which it is believed they die. Downstream migration has been reported as occurring from Spring to Autumn (DSE, 2004). One study reported that onset of downstream migration may be associated with attainment of a certain length and water temperatures exceeding 12°C, with the migration peak coinciding with the highest recorded mean daily temperature (DSE, 2004). The eel larvae, known as leptocephali because of their leaf like flat shape, are carried south by the East Australian Current from their spawning grounds until they reach the continental shelf. At around this time they metamorphose into the normal tubular eel shape although devoid of any pigment and so are known as glass eels. When the glass eels begin to migrate into fresh water they may be anywhere from one to three years old. Migration begins in the autumn in Northern regions reaching Western Victoria by mid-spring. Whilst in the estuarine waters the glass eels quickly develop into fully pigment elvers and adjust to fresh water. Subsequent migrations from the estuaries into fresh water involve both elvers and glass eels and may happen after, during or before the main migration from the sea. These migrations are known as "eel fares" from which the term "elver" is derived. Generally these occur at night and may involve as many as four different age classes. The upstream migration of eels typically continues well into the upper reaches of the river systems (Native Fish Australia, 2006); thus, prior to the drainage of Condah Swamp and Lake Condah, eels may have migrated upstream of Lake Condah.

While migrating eels are known to cross land, steep, high and dry barriers would present a difficulty, so provision of suitable fish passage is preferred. The listed species in Darlot Creek, Yarra Pigmy Perch and Dwarf Galaxias, migrate locally. Dwarf Galaxias are frequently associated with aquatic vegetation and eggs are laid in separate batches on flooded vegetation, leaf litter or rocks – preferred egg site is the underside of leaves or stems. Yarra Pigmy Perch require aquatic plants for spawning and habitat. Vegetation or rocks are required as instream habitat.

Low flows (or base flows) are required to support the marsh vegetation in Darlot Creek [which is particularly important fish habitat for Dwarf Galaxiids and both Pigmy Perch species (Yarra and Southern)]. Flows arsing from spills or base flows will be required to support the maintenance of pools over summer. These pools are critical to the sustainable population of eels and other freshwater fish in this section. Freshes during spring will provide triggers for breeding and then recruitment.

River Blackfish (*Gadopsis marmoratus*) are relatively long lived (at least 4 years and up to 7 years) they breed each year in November to January. Sticky demersal eggs are laid on hard substrates (large woody debris or rocks), large eggs which hatch after 7 - 10 days. The larvae remained “tethered” by their large egg sacs for a further 21 days as the larvae mature (Allen et al., 2002; Koehn and O'Connor, 1990; Treadwell and Hardwick, 2003).

Blackfish will require freshes to provide conditions suitable for reproduction. These conditions are created when in-channel bars and benches are inundated to deliver terrestrial carbon (energy and food) into the system and provide habitat for spawning adults and juvenile fish. These flows should in late winter, spring and early summer to create extensive habitat across the stream to enable energy and food resources to be swept into the stream channel which enable fish to build condition to allow spawning (Pusey and Arthington, 2003; King, 2004). Inundation of new habitat will create habitat and stimulate invertebrate production and growth. After breeding, this habitat provides conditions for eggs and larvae to hatch and grow. Ideally, long duration flows (which last 7 to 10 days) which cover in-stream vegetated bars and benches are required to support a range of fish species. Given that many of the small bodied fish and macro-invertebrates (blackfish prey) live only one or two years, then these flows are required in most years.

It is known that the instream habitat of Darlot Creek immediately downstream of Lake Condah is degraded, being formed into a drain. These altered habitats do not provide the range of habitats required by diverse fish populations, reducing the smaller fish species through habitat loss or reducing breeding potential. Habitat management (willow and weed removal, bed and bank stabilisation, woody debris, undercut banks and planting over-hanging vegetation) will support fish populations to enable them to respond to flow pulses (freshes) over the structure. Large fish such as eels will depend on good populations of small fish (as prey) to support the eel fishery.

The heavily modified section of Darlot Creek immediately downstream of Lake Condah will improve in condition if both non-flow and flow options are used to improve the fish populations. The Creek will be more resilient to impacts from changes upstream if environmental flows are delivered as a series of pulsed flows or freshes, rather than simply as a constant minimum flow. Recovery of fish populations in the Creek may require active management input (including non-flow actions) of supportive stakeholder agencies (CMA and water authority, etc.) over several years. The modified Darlot Creek environment will support a lower biodiversity of fish and aquatic fauna, and changes to the flow regime will have less impact than on the fauna of an unmodified system. However, non-flow management interventions would also mitigate these changes. Such management actions would include willow removal and replacement with native bushes and trees (e.g. Tea-tree), erosion control and establishment of a pool-riffle sequence in the Drain.

Fish passage will be required to allow eel migration upstream during spring and summer and downstream in summer and autumn. Most other fish species would be opportunistic about movement requirements past any structure built on Condah Drain, as they would be for the natural barrier near Condah Mission.

7.3 Summary

Most native shrub and sedge vegetation has been cleared from Lake Condah. The Lake bed has a long history of grazing. The original structure of the Lake Condah ecosystem can be interpreted from remnant vegetation geomorphology, hydrology and historical records. The deepest pools would have provided permanent habitat for aquatic fauna and would have supported aquatic macrophytes. Beds of macrophytes would have provided habitat for fish, dabbling duck, piscivorous waterbirds and other fauna groups. The perimeter of these pools would have been permanently waterlogged but seasonally inundated. This environment would most likely have supported dense stands of sedges. Reed beds would have provided seasonal feeding and breeding habitat for small fish and breeding habitat for waterbirds which build nest platforms on flooded reed beds.

The central and deepest areas of Lake Condah are occupied by Aquatic Herbfield Complex, which is a remnant of the former permanent water habitat. The deeper areas are flooded to 1.5 m and support soft-leaved aquatic species. The surrounding mud flats are regularly exposed and support aquatic herbs. The intermittently flooded parts of the lake bed are occupied by an Amphibious Herbfield Complex. This plant community is a highly modified remnant of the former sedgelands and *Leptospermum* shrublands and has been affected by the reduction in flood duration and depth, the reduced persistence of waterlogging and the long history of grazing. The vegetation supports a high proportion (45%) of weed species. Yarra Pigmy Perch (*Nannoperca obscura*), Common Galaxias (*Galaxias maculatus*), Southern Pigmy Perch (*Nannoperca australis*) and the exotic species Tench (*Tinca tinca*), were recorded in the Lake in 1990. Cape Barren Goose (*Cereopsis novaehollandiae*) and Yarra Pygmy Perch (*Nannoperca obscura*) are the only fauna species of conservation significance that have been recorded in Lake Condah. This probably reflects of a lack of observations rather than the potential of the Lake to support threatened species, particularly when in flood.

There is little information to describe the original habitat of Darlot Creek below Lake Condah. It is known to have flowed permanently with infrequent flood events generated by overflow from Lake Condah, and more frequent events generated from the catchment downstream of Lake Condah. The Creek is likely to have supported a range of semi-emergent, flow-tolerant macrophytes in the permanently flowing reaches, with dense marshy vegetation on the creek banks. The vegetation is likely to have comprised salt-tolerant species due to the salinity contributed by groundwater inflows. Despite the disturbance, Darlot Creek retains some highly significant aquatic and riparian habitat. This is partly attributed to the permanent flow in the Creek. Many species of waterbirds, frogs and fish have been recorded in or near Darlot Creek.

Hall (1991) recommended a minimum environmental flow of 30 ML/d for Darlot Creek downstream of Lake Condah, on the basis of maximising fish habitat, with regard to the natural flow regime.

Maintenance of Lake Condah's existing ecological values, including habitat for threatened aquatic plants and animals requires: permanent flooding with a median seasonal depth range of 1 m in the Aquatic Herbfield habitat; and seasonal inundation to the greater Lake bed between August and November.

In determining the environmental flows for Darlot Creek it is important to consider the fish community and the life history of key species, together with other organisms. Low flows (or base flows) are required to support the marsh vegetation in Darlot Creek [which is particularly important fish habitat for Dwarf Galaxiids and both Pigmy Perch species (Yarra and Southern)]. Flows arsing from spills or base flows will be required to support the maintenance of pools over summer. These pools are critical to the sustainable population of eels and other freshwater fish in this section. Freshes during spring will provide triggers for breeding and then recruitment. It is known that the instream habitat of Darlot Creek immediately downstream of Lake Condah is degraded, being formed into a drain. These altered habitats do not provide the range of habitats required by diverse fish populations, reducing the smaller fish species through habitat loss or reducing breeding potential.

Fish passage will be required to allow eel migration upstream during spring and summer and downstream in summer and autumn. Most other fish species would be opportunistic about movement requirements past any structure built on Condah Drain, as they would be for the natural barrier near Condah Mission.

8 Control Structure for Restoration of Lake Condah Hydrology

8.1 Requirements

The objective of the Lake Condah water restoration project is to achieve a reasonable depth of water in Lake Condah for as long as possible throughout the year, avoiding drying of the Lake if possible. This can only be achieved through structural intervention. Kammler (2006) rescribed the key requirements of a structure on Condah Drain as:

- Structure should be nestled into the natural environment and visually pleasing
- Avoid straight lines
- Avoid exposed concrete
- Allow for fish passage
- Water level regulating device, mechanical or others
- Safe discharge of flood water
- Constant discharge of environmental flow requirements
- Access and walkway at "dam wall" for maintenance and visitors

Two additional requirements arose during the course of this project. These were that the structure should:

- Be designed in such a way that there was potential to modify the structure in the future to raise the crest height, without compromising the functionality
- Have potential to allow freshes (small flow events) to pass the structure

8.2 Potential structural solutions

The approach taken to water restoration in 1991 was to construct a diversion weir on the upstream end of the Lake and divert water into the Lake. This approach was not judged successful for three main reasons:

- The Lake could not retain water after the level of Darlot Creek fell during the flood recession period,
- The performance of the structure in terms of delivery of water to the Lake was not as good as expected, and
- The structure required maintenance for normal operation

The offtake weir could be upgraded in an attempt to improve its performance in delivery of water to the Lake, however, to achieve the objectives of Lake Condah hydrological restoration, it would be necessary to retain water in the Lake. This could be achieved by constructing a levee along the eastern side of Condah Drain through Lake Condah. This would require a vast amount of fill, the levee would be quite noticeable in the landscape, and it would be prone to erosion from wind-generated waves (and thus require maintenance). Also, the offtake channel from the weir to the Lake will require maintance, as it would be prone to sedimentation and excessive growth of macrophytes. For these reasons, persisting with the upper offtake weir it is not a recommended approach.

The alternative solution to maintaining water in Lake Condah is to construct a barrier in Condah Drain at the downstream end of Lake Condah, with the crest height corresponding to the desired maximum water level. Kammler (2006) provided a sketch of a preliminary design that involved regulators at three different levels.

To allow a cost and performance comparison, two alternative structures were evaluated. For both options, a weir style structure is envisaged that would be similar in form to a conventional rock chute. The best location for the structure is at the downstream end (south west) of Lake Condah, where the Condah Drain is most hydraulically constrained.

8.2.1 Option 1

Option 1 is a fixed weir crest grouted rock structure that cannot be adjusted. The crest height of the structure would remain fixed at the desired inundation level (to be decided by the Lake Condah Facilitation Group on the basis of advice provided in this report). Fish passage (1:20 slope) is provided on face of structure, and a fixed capacity through-pipe allows transfer of water downstream when Lake is below crest height. A smaller secondary weir downstream reduces the size of the drop from the first weir.

Whilst the weir crest is fixed, some flexibility is included in the structure concept to prolong the period of fish passage. The insertion of a slot in the weir crest to supply water to the fish passage channel is intended to allow water to flow through the fish channel when the Lake water level drops up to 0.5 metres below the weir crest. The width of the slot is designed to ensure that it is wide enough for small native fish (100 to 150 mm in length). Velocities through the slot have to be within the limits of the swimming capacity of the fish using the fishway, so the slot will have to be designed with the appropriate hydraulic characteristics. This will mean quite low flow rates through the slot. The inclusion of a slot will slightly increase the rate of drainage of the Lake over the first 0.5 m fall in level.

The structure (assuming a 53.0 m AHD crest height) is illustrated in Figure 125. If a lower crest level is adopted the height of both weirs can be reduced in proportion without compromising the overall design concept.

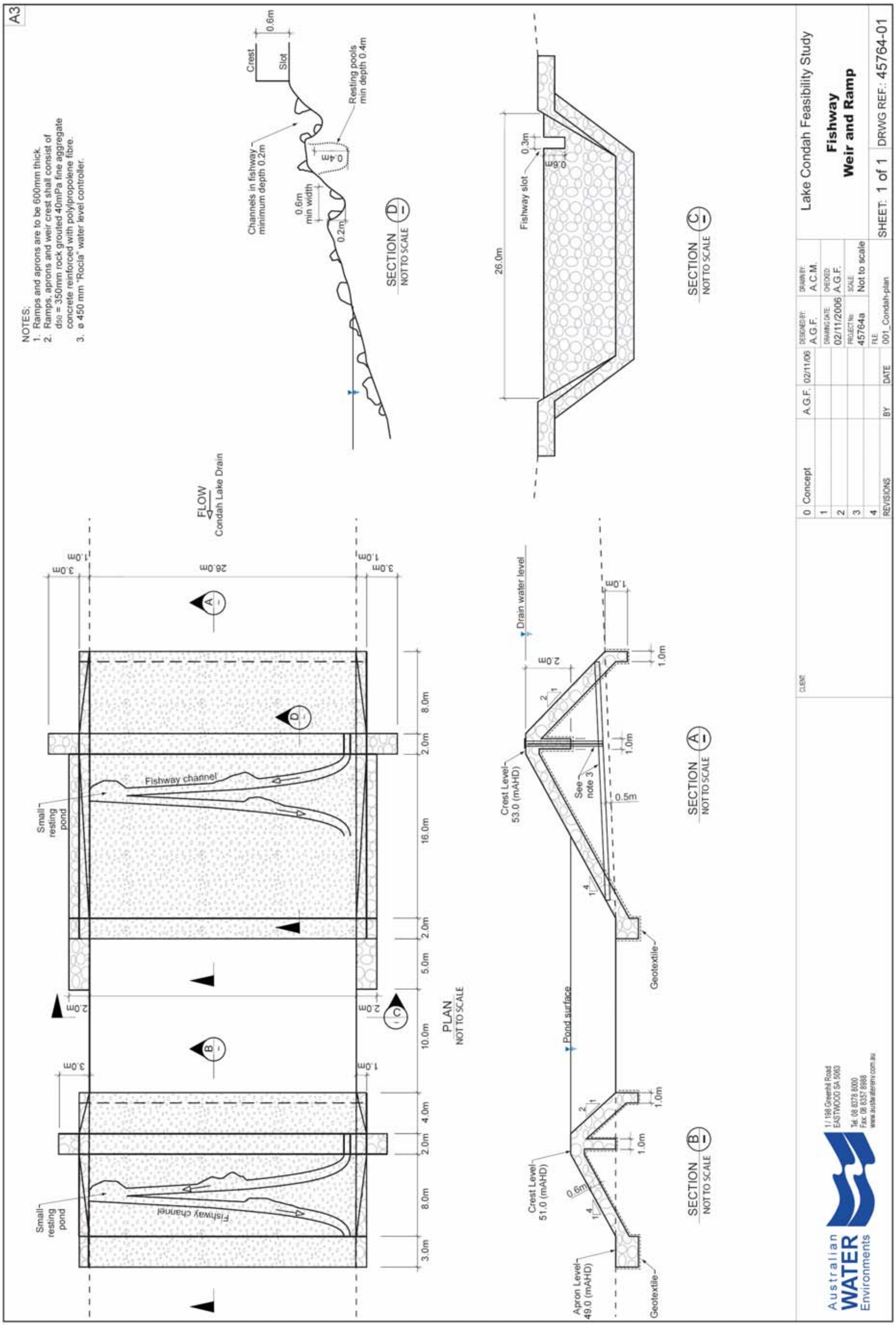


Figure 125. Plan of proposed structure on Condah Drain at Lake Condah.

Key features of Option 1 include:

- A two stage drop structure comprising two interconnected weirs. The purpose of the second weir is to create a pool between it and the main weir. This is to reduce the size of the drop from the first weir to around two metres. The second structure increases the overall cost and is not hydraulically necessary so it could be deleted from the scope of works if preferred. However there are three important reasons why it has been included and is considered desirable. These reasons remain valid if the main weir crest height is set at 51.5 m or above.
- The upstream structure would be more than 2 metres above the drain invert and potentially could be as high as 4 metres above the invert level of the channel. The pool between the two effectively reduces the drop from the weir crest to the downstream water level to two is to two so that much of the erosive forces of water flowing over the pool or returning from the floodplain will be absorbed by the pool.
- Creating a series of two smaller drops shortens the time and length the fish or eels need to be in the ladder at any one climbing session; and
- Creating two smaller steps in this way makes the main structure less visually intrusive and should soften the whole appearance of the works when completed.
- A grouted rock structure rather than a conventional loose rock structure. Reasons why a grouted structure has been suggested include:
    - It could be installed with steeper upstream and downstream slopes. This reduces the overall length of the structure. If a loose rock structure were adopted it would need to be over 5 times as long to still provide the same fish passage opportunities.
    - A more formal and stable mechanism for fish passage can be created.
    - It will leak less and hence will help to retain water in the main drain near the crest of the structure for longer.
    - Less rock will be needed and the overall disturbance to the site during construction will be less.
    - A grouted structure (in this instance) is likely to cost less.
- Fish passage is provided by a fish way channel that has an effective slope of 1 in 20. This should accommodate the requirements of fish and eels thought to be present in the Lake Condah system. The fish passage can meander slightly across the structure to create a curved (rather than straight line) appearance and would include resting pools for small fish at appropriate intervals.
- A Rocla Water level controller (or an equivalent product) is included so that the water behind the weir can be drained and kept low for maintenance purposes. Also, the baffles in the pipe allow adjustment of the outflow to provide the desired minimum environmental flow (which would apply when the Lake is not spilling over the crest). Once adjusted to the desired flow rate, the controller would not require further attention. A 375 mm pipe will pass up to 30 -40 ML/d depending on the head behind the weir.
- There are no moving parts or requirements to actively manage the weir structure or water levels.

8.2.2 Option 2

Option 2 is the same as Option 1, but with either an over top adjustable regulator plate or a lay flat regulator gate inserted into the weir structure. It is envisaged that such an arrangement would provide additional periods when the fish passage channel could be supplied with water. It is envisaged that the water level behind the main weir woud be set at between 1 m and 1.5 m below the weir crest level. There would be three fixed off-take points for the fish passage channel with each one at different levels. The regulator would need to be set seasonally. There would be three different lake levels during the rise in water levels in Lake Condah and the reverse procedure would apply during the lake level lowering phase.

8.2.3 Allowing for possible future raising of the crest height

It would be a simple process to allow for increasing the height of the structure in the future. The way that this would be done would be to increase the width of the crest of the structure so that the additional height could be added on at a later stage and not compromise the downstream slope.

For example to allow for a future raising to 53 mAHD:

- If the interim level were set at 52 mAHD then the weir crest width (parallel with the flow) should be increased from 2 metres to 7 metres.
- If the interim level were set at 52.5 mAHD then the crest width should be 5 metres wide.

The additional height can then simply be added on in the future without changing the downstream slope. There would need to be a realignment of the fishway section to accommodate this modification, but this could also be incorporated into the original detailed design. The fishway slot in the crest would simply need to be filled and reset at the higher level.

There would not be a huge cost penalty involved provided this thinking was incorporated into the original detailed design. The cost of weir raising would have to be determined at the time when the modification was required.

8.2.4 Allowing for passage of freshes

For passage of baseflows, this report recommeds a single Rocla Water Level Controller (or an equivalent product) be inserted into a single pipe so that the pipe could be blocked for maintenance or the level manipulated if this was later desired. The Rocla Water Level Controller currently can fit a maximum pipe diameter of 375 mm. Such a pipe would pass up to 30 – 40 ML/d depending on the head behind the weir, which covers the range expected for baseflow releases.

If higher flow rates were required, to release freshes downstream for example, this could be achieved by inserting multiple pipes, each with a level controller so that the through flow rate could be increased as desired to pass the freshes. This would require the levels to be adjusted at the end of summer (to allow the freshes to pass) and then again once break of season flows had occurred (to wind the environmental flow release back to baseflows – spill could still occur). This could be done by one person with no need for plant or equipment (just a specific but simple lifting tool). Each additional regulator/pipe would cost an extra $5,000. Three pipes would allow passage of freshes up to 100 ML/d peak flow.

An alternative (and in some respects a better) approach would be to insert a lay flat regulator gate in the weir crest. This could be varied throughout the year as desired and effectively lower the weir height from between 0 to 1.5 metres as required. Alternatively, it could be manipulated just twice (as per the above option) in the fully open or shut positions. This would require a higher level of ongoing maintenance and operation, and it would add an extra $20,000 to the cost. This approach will not guarantee passage of the early wet season freshes, because the Lake may be at a low level, with enough airspace to absorb the fresh.

Early season freshes in the Darlot Creek near Lake Condah range from around 100 ML/d to 400 ML/d. The multi-pipe approach would not be feasible to pass peak flows of 400 ML/d straight through the structure - the lay flat regulator would be better suited for passing these higher flows.

8.3 Evaluation of structural options

8.3.1 Practical considerations

One issue with Option 2 [similar to the design of Kammler (2006)] is that the Lake Condah Facilitation Group has formed the opinion that the structure should have no moving parts. This is largely because of the ongoing issue of maintenace and operation – resources are not available locally to attend to this. Option 1 has no real operational requirements once the environmental flow/drainage pipe setting has been established.

8.3.2 Costing

The insertion of the regulator (Option 2) adds a number of additional complications to the structure, which increases its cost significantly. These include the need to:

- Provide an all weather access track so that the regulator can be adjusted;
- Provide an open access walkway across the top of the regulator so that the regulator can be operated;
- Provide an allowance for operating and maintaining the structure on a regular basis through the year;
- Allow for repairs to the structure and walkway in the event of damage during a large flood;
- Increase the width of the weir crest to support the installation of the walkway and regulator structure.

In both cases the smaller secondary weir would be same.

An indicative cost estimation was made based on present value. Operation and maintenance costs were converted into present values using a discount rate of 7% over a 30 year time frame.

The completely fixed structure (Option 1) has been estimated to have a present value cost of $253,000 inclusive of operation and maintenance costs. The fixed structure with weir regulator (Option 2) would have a present value cost of around $420,000. A summary of the costs for each alternative is presented in Table 21.

8.3.3 Risk assessment of environmental performance

The two structural options were assessed from the perspective of the following issues:

- Lake hydrology
- Environmental flows to Darlot Creek
- Fish Passage
- Impacts on downstream environments
- Impacts on the estuary

<u>Lake hydrology</u>

The creation of a structure at the downstream outlet of the Drain will allow the restoration of closer to natural hydrology in Lake Condah, which was lost when the Drain was constructed. Either option will provide this significant benefit to the region's fish, macro-invertebrates, waterbirds and other wetland species. This will be achieved by the re-creation of both lake and wetland habitats in the system which will have a natural hydrology driven by upstream flows, with the water levels rising and falling according to rainfall, seepage and evaporation factors.

The proposed grouted rock nature on the face of the structure will allow downstream migration of eels (and perhaps other fish) during high flow periods and lake spills. The habitats created by this structure will include open water zones, areas of submerged aquatic vegetation, zones of emergent vegetation (reeds), and zones of seasonally flooded Tea Tree stands. All of these habitats are important to fish and aquatic fauna and the diversity of the habitat types will support several species. The increase in water levels (in most years) will create new habitat, release nutrients and create a boost in aquatic fauna productivity, and trigger the breeding and recruitment of many fish and aquatic species. This will provide a great ecological benefit to the regions aquatic ecosystems, and in particular, to lake and wetland ecosystems which have declined due to the drainage of the system.

Table 21.
Indicative present value costs of constructing and operating (over 30 years) two alternative structures for Lake Condah hydrological rehabilitation.

Item	Option 1	Option 2
Capital Costs		
Site establishment and dis-establishment	$9,000	$12,000
Ramp 1		
Beaching	$44,000	$44,000
Approach	$20,000	$20,000
Ramp 1	$35,000	$36,000
Weir crest	$18,000	$36,000
Apron	$4,000	$4,000
Floodplain extensions	$11,000	$11,000
Fishway	$6,000	$19,000
Pipework	$8,000	$8,000
Regulator structure	-	$18,000
Walkway superstructure	-	$25,000
Placement and fixing	-	$11,000
Access track	-	$5,000
Ramp 2		
Approach	$10,000	$10,000
Weir crest	$4,000	$4,000
Ramp 2	$18,000	$18,000
Apron	$7,000	$7,000
Fishway	$6,000	$6,000
Contingency	$40,000	$58,000
Capital Total	$240,000	$352,000
Operation and Maintanace Costs		
Weir structures	$13,000	$13,000
Operation	-	$40,000
Maintenance	-	$15,000
Operation and Maintanace Total	$13,000	$68,000
Total cost	**$253,000**	**$420,000**

<u>Environmental flows to Darlot Creek</u>

The provision of environmental flows is important for the Darlot Creek system downstream of Lake Condah and both options will allow flows to be provided downstream.

The flows required for the Creek downstream are difficult assess without a full environmental flow determination study. Environmental flows should consist of a flow regime which has all the flow components recommended over the course of a typical year. The downstream environment will receive all the flows that overtop over the structure when the Lake is full. When the Lake level drops below the structure's crest level, flow will be delivered downstream via the fish passage channel (until the Lake falls to the lower level of the slot in the case of Option 1, or through progressively lowered sill levels in the case of Option 2), or through the pipe under the structure.

When the Lake level falls below the crest, Option 1 will allow a pre-set discharge to pass from the Lake (the discharge is set using baffles, but these baffles are not intended for routine, i.e. seasonal, adjustment). This minimum environmental flow is not necessarily related to the inflows to Lake Condah from Condah Drain. The outflows from Lake Condah could be:

- Greater than the inflows, in which case the flow in Darlot Creek is greater than would otherwise occur, with the Lake storage being used to supplement the Creek flow. The environmental flow release will act to increase the rate of water level decline in the Lake.
- Less than the inflows, in which case the flow in Darlot Creek is less than would otherwise occur. This situation would arise when there is airspace in the Lake, and the inflows exceed the environmental flow release, with the Lake level possibly rising, or falling if seepage rates are sufficiently high.

Under Option 1, the lower is the environmental flow the longer is water retained in Lake Condah.

Option 2 will allow a flexible hydrological regime (yet to be determined) for the downstream environment, with the releases likely to vary according to the inflows. Over a year, such a regime would tend to release more water to Darlot Creek compared to Option 1, and thus water levels in Lake Condah would tend to be lower.

The proposal under Option 1 closely resembles the original (1750) hydrology of the system where flows were held in the Lake and spilled into the Darlot Creek system only when it was full. Flows would still have reached Darlot Creek downstream, but via sub-surface pathways. One risk of Option 2 is that by having a generally lower Lake level, there is statistically less potential to release flows throughout the entire low flow period.

Option 1, which utilises a pipe to deliver flow downstream, is less than ideal as it could result in changes to the temperature regimes downstream, it only provides a constant base flow and fish and other aquatic organisms can't easily pass through such structures.

Thermal changes are a possible result of drawing water from the deeper sections of the Lake. If these waters have reduced temperatures, this may prevent or delay the breeding of fish (and other aquatic fauna). At 3 – 4 m deep (or even 2 m), the water column could stratify and have several degrees difference in temperature compared to inflow. However, given that stratification is more likely in summer, and lake levels are declining in summer, stratification will not necessarily be common. A slotted standpipe to integrate inflows through the water column reducing any water temperature differences could reduce these possible impacts.

A constant base flow is only one component of the flows required for Darlot Creek but it is an extremely important aspect of the flow regime. Low flows are critical for the provision of water for marshy vegetation along the Creek's margins and in turn this provides critical habitat for many of the small fish and aquatic fauna within the Creek. Flow freshes will occur in Option 1 when the Lake spills but there is no doubt that the Lake will absorb some inflowing freshes (most likely in summer and autumn, at times when airspace is available). Spills will occur when the Lake is full in late winter and spring, when several of the small fish breed, so these flows will facilitate these ecological functions, especially for blackfish, given its slightly later season breeding period.

Fish passage

Fish passage will be required during spring and summer to allow eel migration upstream, and during summer and autumn for downstream migration. Most other fish species would be opportunistic about movement requirements past any structure built to create Lake conditions in Lake Condah.

Option 1 proposes a simple fish passage device - a low slope channel (1:20) which meanders across the face of the grouted-rock face of the structure. This device would provide for both upstream and downstream movement of eels as well as delivery of water downstream in a more natural manner. It is assumed that such a structure would direct low flows and allow fish passage for a longer period than the period the structure would spill, due to the entrance slot being built below the main sill level. The grouted nature of the structure will allow the whole structure to be used as a rock ramp fishway during high flows.

It is very likely that eels will be able to use the structure, provided there is some water flow. While eels are well known for crossing dry land, this is usually on damp nights across vegetated areas. It is unlikely they will travel up the rocky face of the proposed structure without water. Eels are a long lived species, however, and take several years to migrate upstream and then return downstream, so the occurrence of some dry years, when spill does not occur over the structure, would not impact significantly on eel populations.

Most other fish species would be opportunistic about movement across the face of the structure and the proposed type of structure and fish passage device would appear to provide some passage opportunities for these smaller native fish. Smelt, gudgeons and eels are the most likely species to use the fishway. It is likely that the slope of the fish passage channel will be low enough to enable other species such as the pigmy perches, dwarf galaxiids and river blackfish to also use the structure for local movements. This may be important to enable these species to recolonise areas after dry periods or random local extinction events. Congolli and common galaxiids are strong migratory species but need to travel to and from the estuary and may be prevented by downstream barriers to reach this point. If these barriers can be overcome, then these two species will also use the structure proposed.

Option 2 will have a functional fishway over a greater range of Lake levels. However, the operation of this structure requires that the Lake level is progressively reduced, so with spill occurring over a greater range of Lake levels, the Lake will most likely drain faster, compared to Option 1. Faster draining of the Lake is undesirable from the perspective of maintaining the values of the Lake itself, and also because there may be reduced possibilities for releasing environmental flows late in the season (the stored water held in a fuller Lake, under Option 1, could be used to contribute to environmetal flows).

Given the risks and uncertainty of operation associated with the full fishway option and the likelihood that the simple structure of Option 1 will provide fish movement for eels, at least, the full fishway option is probably not worth further consideration.

<u>Impacts on downstream stream environments</u>

The flow regime of Darlot Creek immediately downstream of Lake Condah will be affected by the structure. Under the natural (1750) regime Darlot Creek may have received year round baseflows through sub-surface flows (leakage from the Lake and from the surrounding Stony Rises). Under the current regime, Darlot Creek flows reflect flows in Condah Drain. The structure will absorb some freshes completely, and others partially. Both options will affect this regime differently, as discussed above. The operation of Option 2 could potentially lead to the Lake being more often at a lower level than under Option 1, which would place the downstream environment at more risk. The likely downstream flow regime from Option 1 will allow a substantial period of possible fish and aquatic fauna breeding and is considered adequate from this perspective.

By holding water in Lake Condah for longer, the duration of baseflows in Darlot Creek downstream of the Lake could increase. Presuming that some of the baseflow that reaches Darlot Creek originates from Stony Rises sub-surface flow, the Lake could act as a reservoir to supplement these sub-surface flows. It is not known where the water would re-emerge, but it would most likely be somewhere in the drainage system upstream of Homerton.

<u>Impacts on the estuary</u>

A structure on Condah Drain at Lake Condah will have a small impact on the estuary. This conclusion is based on a review of the ecology of the species involved, the likely operation of the structure and the natural of the hydrology of the system. The same conclusion was drawn by Hall (1991). Restoration of the hydrology of Lake Condah will mean an increase in the annual evaporation, but information supplied on the hydrogeology indicates a significant portion of the water will travel through the fractured rock to reach the downstream sections, thereby mitigating the impacts from evaporation and the loss of small freshes. In high rainfall periods the Lake will fill and spill. It is likely that the impacts of the reinstated Lake hydrology will also be dampened by the tributary flows joining the Creek downstream. The only way to determine the exact impact of the actions to re-instate Lake hydrology on the estuary would be to do a detailed study of the estuary and identify the contribution of upstream flows to the estuary values and also to determine what proportion of these flows would arise from the Lake Condah system. Overall the impacts on the estuary are not likely to be measurable.

The flows required for Darlot Creek downstream of Lake Condah are difficult to assess without a full environmental flow determination study. The lack of work on environmental flows provides little reason to change Hall's (1991) previous minimum flow recommendation of 30 ML/d. However, it must be remembered that this value was based on a flow index; it was not based on an understanding of the Creek's hydraulics. Also, environmental flows should consist of a flow regime that has all the flow components recommended over the course of a typical year. To establish these needs is large project in itself.

8.4 Recommended structural option

Restoration of a close to natural hydrology to Lake Condah will improve the wetland and lake ecosystem (including a large area of potential eel habitat), which is significantly degraded under current conditions. The structural solutions to this pose some risks to the ecology of the system. The risk assessment suggests that Option 1 presents no greater risks to the environment than Option 2, and in some respects the risks are lower. On the basis of the above evaluation of the structural alternatives, Option 1 (Figure 125) is the preferred option because it provides overall equal or lower risk at lower cost than Option 2. An example of a grouted rock weir structure is illustrated in Figure 126.

Figure 126. Example of grouted rock weir structure. Note that detail of the illustrated structure differs from that of the structure proposed for Lake Condah. Photo credit: Geoff Fisher (Australian Water Environments).

8.5 Summary

The objective of the Lake Condah water restoration project is to achieve a reasonable depth of water in Lake Condah for as long as possible throughout the year, avoiding drying of the Lake if possible. This can only be achieved through structural intervention.

To allow a cost and performance comparison, two alternative structures were evaluated. Option 1 is a fixed weir crest grouted rock structure that cannot be adjusted. Option 2 is the same as Option 1, but with either an over top adjustable regulator plate or a lay flat regulator gate inserted into the weir structure. For both options, a weir style structure is envisaged that would be similar in form to a conventional rock chute. The best location for the structure is at the downstream end (south west) of Lake Condah, where the Condah Drain is most hydraulically constrained.

It would be a simple process to allow for increasing the height of the structure in the future. The way that this would be done would be to increase the width of the crest of the structure so that the additional height could be added on at a later stage and not compromise the downstream slope.

For passage of baseflows, this report recommeds a single pipe through the weir. The pipe would pass up to 30 – 40 ML/d depending on the head behind the weir, which covers the range expected for baseflow releases. If higher flow rates were required, to release freshes downstream for example, this could be achieved by inserting multiple pipes, each with a level controller so that the through flow rate could be increased as desired to pass the freshes. This would require the levels to be adjusted at the end of summer (to allow the freshes to pass) and then again once break of season flows had occurred (to wind the environmental flow release back to baseflows – spill could still occur). This could be done by one person with no need for plant or equipment (just a specific but simple lifting tool). An alternative (and in some respects a better) approach would be to insert a lay flat regulator gate in the weir crest. This would require a higher level of ongoing maintenance and operation. This approach will not guarantee passage of the early wet season freshes, because the Lake may be at a low level, with enough airspace to absorb the fresh.

A risk assessment suggested that Option 1 presents no greater risks to the environment than Option 2, and in some respects the risks are lower. On the basis of the above evaluation of the structural alternatives, Option 1 is the preferred option because it provides overall equal or lower risk at lower cost than Option 2.

The indicative cost of installing and maintaining the simpler structure (Option 1) over a 30 year time frame is in the order of $250,000. Costs will be a little higher if the structure is built so as to facilitatate later raising of the crest height.

9 Hydraulics of Lake Condah Under Flood Conditions

9.1 Introduction

With a weir structure in place, under conditions of a full lake and steady relatively low to moderate inflows water will spill gently over the crest of the weir. However, when a flood event occurs, the structure causes a backwater effect, which raises the level of the water over the crest (known as the afflux) and this raised water surface elevation extends a considerable distance upstream. This is important, because although the weir crest height is set to the desirable steady lake level, on occasions the lake level can exceed this, resulting in local and upstream impacts. The height of the afflux and extent of the backwater can be predicted by a hydraulic model. In this project the HEC-RAS model was used to make these predictions.

9.2 HEC-RAS model

A steady-state hydrological model for Darlot Creek and Lake Condah was developed in order to investigate the effect of constructing a weir on Darlot Creek for the purpose of flooding Lake Condah. HEC-RAS 3.1.3 was employed for this modelling. The extent of the model was limited by the extent of the DEM and the topography of the area. The model extent is shown in Figure 127. The total length of the channel modelled was 7,835 m.

Cross-sections were extracted from the 2005 DEM along the channel at regular intervals with additional cross-sections included at special points of interest such as inline structures and road crossings. HEC-RAS, by default, represents cross sections perpendicular to the channel. In order to maintain consistency with the HEC-RAS model, cross sections were taken from the 2005 DEM perpendicular to the channel. Station and elevation data for the cross sections was derived from the 2005 DEM using Surfer 8. As the 2005 DEM readings recorded the water surface level in the Drain rather than the Dreek bed elevation, channel bed elevations in each of the Surfer cross sections were adjusted to comply with the bed elevation taken in the 1980 survey of Lake Condah (SR&WSC, 1980), after first correcting the 1980 elevations for AHD (+0.4 m to obtain AHD). This was done by comparing the difference between the survey levels and the 2005 DEM for a set of known points along the Lake Condah channel. An average difference between the readings was estimated and used to adjust the bed levels in the cross sections. Cross sections were then entered into HEC-RAS 3.1.3.

The model was calibrated against the Lake Condah rating curve (Figure 42) by adjusting Manning's roughness coefficient in an attempt to reproduce in the model the water surface levels of the rating curve for a given set of flow rates. The calibration point was located at a chainage of approximately 2,668 m. The model produced the most accurate results (r-squared 0.994) with respect to the rating curve where a Manning's roughness of 0.06 was used.

For the purposes of this steady state model, Lake Condah was assumed to be full at the time of analysis. A theoretical levee bank was constructed in the model to simulate this.

The following scenarios were modelled:

- No Weir
- 53.0 m AHD Weir
- 52.4 m AHD Weir
- 52.0 m AHD Weir
- 51.6 m AHD Weir

These weir height scenarios were developed by the Lake Condah Facilitation Group.

The form of the Weir was assumed to be as for the preferred Option 1 (Figure 125). The following assumptions were made relevant to the modelling of the Weir:

- Located at a chainage of 1,656 m
- Upstream face slope 1:5
- Downstream face slope 1:2
- Top width (in direction of flow) 2 m

Models were run to simulate the 1, 2, 5, 10, 50 and 100 year Annual Recurrence Intervals (ARIs). The magnitude of these events was calculated on the basis of flood frequency analysis of 115 years of modelled daily flows for Condah Drain at Lake Condah, under the "Current" scenario (Table 16).

The model results were interrogated to develop a set of water surface elevations under each scenario modelled. These water surface elevations were then used to develop water surface profile plots along the length of the channel for each scenario and ARI.

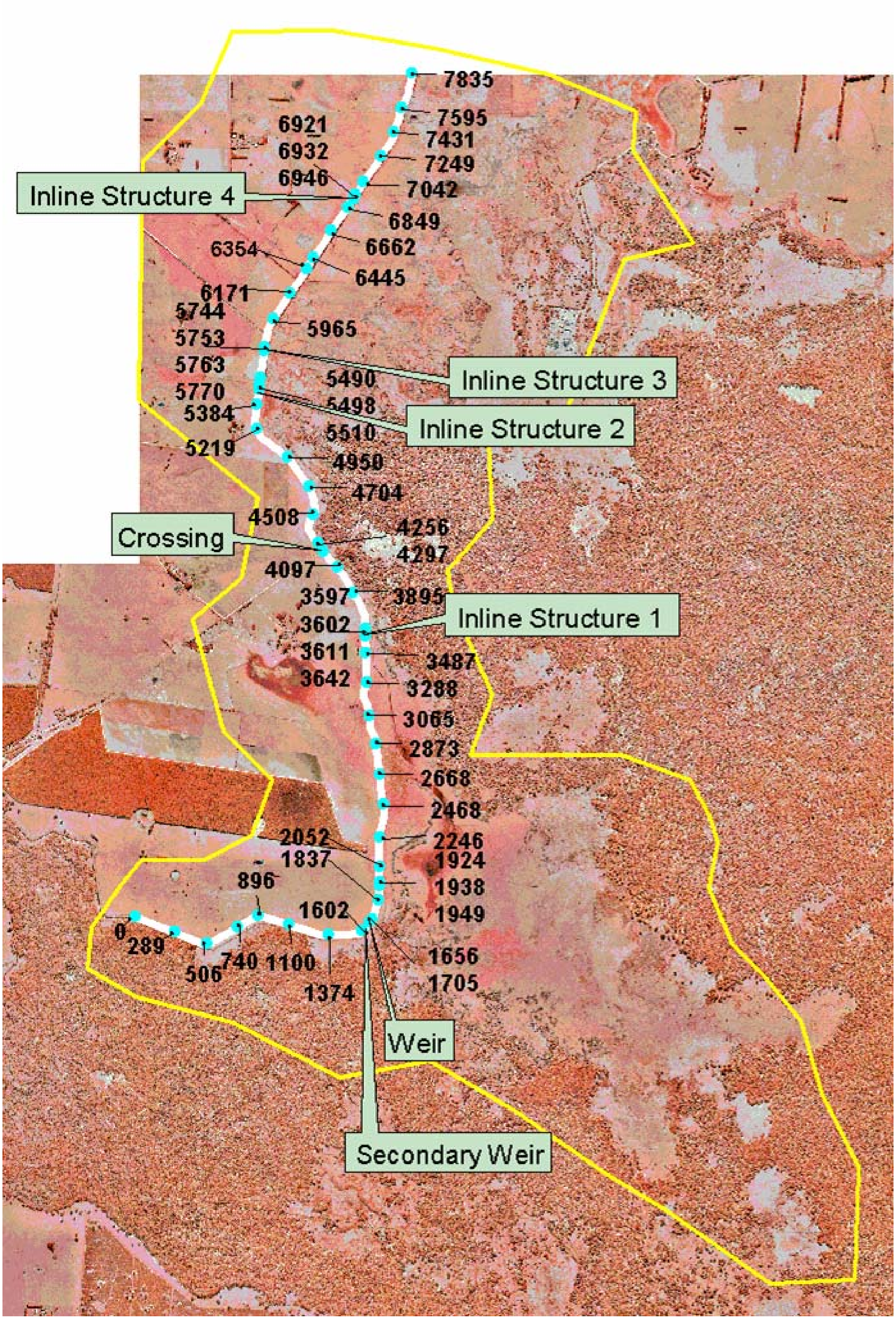


Figure 127. Layout of Hec-Ras model of Condah Drain through Lake Condah and lower Condah Swamp. Yellow line indicates boundary of cross-sections used in the model. Numbers indicate positions of cross-sections in metres chainage from arbitrary starting point. Inline structures are existing weirs. Weir and secondary weir are the proposed structures. North is vertical.

9.3 Predicted water surface profiles

The predicted water surface profiles (Figure 128 to Figure 133) showed that the Condah Drain does not have an even water surface profile. For the current (no weir) scenario the gradient is quite high over the first 200 m of the modelled reach. Through Lake Condah the gradient is very low, the gradient increases in the section of the Drain between Lake Condah and Condah Swamp, and then the gradient flattens through Condah Drain. Lake Condah is extensively inundated at around 51.0 – 51.5 m AHD, and Condah Swamp is extensively inundated at around 53.0 m AHD, so the 1 year ARI event (850 ML/d) results in widespread flooding in both areas. It is concluded that flooding is a common phenomenon in both areas, even though flood waters may not persist for long in Lake Condah.

For the 1 year ARI event weir heights of 52.4 m and 53 m have a noticeable impact on water elevations in Condah Swamp, with the latter raising the level from the no weir situation by 0.22 m. In Lake Condah, the weir raises the water level to the weir crest height, plus a further amount (afflux above the crest). For the 50 year ARI event (3,150 ML/d) and above, the weir is totally drowned out, regardless of the weir height. Thus, it can be concluded that the weir only affects flood events of a magnitude lower than this.

The results of the hydraulic modelling are summarized in Figure 134. These relationships demonstrate that the relative impact of the weirs on water elevations is much greater at Lake Condah compared to Condah Swamp.

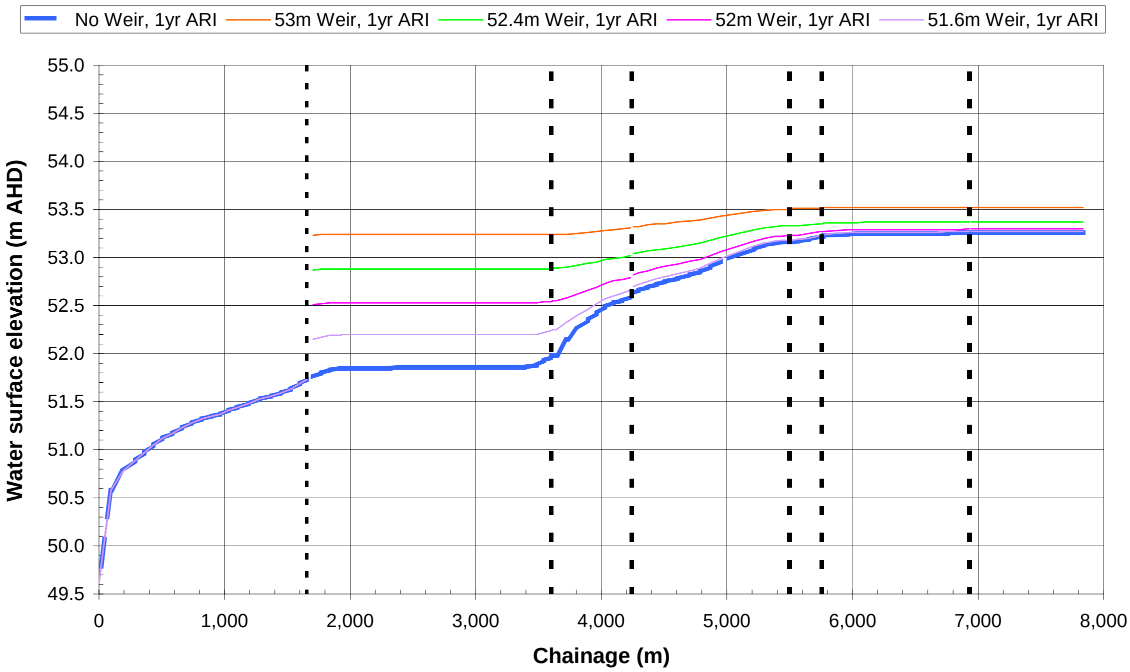


Figure 128. HEC-RAS predicted water surface profile for Condah Drain for the 1 year event (850 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structure.

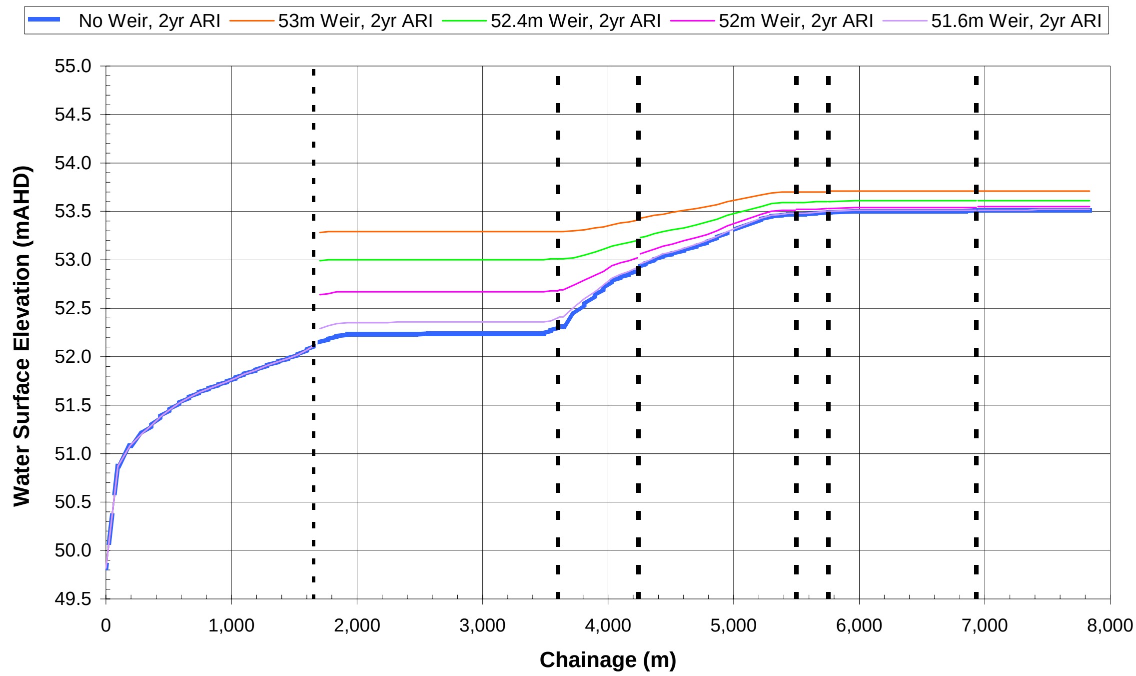


Figure 129. HEC-RAS predicted water surface profile for Condah Drain for the 2 year event (1,200 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structure.

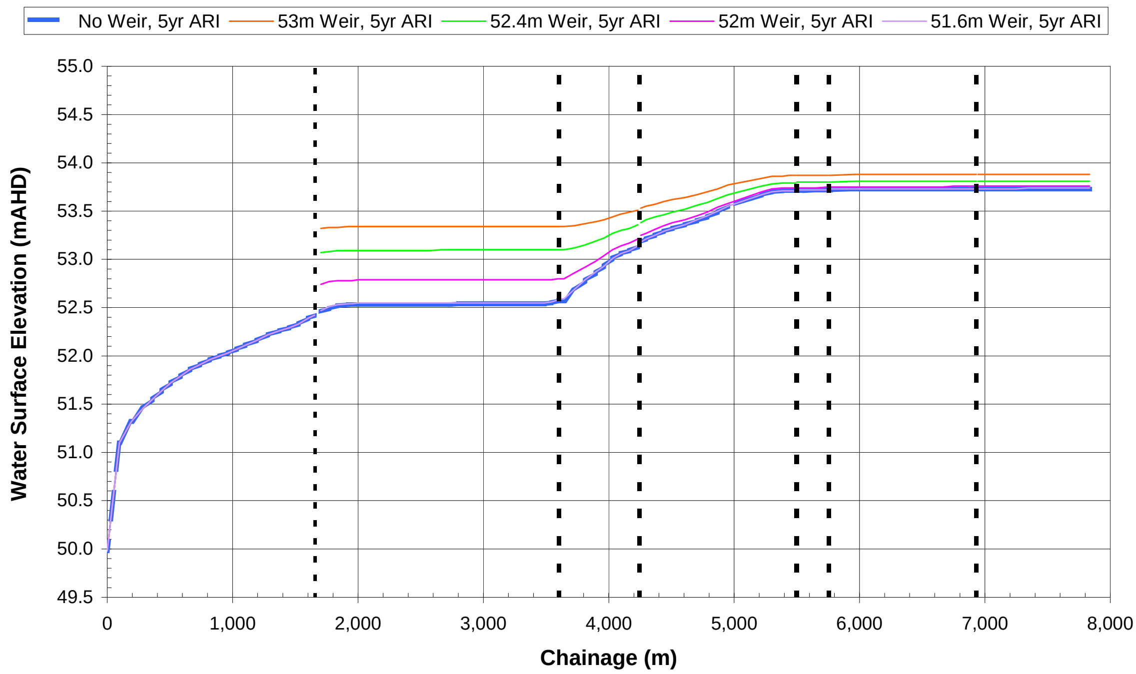


Figure 130. HEC-RAS predicted water surface profile for Condah Drain for the 5 year event (1,550 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structure.

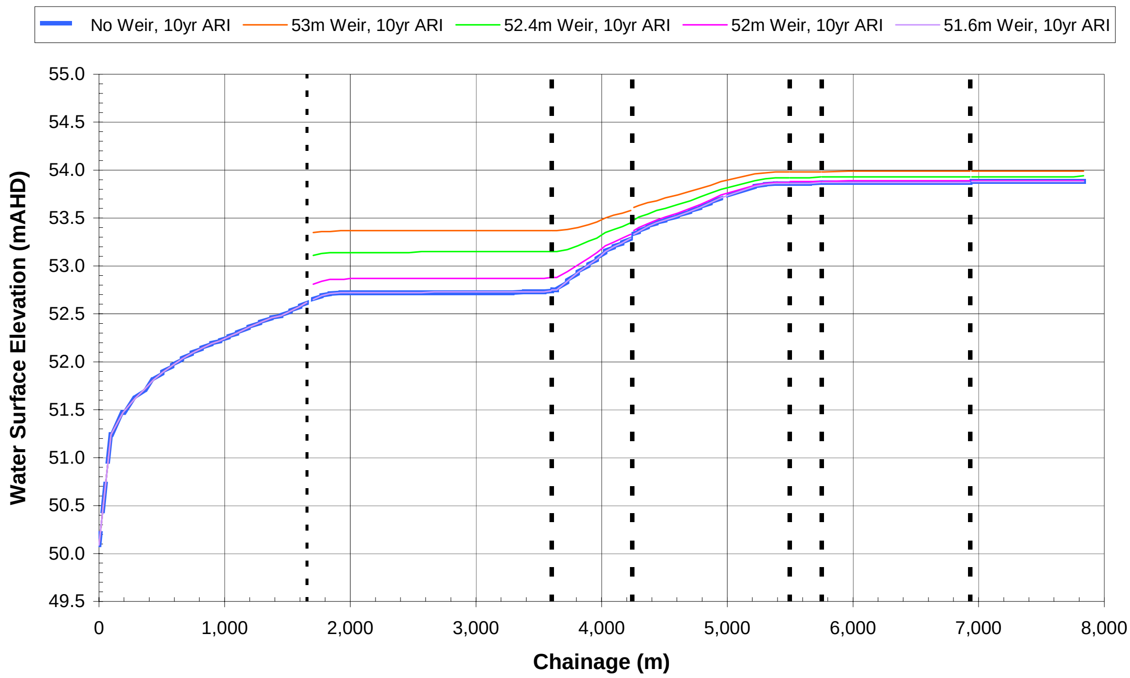


Figure 131. HEC-RAS predicted water surface profile for Condah Drain for the 10 year event (1,800 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structure.

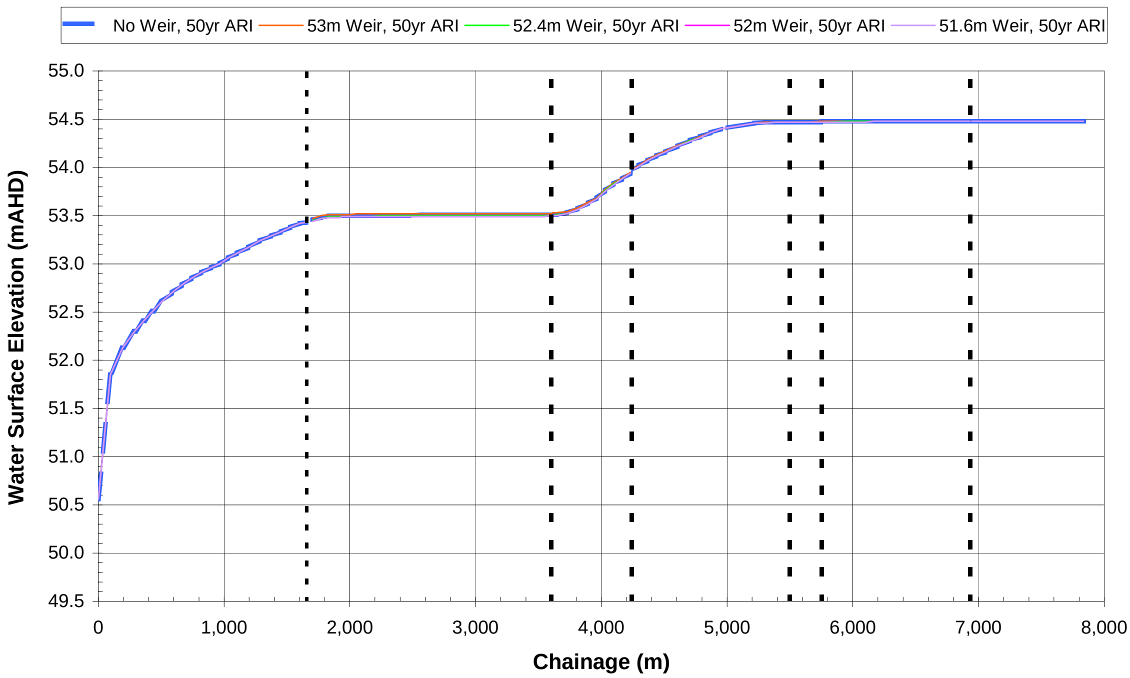


Figure 132. HEC-RAS predicted water surface profile for Condah Drain for the 50 year event (3,150 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structure.

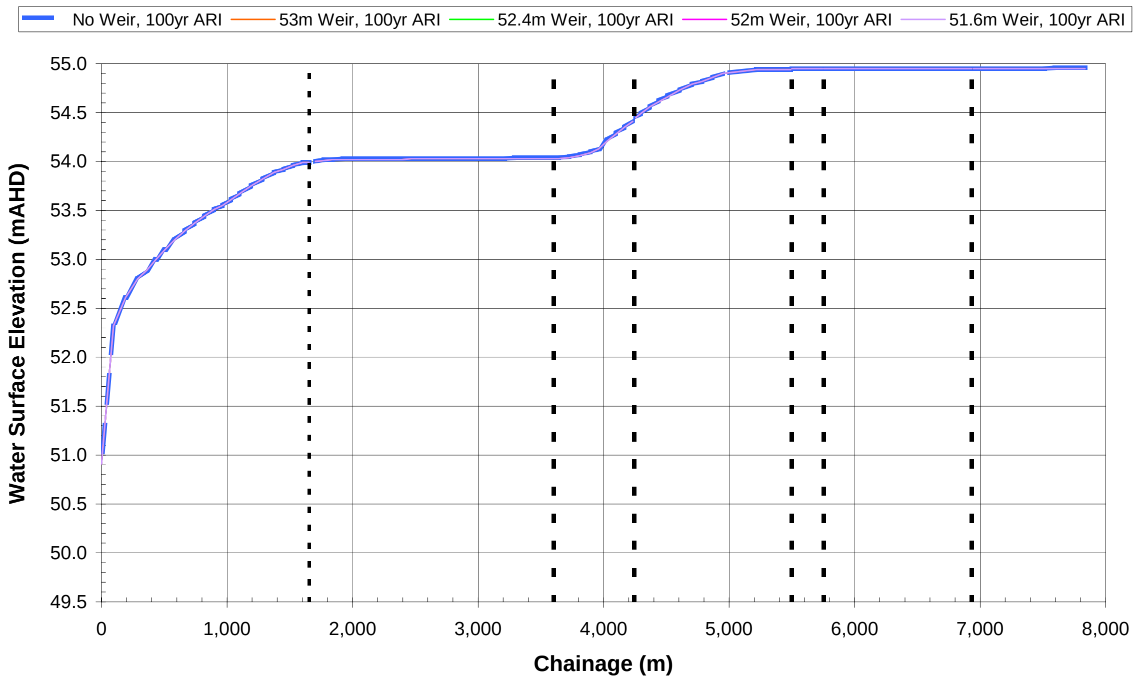


Figure 133. HEC-RAS predicted water surface profile for Condah Drain for the 100 year event (4,500 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structure.

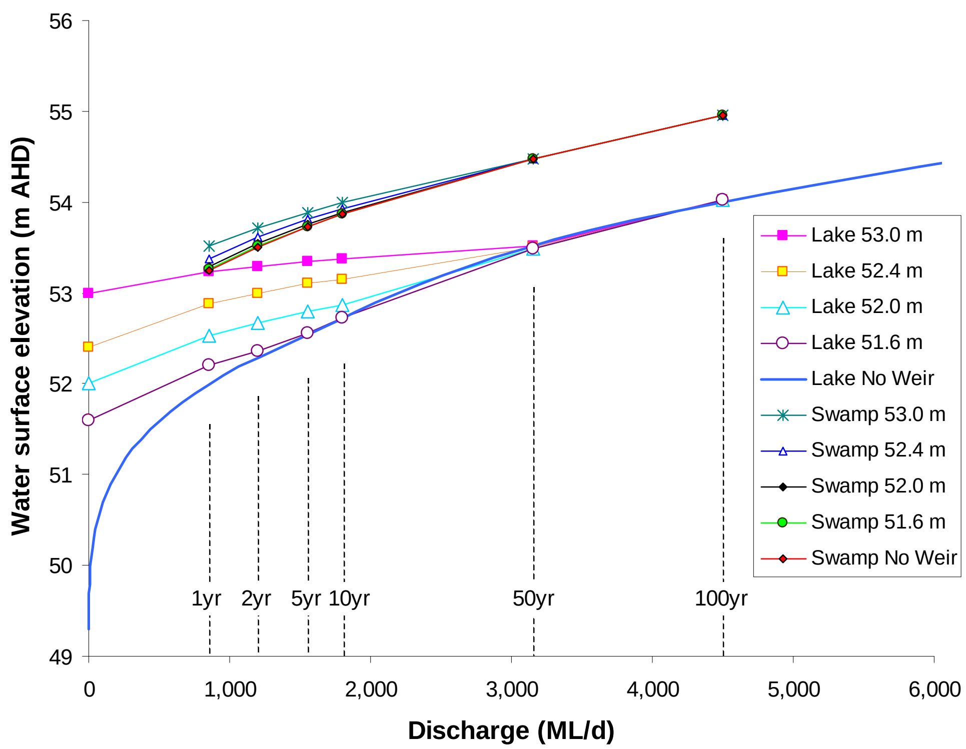


Figure 134. Predicted water surface elevations for Lake Condah and Condah Swamp at a range of discharges, for a range of weir elevations.

9.4 Summary

With a weir structure in place, under conditions of a full lake and steady relatively low to moderate inflows water will spill gently over the crest of the weir. However, when a flood event occurs, the structure causes a backwater effect, which raises the level of the water over the crest (known as the afflux) and this raised water surface elevation extends a considerable distance upstream. This is important, because although the weir crest height is set to the desirable steady lake level, on occasions the lake level can exceed this, resulting in local and upstream impacts. The height of the afflux and extent of the backwater were predicted by the HEC-RAS hydraulic model.

Models were run to simulate the 1, 2, 5, 10, 50 and 100 year Annual Recurrence Intervals (ARIs). The magnitude of these events was calculated on the basis of flood frequency analysis of 115 years of modelled daily flows for Condah Drain at Lake Condah, under the "Current" scenario. The relative impact of a weir in Condah Drain on water elevations is much greater at Lake Condah compared to Condah Swamp.

10 Daily Water Balance Model of Lake Condah

10.1 SWET Water Balance Model

Development of a water balance (also termed a water budget) is fundamental to most wetland hydrological modelling (Gippel, 2005a). A basic wetland water balance calculates the change in storage as a simple function of inputs of precipitation, surface runoff and groundwater and outputs of evapotranspiration, groundwater and surface runoff. The balance is calculated on a time step limited by data availability or as appropriate to the objectives of the investigation. This approach is generally not concerned with water flow paths or velocities (hydrodynamics), but inflow and outflow hydraulics require basic characterization if the constraints are sufficient that they significantly limit the rate of exchange between river and wetland.

The water budget of a lake or wetland can be described, over a specified time interval (t), as:

$$\Delta S(t) = [Q_i - (Q_o + Q_p)] + [G_i - G_o] + [A * (P - ET)] + e$$

where:

ΔS = change of water quantity stored in the water body (m^3)

Q_i = surface water flowing into the water body (m^3)

Q_o = surface water flowing out of the water body (m^3)

Q_p = pumped extraction (m^3)

G_i= groundwater flowing into the water body (m3)

G_o = seepage to groundwater (m^3)

A = surface area of wetland (m^2)

P = precipitation falling on the water body (m)

ET = evapotranspiration (m)

e = error term

The main problem in developing a water budget model lies in measuring or estimating the various components. Groundwater is particularly difficult to include, and for this reason is often ignored or represented merely as the residual term of the equation. Unfortunately, there are large errors associated with the measurements or estimates of the individual components of the budget, and the residual term will contain the sum of all these errors (Gippel, 2005a).

Gippel (2005a; 2005b; 2005c) developed the numerical water balance model known as SWET (Savings at Wetlands from Evapotranspiration daily Time-series). Although originally intended for the purpose of estimate water savings, the model can be applied to any water balance problem. SWET is a spreadsheet model that is available free of charge from the Murray-Darling Basin Commission.

10.2 Data Inputs

The SWET model requires data inputs on bathymetry and climate, which have been desciribed in previous sections of this report. Evaporation was assumed to be approximated by FAO 56 ET_O, factored by monthly coefficients. When the DataDrill pan evaporation data and FAO56 ET_O were compared, it was found that FAO56 ET_O could be factored by monthly variable coefficients, being higher in the growing season than in the winter, so as to closely match average monthly pan evaporation data factored according to Lake Wyangan monthly coefficients from Hoy and Stephens (1979), which is an alternative approach to using the factored FAO56 ET_O data.

The rate of inflow and outflow between Lake Condah and Darlot Creek is determined by the head difference between the two water bodies and the hydraulic characteristics of the connecting channel. For the Current no-structure scenario it was assumed that inflow was relatively unconstrained, entering by overtopping the Drain in the northern section of the Lake. For the Future scenarios, with a weir installed on the downstream end of the Lake, inflows were unconstrained, simply emptying into the Lake from Condah Drain.

SWET allows for initial loss of water into the dry bed. No data were available regarding the thickness of the Lake bed sediment, its material composition, or its porosity. Values for these parameters were estimated on the basis of professional experience. The bed material was assumed to be clay rich with a porosity of 0.33 and a wetting depth to 0.3 m. In the case of Lake Condah this process of loss was small compared to seepage to groundwater.

The basis of the groundwater component in SWET is Darcy's Law. As the hydraulic conductivity, and other necessary parameters, were essentially unknown, the equation was used as a calibration function, simply adjusting parameters by trial and error to achieve a fit to the gauged lake level series, from 1988 to 1992.

Local runoff to the Lake was provided as direct rainfall on the Lake's surface, whether wet or dry, and from the surrounding local land within the defined wetland domain up to the maximum Lake level. Appropriate rainfall intensity-dependent runoff coefficients were applied to determine the volume of water entering the wetland during rainfall events.

10.3 Scenarios

Five basic climate/land use scenarios were run (Table 6). Within each model run there was scope to adjust the environmental flow released downstream to Darlot Creek, and the elevation of the Weir. An additional conditon assuming winterfill diversions was run for some future scenarios.

10.4 Calibration

The only calibration undertaken on the model was to adjust the groundwater parameters in order to achieve the best possible model fit to the observed Lake level data from 1988 to 1993. After calibration, the model fitted the 1992/93 data very well, but was less than ideal for the other years (Figure 135). However, considering the difficulty of the modelling task, the model makes adequate predictions of water levels. Once the parameters that determine the rate of groundwater seepage were optimized to achieve the best model fit, these parameters were not adjusted for other model runs.

The model predicted water level should be interpreted as the Lake level in the southwestern part of the Lake, where the gauge is located. This area has sinkholes and is known to experience rapid drawdown (the model was calibrated to fit the observed pattern of drawdown). The northern and western parts of the Lake (which do not have sinkholes) should be expected to recede slowly from a level of 50.9 m while the southwestern section is receding rapidly.

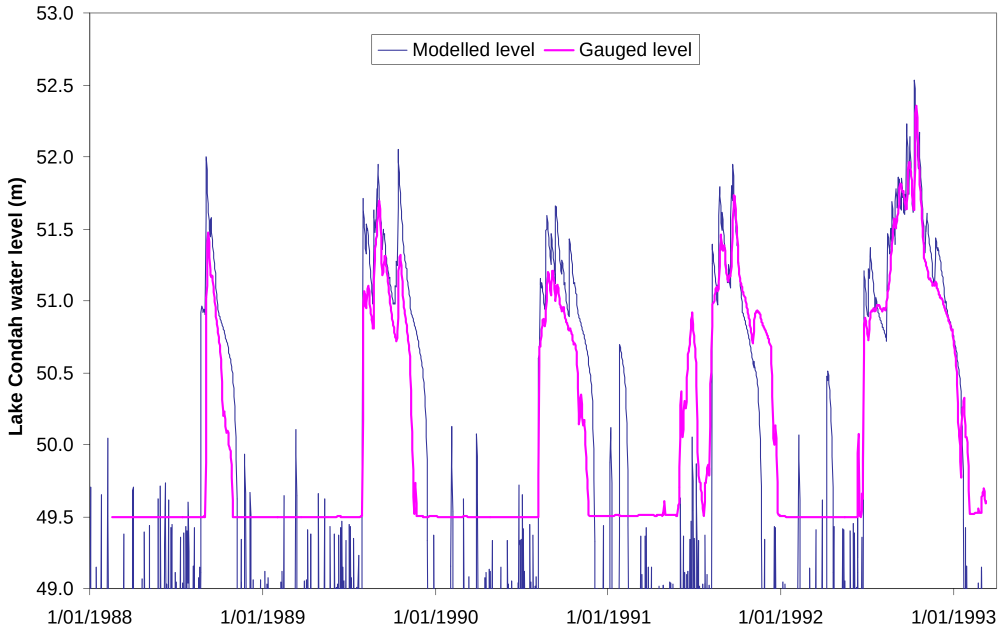


Figure 135. Predicted water level time series and observed Lake water level time series for 1988 to 1993. The level of 49.5 m is the limit of the stilling well, so does not represent the bed of the Lake.

10.5 Model accuracy, sensitivity and uncertainty

Although the water balance model calculates daily water level to two significant figures (i.e. centimetres), this should not be interpreted as being equivalent to model accuracy. The accuracy of the model is unknown and cannot be calculated. The accuracy is dependent on the input data and the calibration. In terms of input data, the model is relatively insensitive to the unknown bed material properties (which affect initial losses). The model is sensitive to the bathymetric relationships, but these are accurate for Lake Condah. The model is highly sensitive to inflows from Darlot Creek, which is apparent from a comparison of the results from different climate and land use scenarios. The accuracy of the modelled inflows over the entire 115 modelling period is unknown, but every effort was made to calibrate the rainfall-runoff model to the observed data, and a good fit was achieved. The water balance model is sensitive to rainfall and evapotranspiration input data, although net evaporation from the surface of the Lake appears to be less important than seepage to groundwater. The seepage function is the most uncertain term in the water balance model. Trial and error model runs demonstrated that output (Lake water level time series) was sensitive to the selection of parameter values for groundwater interaction.This term was used to calibrate the model to fit the observed Lake level recessions, so for the calibration period at least, the seepage function was a realitic representation of reality. It is not known how well the function represents seepage when the Lake is at levels higher than the range over which it was calibrated (up to 52.5 mAHD). Based on the five years of observed Lake level data, the water balance model correctly predicted the patterns of water level. Although predicted Lake levels on any particular day would be accurate to only ±0.5 m at best, there was no evidence of systematic bias in the predictions.

For model runs with scenarios that involved a weir being in place, the predicted Lake water levels are regarded as being more accurate than scenarios without a weir (i.e. Current and Natural). With a weir in place, the water levels are often controlled by the hydraulics of the weir. The hydraulic behaviour of the weir was modelled using the Hec-Ras model, which is the industry standard. The accuracy of the Hec-Ras predictions depends mainly on the bathymetry, which was well characterised.

There was little point in undertaking formal model sensitivity testing because the model was calibrated to fit observed data. Thus, the model predictions are as accurate as possible.

Uncertainty in the model predictions arises from unavoidable inaccuracies in the modelling process. However, possibly a greater source of uncertainty, from the management perspective, is the uncertainty of future climate and runoff. A number of scenarios were generated, but there is no guarantee that any of these scenarios will eventuate in the future.

The modelled scenarios were all based on the 115 year rainfall time series from 1890 to 2004. A range of alternative rainfall time series having the same statistical properties could have been synthetically generated for comparison, but given the large number of scenarios that required modelling due to various combinations of land use, climate, weir height, winterfill diversion, and environmental flow characteristics, this was not feasible within the budget and resource constraints of the project.

Overall, the predicted Lake water levels are regarded as an adequate basis for decision making.

10.6 Predicted Lake water level time series'

10.6.1 Natural (1750) land use and pre-Condah Drain Lake configuration

A scenario was generated by assuming that the outflow sill of the Lake was 54.5 m AHD, and the catchment hydrology reflected the pre-European disturbance land cover. Under this scenario runoff was less than current, and Lake spills were relatively minor and did not occur every year (Figure 136). The lake level was variable, but generally above 52 m.

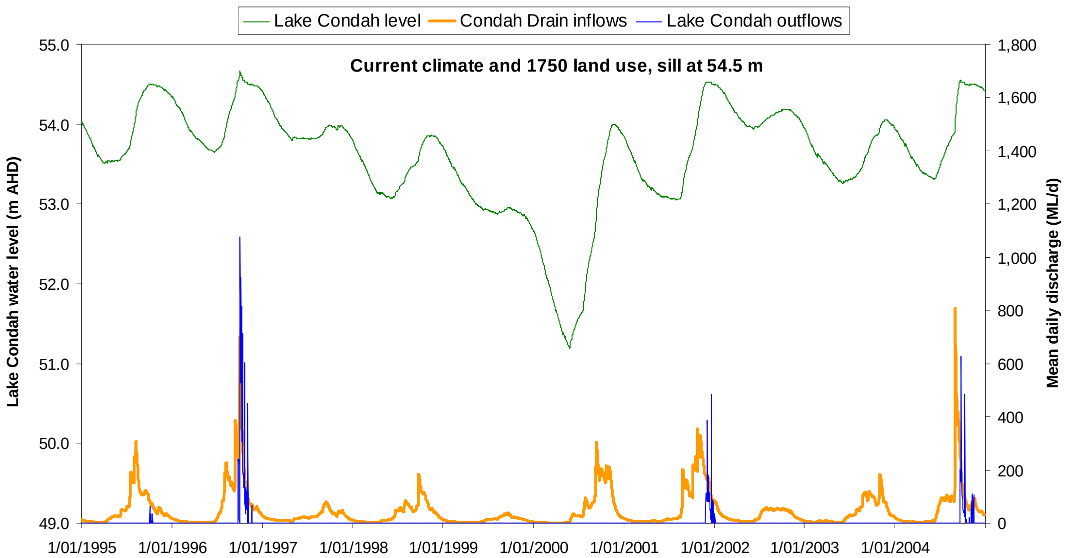


Figure 136. Predicted water level time series for final 10 years of the modelled 115 year period for Natural conditions (1750).

10.6.2 Current climate, land use and post-Condah Drain Lake configuration scenario

Under the current scenario, the Lake level responds to the level of water in the Drain, with a threshold flow required before inundation will commence. The model predicts that the Lake remains inundated for relatively short periods, as reported anecdotally (Figure 137).

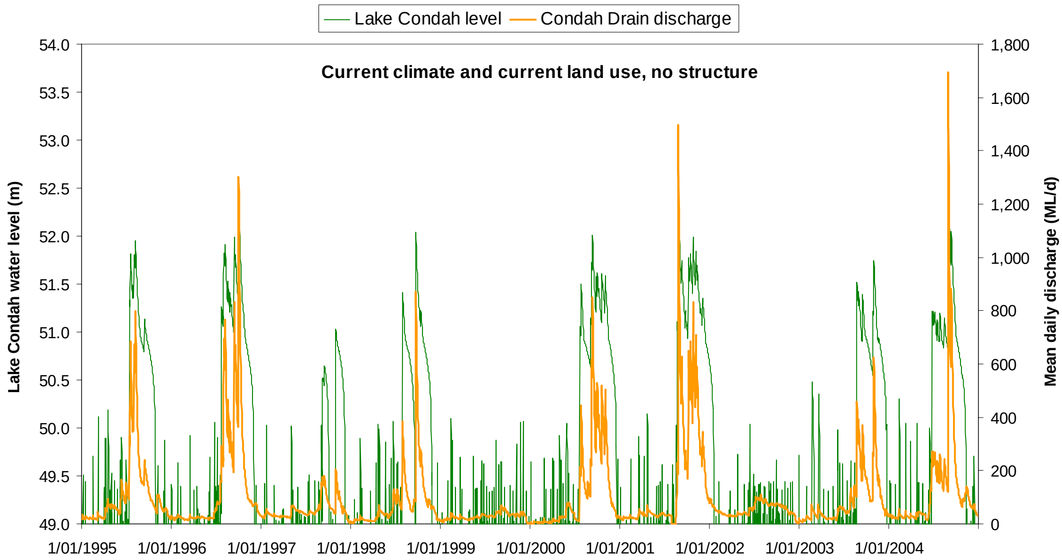


Figure 137. Predicted water level time series for final 10 years of the modelled 115 year period for Current conditions.

10.6.3 Variation between scenarios – for Weir crest height 53 m and environmental flow 20 ML/d

A comparison was made between the climate and land use scenarios, for conditions of holding the Weir height at 53 m and the environmental flow at 20 ML/d. A graphical comparison was made over the ten year long period 1995 to 2004 (the model runs extend for 115 years); this represents a relatively dry period. The predicted time series' revealed little difference between the Current scenarios (Current land use and 2030 land use) and the Future Wet climate scenario (with 2030 land use) (Figure 138 to Figure 141). The Lake was generally inundated, except for the 3-month period March to May 2000, when the southwestern section of the Lake was predicted to be effectively dry. The 2030 Dry climate scenario produced three significant Lake drying events over the 10 year period 1995 – 2004, with the longest lasting almost a year from mid-1999 to mid-2000 (Figure 141).

10.6.4 Variation between environmental flow – for Current scenario and Weir crest height 53 m

There is a direct trade-off between releasing an environmental flow and maintaining the water level in the Lake. Having no environmental flow means that the summer and autumn baseflow is fully absorbed by the Lake (Figure 142). However, one consequence of this is that the Lake is generally at a higher level than if an environmental flow is released. These higher Lake levels mean that the freshes and winter storm events are translated downstream to Darlot Creek. In contrast, as the environmental flow is increased (Figure 143 to Figure 146), the duration of the high flow periods in Darlot Creek reduces. Also, the Lake level is generally lower as the environmental flow is increased.

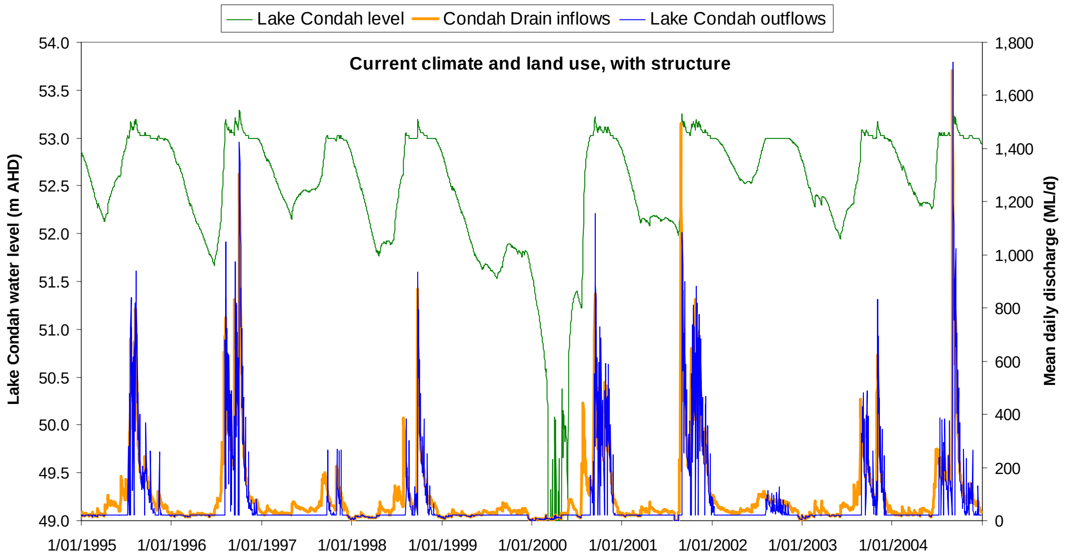


Figure 138. Predicted water level time series for final 10 years of the modelled 115 year period for Current conditions, with 53 m crest Weir installed, and 20 ML/d environmental flow.

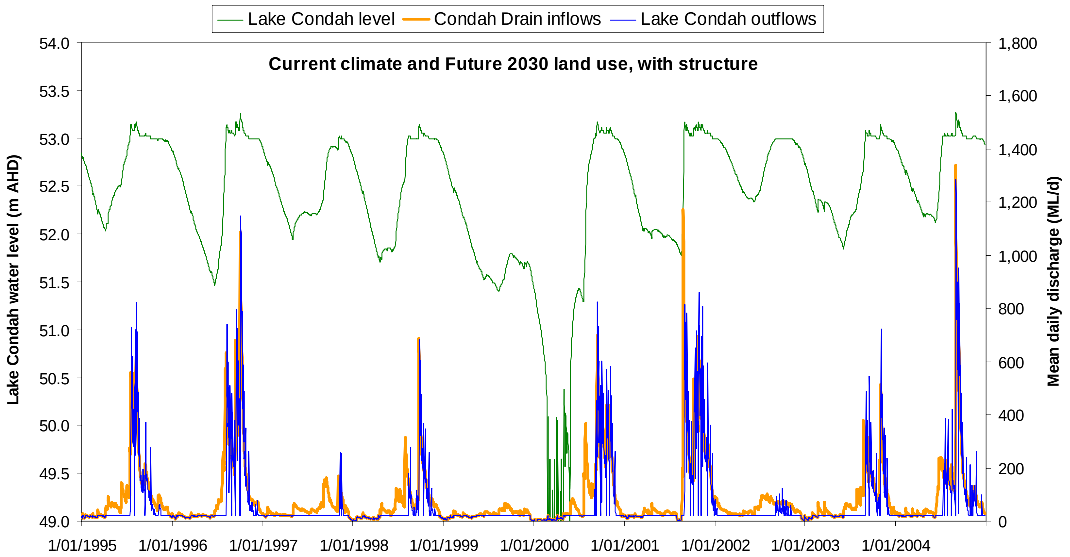


Figure 139. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and 2030 land use conditions, with 53 m crest Weir installed, and 20 ML/d environmental flow.

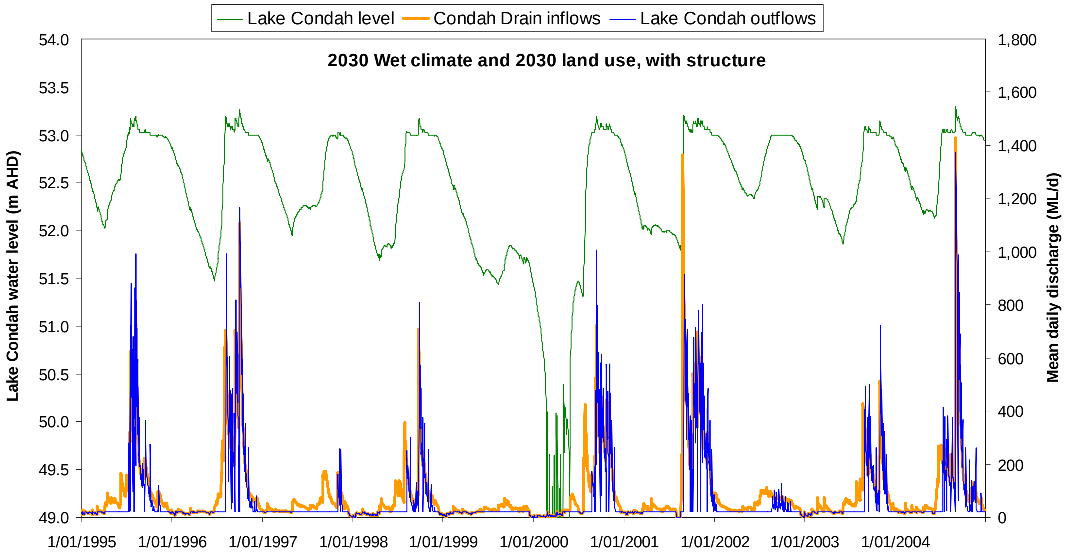


Figure 140. Predicted water level time series for final 10 years of the modelled 115 year period for 2030 Wet climate conditions, with 53 m crest Weir installed, and 20 ML/d environmental flow.

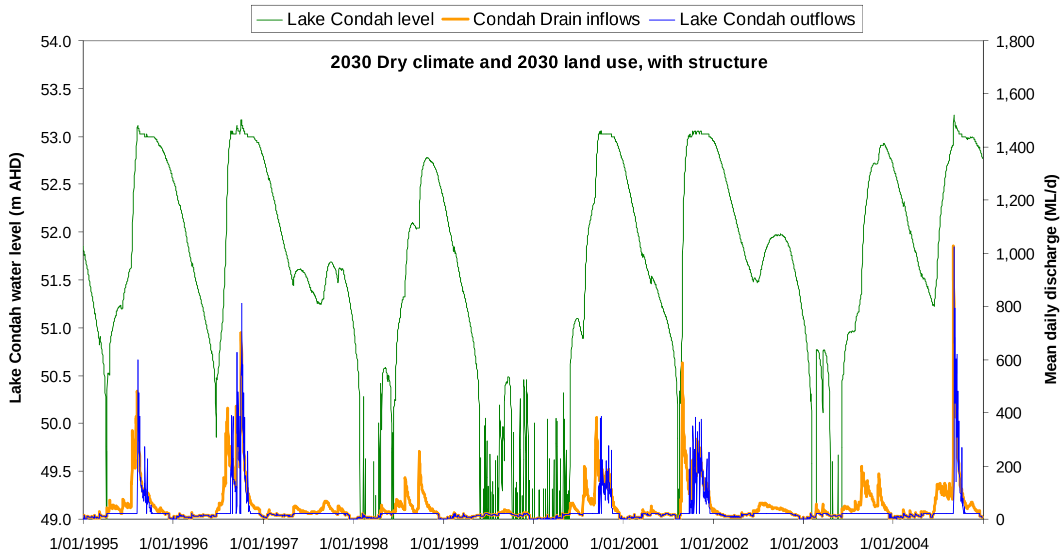


Figure 141. Predicted water level time series for final 10 years of the modelled 115 year period for 2030 Dry climate conditions, with 53 m crest Weir installed, and 20 ML/d environmental flow.

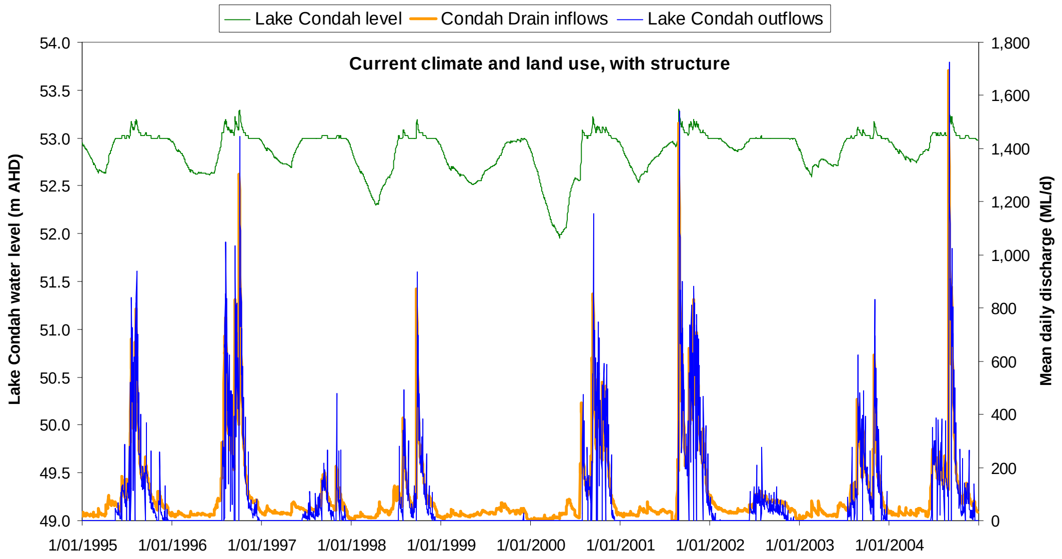


Figure 142. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 53 m crest Weir installed, and no environmental flow.

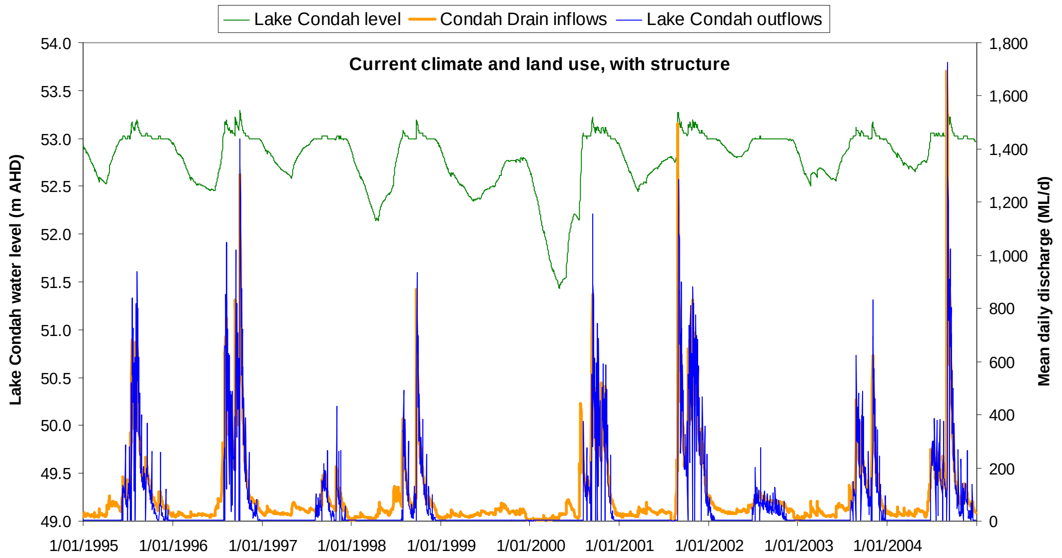


Figure 143. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 53 m crest Weir installed, and 5 ML/d environmental flow.

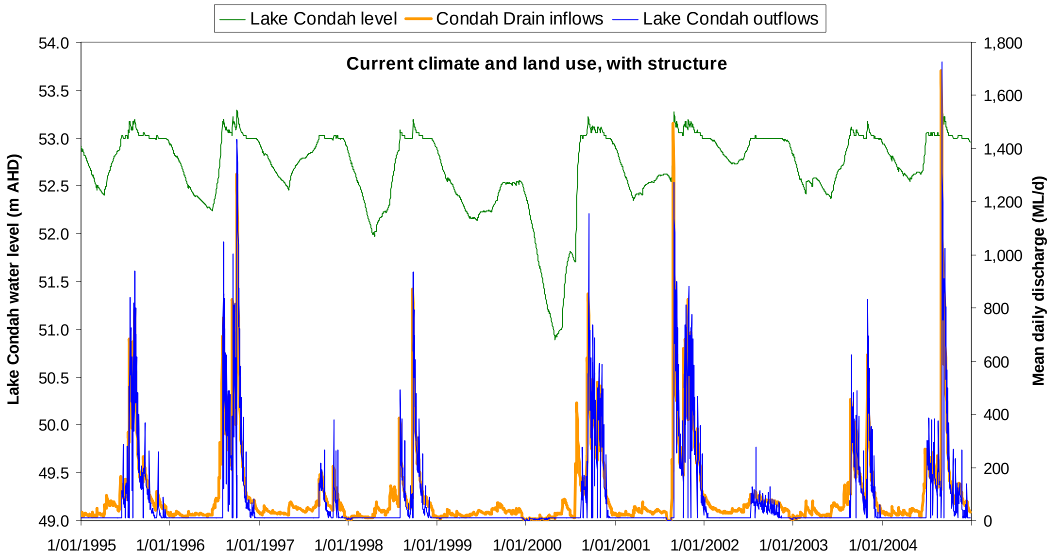


Figure 144. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 53 m crest Weir installed, and 10 ML/d environmental flow.

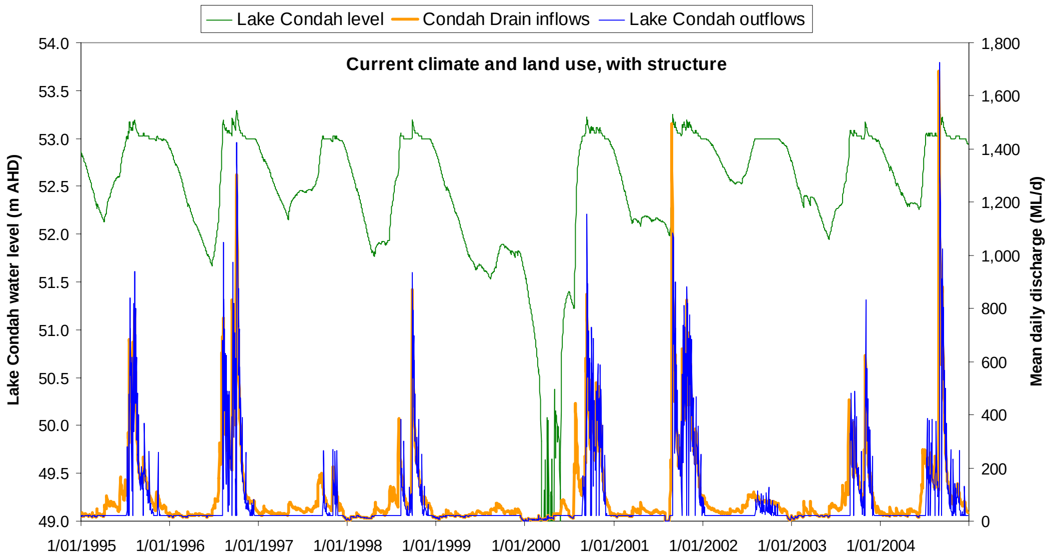


Figure 145. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 53 m crest Weir installed, and 20 ML/d environmental flow.

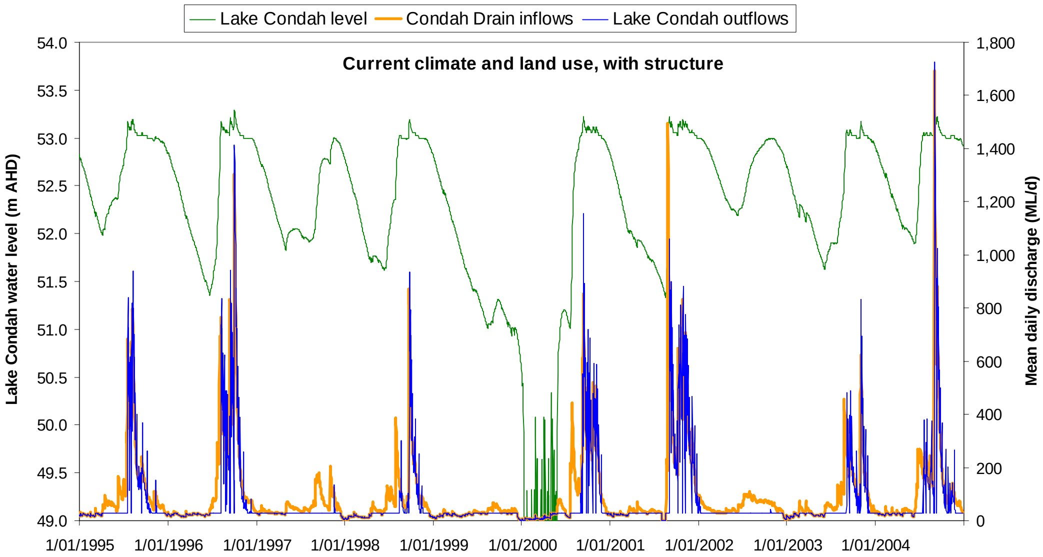


Figure 146. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 53 m crest Weir installed, and 30 ML/d environmental flow.

10.6.5 Variation between Weir crest heights – for Current scenario and environmental flow 20 ML/d

The time series of Lake water level is sensitive to the height of the Weir crest. The higher is the crest, the longer the duration of high water levels, and the less frequent are dry spells (Figure 147 to Figure 150). The 52 m and 51.6 m high weir crests produced four significant dry spells in the period 1995 to 2004 (Figure 149, Figure 150). There is a trade-off between weir height and flows in Darlot Creek. The lower the crest, the more complete are the flood hydrographs in Darlot Creek.

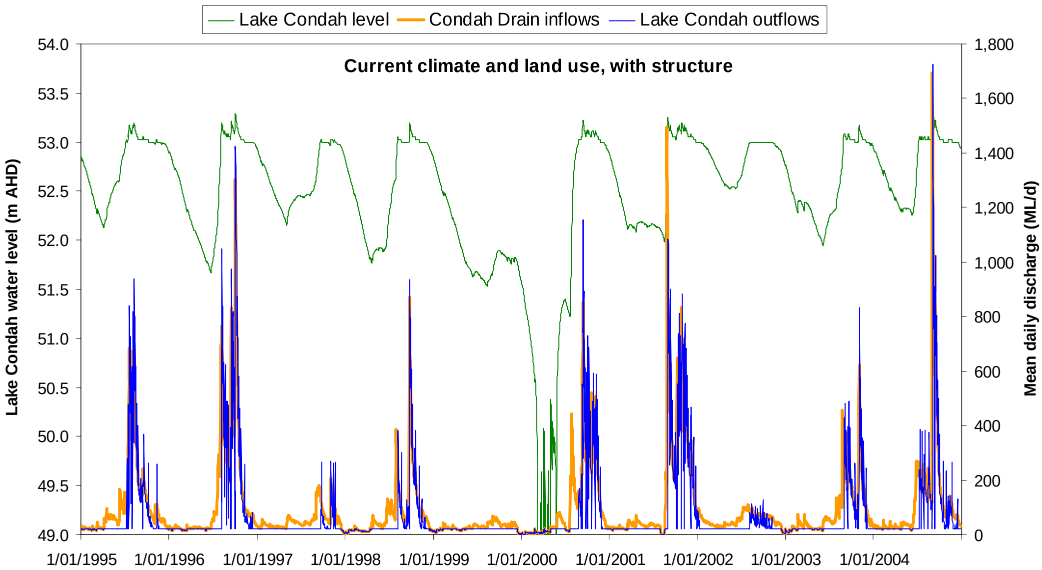


Figure 147. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 53.0 m crest Weir installed, and 20 ML/d environmental flow.

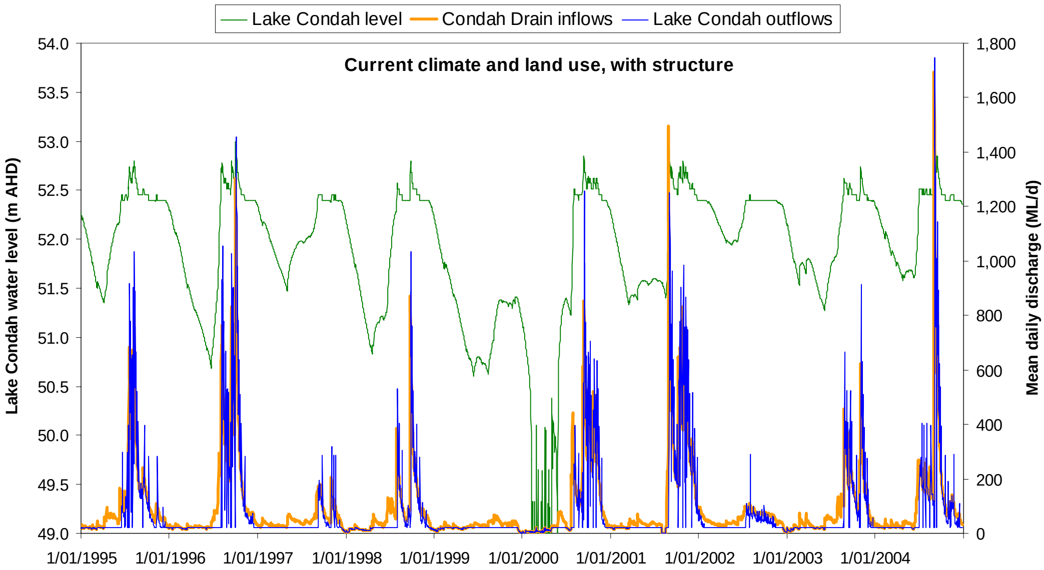


Figure 148. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 52.4 m crest Weir installed, and 20 ML/d environmental flow.

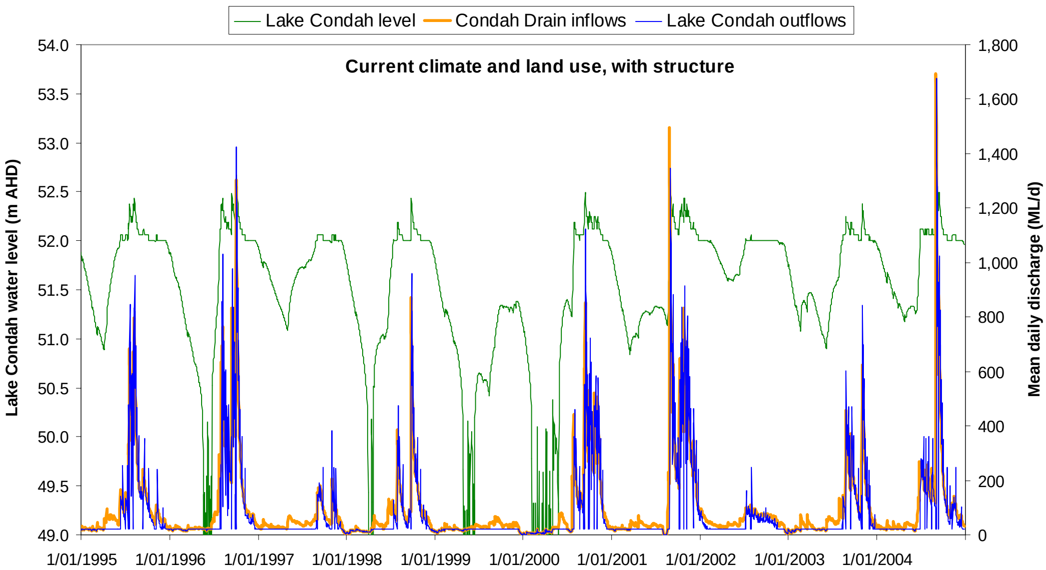


Figure 149. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 52.0 m crest Weir installed, and 20 ML/d environmental flow.

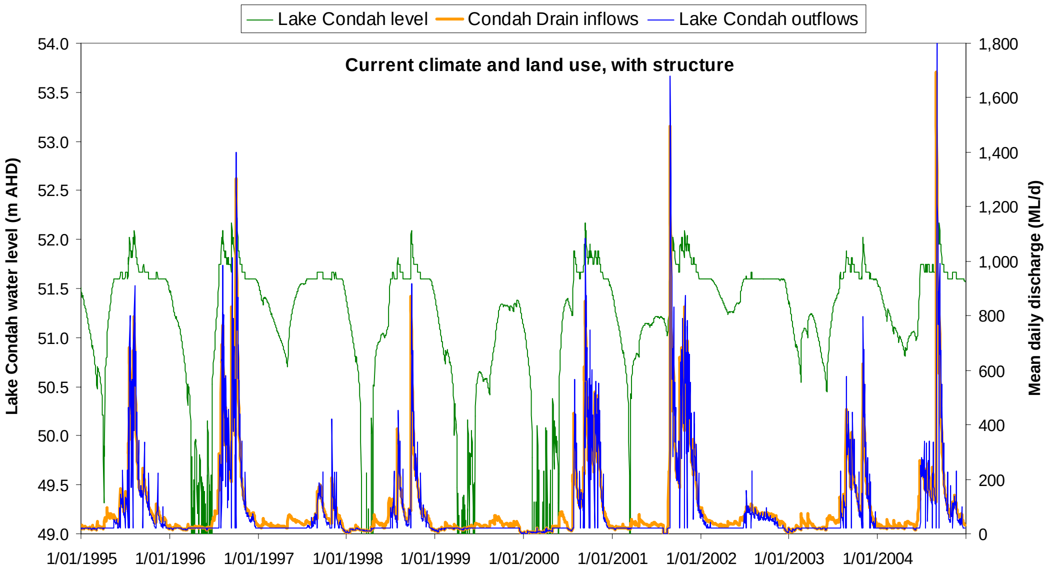


Figure 150. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with 51.6 m crest Weir installed, and 20 ML/d environmental flow.

10.6.6 Impact of winterfill diversions, with 53 m Weir and 20 ML/d environmental flow

Three scenarios were re-run with winterfill diversions, all with a 52.4 m Weir and 20 ML/d environmental flow: Current land use and climate, Current climate and Future 2030 landuse, and Future Dry 2030 climate and Future 2030 land use. Winterfill diversions are made during the wettest part of the year, so in average and wet winters when the Lake is spilling over the Weir, the diversions would be expected to have little impact on Lake levels. Winterfill diversions would be expected to impact Lake levels mainly during dry years, especially in dry future scenarios.

Winterfill diversions had the effect of reducing the spills to Darlot Creek and slightly lowering Lake water levels. Winterfill diversions did not alter the basic pattern of Lake filling for the Current climate scenarios (Figure 151 and Figure 152), but for the Future Dry climate scenario (Figure 153), there was a substantial lowering of Lake water levels in the drier years, increased duration of low Lake levels and increased frequency of low Lake levels (compare Figure 153 and Figure 141).

10.7 Impact of hydrological restoration on Lake water level duration curves

Water level duration curves summarise the percent of the total time that the Lake is at various levels. This is illustrated for two climate and land use scenarios, and a range of Weir crest heights. For the current climate and land use scenario, under the current (no Weir) situation (Figure 154), the Lake water surface is contiguous over its various sections for only 20% of the time. Installing a Weir increases this to over 80% of the time. For the modelled weir heights, the Lake is at the crest height or spilling for 50% – 60% of the time.

For the Future 2030 Dry climate and Future 2030 land use scenario (the driest scenario) (Figure 155), the Lake water surface is contiguous over the various sections for 60% - 85% of the time (depending on Weir crest height). For the modelled weir heights, the Lake is at the crest height or spilling for 20% – 35% of the time.

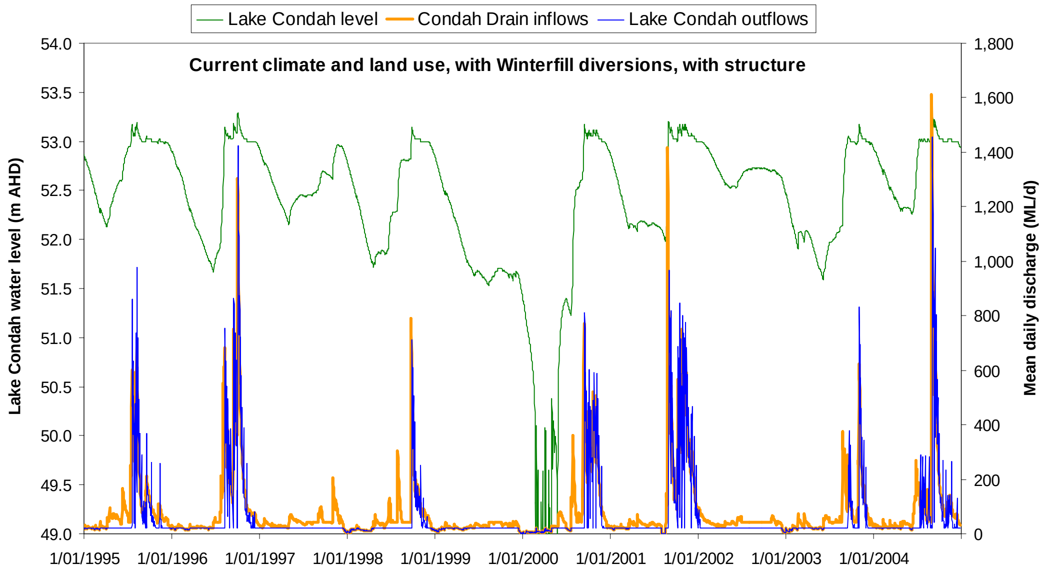


Figure 151. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and land use conditions, with winterfill diversions, with 53 m crest Weir installed, and 20 ML/d environmental flow. Compare with Figure 138.

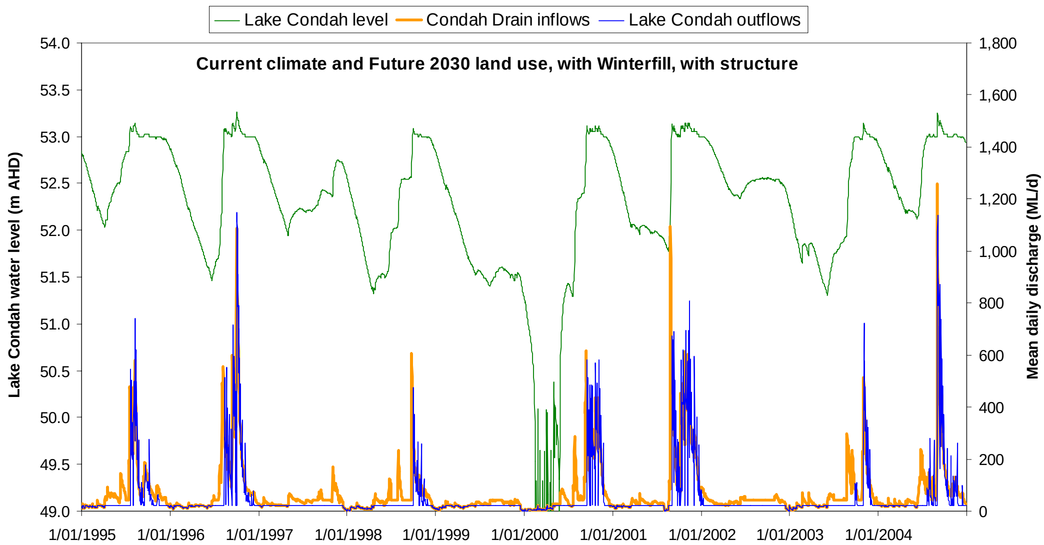


Figure 152. Predicted water level time series for final 10 years of the modelled 115 year period for Current climate and Future 2030 land use conditions, with winterfill diversions, with 53 m crest Weir installed, and 20 ML/d environmental flow. Compare with Figure 139.

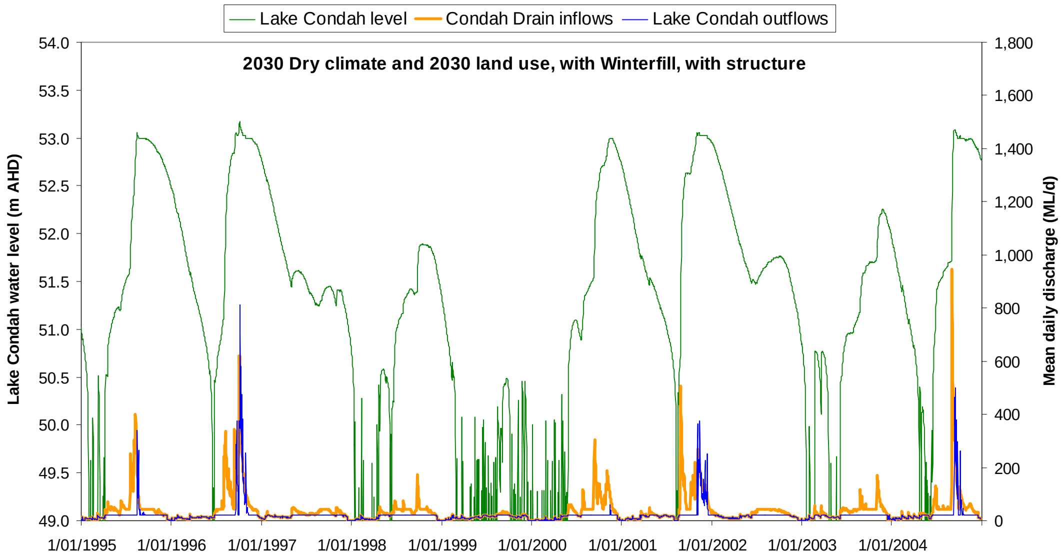


Figure 153. Predicted water level time series for final 10 years of the modelled 115 year period for Future 2030 Dry climate and Future 2030 land use conditions, with winterfill diversions, with 53 m crest Weir installed, and 20 ML/d environmental flow. Compare with Figure 141.

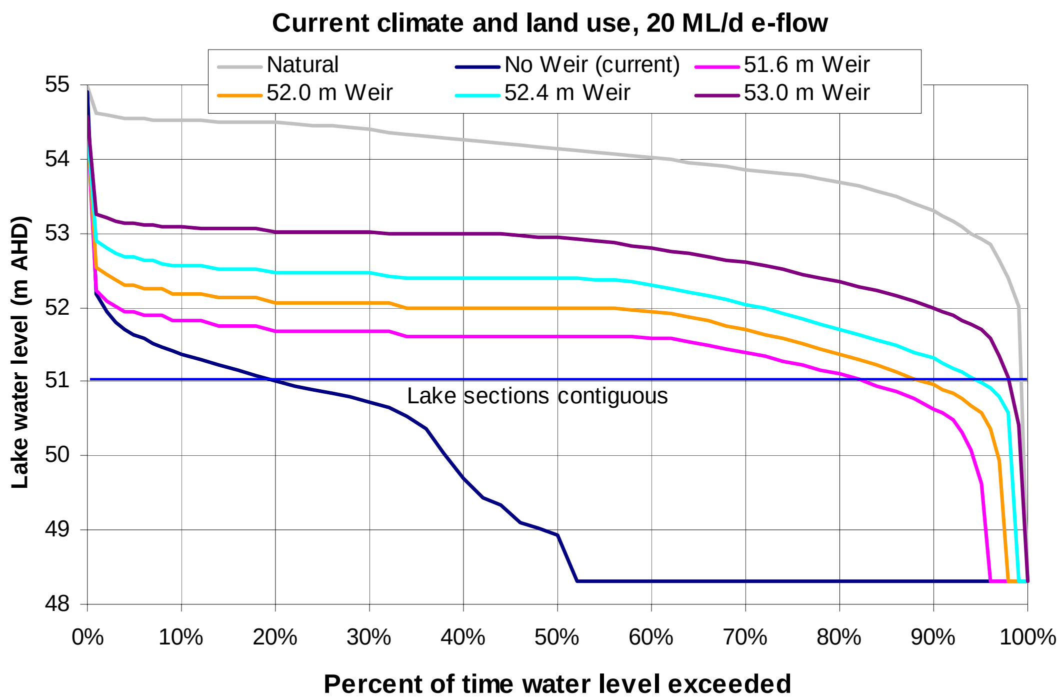


Figure 154. Duration of water levels in Lake Condah under Current climate and land use scenario (115 year daily time series), for no Weir situation (current), and four future Weir crest heights with 20 ML/d environmental flow. Natural scenario (1750 land use and current climate) shown for reference.

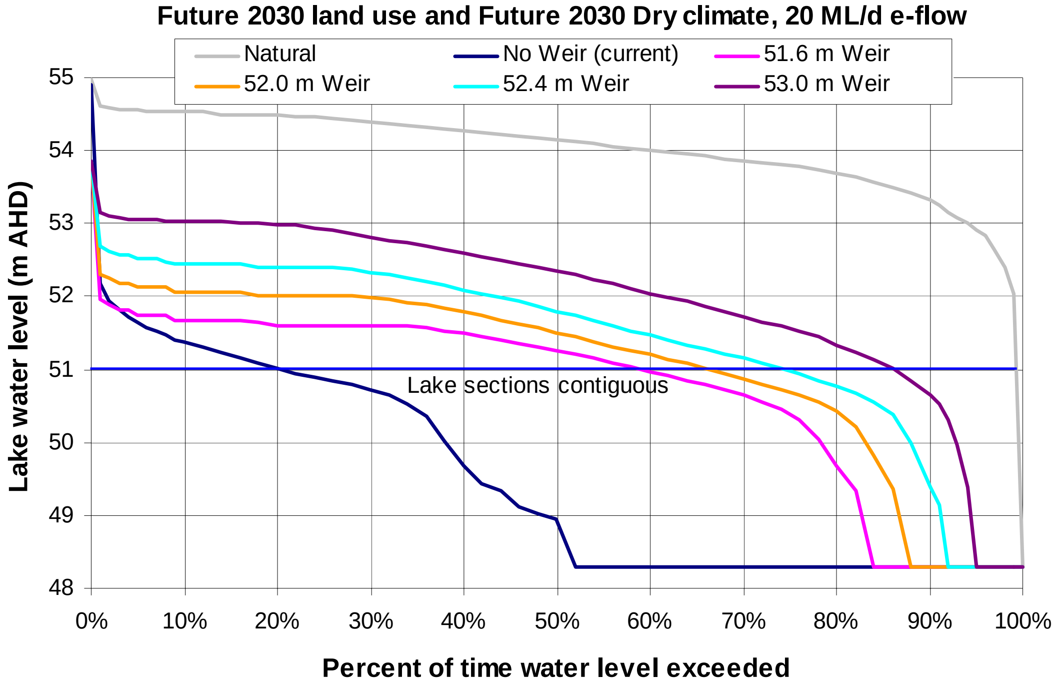


Figure 155. Duration of water levels in Lake Condah under Future 2030 Dry climate and Future 2030 land use scenario (115 year daily time series), for no Weir situation (current), and four future Weir crest heights with 20 ML/d environmental flow. Natural scenario (1750 land use and current climate) shown for reference.

10.8 Spells of Lake spilling (open fish passage)

Fish passage is open between Darlot Creek and Lake Condah when water is spilling over the crest of the Weir, or flowing through the slot in the crest that joins onto the fishway (Figure 125). The slot is nominally 0.6 m deep, so it can be assumed that fish passage will be available at least until the Lake water level falls to 0.4 m below the crest level. Velocities through the slot have to be within the limits of the swimming capacity of the fish using the fishway, so the slot will have to be designed with the appropriate hydraulic characteristics. This will mean quite low flow rates through the slot. The water balance model did not account for the loss of water through the slot, but because this would be a relatively minor volume it would not greatly accelerate the rate of fall of the water level of the Lake.

The spells of Lake spills (i.e. water 0.4 m below the weir crest or higher) were calculated for four scenarios, and for a range of Weir crest heights, with all assuming 20 ML/d environmental flow release. The environmental flow release rate was relatively inconsequential for spill frequency and duration. The scenarios were: Current climate and land use (Figure 156), Current climate and land use with maximal winterfill diversions (Figure 157); 2030 Dry climate and 2030 land use (Figure 158); and 2030 Dry climate and 2030 land use with maximal winterfill diversions (Figure 159). These scenarios are progressively drier, and showed progressively shorter spells of spill and less frequent spells of spill. As the Weir crest height was raised, for all scenarios, the spells of spill became shorter and less frequent. Spills generally occurred during the winter-spring (July -December) period.

Under the current climate and land use scenario, spills occurred in most years, and they were of a relatively long duration (often 3 – 4 months) (Figure 156). Winterfill diversions had little impact on this pattern (Figure 157). The Future 2030 Dry climate combined with Future 2030 land use scenario significantly reduced the duration of spells, there were more years without a spill, and there were instances of sequential years without a spill (Figure 158). Winterfill diversions slightly reduced the frequency and durations of spills under the Future Dry climate (Figure 159).

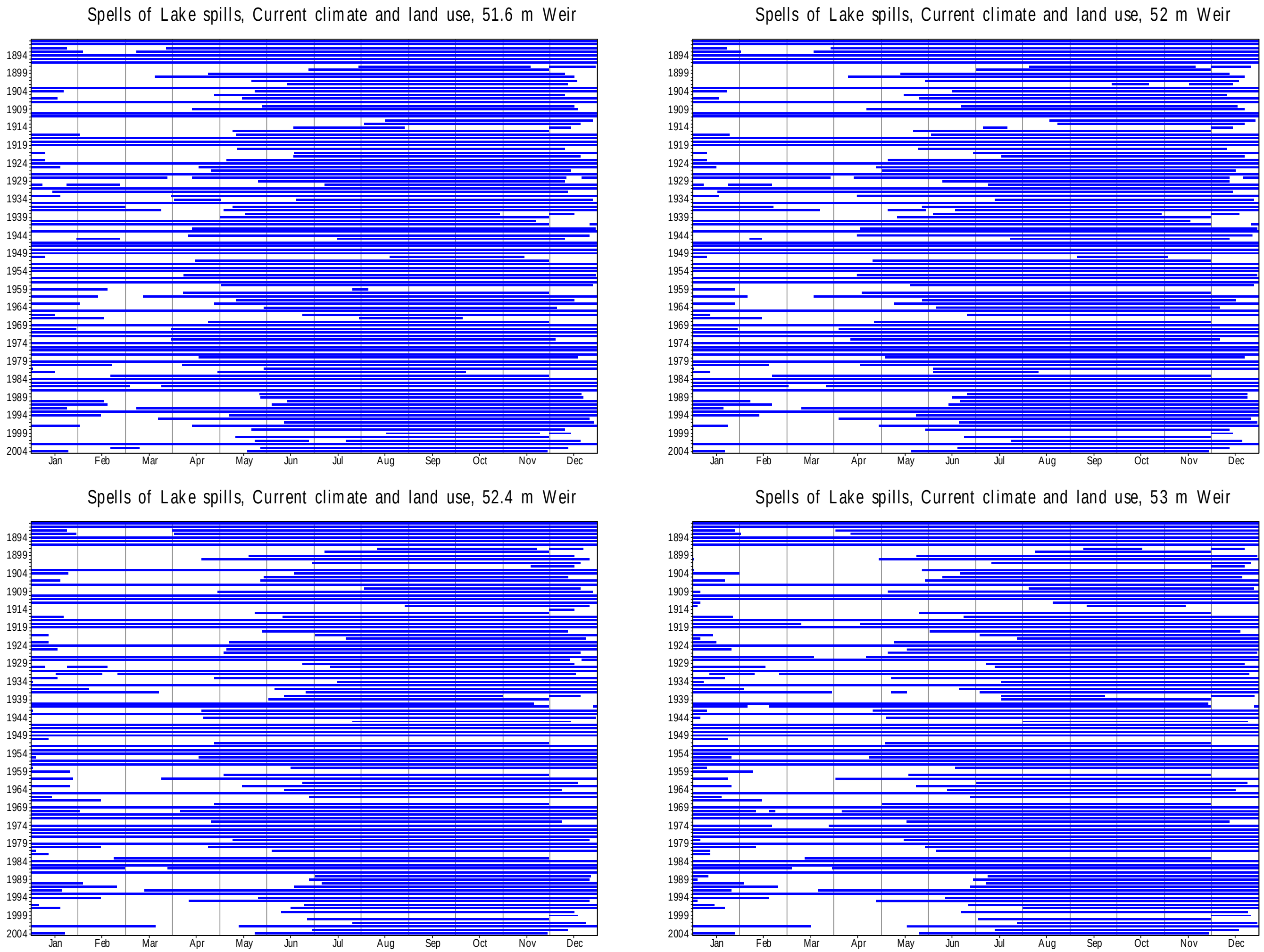


Figure 156. Distribution of spells of Lake spills, Current climate and land use, for a range of Weir crest heights, with 20 ML/d environmental flow.

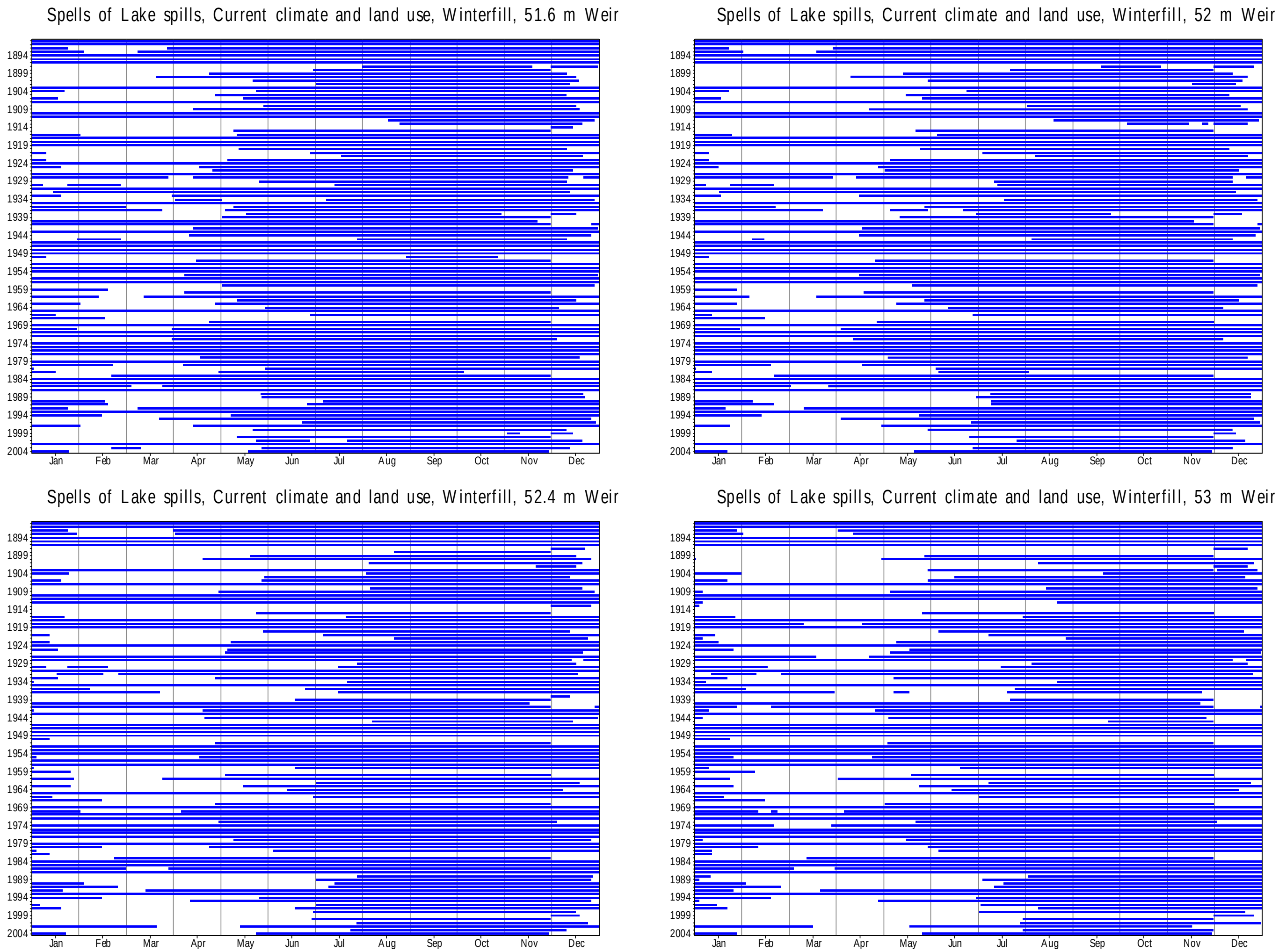


Figure 157. Distribution of spells of Lake spills, Current climate and land use, with Winterfill diversions, for a range of Weir crest heights, with 20 ML/d environmental flow.

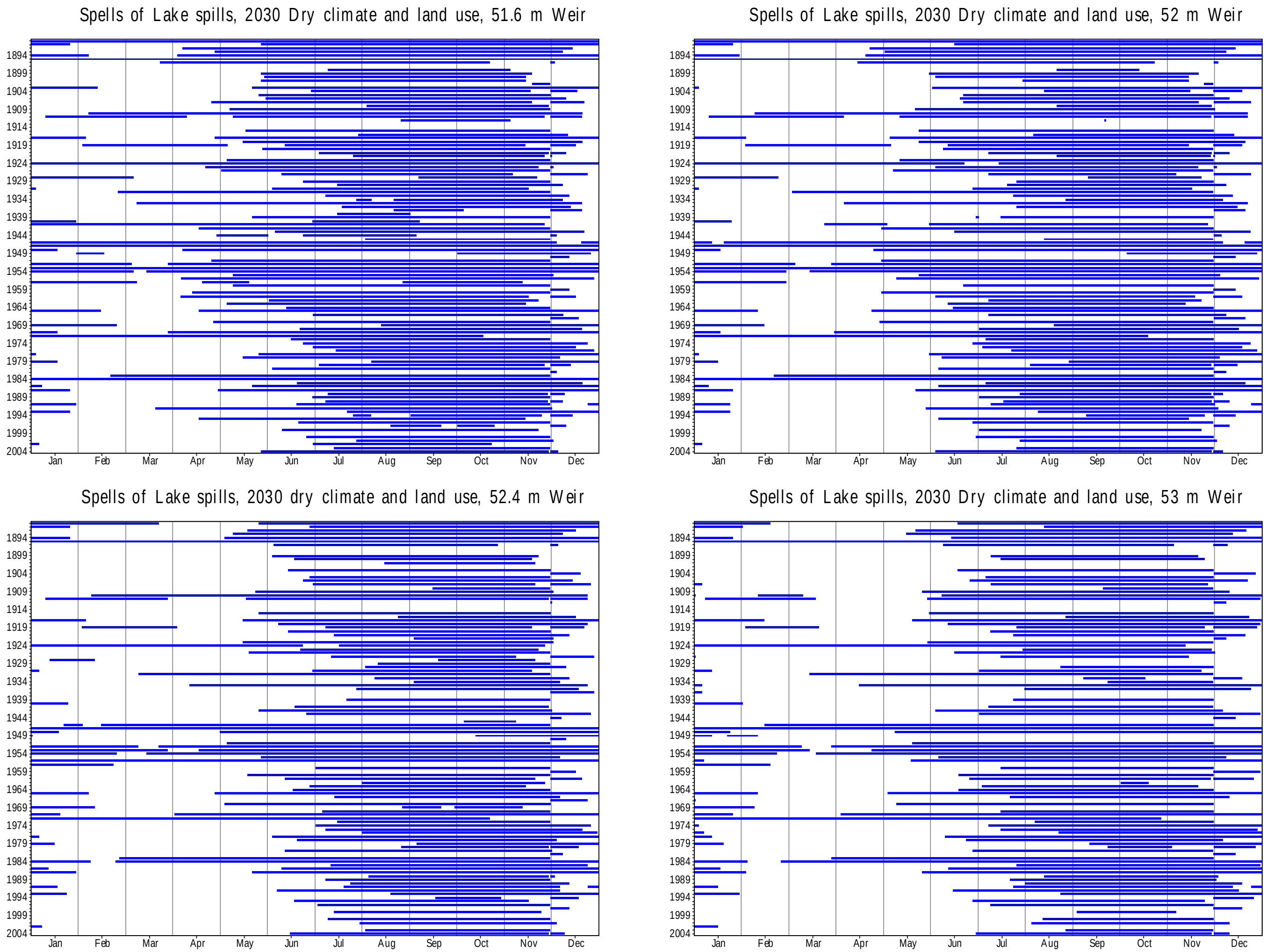


Figure 158. Distribution of spells of Lake spills, 2030 Dry climate and 2030 land use, for a range of Weir crest heights, with 20 ML/d environmental flow.

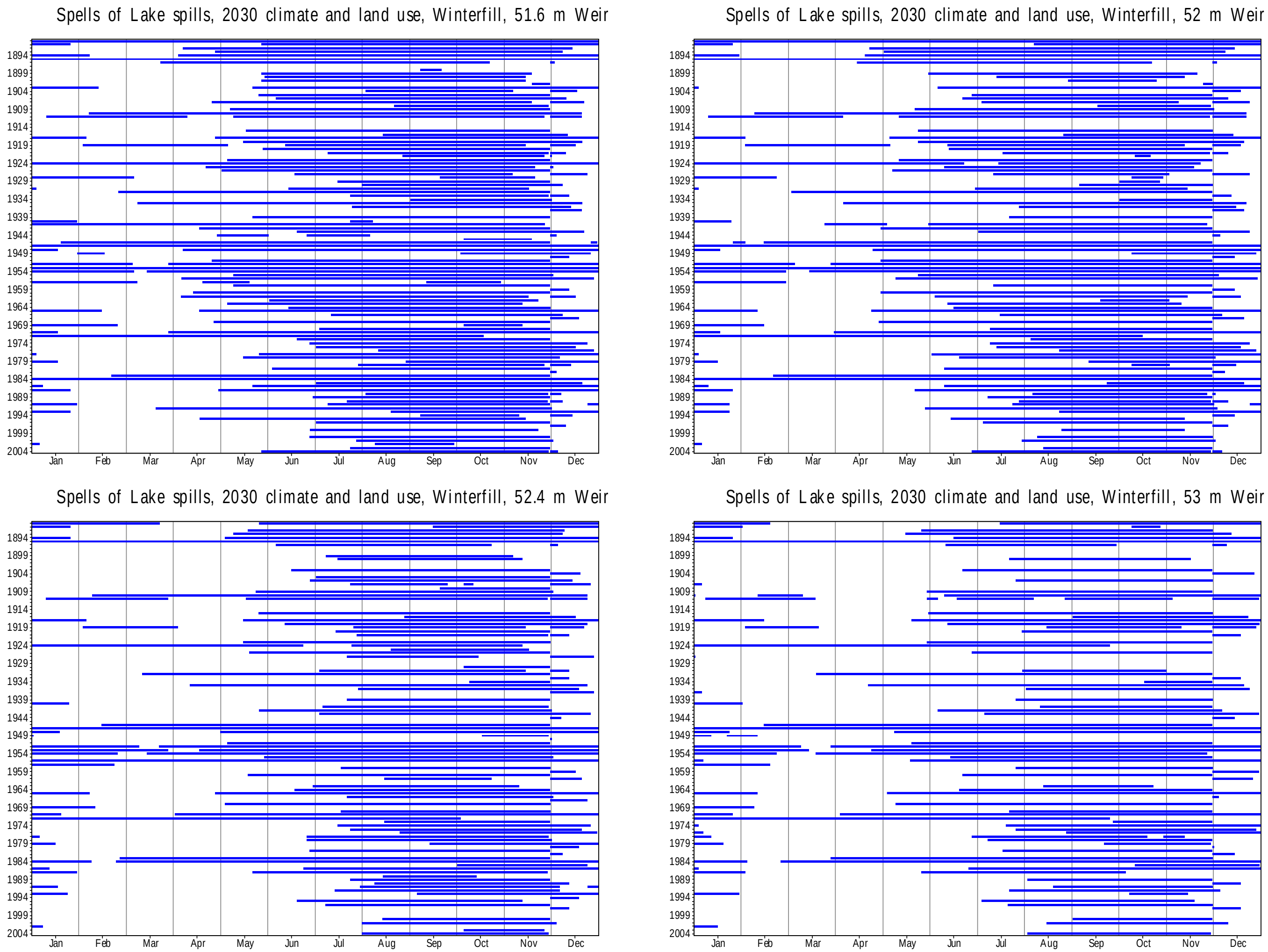


Figure 159. Distribution of spells of Lake spills, 2030 Dry climate and 2030 land use, with Winterfill diversions, for a range of Weir crest heights, with 20 ML/d environmental flow.

10.9 Impact of hydrological restoration on the pattern of inundation of private land on the northwestern corner of the Lake

10.9.1 Area of land affected

The northwestern corner of Lake Condah lies on privately owned land – T.A.H. Morton, Block 4^{D} (Figure 16, Figure 160). Although there are areas as low as 50.8 mAHD on the property, a sill prevents entry of water until the Lake level reaches 51.1 mAHD (Figure 24). The area of land inundated varies according to the Lake level, with a predicted maximum being 41 ha at the assumed 1946 flood (largest post-European settlement flood) level of 55 mAHD (Table 22 and Figure 161). The total area of the property was measured from the Cadastral Plan to be 98 ha (Note: this is approximate – the true area can only be measured by a registered surveyor through field survey).

Table 22.
Estimated area of Morton's property inundated for a range of flood frequencies (Current conditions).

ARI (years)	Elevation (mAHD)	Area inundated (ha)
1	51.9	15.4
2	52.2	19.0
5	52.5	23.4
10	52.7	25.6
50	53.5	32.2
100	54.0	36.0
1946 flood	55.0	41.2

10.9.2 Impact on duration of inundation

The relationship shown in Figure 161 was used to convert the modelled time series' of Lake Condah water level to time series' of area of Morton's property inundated. The duration (percent of total time) that the private land was inundated for the Natural, Current (no Weir) and Future (with a range of Weir heights) situations was then plotted for the Current climate and land use scenario (Figure 162) and the Future 2030 Dry climate and land use scenario, i.e. the driest case scenario (Figure 163). The curves are read as follows (for example):

For the Current climate and 1750 land use scenario (Figure 162):

I. Under the Natural situation:

- At least some private land is inundated for >99% of the time
- 10 ha or greater is inundated for >99% of the time
- 20 ha or greater is inundated for 98% of the time
- 30 ha or greater is inundated for 91% of the time
- 35 ha or greater is inundated for 68% of the time
- 40 ha or greater is inundated for <1% of the time

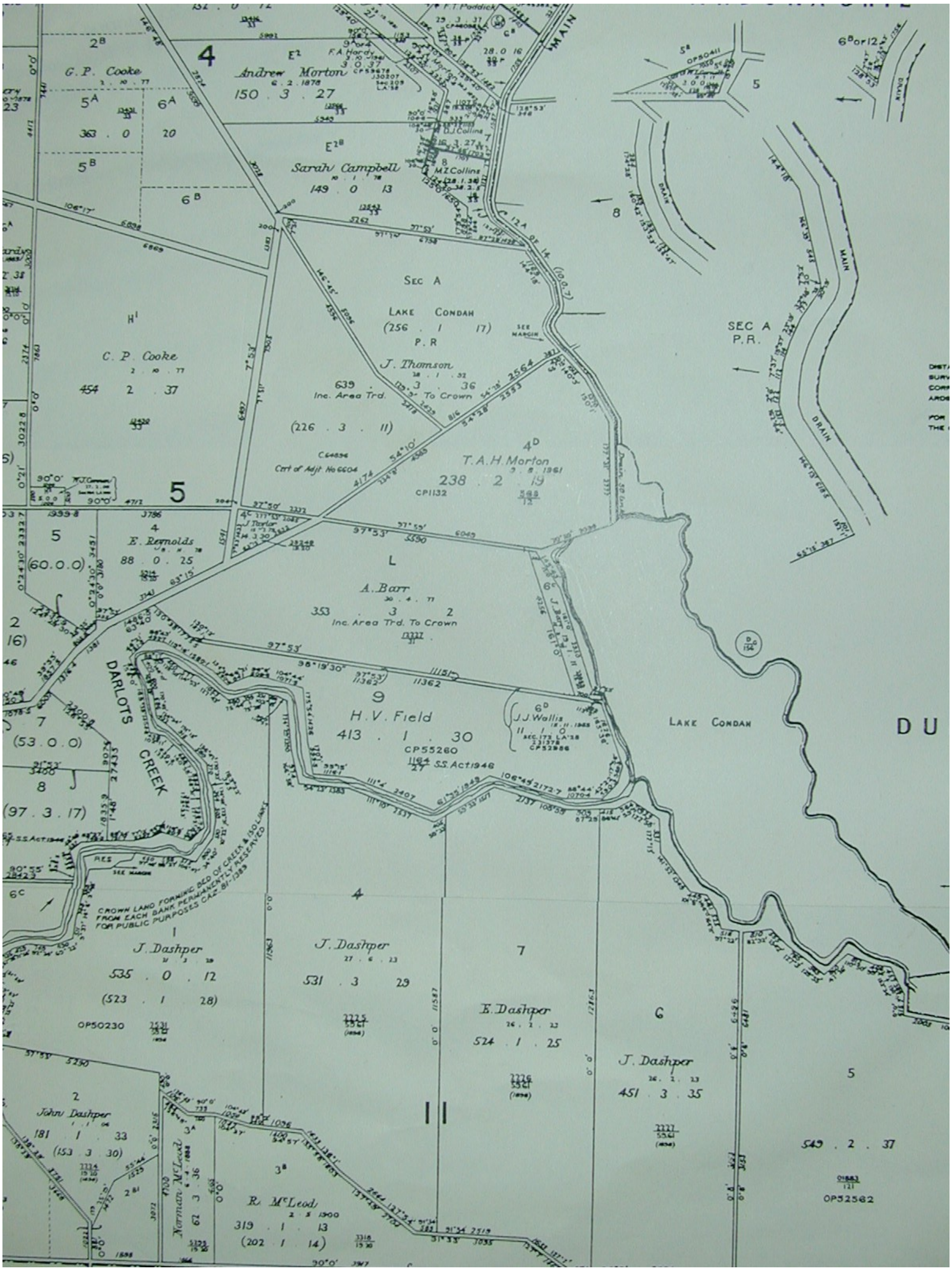


Figure 160. Cadastral Plan of the Lake Condah Area. Part of Block 4D (T.A.H. Morton) occupies the bed of the northwest corner of the Lake.

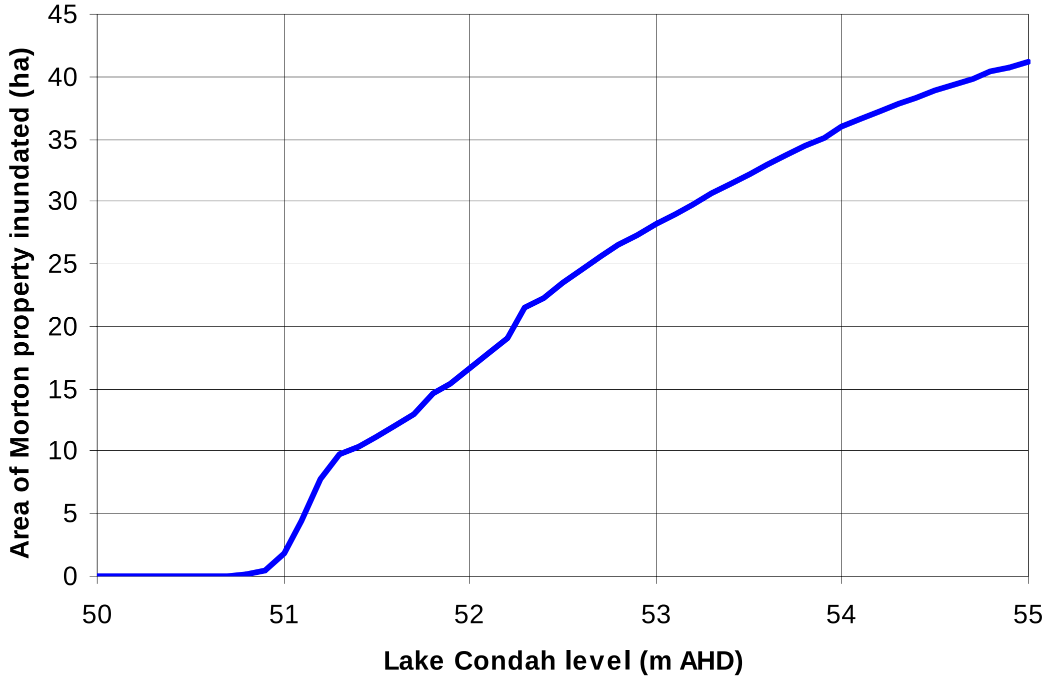


Figure 161. Area of Morton's property inundated for Lake Condah levels up to 55 mAHD (corresponding to the record 1946 flood).

For the Current climate and land use scenario (Figure 162):

II. Under the 52.4 m Weir situation:

- At least some private land is inundated for 94% of the time
- 10 ha or greater is inundated for 89% of the time
- 20 ha or greater is inundated for 63% of the time
- 30 ha or greater is inundated for <1% of the time

For the Future 2030 Dry climate and 2030 land use scenario (Figure 163):

III. Under the 52.4 m Weir situation:

- At least some private land is inundated for 74% of the time
- 10 ha or greater is inundated for 64% of the time
- 20 ha or greater is inundated for 34% of the time
- 30 ha or greater is inundated for <1% of the time

For the Current climate and land use scenario (Figure 162):

IV. Under the current situation with no Weir:

- At least some private land is inundated for 18% of the time
- 10 ha or greater is inundated for 11% of the time
- 20 ha or greater is inundated for <1% of the time

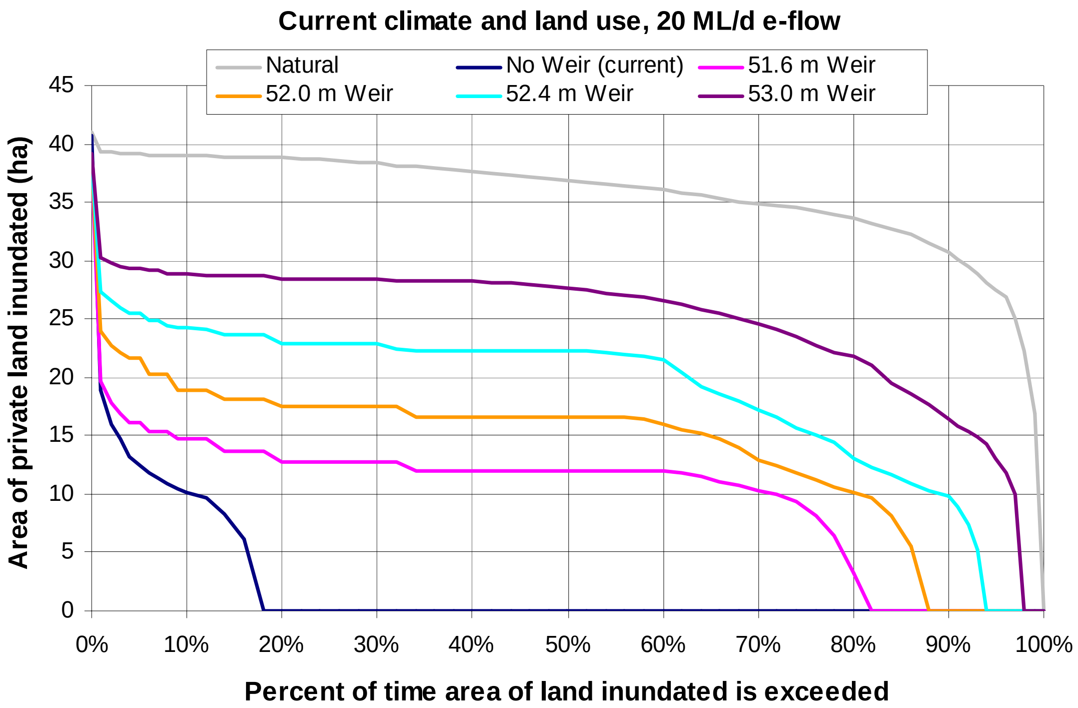


Figure 162. Duration of inundation of private land under Current climate and land use scenario, for no Weir situation (current), and four future Weir crest heights with 20 ML/d environmental flow. Natural scenario (1750 land use and current climate) shown for reference.

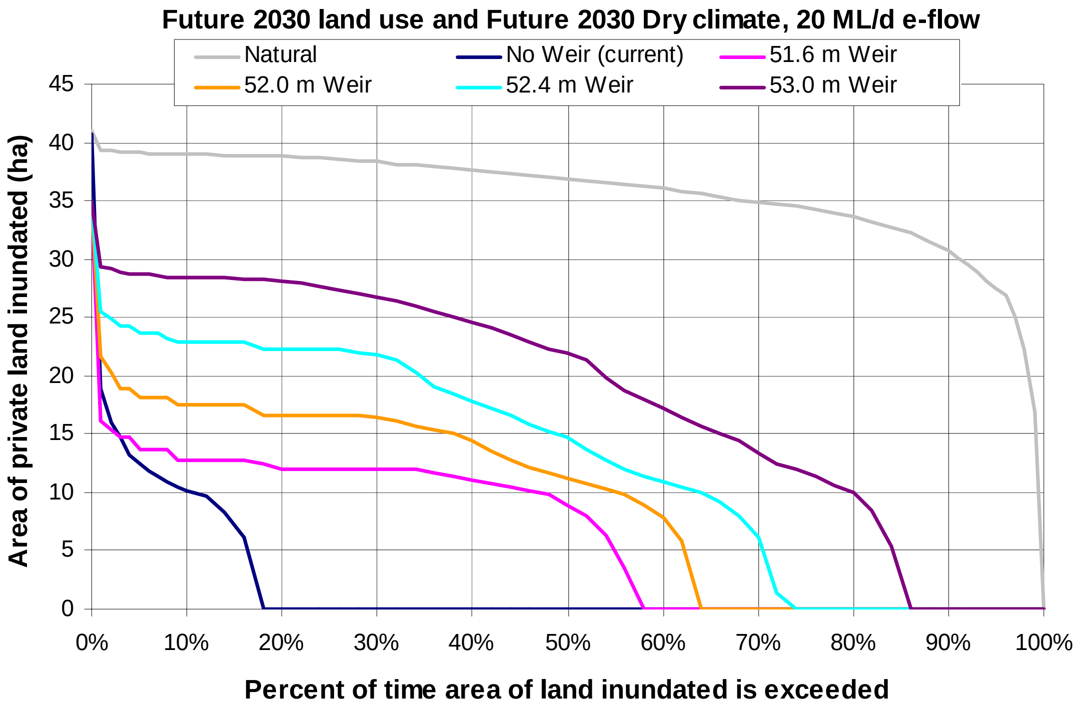


Figure 163. Duration of inundation of private land under Future 2030 land use and Dry climate scenario, for four future Weir crest heights with 20 ML/d environmental flow. Natural scenario (1750 land use and Current climate) and current no Weir situation (with Current climate and land use) shown for reference.

10.9.3 Impact on frequency of inundation

The average recurrence interval of area of inundated private land for the Natural, Current (no Weir) and Future (with a range of Weir heights) situations was plotted for the Current climate and land use scenario (Figure 164) and the Future 2030 Dry climate and land use scenario, i.e. the driest case scenario (Figure 165). The frequency of the land area inundation events was calculated as a partial duration series, with independence defined by conditions of:

- a minimum period of 7 days between independent event peaks and
- the value between two independent events must be less than 75% of the smaller peak.

The plotting position was determined using the Cunnane formula with $\alpha = 0.4$, as recommended in Gordon et al. (2004, p. 207). The relationships are read as follows (for example):

For the Current climate and 1750 land use scenario (Figure 164):

I. Under the Natural situation:
  - On average, once per year, at least 39 ha is inundated
  - On average, once every 2 years, at least 39 ha is inundated
  - On average, once every 5 years, at least 40 ha is inundated
  - On average, once every 10 years, at least 40 ha is inundated
  - On average, once every 20 years, at least 40 ha is inundated
  - On average, once every 50 years, at least 41 ha is inundated

For the Current climate and land use scenario (Figure 164):

II. Under the current situation with no Weir:
  - On average, once per year, at least 12 ha is inundated
  - On average, once every 2 years, at least 21 ha is inundated
  - On average, once every 5 years, at least 23 ha is inundated
  - On average, once every 10 years, at least 24 ha is inundated
  - On average, once every 20 years, at least 25 ha is inundated
  - On average, once every 50 years, at least 29 ha is inundated

For the Current climate and land use scenario (Figure 164):

III. Under the 52.4 m Weir situation:
  - On average, once per year, at least 25 ha is inundated
  - On average, once every 2 years, at least 27 ha is inundated
  - On average, once every 5 years, at least 29 ha is inundated
  - On average, once every 10 years, at least 29 ha is inundated
  - On average, once every 20 years, at least 30 ha is inundated
  - On average, once every 50 years, at least 32 ha is inundated

For the Future 2030 Dry climate and 2030 land use scenario (Figure 165):

IV. Under the 52.4 m Weir situation:
  - On average, once per year, at least 23 ha is inundated
  - On average, once every 2 years, at least 25 ha is inundated
  - On average, once every 5 years, at least 27 ha is inundated
  - On average, once every 10 years, at least 27 ha is inundated

- On average, once every 20 years, at least 28 ha is inundated
- On average, once every 50 years, at least 29 ha is inundated

Some general conclusions of the analysis of inundation of the privately owned land on the bed of the Lake in the northwestern corner are that:

1. Under Natural conditions the area of land in question was normally inundated.
2. Under Current conditions the private land is at least partially inundated for 18% of the time and, on average, once every 2 years an event occurs that inundates at least 21 ha.
3. A weir with a crest level of 52.4 m will inundate 22 ha when the Lake is level with the crest.
4. A weir with a crest level of 53.0 m will inundate 28 ha when the Lake is level with the crest.
5. Under Current land use and climate conditions, with a Weir set at 52.4 m, the private land is at least partially inundated for 94% of the time and, on average, once every 2 years an event occurs that inundates at least 27 ha.
6. Under Future 2030 Dry climate and land use conditions, with a Weir set at 52.4 m, the private land is at least partially inundated for 74% of the time and, on average, once every 2 years an event occurs that inundates at least 25 ha.

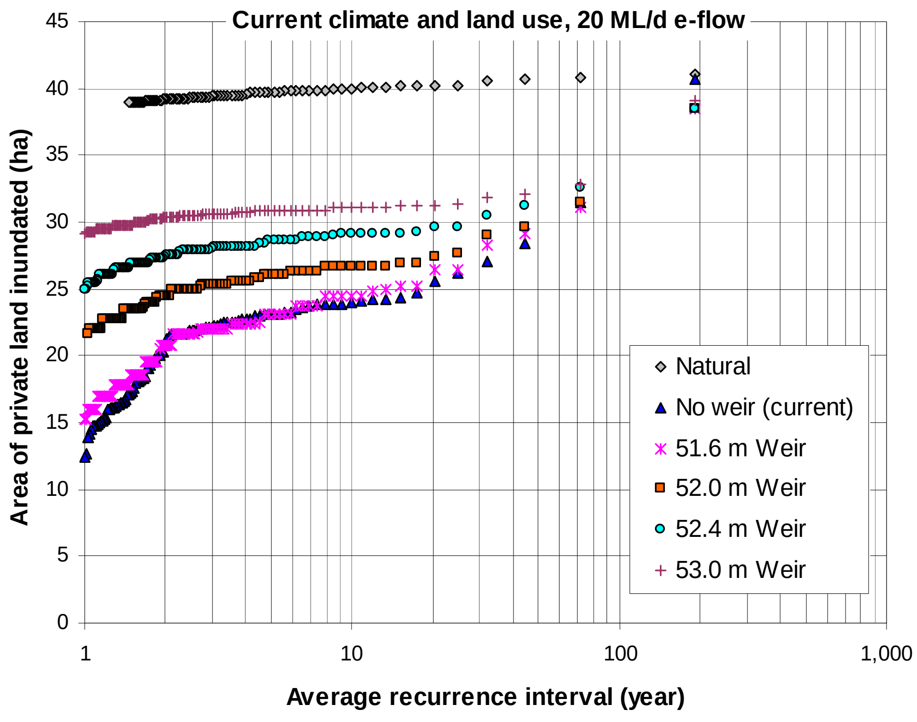


Figure 164. Average recurrence interval of area of inundated private land under Current climate and land use scenario, for no Weir situation (current), and four future Weir crest heights with 20 ML/d environmental flow. Natural scenario (1750 land use and current climate) shown for reference.

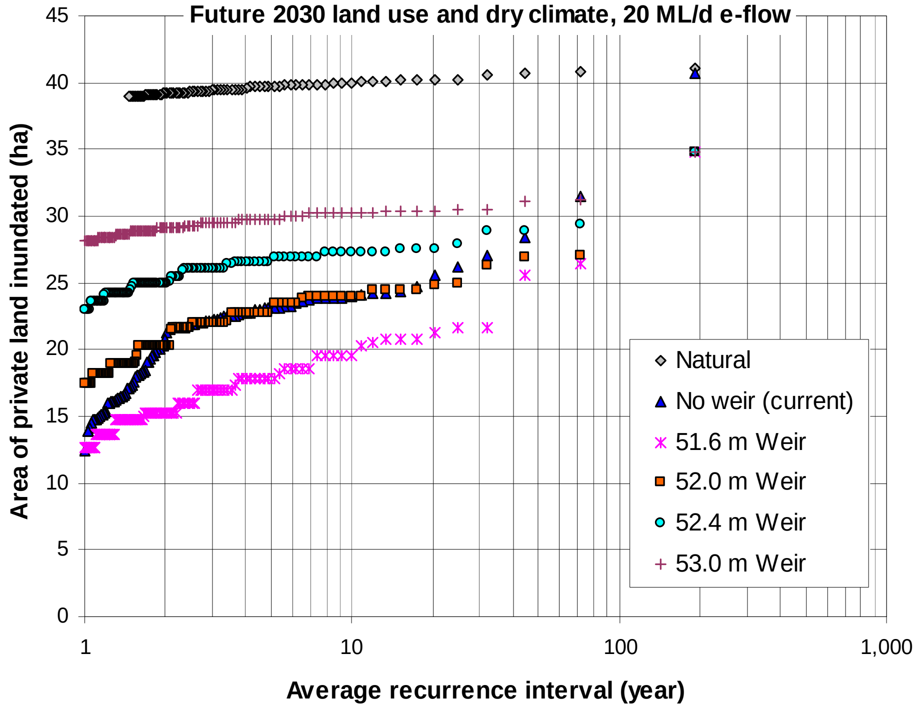


Figure 165. Average recurrence interval of area of inundated private land under Future 2030 land use and Dry climate scenario, for four future Weir crest heights with 20 ML/d environmental flow. Natural scenario (1750 land use and Current climate) and current no Weir situation (with Current climate and land use) shown for reference.

10.9.4 Impact on spells of inundation

The distribution of spells of inundation of private land were calculated for a limited range of scenarios. The spells were calculated for two thresholds: more than 15 ha inundated and more than 25 ha inundated. These land area thresholds are arbitrary – they have no particular significance. The scenarios considered were Natural, Current (no Weir and 52 m Weir) and Future Dry climate (with 52 m Weir). The spells were considered independent if they were separated by a minimum period of 7 days.

It is clear that under the Natural scenario the area of privately owned Lake bed was usually inundated (Figure 166 and Figure 167). Condah Drain had the effect of largely drying out the privately owned part of the Lake bed, with scattered spells of >15 ha inundated, the majority occurring in the period June to October (Figure 166). Spells of >25 ha inundated were extremely rare (Figure 167). Installation of 52.4 m Weir, and assuming Current climate and land use conditions, resulted in long and frequent spells of >15 ha of land inundated, and scattered spells of >25 ha inundated in the winter months (Figure 166 and Figure 167). The Dry climate scenario produced a similar pattern of spells, but they were shorter and less frequent (Figure 166 and Figure 167).

10.10 Summary

The numerical water balance model known as SWET was used to model the water level time series' in Lake Condah. The only calibration undertaken on the model was to adjust the groundwater parameters in order to achieve the best possible model fit to the observed Lake level data from 1988 to 1993. After calibration, the model fitted the 1992/93 data very well, but was less than ideal for the other years. However, considering the difficulty of the modelling task, the model makes adequate predictions of water levels. Once the parameters that determine the rate of groundwater seepage were optimized to achieve the best model fit, these parameters were not adjusted for other model runs. The model predicted water level should be interpreted as the Lake level in the southwestern part of the Lake, where the gauge is located. This area has sinkholes and is known to experience rapid drawdown (the model was calibrated to fit the observed pattern of drawdown). The northern and western parts of the Lake (which do not have sinkholes) should be expected to recede slowly from a level of 50.9 m while the southwestern section is receding rapidly.

Uncertainty in the model predictions arises from unavoidable inaccuracies in the modelling process. However, possibly a greater source of uncertainty, from the management perspective, is the uncertainty of future climate and runoff. A number of scenarios were generated, but there is no guarantee that any of these scenarios will eventuate in the future. Overall, the predicted Lake water levels are regarded as an adequate basis for decision making.

The climate and land use change scenarios suggest that future conditions would not be favourable for maintaining year-round high water levels in Lake Condah. The future Dry climate scenario in particular creates reasonably frequent dry periods in the Lake. This can be offet to some degree by selecting a high weir crest and adopting a low value for the minimum environmental flow.

Weir heights of 51.6 m to 53 m will produce different Lake water level regimes. The higher the weir crest, the closer is the regime to the natural regime. However, the higher the crest, the less complete are the flood hydrographs passing to downstream to Darlot Creek. A higher weir crest will maintain Lake levels longer, but a higher weir crest will also have shorter and less frequent periods of spill (when fish passage is open).

The calculated SDL winterfill volume for Darlot Creek catchment, if diverted, will result in a reduction in the mean annual flow of around 11% - 16%, depending on the future flow scenario. The SDL rules prevent impact on low flows and they have a relatively minor impact on the magnitude of high flows, so winterfill diversions will not have a drastic impact on the hydrology of a restored Lake Condah. The impact of winterfill diversions on the hydrology of a restored Lake Condah is greater the drier is the future runoff regime and the higher is the weir crest.

There is a direct trade-off between the objectives of releasing environmental flows to Darlot Creek and maintaining high water levels in Lake Condah. Management of these conflicting objectives requires careful consideration by stakeholders.

Depending on the combination of weir height and environmental flow, the simple fixed weir design will provide fish passage for much of the critical migration period – spring and early summer.

Up to 40 ha of the northwestern corner of the Lake bed is privately owned land. This area applies during extreme floods, while for the 1 in 1 year flood the area is 15 ha. Presently, the private land floods relatively frequently, but for very short periods. For example, 10 ha or more is flooded for 10% of the time. Restoration of the hydrology of Lake Condah increases the duration and frequency of flooding of the private land. The higher is the weir, the greater is the effect; the drier is the future runoff regime, the less is the effect. For example, for a 52.4 m weir, for current runoff conditions, 10 ha or more will be flooded for 90% of the time, while for future dry climate conditions 10 ha or more will be flooded for 65% of the time.

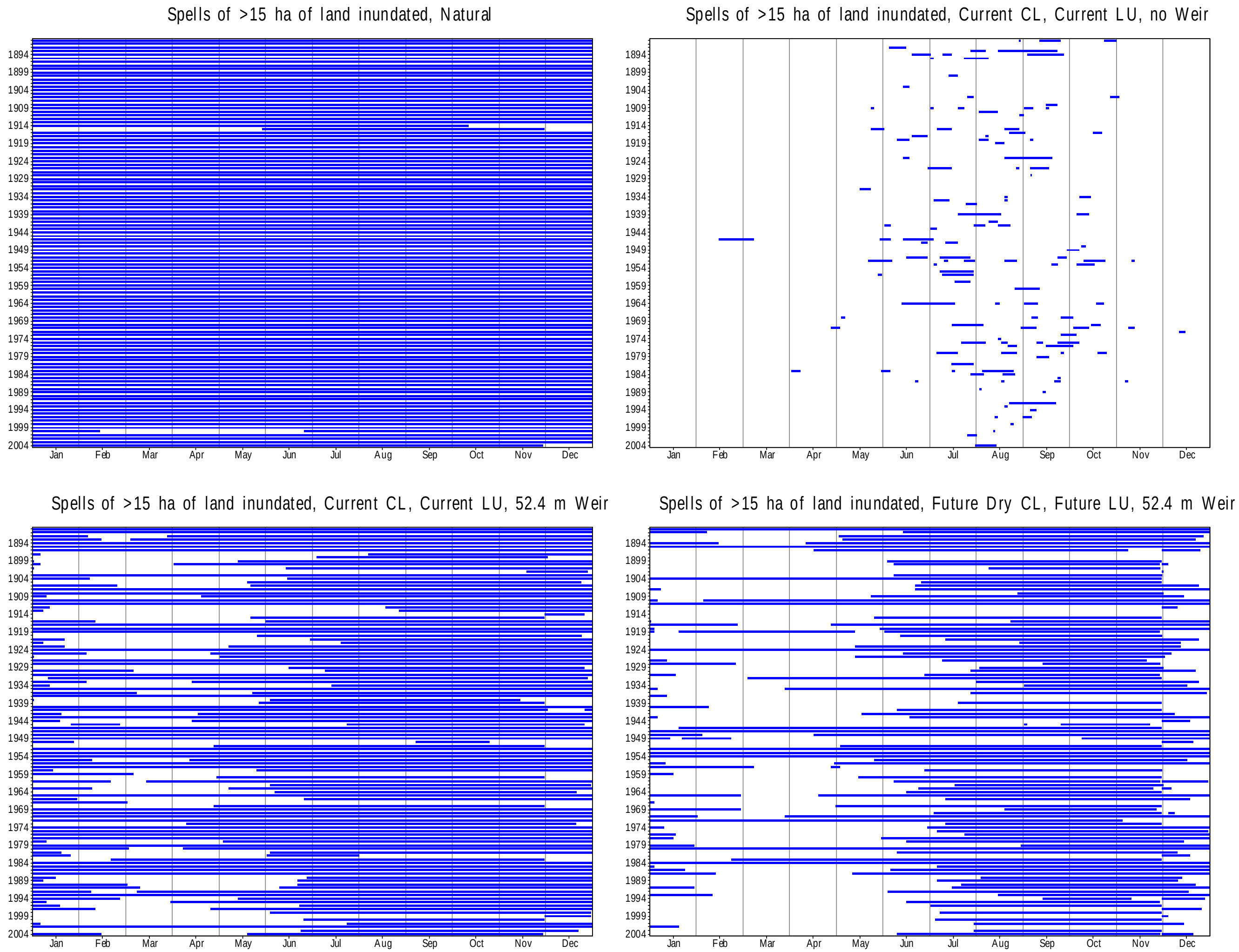


Figure 166. Distribution of spells of >15 ha of private land inundated under Natural scenario, Current (no Weir and 52.4 m Weir situation) scenarios and Future Dry climate scenario (with 52.4 m Weir). CL is climate, LU is land use scenarios.

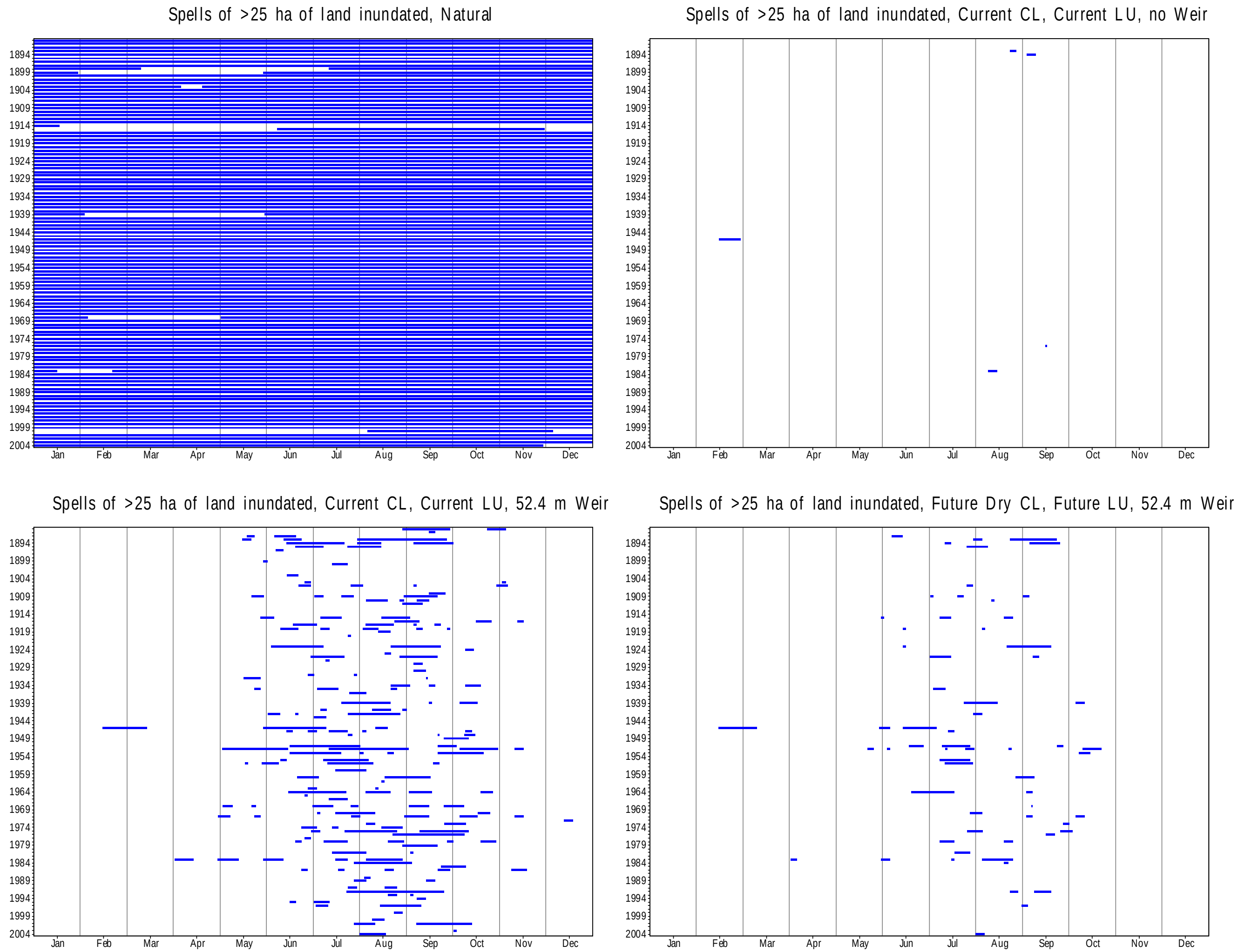


Figure 167. Distribution of spells of >25 ha of private land inundated under Natural scenario, Current (no Weir and 52.4 m Weir situation) scenarios and Future Dry climate scenario (with 52.4 m Weir).

11 Conclusions and Recommendations

11.1 Conclusions

[1] It is possible to restore the water regime of Lake Condah to a close to natural regime. The natural regime can be fully recreated but this would require a very high structure (around 54.5 m AHD) that would pose difficulties for fish passage, and generate flooding over much of Condah Swamp. The natural Lake Condah appeared not to spill very frequently, but it is likely that sub-surface flows maintained baseflow in Darlot Creek virtually year-round.

[2] The climate and land use change scenarios suggest that future conditions would not be favourable for maintaining year-round high water levels in Lake Condah. The future Dry climate scenario in particular creates reasonably frequent dry periods in the Lake. This can be offet to some degree by selecting a high weir crest and adopting a low value for the minimum environmental flow.

[3] Weir heights of 51.6 m to 53 m will produce different Lake water level regimes. The higher the weir crest, the closer is the regime to the natural regime. However, the higher the crest, the less complete are the flood hydrographs passing to downstream to Darlot Creek. A higher weir crest will maintain Lake levels longer, but a higher weir crest will also have shorter and less frequent periods of spill (when fish passage is open).

[4] The calculated SDL winterfill volume for Darlot Creek catchment, if diverted, will result in a reduction in the mean annual flow of around 11% - 16%, depending on the future flow scenario. The SDL rules prevent impact on low flows and they have a relatively minor impact on the magnitude of high flows, so winterfill diversions will not have a drastic impact on the hydrology of a restored Lake Condah. The impact of winterfill diversions on the hydrology of a restored Lake Condah is greater the drier is the future runoff regime and the higher is the weir crest.

[5] There is a direct trade-off between the objectives of releasing environmental flows to Darlot Creek and maintaining high water levels in Lake Condah. Management of these conflicting objectives requires careful consideration by stakeholders.

[6] Depending on the combination of weir height and environmental flow, the simple fixed weir design will provide fish passage for much of the critical migration period – spring and early summer.

[7] Up to 40 ha of the northwestern corner of the Lake bed is privately owned land. This area applies during extreme floods, while for the 1 in 1 year flood the area is 15 ha. Presently, the private land floods relatively frequently, but for very short periods. For example, 10 ha or more is flooded for 10% of the time. Restoration of the hydrology of Lake Condah increases the duration and frequency of flooding of the private land. The higher is the weir, the greater is the effect; the drier is the future runoff regime, the less is the effect. For example, for a 52.4 m weir, for current runoff conditions, 10 ha or more will be flooded for 90% of the time, while for future dry climate conditions 10 ha or more will be flooded for 65% of the time.

[8] There are two licenced diverters downstream of Lake Condah. Their requirements are to each pump around 15 ML/d from the Darlot Creek for 2 – 3 days per month during February and March (for an annual total of 90 ML per licence). The pumps are all located downstream of Homerton. The low flow hydrology of Darlot Creek at Homerton and further downstream is partly determined by flows from above Lake Condah and partly by groundwater inflows (which comprise a significant component of the flow). Restoration of Lake Condah could mean reducing the outflows to Darlot Creek, but this could well be compensated by increased groundwater inflows to the Creek. In fact, storage of water in Lake Condah (which is known to be leaky) could increase the duration of the baseflow recession in Darlot Creek, perhaps increasing the security of supply for these licence holders. If, under conditions of a restored Lake Condah, baseflows in Darlot Creek are lower than present, one option might be for pumpers to reduce their pumping rate, and pump for longer. These issues are best resolved through adaptive management.

[9] Of all the aspects investigated in this study, seepage from the Lake is the most uncertain. There was very little calibration data available, so it is not known whether the assumed seepage function applies over the wider range of Lake levels.

[10] The surface water hydrology of Lake Condah and Darlot Creek was reasonably well characterized by this study, although only a few years of reliable calibration data were available. Until more gauged flow data are collected from Myamyn and more gauged Lake level data are collected, nothing more can be done to improve on the knowledge of the hydrology.

[11] The ecology of Lake Condah was reasonably well described in this study, but the environmental flow needs of Darlot Creek are known only to a rudimentary level.

[12] In terms of the plants and animals (fish and macroinvertebrates) becoming adapted to the last 50 years of altered hydrology, the ecosystem will have adjusted to some degree (it may still be in some sort of transition). It is likely that all or most of the components of the original system are still in existence, but in a different combination or abundance. The native species have a deal of resilience and ability to survive (although not necessarily flourish) under altered hydrological conditions.

[13] When the Lake Condah regime is restored to something more closely resembling its previous condition, the species present will re-adjust to this regime, with a likelihood of increased abundance and diversity. In Darlot Creek, the upper section immediately downstream of Lake Condah was once fed almost exclusively by groundwater, although the flow rate would have varied seasonally, and occasionally a large flood event would overtop the Lake and pass into the Creek. Downstream of around Homerton, inflows from tributaries would have added to flow variability. Under conditions of a restored Lake Condah, the flow regime of the section of Darlot Creek from Lake Condah to around Homerton will become more groundwater dependent, but still have more freshes and floods than under the natural regime. Flow from the outflow pipe from the Lake will vary slightly with lake level, and additional variability will be added by seasonal variations in groundwater contributions. Downstream of around Homerton, the regime will be similar to the current regime, but with more extended baseflows, a few less early season freshes (i.e. those sources exclusively in the upper catchment) and some freshes muted in magnitude (i.e. lacking the stormflow contribution from the upper catchment). These changes do not present a substantial risk to the native species that are present.

11.2 Recommendations

[1] The results of the modelling undertaken in this study should be viewed with a degree of caution, but not necessarily more so than is normally warranted for a study of this type. The results are an adequate basis on which to make management decisions. It is recommended that the Lake Condah hydrological restoration project proceed, using the results presented in this report to help guide the planning.

[2] There are tradeoffs involved between weir height, environmental flows, Lake levels and flooding of Condah Swamp and private land on the lake bed. In general, the results of this study suggest that the higher the weir crest, the closer will be the flow regime to the former “natural” regime. If the negative impacts of high Lake water levels can be tolerated or ameliorated, then a weir crest towards the high end should be selected.

[3] Given the range of factors considered in this study, a weir crest height of 52.4 m is recommended. This aligns with previous recommendations made in respect to potential weir height. A weir of 52.4 m is a good balance between the need to: maintain generally high water levels in the Lake for ecological restoration (i.e. provide fish habitat and conditions suitable for weland vegetation); activate existing eel trap systems; maintain a large surface area of inundated Lake bed; provide seasonal spills over the crest to Darlot Creek (also allowing open fish passage); and minimize the impact on uncontrolled flooding of Condah Swamp. The restoration project should be reviewed periodically (say every 5 to 10 years), and the desirability, or otherwise, of raising the weir crest height can be investigated then.

[4] A simple fixed crest weir structure is recommended over a more complex and expensive structure that requires operational attention. The structure should be built in such a way that it would be relatively strightworward to raise the crest height at a later date if it was so desired.

[5] The issue of environmental flows to Darlot Creek is not fully resolved. It is recommended that a FLOWS study be commissioned for Darlot Creek. This should be completed prior to final design and construction of a weir at Lake Condah.

[6] At present the required environmental flows is unknown, so any structure that is being considered should include a facility for passing flows up to 30 ML/d as a minimum requirement.

[7] The diversion wier on the northern end of Lake Condah will become obsolete once a weir is installed on the southwestern end of the Lake. This weir should be decommissioned, thereby removing a potential barrier to fish movement (when the Lake is at a low level).

[8] Improved understanding of the hydrogeology will be gained by implementing a program of monitoring bores, and flow gauging in Darlot Creek.

[9] Ultimately, management of Lake Condah will require an adaptive approach. Some aspects of the Lake's hydrology (under a future scenario) can only be known through observation. It is recommended that any attempt to restore the Lake's hydrology be incorporated into a well planned and well funded adaptive management program.

[10] There will be risks and uncertainties associated with hydrological restoration. A continued dry climate period may result in a managed Lake drying out for periods of time, regardless of the type of structure installed. Future management of the Lake will need to embrace uncertainty, and an effort will be required to ensure that community expectations are aligned with this principle.

11.3 Recommended further work

11.3.1 Environmental flows study for Darlot Creek

Progress was made in this study with environmental flows for Darlot Creek, and most of the relevant issues have been established. However, the work was constrained by lack of time and resources (i.e. beyond the project scope), and lack of ecologically-related hydraulic modelling of the Creek downstream of Lake Condah. It is recommended that a FLOWS study be undertaken. The following points are relevant to preparing a brief for such a study:

- The study area should be from Lake Condah to, and including, the estuary.
- There is no need to commission a REALM model for the Darlot Creek catchment. There is only low level water resources development tin the catchment, and suitable data are available from gauges on Darlot Creek at Homerton and the Fitzroy River at Heywood. Flows from Lake Condah and water levels in Lake Condah have been well characterized in this study and are ideal for use in the FLOWS study. The study area should be divided into five reaches:
    1. Lake Condah
    2. Artificially excavated channel section downstream of Lake Condah (terminates upstream of Condah Mission);
    3. Natural course of Darlot Creek to Homerton;
    4. Homerton to Fitzroy River; and
    5. Fitzroy junction to and including estuary.
- Channel and floodplain surveys are required in a representative area of Reaches 2 to 5.
- The study will require consideration of groundwater inflows to Darlot Creek.
- The study needs to consider the water requirements of wetlands downstream of Homerton.
- The study needs to consider the water requirements of any culturally significant sites.
- The study will need to consider the historical impact of construction of Condah Drain through Lake Condah on the ecology of Darlot Creek, and the potential impacts (both positive/negative) of restoring a more baseflow driven hydrological regime to Darlot Creek as part of the Lake Condah hydrological restoration Plan.

- The study will need to address the possible tradeoff in ecological value between the current and a restored Lake Condah wetland environment versus the current and a future (under a restored Lake Condah regime) Darlot Creek aquatic environment.

11.3.2 Groundwater monitoring

The groundwater monitoring program should be centred on Lake Condah with 5 sites, each having two piezometers (shallow and deep) as a nest covering both the alluvial aquifer and the basalt aquifer. The bores should be constructed as piezometer nests, with a shallow and deeper bore at each site to establish the direction and extent of vertical groundwater flux as well as lateral flow parameters. The screens would be at perhaps 5 – 6 m and 20 – 22 m depending on lithologies. In order to test the relationship between the Lake and the Tertiary aquifers, especially the Clifton Formation (which is utilized in the Condah WSPA where it shows falling groundwater levels which might affect the Lake), one of the Lake sites should also include two additional bores, one screened in the Port Campbell Limestone (say 35 – 38 m) and the other in the Clifton Formation (approx. 75 – 80 m). In addition, 3 sites should be established on the stony rise areas to the south across the likely flow path to monitor the response in the basalt aquifer to Lake level fluctuations. These could be perhaps from 0.5 km to 1 km from the Lake; however these sites as well as the lakeside sites can only be determined after a further inspection of the area.

The number of sites for a meaningful monitoring system would probably be about 8, with dual piezometers at each site, but with three or four piezometers as a nest (including the two deeper Tetriary bores) at a main site probably near the central sink hole near the gauge pool. The original SR&WSC work suggested about 8 sites with piezometer nests around the Lake. The program recommended here has 5 sites near the Lake and 3 sites on the downbasin side of the Lake in the stony rise basalt.

The bore sitings described above are only provisional; any final siting of monitoring bores would require some additional work including a trip to Lake Condah to determine the suitability of sites around the Lake and the sites further downbasin on the basalts. Final site selection could only be made after closer inspection of the Lake and surroundings. This would require several days for field work and a further 2 days for reporting.

The cost of drilling can only be determined by obtaining quotes from three drillers in SW Victoria who have the hard rock drilling capacity (down the hole hammer and compressor) required for the basalts.

Summary of bore requirements:

1. Lake Condah

   Five monitoring sites:

   - 5 shallow holes in alluvium, each to 5 – 6 m
   - 5 deeper holes in basalt, each to 25 m depending on thickness of the basalt
   - 1 deeper bore in the Port Campbell Limestone ~80 m
   - 1 deeper bore in the Clifton Formation ~200 m

2. Stony Rises to south of Lake Condah

   Three monitoring sites:

   - Each with a bore in the basalt to 25 m
   - Each bore will be completed with PVC casing and require a 2 m screen

No specific costs have been sought from contractors, but down-the hole hammer work can be done at an approximate cost of about $120/metre (including PVC screen and casing). It is more expensive than other drilling because of the large amount of diesel used in the process. On this basis a very rough estimate of drilling costs based on 510 m is about $60,000. This is at best approximate and would have to be properly determined should any such monitoring program be proceeded with.

Given that the actual thickness of the stratigraphic units is poorly known, and there is a requirement for flexibility on siting, the drilling should be closely supervised by a qualified hydrogeologist. The establsihment of specific monitoring sites and the costing of the drilling program prior to the event would also require funding of a two to three day firld trip and a small report.

11.3.3 Surface water monitoring

The Lake Condah water level gauge needs to be recommissioned and maintained.

Mayamyn gauge has recently been recommissioned. This gauge provides important data and operation of the gauge should be maintained.

A study of inflows to Darlot Creek from Lake Condah to Homerton (during non-storm flow conditions) should be undertaken. This would take the form of gauging the stream flow (and recording hydraulic conductivity) at a number of approximately equally spaced locations (say 10) on a number of occasions (say 3 occasions initially, and then review the data). This study should be undertaken before and after the hydrological restoration at Lake Condah. A rough estimate of the cost of this gauging exercise, including data processing and reporting, is around $6,000 - $8,000 per round of surveys; the cost could be firmed by obtaining quotes from specialist hydrographers.

11.3.4 Ecological monitoring

It is recommended that the ecosystem is monitored to measure how plant and waterbird habitat responds to changes in water regime. Fish monitoring is obviously required, as restoration of eel populations is one of the main objectives of the Lake Condah water restoration project. Fish monitoring will also be required to check the effectiveness of the fishway. No details are provided here on fish and macroinvertebrate monitoring, as it is assumed that this will be addressed by a more specific investigation. A program based on SRA (Sustainable Rivers Audit) for fish and EPA Rapid Bioassessment for invertebrates would be suitable.

Vegetation monitoring:

- It is expected that by changing the water regime of the Lake, the distribution of plant communities will change. It is expected that as the Lake becomes wetter, the area available to aquatic species will expand and other wetland plant communities will expand and take up more of the Lake bed area. It is expected that terrestrial plant communities will be displaced.
- Survey data can be collected to test whether the intended balance of plant habitats is achieved. This is best done with a linear transect radiating from the deepest part of the Lake to the shallowest, with replicated samples of plant abundance taken at fixed points. The transect represents a gradient in water regime and plants will migrate up or down the gradient as water management in the Lake changes. The survey would be repeated annually of every two years. Trends can be reported as each survey is completed.
- Aerial photography can supplement the survey. Photographs should be collected (or commissioned if not available) for the same time of year, preferrably late spring. The boundaries of major plant communities can be digitised and simple statistics produced to report changes, such as the total area of each plant community. Historical aerial photographs could provide useful context to ongoing monitoring.
- A baseleine vegetation survey, data entry templates and a manual for ongoing monitoring could be prepared for around $7,000.

Waterbird monitoring:

- Annual waterbird counts are recommended every spring. The counts should report the number of birds of each species and their general behaviours (such as nesting, roosting, loafing, diving, foraging etc.) in the available habitat components such as open water, reeds, shrubs, grassland etc. Every two years these data should be reviewed and linked to the vegetation data to confirm that habitats are being managed in accordance with ecological objectives.
- A baseline waterbird survey, data entry templates and a manual for ongoing monitoring could be prepared for around $7,000.

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Appendix A

List of plants recorded in Lake Condah and Darlots Creek and date of last reported sighting. Ecology Australia (2006) provides a complete list of species associated with the Mount Eccles Lava Flow.

Scientific Name	Common Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act
Acacia mearnsii	Black Wattle		16/8/91			
Acacia melanoxylon	Blackwood	14/8/91	30/4/04			
Acaena echinata	Sheep's Burr	14/8/91	16/8/91			
Acaena novae-zelandiae	Bidgee-widgee	11/12/91	30/4/04			
**Acetosella vulgaris*	Sheep Sorrel		16/8/91			
Adiantum aethiopicum	Common Maidenhair		16/8/91			
Agrostis s.l. spp.	Bent/Blown Grass	11/12/91				
**Agrostis stolonifera*	Creeping Bent		30/4/04			
Ajuga australis	Austral Bugle		16/8/91			
**Alopecurus geniculatus*	Marsh Fox-tail	11/12/91	11/12/91			
Amphibromus sinuatus	Wavy Swamp Wallaby-grass	11/12/91			Vul	
Amphibromus spp.	Swamp Wallaby-grass		16/8/91			
Amyema preissii	Wire-leaf Mistletoe	14/8/91	16/8/91			
**Anagallis arvensis*	Pimpernel	14/8/91	30/4/04			
Anogramma leptophylla	Annual Fern		4/9/49			
**Anthoxanthum odoratum*	Sweet Vernal-grass		16/8/91			
**Aphanes arvensis*	Parsley Piert	14/8/91	16/8/91			
**Arctotheca calendula*	Cape Weed		16/8/91			
Asperula subsimplex	Water Woodruff	11/12/91	11/12/91			
Asplenium flabellifolium	Necklace Fern	14/8/91	6/8/91			
**Atriplex prostrata*	Hastate Orache		30/4/04			
Austrodanthonia racemosa var. racemosa	Stiped Wallaby-grass	14/8/91	16/8/91			
Azolla filiculoides	Pacific Azolla		30/4/04			
Bolboschoenus medianus	Club-sedge	11/12/91	30/4/04			
**Bromus catharticus*	Prairie Grass	11/12/91	11/12/91			
**Bromus diandrus*	Great Brome	11/12/91	11/12/91			
**Bromus hordeaceus subsp. hordeaceus*	Soft Brome		16/8/91			
Calandrinia calyptrata	Pink Purslane	14/8/91				
**Callitriche stagnalis*	Common Starwort	25/1/77				
Calystegia sepium subsp. roseata	Large Bindweed		30/4/04			
Cardamine paucijuga s.l.	Annual Bitter-cress		16/8/91			
**Carduus pycnocephalus*	Slender Thistle	11/12/91	11/12/91			
**Carduus tenuiflorus*	Winged Thistle	11/12/91	11/12/91			
Carex appressa	Tall Sedge	11/12/91	30/4/04			
Carex incomitata	Hillside Sedge		6/8/91			
Carex inversa	Knob Sedge	11/12/91				
Carex tereticaulis	Poong'ort		16/8/91			
Cassinia longifolia	Shiny Cassinia	14/8/91	16/8/91			
**Cerastium glomeratum s.l.*	Common Mouse-ear Chickweed	11/12/91	11/12/91			
Cheilanthes austrotenuifolia	Green Rock-fern	14/8/91				
**Cirsium vulgare*	Spear Thistle	11/12/91	30/4/04			
Clematis microphylla	Small-leaved Clematis	14/8/91	16/8/91			
**Conyza sumatrensis*	Tall Fleabane	11/12/91	11/12/91			

Scientific Name	Common Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act
**Cotula coronopifolia*	Water Buttons	11/12/91	30/4/04			
Crassula helmsii	Swamp Crassula	11/12/91	30/4/04			
Crassula tetramera	Australian Stonecrop	11/12/91	11/12/91			
Cyperus gunnii subsp. gunnii	Flecked Flat-sedge		30/4/04			
**Dactylis glomerata*	Cocksfoot		30/4/04			
Dichondra repens	Kidney-weed	11/12/91	30/4/04			
**Dipsacus fullonum subsp. fullonum*	Wild Teasel	14/8/91	30/4/04			
Doodia caudata	Small Rasp-fern		3/4/99			
Eleocharis acuta	Common Spike-sedge	11/12/91	30/4/04			
Eleocharis gracilis	Slender Spike-sedge	11/12/91	15/8/91			
Eleocharis sphacelata	Tall Spike-sedge	14/8/91	30/4/04			
Epilobium billardierianum subsp. cinereum	Grey Willow-herb	14/8/91	16/8/91			
Eucalyptus ovata var. ovata	Swamp Gum		30/4/04			
Eucalyptus viminalis	Manna Gum	14/8/91	16/8/91			
Euchiton collinus s.s.	Creeping Cudweed	14/8/91	16/8/91			
Euchiton involucratus s.s.	Star Cudweed	25/1/77	30/4/04			
**Galium aparine*	Cleavers		30/4/04			
**Geranium molle var. molle*	Dovesfoot	14/8/91	16/8/91			
Geranium retrorsum s.l.	Grassland Cranesbill		6/8/91			
Geranium solanderi s.l.	Austral Cranesbill	11/12/91	11/12/91			
Glyceria australis	Australian Sweet-grass		11/12/91			
**Helminthotheca echioides*	Ox-tongue		30/4/04			
**Holcus lanatus*	Yorkshire Fog	11/12/91	30/4/04			
**Hordeum hystrix*	Mediterranean Barley-grass	25/1/77				
**Hordeum marinum*	Sea Barley-grass	11/12/91	11/12/91			
**Hordeum murinum s.l.*	Barley-grass		16/8/91			
Hydrocotyle laxiflora	Stinking Pennywort		16/8/91			
Hydrocotyle sibthorpioides	Shining Pennywort		16/8/91			
Hydrocotyle tripartita	Slender Pennywort	11/12/91	11/12/91			
Hypericum gramineum	Small St John's Wort	14/8/91	16/8/91			
**Hypochoeris glabra*	Smooth Cat's-ear	11/12/91				
**Hypochoeris radicata*	Cat's Ear	11/12/91	11/12/91			
Imperata cylindrica	Blady Grass		5/4/63			
Isolepis cernua var. cernua	Nodding Club-sedge	11/12/91				
Isolepis fluitans	Floating Club-sedge	11/12/91	30/4/04			
Isolepis inundata	Swamp Club-sedge		30/4/04			
Isolepis producta	Nutty Club-sedge	11/12/91	11/12/91			
Isolepis spp.	Club Sedge	11/12/91	11/12/91			
Isotoma fluviatilis subsp. australis	Swamp Isotome		15/8/91			
**Juncus articulatus*	Jointed Rush	11/12/91	11/12/91			
Juncus bufonius	Toad Rush	11/12/91				
Juncus pallidus	Pale Rush	11/12/91	11/12/91			
Juncus procerus	Tall Rush	11/12/91	30/4/04			
Lachnagrostis filiformis	Common Blown-grass	11/12/91	30/4/04			
Lastreopsis acuminata	Shiny Shield-fern	1/1/50				
Lemna disperma	Common Duckweed		30/4/04			
**Leontodon taraxacoides subsp. taraxacoides*	Hairy Hawkbit	11/12/91	30/4/04			

Scientific Name	Common Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act
Leptinella reptans s.l.	Creeping Cotula	11/12/91	11/12/91			
#Leptospermum laevigatum	Coast Tea-tree	12/10/68				
Lilaeopsis polyantha	Australian Lilaeopsis	11/12/91	30/4/04			
Lobelia pratioides	Poison Lobelia	11/12/91				
**Lolium perenne*	Perennial Rye-grass	11/12/91	30/4/04			
**Lolium rigidum*	Wimmera Rye-grass		11/12/91			
**Lotus corniculatus*	Bird's-foot Trefoil		15/8/91			
Lythrum hyssopifolia	Small Loosestrife	11/12/91	30/4/04			
**Lythrum junceum*	Mediterranean Loosestrife		30/4/04			
Malva australiana s.s.	Australian Hollyhock	11/12/91	11/12/91			
Mazus pumilio	Swamp Mazus	11/12/91				
**Medicago minima*	Little Medic	14/8/91				
Melicytus spp.	Tree Violet	11/12/91	11/12/91			
Mentha australis	River Mint	14/8/91				
Mentha satureoides	Creeping mint	11/12/91				
**Mentha spicata*	Spearmint		11/12/91			
Microlaena stipoides var. stipoides	Weeping Grass		16/8/91			
Myriophyllum crispatum	Upright Water-milfoil	11/12/91				
Myriophyllum integrifolium	Tiny Water-milfoil		2/8/52			
Myriophyllum salsugineum	Lake Water-milfoil	11/12/91	11/12/91			
Myriophyllum simulans	Amphibious Water-milfoil	11/12/91	15/8/91			
Myriophyllum verrucosum	Red Water-milfoil	11/12/91				
**Nasturtium microphyllum*	Brown Watercress		21/1/70			
**Nasturtium officinale*	Watercress		30/4/04			
Neopaxia australasica	White Purslane	11/12/91	30/4/04			
Oxalis exilis	Shady Wood-sorrel		30/4/04			
**Parentucellia viscosa*	Yellow Bartsia	11/12/91				
Parietaria debilis s.l.	Shade Pellitory	14/8/91	16/8/91			
**Paspalum distichum*	Water Couch		11/12/91			
Pellaea falcata s.l.	Sickle Fern		3/4/99			
Pellaea falcata s.s.	Sickle Fern		1/9/49			
Persicaria decipiens	Slender Knotweed	14/8/91	30/4/04			
Persicaria prostrata	Creeping Knotweed	11/12/91	30/4/04			
**Petrorhagia spp.*	Pink		16/8/91			
Phragmites australis	Common Reed		30/4/04			
Pilularia novae-hollandiae	Austral Pillwort		15/10/52		Rare	
**Plantago coronopus*	Buck's-horn Plantain	11/12/91				
**Plantago lanceolata*	Ribwort		30/4/04			
Pleurosorus rutifolius s.s.	Blanket Fern		4/9/49			
**Poa annua*	Annual Meadow-grass	11/12/91	11/12/91			
Poa ensiformis	Sword Tussock-grass	14/8/91	16/8/91			
Poa labillardierei	Common Tussock-grass		6/8/91			
**Poa pratensis*	Kentucky Blue-grass	11/12/91	11/12/91			
**Polycarpon tetraphyllum*	Four-leaved Allseed	14/8/91	2622			
Potamogeton ochreatus	Blunt Pondweed		30/4/04			
Potamogeton pectinatus	Fennel Pondweed		11/12/91			
Potamogeton tricarinatus s.l.	Floating Pondweed	11/12/91	11/12/91			
**Potentilla anserina*	Silverweed	11/12/91	30/4/04			
**Prunella vulgaris*	Self-heal	11/12/91				
Pteridium esculentum	Austral Bracken	14/8/91	16/8/91			
Pterostylis curta	Blunt Greenhood	14/8/91				

Scientific Name	Common Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act
Ranunculus amphitrichus	Small River Buttercup	11/12/91	11/12/91			
**Ranunculus muricatus*	Sharp Buttercup		21/8/49			
**Ranunculus repens*	Creeping Buttercup	11/12/91				
Ranunculus sessiliflorus var. sessiliflorus	Annual Buttercup		16/8/91			
Ranunculus spp.	Buttercup		30/4/04			
Ricciocarpos natans	Fringed Heartwort		3/4/99			
**Rosa rubiginosa*	Sweet Briar	11/12/91	30/4/04			
Rubus parvifolius	Small-leaf Bramble		16/8/91			
Rumex bidens	Mud Dock		30/4/04			
Rumex brownii	Slender Dock		11/12/91			
**Rumex conglomeratus*	Clustered Dock		30/4/04			
**Rumex crispus*	Curled Dock		30/4/04			
Schoenoplectus tabernaemontani	River Club-sedge		11/12/91			
Schoenus apogon	Common Bog-sedge	11/12/91				
Schoenus maschalinus	Leafy Bog-sedge	11/12/91				
Senecio pinnatifolius	Variable Groundsel	11/12/91	11/12/91			
Senecio quadridentatus	Cotton Fireweed		16/8/91			
**Silybum marianum*	Variegated Thistle	11/12/91	11/12/91			
Solanum laciniatum	Large Kangaroo Apple	11/12/91	11/12/91			
**Solanum nigrum sensu Willis (1972)*	Black Nightshade	14/8/91				
**Solanum pseudocapsicum*	Madeira Winter-cherry		15/10/52			
**Sonchus asper s.l.*	Rough Sow-thistle	14/8/91	30/4/04			
**Sonchus oleraceus*	Common Sow-thistle	11/12/91	30/4/04			
**Sparganium erectum*	Branching Bur-reed		30/4/04			
Stellaria angustifolia	Swamp Starwort	11/12/91	15/8/91			
**Stellaria media*	Chickweed	14/8/91	16/8/91			
**Stellaria pallida*	Lesser Chickweed	11/12/91	11/12/91			
**Taraxacum officinale spp. agg.*	Garden Dandelion		16/8/91			
**Trifolium dubium*	Suckling Clover		16/8/91			
**Trifolium fragiferum var. fragiferum*	Strawberry Clover	11/12/91				
**Trifolium fragiferum var. fragiferum*	Strawberry Clover		30/4/04			
**Trifolium repens var. repens*	White Clover	11/12/91	30/4/04			
**Trifolium spp.*	Clover	14/8/91				
**Trifolium subterraneum*	Subterranean Clover	14/8/91	16/8/91			
Triglochin procera s.l.	Water Ribbons	11/12/91	30/4/04			
Triglochin spp.	Water Ribbons		11/12/91			
Triglochin striata	Streaked Arrowgrass	11/12/91				
Typha domingensis	Narrow-leaf Cumbungi		11/12/91			
**Ulex europaeus*	Gorse		30/4/04			
Urtica incisa	Scrub Nettle	11/12/91	30/4/04			
**Urtica urens*	Small Nettle	14/8/91				
Vallisneria americana var. americana	Eel Grass		30/4/04			
**Verbascum virgatum*	Twiggy Mullein		11/12/91			
**Veronica catenata*	Pink Water-speedwell		11/12/91			
**Veronica persica*	Persian Speedwell	11/12/91	16/8/91			
**Vicia sativa*	Common Vetch	11/12/91	16/8/91			

Scientific Name	Common Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act
**Vulpia bromoides*	Squirrel-tail Fescue	14/8/91	11/12/91			
Wolffia australiana	Tiny Duckweed		30/4/04			
**X Agropogon littoralis*	Perennial Beard-grass	25/1/77				

EPBC Status= Conservation status under the *Environmental Protection and Biodiversity Conservation Act*
Vic Status = Conservation status in Victoria according to the Department of Sustainability
FFG Act = Species listed under the *Flora and Fauna Guarantee Act*

Appendix B

List of water-dependent fauna species recorded in an approximate 20 km radius of the study area and date of last sighting for all species observed in Lake Condah and Darlot Creek.

Common Name	Scientific Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act	CAMBA or JAMBA
Musk Duck	*Biziura lobata*		1983		VU		
Great Cormorant	*Phalacrocorax carbo*	1993	1999				
Baillon's Crake	*Porzana pusilla*		1999		VU	L	
Whiskered Tern	*Chlidonias hybridus*		1999		NT		
Australian Spotted Crake	*Porzana fluminea*		1999				
Darter	*Anhinga melanogaster*		1999				
Banded Stilt	*Cladorhynchus leucocephalus*		1999				
Pink-eared Duck	*Malacorhynchus membranaceus*		1999				
Little Grassbird	*Megalurus gramineus*		1999				
Clamorous Reed Warbler	*Acrocephalus stentoreus*		1999				
Cattle Egret	*Ardea ibis*		1999				+
Latham's Snipe	*Gallinago hardwickii*		2000		NT		+
Australian Wood Duck	*Chenonetta jubata*		2000				
Purple Swamphen	*Porphyrio porphyrio*	1993	2001				
Little Pied Cormorant	*Phalacrocorax melanoleucos*	1993	2001				
Australian White Ibis	*Threskiornis molucca*	1993	2001				
Straw-necked Ibis	*Threskiornis spinicollis*	1993	2001				
Yellow-billed Spoonbill	*Platalea flavipes*	1993	2001				
White-faced Heron	*Egretta novaehollandiae*	1993	2001				
Black Swan	*Cygnus atratus*	1993	2001				
Australian Shelduck	*Tadorna tadornoides*	1993	2001				
Pacific Black Duck	*Anas superciliosa*	1993	2001				
Grey Teal	*Anas gracilis*	1993	2001				
Swamp Harrier	*Circus approximans*	1993	2001				
Wood Sandpiper	*Tringa glareola*		2001		VU		+
Brolga	*Grus rubicunda*		2001		VU	L	
Royal Spoonbill	*Platalea regia*		2001		VU		
Great Egret	*Ardea alba*		2001		VU	L	+
Magpie Goose	*Anseranas semipalmata*		2001		VU		
Australasian Shoveler	*Anas rhynchotis*		2001		VU		
Hardhead	*Aythya australis*		2001		VU		
Black-tailed Native-hen	*Gallinula ventralis*		2001				
Dusky Moorhen	*Gallinula tenebrosa*		2001				
Eurasian Coot	*Fulica atra*		2001				
Australasian Grebe	*Tachybaptus novaehollandiae*		2001				
Hoary-headed Grebe	*Poliocephalus poliocephalus*		2001				

Common Name	Scientific Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act	CAMBA or JAMBA
Little Black Cormorant	*Phalacrocorax sulcirostris*		2001				
Australian Pelican	*Pelecanus conspicillatus*		2001				
Red-kneed Dotterel	*Erythrogonys cinctus*		2001				
Black-fronted Dotterel	*Elseyornis melanops*		2001				
Black-winged Stilt	*Himantopus himantopus*		2001				
Sharp-tailed Sandpiper	*Calidris acuminata*		2001				+
White-necked Heron	*Ardea pacifica*		2001				
Chestnut Teal	*Anas castanea*		2001				
Cape Barren Goose	*Cereopsis novaehollandiae*	1981			NT		
Painted Snipe	*Rostratula benghalensis*			VU	CR	L	+
Lewin's Rail	*Rallus pectoralis*				VU	L	
Hooded Plover	*Thinornis rubricollis*				VU	L	
Black-faced Cormorant	*Phalacrocorax fuscescens*				NT		
Pied Cormorant	*Phalacrocorax varius*				NT		
Caspian Tern	*Sterna caspia*				NT	L	+
Pacific Golden Plover	*Pluvialis fulva*				NT		+
Sanderling	*Calidris alba*				NT		+
Glossy Ibis	*Plegadis falcinellus*				NT		+
Nankeen Night Heron	*Nycticorax caledonicus*				NT		
Terek Sandpiper	*Xenus cinereus*				EN	L	+
Australasian Bittern	*Botaurus poiciloptilus*				EN	L	
Freckled Duck	*Stictonetta naevosa*				EN	L	
Intermediate Egret	*Ardea intermedia*				CR	L	
Spotless Crake	*Porzana tabuensis*						
Great Crested Grebe	*Podiceps cristatus*						
Short-tailed Shearwater	*Puffinus tenuirostris*						+
Australasian Gannet	*Morus serrator*						
Crested Tern	*Sterna bergii*						
Ruddy Turnstone	*Arenaria interpres*						+
Pied Oystercatcher	*Haematopus longirostris*						
Double-banded Plover	*Charadrius bicinctus*						
Red-capped Plover	*Charadrius ruficapillus*						
Bar-tailed Godwit	*Limosa lapponica*						+
Common Greenshank	*Tringa nebularia*						+
Curlew Sandpiper	*Calidris ferruginea*						+
Red-necked Stint	*Calidris ruficollis*						+
Southern Emu-wren	*Stipiturus malachurus*						
Hutton's Shearwater	*Puffinus huttoni*						
Kelp Gull	*Larus dominicanus*						
*Mallard	*Anas platyrhynchos*						
Swamp Rat	*Rattus lutreolus*						
Southern Water Skink	*Eulamprus tympanum tympanum*		1998				

Common Name	Scientific Name	Lake Condah	Darlot Creek	EPBC Status	Vic Status	FFG Act	CAMBA or JAMBA
Tiger Snake	*Notechis scutatus*						
Spotted Marsh Frog	*Limnodynastes tasmaniensis*		1966				
Striped Marsh Frog	*Limnodynastes peronii*	1993	1992				
Common Froglet	*Crinia signifera*		1992				
Southern Toadlet	*Pseudophryne semimarmorata*				VU		
Southern Smooth Froglet	*Geocrinia laevis*						
Southern Bullfrog	*Limnodynastes dumerilii*						
Southern Brown Tree Frog	*Litoria ewingii*						
Pouched Lamprey	*Geotria australis*		1990				
Mountain Galaxias	*Galaxias olidus*		1990			L	
*Tench	*Tinca tinca*	1990	1999				
Shortfin Eel	*Anguilla australis*		1999				
Common Yabbie	*Cherax destructor*		1999				
Common Galaxias	*Galaxias maculatus*	1990	2001				
Southern Pigmy Perch	*Nannoperca australis*	1990	2001				
Flatheaded Gudgeon	*Philypnodon grandiceps*		2001				
Common Freshwater Shrimp	*Paratya australiensis*		2001				
Glenelg Spiny Cray	*Euastacus bispinosus*		2003		DD	L	
River Blackfish	*Gadopsis marmoratus*		2003				
Yarra Pigmy Perch	*Nannoperca obscura*	1990		VU	NT	L	
Dwarf Galaxias	*Galaxiella pusilla*			VU	VU	L	
*Rainbow Trout	*Oncorhynchus mykiss*						
*Mosquitofish	*Gambusia holbrooki*						
*Redfin	*Perca fluviatilis*						

EPBC Status= Conservation status under the *Environmental Protection and Biodiversity Conservation Act*
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Appendix C

Ecological requirements of key fish species actually or likely to inhabit the Lake Condah and Darlot Creek system.

These data are based on current knowledge but these can only be considered as approximate until further research is conducted on these species [derived from www.fishbase.org; Allen et al. (2002); Koehn and O'Connor (1990); Lloyd (1987); Merrick and Schmida (1984); McDowall (1980); Treadwell and Hardwick (2003)].

Fish Species		Life Span	Spawning Season	Incubation Duration*	Migration	Other
Common Name	Scientific Name					
Australian Smelt	*Retropinna semoni*	1-2 years	Sept - Nov	9-10 days	Active movers between habitats and along anabranches	Aquatic vegetation required as a substrate for laying eggs
Tupong (Congolli)	*Pseudaphritis urvillii*	>5years	Sept - Dec	Unknown (likely to be short 3 or so days)	Adults migrate downstream to estuary for breeding. Juveniles migrate upstream	Congolli are susceptible to impacts from the presence of water flow barriers
Common Jollytail	*Galaxias maculatus*	2-3 years	Aug-Nov	Normally take 10-16 days between flow events or tides (in estuary	Downstream to estuary in Autumn.	Riparian macrophytes (intertidal in estuary) or required as a substrates for laying eggs
Dwarf Galaxias	*Galaxiella pusilla*[^NT, @V]	1 year	Aug - Oct	10-17 days	Local	Frequently associated with aquatic vegetation and eggs are laid in separate batches on flooded vegetation, leaf litter or rocks – preferred egg site is the underside of leaves or stems. Adults probably die after spawning. May use yabby holes to over summer.
River Blackfish	*Gadopsis marmoratus*	4-7 years	Nov - Jan	7 - 10 days (plus 21 days “tethered” larvae)	Local	Hard substrate required – hollow logs as a substrate for laying eggs

Fish Species		Life Span	Spawning Season	Incubation Duration*	Migration	Other
Common Name	Scientific Name					
Pigmy Perch	*Nannoperca australis*	2-5yrs	Sept - Nov	2-4 days	Local	Aquatic plants for spawning and habitat Vegetation or rocks instream habitat required
Yarra Pigmy Perch	*Edelia obscura*^NT, @V	2-5yrs (assuming similar to Southern Pigmy Perch)	Sept - Oct	2-4 days (assuming similar to Southern Pigmy Perch)	Local	Aquatic plants for spawning and habitat Vegetation or rocks instream habitat required
Flat-headed Gudgeon	*Philypnodon grandiceps*	4-7 years	Oct - Feb	4-6 days	Local only	Hard surfaces required as a substrate for laying eggs
Short-finned Eel	*Anguilla australis*	32 years	June - Mar	Unknown as it occurs in the marine environment	Adults migrate to sea during summer and autumn and elvers return into estuaries from Jan - Feb and migrate upstream in subsequent years	Flow requirements really need to consider preservation of adult habitat - rivers and lakes. Breeding is cued by non-flow factors and occurs at sea.

* Time that eggs take to develop into larvae (eggs require inundation at least for this period)
^ FFG listed species in Victoria (FFG Act); ^X = Listed as an Extinct Species under FFG Act; ^CE = Listed as a Critically Endangered Species under FFG Act; ^E = Listed as an Endangered Species under FFG Act; ^V = Listed as a Vulnerable Species under FFG Act; ^NT = Listed as a Near Threatened Species under FFG Act; ^DD = Data Deficient in Victoria (DNRE 2000); V = Listed as Vulnerable (DNRE 2000)
@E = Endangered under EPBC Act; @V = Vulnerable under EPBC Act

Environmental Water Requirements of Darlot Creek and Lake Condah

Final Recommendations

Glenelg Hopkins Catchment Management Authority

by

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Marcus Cooling
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February 2008

FLUVIAL SYSTEMS

in association with

WATER TECHNOLOGY

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Lloyd Environmental

ENVIRONMENTAL WATER REQUIREMENTS OF DARLOT CREEK AND LAKE CONDAH: FINAL RECOMMENDATIONS

For Glenelg Hopkins Catchment Management Authority

Fluvial Systems Pty Ltd

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1 Introduction

1.1 Project context

Lake Condah, as well as being recognised as a Wetland of National Importance, once supported an internationally recognised Kooyang (Eel) aquaculture system. Reinstatement of a more natural inundation regime to Lake Condah is expected to restore ecological, biodiversity and cultural values, including enabling traditional owners to reactivate the Kooyang (Eel) aquaculture system. Hydrological restoration of Lake Condah is central to the broader Lake Condah Sustainable Development Project. While the recent Lake Condah Water Restoration Hydrological Feasibility Study (Gippel et al., 2006) concluded that restoration of the Lake was feasible, one remaining uncertainty from a water resource point of view was environmental flows, which is the focus of this project.

This project uses the Victorian endorsed FLOWS – a method for determining environmental water requirements in Victoria (SKM et al., 2002) (Figure 1) to determine the environmental water requirements to meet environmental objectives for Lake Condah and Darlot Creek (Figure 2). In addition, the project will seek to understand the Fitzroy River estuarine flow objectives, although this is not the major part of the project.

It is anticipated that outcomes and recommendations from this study will assist the Lake Condah Facilitation Group (comprised of a range of agencies and stakeholders) in the decision making process regarding the hydrologic feasibility of restoring a more natural inundation regime at Lake Condah.

1.2 FLOWS study objectives

The overall objective of this project is to determine the environmental water requirements of Darlot Creek (also considering the estuary), and including the associated Lake Condah, and to develop options to meet the environmental needs. More specifically, this investigation will:

- Identify the water dependant environmental and social values within each reach;
- Gauge the current health of the environmental values;
- Assess the current and future threats to these environmental values;
- Identify the streamflow regimes that will maintain, rehabilitate or restore the environmental values;
- Recommend environmental objectives to produce a river that is consistent with the targets and principles of the Regional River Health Strategy, that are acceptable to the local community and take into account Lake Condah water restoration objectives;
- Recommend environmental flows to achieve the objectives;
- Analyse the frequency that the recommended streamflow regime is met under current and natural streamflows and determine the shortfalls of achieving those flows;
- Undertake a risk assessment to the environmental values if the recommended environmental flow regime is not met;
- Undertake appropriate modelling to determine the impact of recommended environmental flows and control structure height on Lake Condah water levels; and
- Provide analysis and recommendations regarding ecological value of restoring wetland function of Lake Condah versus ecological values of Darlot Creek downstream. This analysis will also consider objectives for Lake Condah water restoration.

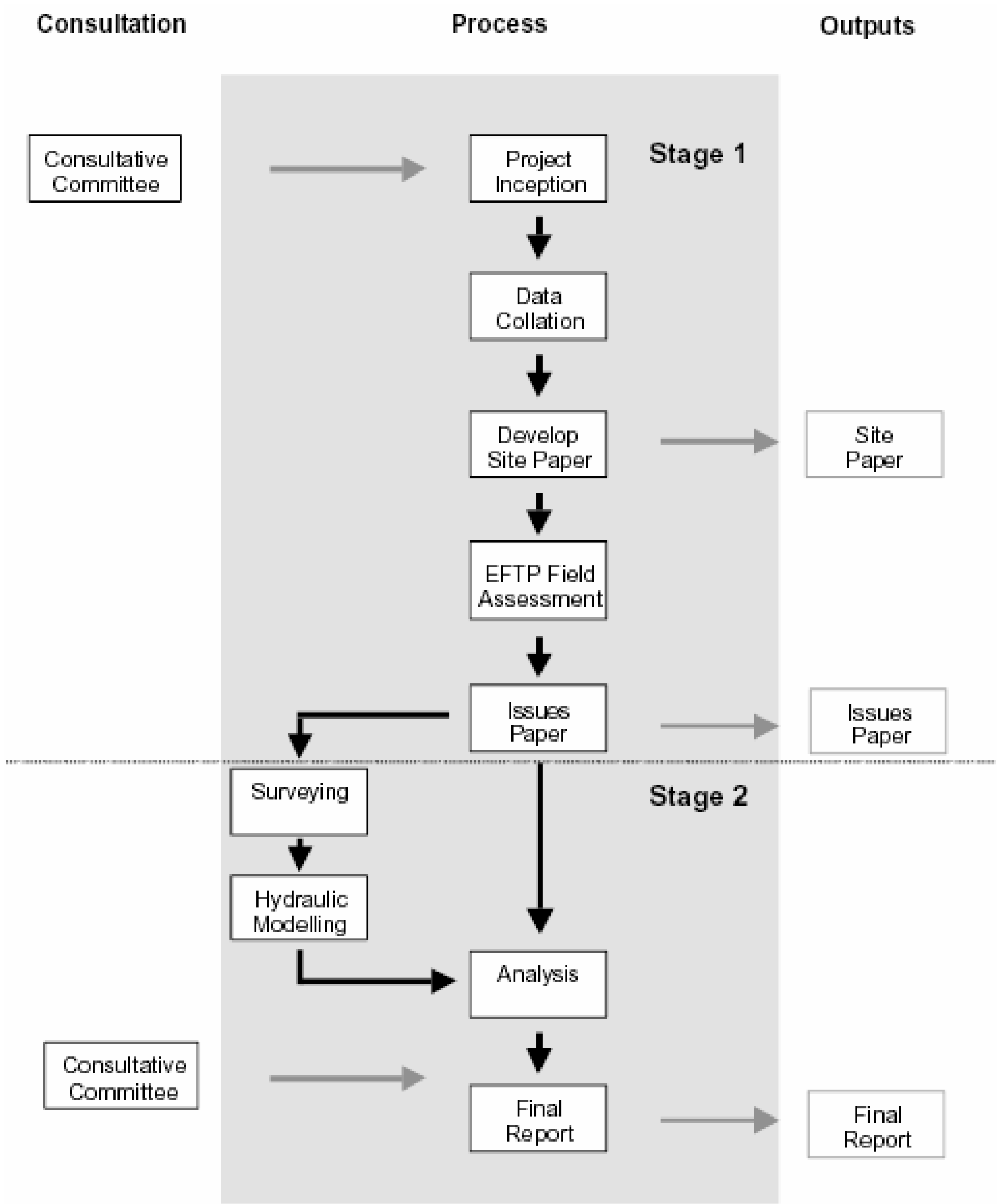

Figure 1. Flow chart illustrating implementation steps of the FLOWS methodology. EFTP refers to Environmental Flows Technical Panel. Source: SKM et al. (2002).

Figure 2. Location of Lake Condah, Darlot Creek and Fitzroy River. Source: Ruge (2004).

1.3 Objectives of Final Recommendations Paper

The Lake Condah and Darlot Creek FLOWS study comprises three reports, Site Paper, Issues Paper and Final Recommendations. The Site Paper (Gippel et al., 2008a) documented the strategic basis for environmental water management of Darlot Creek and Lake Condah; reviewed existing information relevant to the understanding of the Darlot Creek and Lake Condah system; and selected, and provided the rationale for, the reaches and sites to be used in the FLOWS study. The Issues Paper (Gippel et al., 2008b) identified Lake Condah and Darlot Creek values and assets; discussed the condition of the values and assets (i.e. current environmental condition versus natural); discussed the system hydrology including comparison of Current, Unimpaired and potential future regimes with a weir in place at Lake Condah and altered climate and land use; identified key degrading factors, differentiating streamflow related and non-streamflow related issues; identified current threats to the environmental values and assets resulting from consumptive water use and potential future threats from water restoration at Lake Condah; discussed the implications of the current water resource management; and recommended environmental objectives that were specific, measurable and clearly described in terms of the ecological or geomorphic and water quality functions of the streamflows in the catchment. Numerical targets were used to clarify these objectives.

The Final Recommendations Paper (this paper) has a number of objectives:

1. Recommend environmental flows to achieve the objectives;
2. Analyse the frequency that the recommended streamflow regime is met under Current and Unimpaired streamflows and determine the shortfalls of achieving those flows under current flow conditions and under proposed future conditions with a weir in place at Lake Condah;

3. Undertake a risk assessment to the environmental values if the recommended environmental flow regime is not met;
4. Undertake appropriate modelling to determine the impact of recommended environmental flows and control structure height on Lake Condah water levels; and
5. Provide analysis and recommendations regarding ecological value of restoring wetland function of Lake Condah versus ecological values of Darlot Creek downstream. This analysis will also consider objectives for Lake Condah water restoration.

The benchmark flow series' against which the Current and future flow scenarios are compared is the "Unimpaired" scenario. This is equivalent to the current regime with the impacts of water resources development removed. In the case of Darlot Creek this refers to diversions (licenced diversions for irrigation, plus stock and domestic) and farm dams. The Lake Condah water restoration project hydrological feasibility study also generated a "Natural" flow series, which simulated flows and lake levels under 1750 land use. This "Natural" scenario is of interest, but for the purpose of a FLOWS investigation it is not useful as a benchmark for comparison with "Current", because the "Natural" scenario is too far removed from the Current and likely future With Weir flow scenarios. Thus, consistent with the other FLOWS studies undertaken in Victoria, the "Unimpaired" (Current with no development) scenario was used as the benchmark for comparison.

1.4 The Lake Condah and Darlot Creek Technical Panel

The Environmental Flows Technical Panel (EFTP) for this project comprised:

- Dr Brett Anderson (water quality and hydraulics);
- Dr Marcus Cooling (riparian, terrestrial and wetland ecology);
- Dr Chris Gippel (hydrology and geomorphology);
- Dr Greg Kerr (riparian, terrestrial and wetland ecology) and
- Mr Lance Lloyd (fish and macroinvertebrate ecology)

All of the Panel members have expertise in estuarine ecology and/or physical processes.

1.5 Vision and health objectives for the Lake and Creek

The vision for rivers within the Glenelg Hopkins Region is to achieve (Glenelg Hopkins CMA, 2004, p. 28):

> *Healthy waterways for the benefit of all*

This vision encompasses all uses and users of our rivers, including the riverine ecosystem, human enjoyment and productivity, and aims to align the efforts of all involved.

The task of the Technical Panel is to establish stream health objectives for Lake Condah and Darlot Creek. These objectives are framed on the basis of overarching objectives specified by the Victorian River Health Strategy (DNRE, 2002). For the specific case of Lake Condah and Darlot Creek the Panel proposes the following vision:

> *The vision for Lake Condah and Darlot Creek is to achieve a healthy functioning lake and creek ecosystem that supports and complements the conservation values of the creek and lake.*

In the context of this project the stream health objectives proposed will, in the first instance, be addressed in the Final Recommendations Paper without consideration for the operational constraints on the system. The current achievement or otherwise of these objectives will be assessed by examining the current flow regime. This FLOWS study is different from most others in that the Technical Panel is also is required to assess the potential future threats from hydrological restoration at Lake Condah. Hydrological restoration of Lake Condah, if it is implemented, will happen in the future, when there is a risk of climate change and land use change altering the hydrology of the lake and creek system independent of the lake hydrological restoration measures. Thus, the future scenario of a hydrologically restored Lake Condah also includes consideration of the impacts of climate change and land use change on hydrology.

1.6 Definition of hydrological scenarios

For this FLOWS study the definition of "Natural" hydrology is different to what is normally used in FLOWS studies. Normally, natural flows are derived using a REALM model, which accounts only for water resources development, more correctly termed the "Unimpaired" scenario. The Lake Condah Hydrological Restoration Feasibility Study (Gippel et al., 2006) modelled not only the impact of water resources development, but also the impact of land use development. This "Natural" scenario is of interest, but for the purpose of a FLOWS investigation it is not useful as a benchmark for comparison with "Current", because the "Natural" scenario is too far removed from the Current and likely future flow scenarios. Thus, the "Unimpaired" (Current with no development) scenario was used as the benchmark for comparison when testing future "With Weir" scenarios for compliance with flow recommendations. It is reasonable to expect that even the Unimpaired scenario will not have all of the recommended flow components represented in every year of the record (e.g. very dry years may not contain the recommended freshes, and baseflows may be lower than normal). Thus, compliance of the Current and future scenarios with the flow recommendations was expressed as a relative compliance measured against the degree of compliance in the Unimpaired scenario.

Of interest in this FLOWS study is the relative impact on flows of a proposed "future" scenario with a weir in place at Lake Condah. Gippel et al. (2006) also modelled a number of "future" hydrological scenarios for the Lake Condah catchment, involving both predicted climate change and predicted land use change. Standard FLOWS assessments do not assess proposed future flow regimes, rather they are limited to assessing how the "Current" regime meets the flow objectives. This project had access to a number of different predicted future inflow scenarios, with each associated with a number of Lake Condah (proposed) weir operating scenarios. In total, too many Lake Condah outflow scenarios were modelled by Gippel at al. (2006) to be able to reasonably assess every one in this FLOWS project against the flow objectives. Although it is of interest to know the hydrological (and ecological) implications of future climates and land uses it is also of interest to know the impact of the Lake Condah hydrological restoration alone (independent of climate and land use impacts). Thus, it was necessary to consider a future scenario that involved the current flows, but with a weir in place.

For this project the Steering Committee decided that three future scenarios would be assessed:

1. Current climate and current land use with weir at 52.4 m AHD and passing flow of 10 ML/d, 20 ML/d and 30 ML/d (three sub-scenarios).
2. No climate change and WatLUC Base case 2030 land use change scenario (SKM, 2005a; SKM, 2005b) with weir at 52.4 m AHD and passing flow 20 ML/d.
3. CSIRO Dry climate scenario and WatLUC Base case 2030 land use change scenario (SKM, 2005a; SKM, 2005b) with weir at 52.4 m AHD and passing flow 20 ML/d.

The design of the weir must cater for the likelihood of climate change - the Dry climate change scenario was considered as this represent the most extreme possibility that managers will have to confront. The Dry climate scenario involved modelling runoff on the basis of seasonally adjusted rainfall and evaporation (Table 1). Land use change appears inevitable, so it was sensible to incorporate this into the future scenarios. Gippel et al. (2006) modelled the impacts of land use change on runoff on the basis of predicted changes in the percentage cover of various vegetation classes (Table 2). The main projected change is an increase in the area of bluegum plantation, mainly at the cost of a decrease in broadacre agriculture. For a full description of the derivation of the future land use and climate hydrological scenarios refer to Gippel et al. (2006).

After consideration of a range of factors, Gippel et al. (2006) recommended a weir crest height of 52.4 m. This aligns with previous recommendations made in respect to potential weir height at Lake Condah [see Gippel et al. (2006) for a review of literature relating to the proposed rehabilitation of Lake Condah]. A weir of 52.4 m is a good balance between the need to: maintain generally high water levels in the Lake for ecological restoration (i.e. provide fish habitat and conditions suitable for wetland vegetation); activate existing eel trap systems; maintain a large surface area of inundated Lake bed; provide seasonal spills over the crest to Darlot Creek (also allowing open fish passage); and minimize the impact on uncontrolled flooding of Condah Swamp.

Table 1.
Scaling factors for generating future 'Dry' climate scenario from historical climate data. Taken from SKM (2005a).

Season	Rainfall	Potential ET
Spring	-20%	9%
Summer	-15%	7%
Autumn	-10%	7%
Winter	-10%	9%
Annual	-10%	8%

Table 2.
Percentage cover of major land uses in Darlot Creek sub-catchment. 2003 and 2030 values taken from plots in SKM (2005b, p. 107-108). 1990 values are the same as 2003 values except that f oh category set to zero and area attributed to agg_b category.

Land use code	Land use category	Percentage cover		
		1990	2003	2030
agc	agriculture: crop	0.9%	0.9%	2.4%
agg_b	agriculture: broadacre	58.0%	52.1%	37.9%
agg_d	agriculture: dairy	22.1%	22.1%	24.6%
nvg	native vegetation - does not include new native vegetation on rural residential land (2010-2030)	14.6%	14.6%	19.8%
f oh	forestry: hardwood (blue gum plantation)	0.0%	5.8%	10.6%
f os	forestry: softwood (pine)	0.6%	0.6%	0.8%
t ra	transport (roads and railways)	3.8%	3.8%	3.8%

1.7 Selected reaches and sites

In the FLOWS methodology the stream is divided into representative reaches. Five reaches were identified for study in this FLOWS assessment (Figure 3) (Gippel et al., 2008a). The five reaches were bound by locations with distinctive physical and/or ecological characteristics, and each reach was distinct from those up- and downstream, even though it is recognized that there is a great deal of physical and ecological variability within reaches. The five selected reaches provide sufficient information for management of flows in the entire Lake Condah-Darlot Creek system.

A site was selected within each reach (Figure 3) for field inspection, detailed survey work and hydraulic and hydrological modelling. The exception was Site 5, which was inspected, but no survey work or hydraulic modelling was undertaken there because of the technical difficulties associated with it being located in the estuary. The standard FLOWS methodology applies only to non-tidal rivers; assessment of the flow requirements of the Fitzroy estuary requires a separate investigation. The selected sites are considered to be representative of the wider reach within which they were located and they satisfy the requirement of having available access.

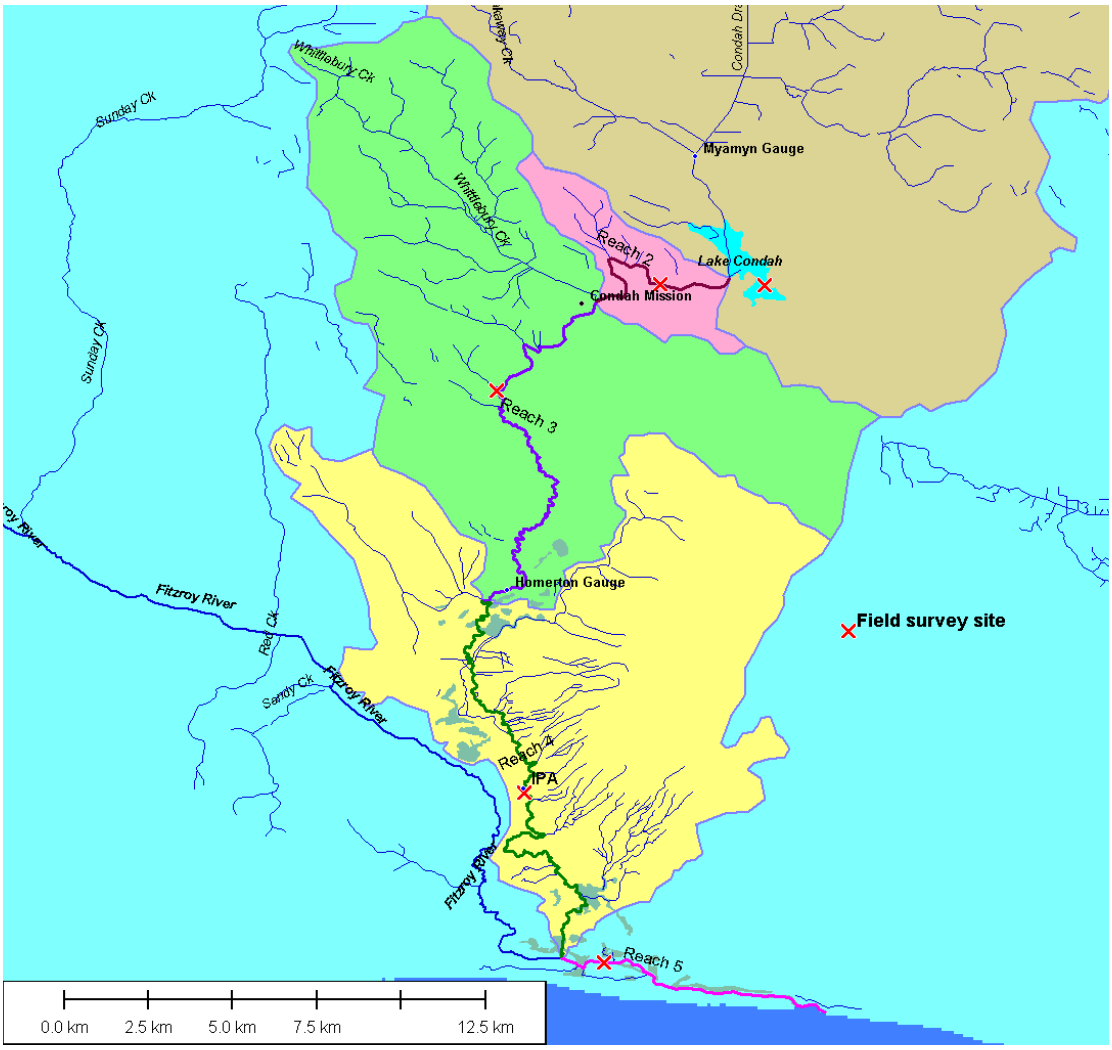

Figure 3. Location of study reaches, and representative field inspection sites.

1.8 Setting environmental objectives in the FLOWS methodology

The FLOWS method requires recommendations to be made for each reach for a number of different flow components (Table 3). Each flow component has a known or assumed important environmental function. The FLOWS method is generic for Victoria, so all components are not necessarily important or critical in all reaches of all rivers. Lake Condah is different to the flowing creek reaches, in that the main hydraulic variable of interest is the water height, rather than flow rate or velocity. Thus, while the FLOWS flow components are relevant to the inflows for Lake Condah, within the lake itself, these flow components were reframed as flow depth bands.

In the FLOWS methodology, the flow components are defined for two seasons, “winter” and “summer”, with “winter” comprising the conventionally defined winter and autumn seasons and “summer” comprising summer and autumn seasons. The FLOWS summer and winter seasons do not each have to be six months long, and they can comprise any particular months. The seasons are defined by Technical Panel to suit the particular river under investigation, and are based on consideration of the seasonal hydrological pattern, ecological processes and the life cycles of key species. In the Lake Condah and Darlot Creek FLOWS study the summer was defined as December to May, and the winter was defined as June to November.

Table 3.
Hydrological description of the generic FLOWS flow components

FLOWS flow component	Hydrological description	Relevant season
Cease-to-Flow (also called "zero flows")	Cease-to-flow is defined as periods where no flows are recorded in the channel.	Not present in some streams, nearly always occurs in Summerr
Low Flows	Low flows are the natural summer/autumn baseflows that maintain water flowing through the channel, maintaining in-stream habitats and pools.	Summer
Low Flow Freshes	Low flow freshes are frequent, small, and short duration flow events that last for one to several days as a result of localised rainfall during the low flow period.	Summer
High Flows	High flows refer to the persistent increase in baseflow that occurs with the onset of the wet season.	Winter
High Flow Freshes	High flow freshes refer to sustained increases in flow during the high flow period as a result of sustained or heavy rainfall events.	Winter
Bankfull Flows	Bankfull flows fill the channel, but do not spill onto the floodplain.	More common in Winter, but occurs in Summer
Overbank Flows	Overbank flows are higher and less frequent than bankfull flows, and spill out of the channel onto the floodplain.	More common in Winter, but occurs in Summer

1.9 A note on heights

A photogrammetric survey of the Mt Eccles Lava Flow region was flown by AEROmetrex on 22nd April 2005, producing a 5 x 5 m DEM. A comparison of the 1980 SR&WSC Plan and the 2005 DEM revealed that the SR&WSC Plan was consistently 0.3 – 0.5 m lower across the floor of the Lake (Gippel et al., 2006). An investigation of available information at the time, plus an assurance from AEROmetrex that the DEM was accurate to AHD, led Gippel et al. (2006) to adopt the DEM as the preferred source of survey data.

During the course of this FLOWS investigation, Darlot Creek was surveyed on the ground at three sites that were also covered by the DEM. As an additional check, three road surfaces that could easily be identified on the DEM were surveyed on the ground. Comparison of the ground surveys revealed that the height of Taylors Rd (running east from the IPA) varied about the DEM height over the range -0.15 to +0.29 m (mean difference was survey 0.01 m higher than DEM). For Wylies Rd (running east and west from the culvert) the height varied from the DEM over the range to +0.37 to +1.02 m (mean difference was survey 0.61 m higher than DEM). For Brians Rd (north of Lake Condah) the height varied from the DEM over the range 0.00 to +0.34 m (mean difference was survey 0.18 m higher than DEM). These differences suggest that there could be a variable error in the DEM, but in general, **the ground surveys were higher than the DEM**.

Comparison of three of the Darlot Creek cross-sections surveyed on the ground at Lake Condah revealed that there was a variable degree of correspondence with the DEM elevations across the surveys. The most important parts of the cross-sections from the perspective of restoration of water levels in Lake Condah are the flat areas, and these areas are likely to be the easiest to overlay and make comparisons between the two surveys. This comparison revealed that for cross-section 2, the difference was -0.41 ±0.02 m (mean and standard deviation of 4 points), for cross-section 4 the difference was -0.25 ±0.06 m (mean and standard deviation of 7 points), and for cross-section 7 the difference was -0.37 ±0.06 m (mean and standard deviation of 5 points). Unlike the road surveys, these surveys indicated that **the ground surveys were lower than the DEM**. This result is virtually identical to the result obtained in the comparison between the DEM and the 1980 SR&WSC Plan done by Gippel et al. (2006).

If the DEM is in error by 0.4 m compared to AHD, then the heights referred to in this report need to be reduced by 0.4 m, such that the recommended weir height of 52.4 m is actually 52.0 mAHD. This relies on the assumption that the ground surveys are accurate to AHD. Even if the ground surveys are not accurate to AHD, if the same benchmark is used to level the weir during construction as was used in the previous ground surveys of the lake, then the corrected height value (i.e. 52.0 mAHD) should be used. There are two unresolved questions: why did the road survey comparisons show ground levels higher than the DEM? and why were the differences in the cross-section levels so variable? It is recommended that the various surveyors involved be asked to resolve these questions prior to weir construction.

It is important to note that the above survey problem does not mean that the modelling work undertaken on Lake Condah by Gippel et al. (2006) or the work undertaken in this FLOWS study has been compromised. Provided the error in the DEM (if indeed there is an error) is systematic around the Lake Condah area, then the results of the bathymetry analysis and hydraulic modelling of Lake Condah (Gippel et al., 2006) still hold, but all reported levels will need to be adjusted.

2 Methodology

2.1 Workshop and final flow recommendations

The workshop was convened in Melbourne on 10th - 11th September, 2007. Present were the EFTP and two representatives of the steering committee. The process involved consideration of the flow magnitudes determined by hydraulic analysis to meet the flow objectives previously identified in the Issues Paper. These magnitudes were shaped into detailed flow recommendations covering duration, frequency and timing by considering the hydrology of the stream and lake, and the specific requirements of the biota.

Site 5, the Fitzroy River estuary, was not hydraulically modelled, so flow recommendations were made using an alternative methodology. For this site, a risk assessment was undertaken on the modelled future flow regime with a Lake Condah weir in place.

There was a known trade-off between the water requirements of Darlot Creek and Lake Condah. The more water released to Darlot Creek from a restored Lake Condah, the more rapidly the lake level would recede when inflows dropped below outflows. This would reduce habitat availability in the lake, and also increase the airspace available to potentially absorb, or partially absorb, inflowing freshes (which would in turn have potential to negatively impact Darlot Creek). This trade-off was examined using a risk assessment methodology.

2.2 Flow-ecology/geomorphology relationships

Flow related objectives were developed in the Issues Paper on a discipline-by-discipline basis (Gippel et al., 2008b). Associations were made between each objective and the components of the flow regime on which it depends. In addition, an approach to determine the associated flow threshold, that is a means of quantifying the magnitude, duration and frequency, was indicated. Finally, the sites at which each objective is relevant are listed.

The flow-ecology/geomorphology tables (Table 4, Table 5, Table 6, Table 7) were a fundamental reference during the workshop process, as ultimately the flow regime that was recommended was designed to satisfy each of the objectives as best as possible. Indeed, each flow component that was recommended at each site is directly traceable back to one of the objectives in the tables. Further, each of the objectives listed in the tables was identified in the flow recommendations, demonstrating which of the flow components ensured that it was satisfied. Note that while a flow component may have caused a number of objectives to be satisfied, usually there was one objective that was the key constraint, and this was noted as the controlling objective.

Note that for waterbird objectives, 3 objectives listed in the Issues Paper (Gippel et al., 2008b) are not considered here. Objective 4d is met by vegetation objective 2c; objective 4e is met by vegetation objectives 2d and 2g; and it is not necessary to consider 4f (slow recession in Lake Condah) as this is largely controlled by natural no-flow phenomena (seepage and evaporation).

Also note that for Reach 5 (estuary) objectives, due to the lack of a hydraulic model, hydraulic thresholds could not be specified. The exception was a tentative hydrological threshold for mouth opening.

Table 4.
Flow components relevant to main geomorphic objectives for each reach and the method used for determination of flow thresholds. There are no geomorphic objectives for Lake Condah.

ID	Geomorphic objective	Main flow components	Hydraulic/hydrologic thresholds	Threshold ID	Reaches where relevant
1a	Scour fine sediments from base of bed to maintain quantity and quality of pool habitat.	High Flow Fresh	Critical shear stress or velocity required to mobilize silt-sized floccs.	max(t1)	3, 4, 5
1b	Prevent excessive macrophyte colonisation of the bed leading to channel capacity reduction and potential erosion.	High Flow Fresh	Critical velocity for stem rupture	median(t7)	2, 3, 4, 5
1c	Maintain channel form and key habitats.	Bankfull	Morphologically defined levels	t13	3, 4, 5
1d	Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones (where present).	Bankfull and Overbank	Morphologically defined bankfull	t13	4, 5
1e	Maintain downstream sediment transport processes to prevent incision and aggradation of the bed.	Effective flows (assume Bankfull magnitude and frequency)	Erosion threshold for cohesive sediment	t5	2, 3, 4, 5
1f	Scour sand from river mouth to open estuary to the sea.	High Flow Fresh and Bankfull	Hydrological threshold for mouth opening: Tentative threshold is 1,000 ML/d for 1 day, then 660 ML/d	t28	5

Table 5.
Flow components relevant to main vegetation biodiversity objectives.

ID	Vegetation biodiversity objective (representative species)	Main flow components	Hydraulic/hydrologic thresholds	Threshold ID	Reaches where relevant
2a	Flow-tolerant submerged aquatic macrophytes (*Vallisneria americana, Potamogeton* sp. aff. *tricarinatus*)	High Flow, Low Flow, and High Flow Fresh	1. Reliable flowing water in winter High Flow period at depth of more than 0.5 m 2. Minimum summer Low Flow hydraulic depths of 0.1 m (0.1 m actual depth) at Drain and 0.2 m at Wylies Rd and IPA (to cover sufficient wetted perimeter) 3. Will tolerate complete exposure for up to one 2 month period per year. 4. One scouring flow every 5 years to rupture emergent vegetation stems. 5. Velocity sufficient to remove dense *Myriophyllum* sp. or *Triglochin procera* during high flow freshes in winter/spring period in 3 out of 5 years to exclude.	1 t18 2 [t11 / t17] 3 cease to flow possible 4 t7 5 proxy = t7	2, 3, 4, 5
2b	Seasonally growing submerged and semi-emergent aquatic vegetation (*Triglochin procera, Eleocharis sphacelata, Carex tabernaemontani*)	High Flow, Low Flow, and High Flow Fresh	1. Waterlogging or flooding up to hydraulic depth of 0.1 m throughout the summer Low Flow period (cannot dry fully) 2. Inundation of at least 0.5 m in the winter High Flow period (5 months) 3. Inundation of 1 - 2 m for 1 to 4 months in the winter High Flow period 4. One scouring flow every 5 years to rupture emergent vegetation stems.	1. [t11 / t17] cease to flow not recommended 2. t18 3. t15, t19 4. t7	2, 3, 4, 5
2c	Aquatic plant species characteristic of ponded deep water (*Myriophyllum* sp.)	High Flow and Low Flow	1. Permanent flooding (however dry events up to 2 successive years are tolerated with long term impacts as long as they are spaced by 3 wet years). 2. Minimum summer/autumn level of 0.5 m 3. Median monthly winter/spring water level of 1 - 2 m. 4. Flooding must exceed 1 m for 6 months over winter/spring for successful development of plant community in any given year.	1, 2, 3, & 4. Inundation to 66% of FSL = >51.7 m for ≥80% of winter period and ≥60% of summer period	1

ID	Vegetation biodiversity objective (representative species)	Main flow components	Hydraulic/hydrologic thresholds	Threshold ID	Reaches where relevant
2d	Emergent aquatic vegetation dependent on seasonal inundation (*Baumea* species)	High Flow, Low Flow and High Flow Fresh	1. Exposure in summer/autumn (minimum duration 4 months) in 4 out of 5 years. 2. Peak level of 0.25 - 1.25 m achieved in at least one month in winter/spring of 3 out of 5 years. 3. Greater depths tolerated for maximum of 1 month in any year. 4. Flooding to at least 0.2 m for 4 to 8 months in winter/spring/summer.	1. Exposure of 100% of FSL = >52.4 m for ≥60% of summer period 2, 3. & 4. Inundation to 100% of FSL = >52.4 m for ≥60% of winter period	1
2e	Floodplain wetland complex communities (*Triglochin aclockiae, Rumex bidens, Villarsia reniformis*)	Bankfull	1. Exposure in summer/autumn (minimum duration 3 months, maximum 6 months) in 4 out of 5 years. 2. Ideally require median monthly level of 0.1 - 0.5 m in winter/spring period (4 to 6 months). 3. Will tolerate no winter spring flooding in 2 out of 5 years but would prefer flooding in all years. 4. Depths over 1 m tolerated for maximum of 60 total days in any year – may occur in 2 out of 5 years.	1. < t13 2. t20 3. <t13 4. t21	4
2f	Floodplain grassland (*Glyceria australis, Carex appressa, Gahnia sp.*)	Bankfull and Overbank	Inundate to any depth for maximum duration of 2 months, at least once per winter/spring. Tolerates no inundation in 4 out of 5 years.	t25 (Site3) t22 (Site 4)	3, 4, 5
2g	Shrubs dependent on permanent waterlogging (*Leptospermum lanigerum*)	High lake levels and Bankfull	1. Waterlogging preferred 2. Tolerates inundation to any depth for a maximum duration of 10% of days in any year.	1. Inundation to 105% of FSL = >52.5 m in 20% of winter period 2. >t13	1, 4, 5
2h	Open water	High Flow	Flooding to more than 1 m for more than 80% of the time to suppress growth of submerged aquatic macrophytes	Inundation to 33% of FSL = >51.1 m in 100% of winter period and ≥80% of summer period	1

Table 6.
Flow components relevant to fish and macroinvertebrate biodiversity objectives.

ID	Aquatic biota (fish and macroinvertebrates) objective (key species or processes listed)	Main flow components	Hydraulic thresholds	Threshold ID	Reaches where relevant
3a	Provide summer refuge: o River Blackfish (key sp.) o Pigmy Perch o Dwarf Galaxias o Mountain Galaxias o Australian Grayling	Low Flow	Flow sufficient to at least maintain permanent pools	t18 (at deepest surveyed pool)	3, 4
3b	Facilitate natural processes to maintain water quality: o maintain high oxygen concentration o buffer temperatures o clear epiphytes and fine sediments	Low Flow Fresh	Flow sufficient to maintain and mix pools or channel during late spring, summer and autumn every 3 - 4 weeks - all years	t1 (proxy) - with adaptive management to deal with algal blooms	3, 4, 5
3c	Provide conditions suitable for reproduction: o Southern Pigmy Perch o Dwarf Galaxias o Australian Smelt o River Blackfish	High Flow Fresh recession	Long duration flows (14 - 21 days) from August to November, 4 out of 5 years 1. To maintain water depth of 1.0 m in 50% of long section, and 2. Max velocity in pools of 0.1 m/s	1. t15 - 50% of reach 2. t12 - at pool xs	3, 4
3d	Provide conditions which initiate fish spawning: o Pigmy Perch o Dwarf Galaxias o Mountain Galaxias o Black Bream (in Estuary)	High Flow Fresh	Short duration fresh (perhaps 3 days) to flood stream margin or shelf with 0.1 m of water over instream benches	t23	all
3e	Provide local fish passage (all fish)	Low Flow Fresh	Low flow freshes which cover most low points on bed, instream barriers or other obstructions by 0.3 m at least twice per season for 3 days.	t24	all
3f	Provide longitudinal fish passage: o Common Jollytail o Spotted Galaxias o Tupong o Short Finned Eel o Australian Grayling	High Flow Fresh and Low Flow Fresh	High flows and high flow freshes which connect the upper reaches to the estuary with: 1. >0.3 m over each barrier at least twice per season 2. >240 ML/d Reach 3 to overcome rock barrier at Condah Mission	1. max(t24) 2. t29 (Reach 3)	all

ID	Aquatic biota (fish and macroinvertebrates) objective (key species or processes listed)	Main flow components	Hydraulic thresholds	Threshold ID	Reaches where relevant
3g	Activate floodplain and wetlands to create extensive habitat for fish and macroinvertebrates: o Southern Pigmy Perch o Yarra Pigmy Perch o Dwarf Galaxias o Short Finned Eel o Flat-headed Gudgeon	Overbank and Very High Flow Fresh	Long duration spring events which occur 1 in 2 years	t20	3, 4
3h	Provide flows to deliver carbon and organic debris from riparian zone into channel.	Overbank	Short duration events which occur once every 5 years	median(t20)	1, 3, 4
3i	Provide conditions suitable for spawning and reproduction by flooding wetlands and floodplain in estuarine reach: o Common Jollytail o Spotted Galaxias o Tupong	Overbank	Short duration events which occur 4 in 5 years	unknown	5
3j	Provide a breeding trigger and recruitment in estuary; inundate vegetation beds and instream benches: o Australian Grayling	Low Flow Fresh	Create salt-wedge and mixing in upper estuary Feb-May Threshold unknown	unknown	5
3k	Provide adult habitat in upper estuary for larval development: o Australian Grayling	High Flow	Maintain permanent deep, well-mixed pools of minimum depth 1-3 m in upper estuary; slow but constant flows (mixing) and high DO and low salinity (April-May) Threshold unknown	unknown	5
3l	Open the estuary mouth and maintain open into summer: o Australian Grayling o Short-finned Eel	High Flow, High Flow Fresh and Bankfull	o Grayling: downstream migration of larvae May-Jul and upstream migration from sea Oct-Dec o Eel: Downstream (to sea) migration of adults Dec-May; return of elvers to estuary winter to spring (Jul-Nov) 1. Opening: tentative threshold is 1,000 ML/d for 1 day, then 660 ML/d 2. Maintenance: threshold unknown	1. t28	5
3m	Spawning flow for Australian Grayling in freshwater reaches	Low Flow Fresh	April-May rise above baseflow. At least 0.3 m depth at all cross-sections to provide complete passage.	t30	3, 4

Table 7.
Flow components relevant to waterbird and other fauna biodiversity objectives.

ID	Waterbird and other fauna objective (key species or processes listed)	Main flow components	Hydraulic/hydrologic thresholds	Threshold ID	Reaches where relevant
4a	Provide foraging and grazing habitat through exposure of in-stream benches and floodplains over summer and autumn	Low Flow	Expose instream benches in summer and autumn	t14 (maximum)	2, 3, 4
4b	Provide seasonal boost to productivity of the in-stream benches through periodic flooding freshes in winter and spring	High Flow Fresh	Inundation of instream benches to 0.3 m at least 2 times winter and spring (minimum 3 days)	t27	2, 3, 4
4c	Maintain permanent deep water refuges to provide year round foraging for resident sedentary fauna in creek	Low Flow and High Flow	No cease to flow; flow depth >0.5 m	t18	2, 3, 4
4g	Maintain reliable freshwater zone in estuary	High Flow and Low flow	No cease to flow events, with unknown lower limit on flow	unknown	5
4h	o Provide foraging and grazing habitat through inundation of the estuary reed beds over winter and spring. o Provide nest and shelter habitat in reed beds in winter and spring through long-term flooding. o Provide nesting and foraging in *Leptospermum lanigerum* habitat in winter and spring through short-term flooding	High Flow and High Flow Fresh	o Depth of inundation in reed beds at least 0.3 m (threshold unknown) o Avoid sudden falls in water level. o In higher elevation *Leptospermum lanigerum* habitat: Inundation for minimum 2 - 3 days, 2 - 3 times in winter and early spring (threshold unknown)	unknown	5

2.3 Summary of hydraulic analysis

Numerical hydraulic models were developed for three of the five reaches in the Darlot Creek and Lake Condah system (Table 8). Lake Condah (site 1) and the estuarine reach (site 5) did not require hydraulic analysis under the method of analysis applied in this investigation. Hydraulic analysis establishes the relationship between flow depth and discharge, as well as information on other flow properties, especially velocities and shear stresses. For this project models were constructed using Mike 11 (DHI Software, 2007 edition: www.dhigroup.com), which is designed to perform one-dimensional steady state calculations for natural and constructed river reaches.

Table 8.
Site number and description

Site	Description	Hydraulic Analysis
1	Lake Condah	No
2	Darlot Creek drain downstream of Lake Condah	Yes
3	Wylies Road	Yes
4	IPA Site	Yes
5	Darlot Creek and Fitzroy River Estuary	No

Three elements are required to define a river reach within Mike 11: reach geometry; a downstream boundary condition; and a specification of hydraulic roughness. The following sections present an overview of the methods used to quantify each of these elements.

Environmental flow recommendations were made by working interactively with Mike11 simulations. As an extra tool to assist with model interpretation the discharge required to satisfy a series of quantitative ecological and geomorphological thresholds (e.g. shear stress required to initiate sediment motion) were precomputed and tabulated. Indicative tables of threshold discharges are also presented herein.

2.3.1 Reach geometry

The channel shape was measured by surveying between 6 and 9 lateral transects for each reach (transects are lines that cut across the stream perpendicular to the flow direction). Surveys provided the geometric data required to define a reach within Mike 11. Transects were located so as to capture the principal features of each reach, particularly geomorphic features such as pools, riffles and runs, and hydraulic features including channel constrictions, expansions and hydraulic controls. Overbank features were also included in the survey, with a series of specific surveys conducted at the IPA site of floodplain wetlands and channels.

Cross-section surveys were completed by Reed & Reed Surveying. They supplied data in both text file format (comma separated values) and as ESRI format shape files (included on the data CD).

2.3.2 Downstream boundary condition

The flow scenarios examined during this analysis were restricted to sub-critical flows, hence only a downstream boundary condition was required (Chow, 1959). Given the information available, normal depth was specified as the downstream boundary condition, applying the so-called 'Slope-Area Method'. Under this condition the flow depth at the outlet is determined by the geometry of the outlet cross-section, the roughness coefficient, and the local water surface slope.

Issues associated with establishing an appropriate downstream boundary condition are described for each reach in Sections 2.4, 2.5, and 2.6. A detailed discussion of the uncertainty associated with the downstream boundary condition is presented in Appendix A (Section 9.1.2).

2.3.3 Determination of hydraulic roughness

Hydraulic resistance (also called 'stream roughness') is a measure of the friction generated between flowing water and the channel boundary. Higher values of resistance are associated with rough-textured boundaries, with highly sinuous channels, and with turbulent flows down rapids and through vegetation. Flows through high resistance channels move more slowly and at a higher stage than through lower resistance channels at the same discharge. The magnitude of resistance determines the discharge at which different channel features are inundated, for example the bankfull flow at which flooding commences, and the speed at which flows are conveyed and accumulate down the network.

The overall value of flow resistance in a natural river comprises contributions from many interdependent sources, including: bed and bank roughness, bend losses, secondary flow resistance as well as the contribution of vegetation (Bathurst, 1993). There are four standard approaches used to estimate the various contributions to resistance in natural rivers and streams; they are: (i) procedural approaches; (ii) roughness tables; (iii) using roughness handbooks; and (iv) empirical or theoretical equations.

A procedural method that builds on the recommendations of Coon (1998) was developed for assessing the roughness of each of the three reaches assessed for in the Darlot Creek and Lake Condah FLOWS study. Coon's (1998) procedure is recommended by the United States Geological Survey and therefore is relevant for North American conditions that are somewhat different from those in Australia. Southern hemisphere data and techniques, for example Hicks and Mason's (1991) work, were therefore adopted in place of some of the references recommended by Coon (1998). There is no single best approach for the estimation of hydraulic resistance. In the absence of calibration data (measured discharge and stage), it is best practice to employ a range of methods (Coon, 1998; Lang et al., 2004). For this project, each of the four approaches (listed earlier) were employed, with the specific methods described in Appendix A (Section 9.2).

2.3.4 Discharge thresholds

In order to quantify the flow required to meet each ecological and geomorphological objective a specific flow criterion was established. For example, in order to entrain medium-grained sand a certain minimum shear stress must be applied. For each of the ecology-flow and geomorphology-flow relationships (listed in Section 2.2) a quantitative threshold, such as the shear stress threshold for sand, was established. Each of these thresholds was defined in terms of one or more of the following flow properties computed by the hydraulic model: shear stress, flow velocity or flow depth. A short description of the threshold for each objective is provided in the tables of Section 2.2. Detailed justifications for the chosen thresholds can be found either in the Issues Paper (Gippel et al., 2007) or in Appendix A (Section 9.3).

This section includes tables that report the indicative[1] discharge required to move sediment or remove vegetation. Complete tables include a larger range of criteria that were evaluated at each surveyed cross-section (rather than the reach average reported here). The full tables of discharge thresholds are not published in this report for a number of reasons: 1) the discharge values are an intermediate step in setting the environmental flow; 2) the tables produced require expert interpretation; and 3) the values listed were developed specifically for use within the framework specified by the FLOWS Method, they are inappropriate for making decisions or predictions outside of this framework. It is important to recognise that these threshold values cannot be simply linked to an environmental flow component (e.g. baseflow, high flow fresh). Some of the complicating factors include:

- some thresholds are only applicable at certain cross-sections (e.g. discharge to entrain riffle sediments is relevant only at riffles) and therefore require careful examination of the longitudinal profile and cross-section morphology;
- multiple threshold criteria must usually be satisfied by a given flow component; and
- many important ecological processes cannot be expressed as a quantitative criterion, hence qualitative considerations are an integral part of producing the final environmental flow recommendation.

To give the reader a feel for the type of information yielded by quantitative criteria a subset of threshold discharges is presented for each of the three sites. The thresholds reported include flow depth, velocity and shear stress conditions. The discharge reported is the median discharge – that is the flow that will meet or exceed the threshold at 50% of the cross-sections. The indicative thresholds reported for each of the three reaches are listed in Table 9.

The following sections present a brief description of the hydraulic models constructed for each reach, including the selection of the roughness parameter and some key results.

[1] The indicative discharge is an average over all the surveyed cross-sections at a given site.

Table 9.
List of indicative discharge thresholds computed to meet or exceed a depth (m), critical shear stress (N/m^2), or velocity (m/s) in order to meet an ecological or geomorphic requirement.

Process / Characteristics	Ecological/Geomorphic Requirement ID	Threshold
depth of flow (sample of thresholds)		
hydraulic depth	2a.2, 2b.1	D_H = 0.1 m
max. flow depth	3e 2b.1	D = 0.3 m D = 0.5 m
in-channel bench	4a	site specific
bankfull	1d	site specific
erosion of consolidated sediment [defined in S9.3.1]		
cohesive sediment (> 45% clay)	1c, 1e	V_{max} = 0.7 m/s τ_c = 11 N/m^2
transport of unconsolidated sediments [defined in S9.3.2]		
fine silt	1a	V_{max} = 1.0 m/s
coarse silt	1a	V_{max} = 0.7 m/s
medium sand (d = 0.5 mm)	1a	V_{max} = 0.2 m/s τ_c = 0.5 N/m^2
coarse sand (d = 1.0 mm)	1a	V_{max} = 0.2 m/s τ_c = 2.0 N/m^2
removal of vegetation [defined in S9.3.3]		
bunch grass	1c	τ_c = 80 N/m^2
macrophytes	1b, 2a.2, 2b.4	$D.V$ = 0.152 $D.V$ = 1.52

2.4 Site 2 – Darlot Creek Drain downstream of Lake Condah

2.4.1 Hydraulics

A MIKE11 model was constructed for this reach using eight surveyed cross-sections along a 1,189 m reach of Darlot Creek. The downstream cross-section was copied 811 m downstream and lowered by 0.05 m providing a suitable location for a downstream boundary. A number of interpolated cross-sections were also inserted around a localised irregularity in the channel bed (sandbank in middle of channel) to ensure model stability.

A Q-H relationship was developed for the downstream boundary using Manning's Equation assuming uniform flow, a representative roughness and an average channel slope.

A detailed assessment of possible roughness coefficients was undertaken utilising a number of methods (Table 11). An average of the estimates was found to be 0.03 (standard deviation of 0.003), and this was adopted for the modelling.

A time-series of discharge was used for the upstream boundary, beginning with a low flow and ramping up to an overbank flow of 40,000 ML/day. This enabled a water surface profile to be estimated along the entire reach for a range of flows. To provide an indication of the nature of the water surface slope along the reach, a longitudinal profile is shown at approximately bankfull discharge[2] in Figure 4.

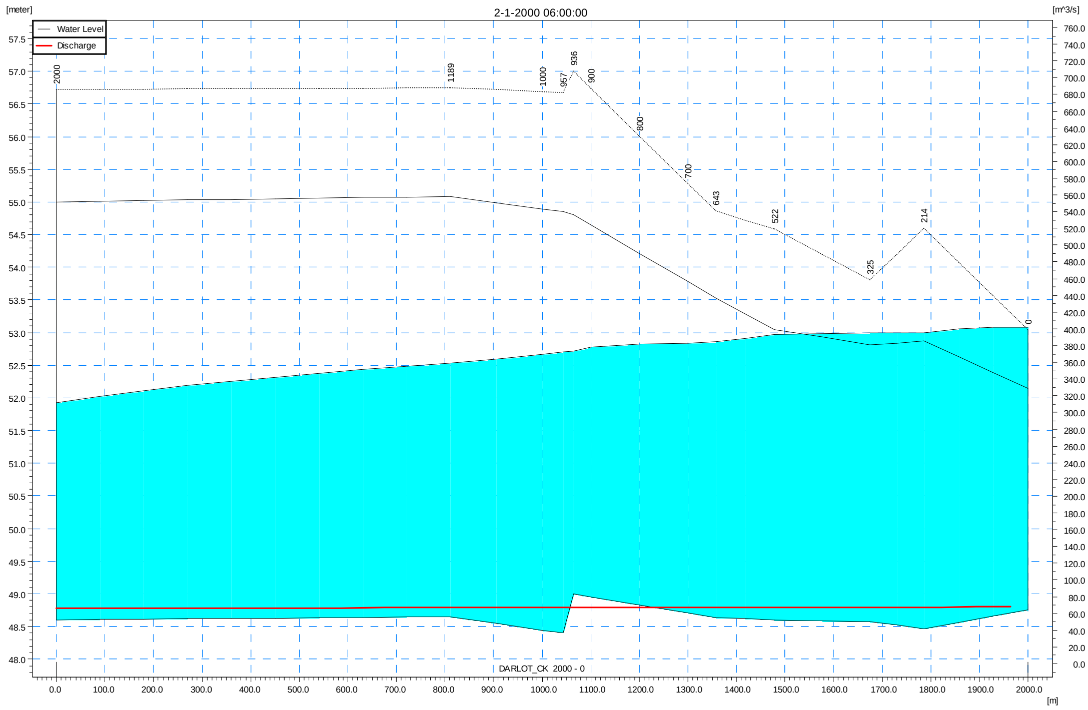

Figure 4. Longitudinal profile for Site 2 at bankfull flow.

A summary of some of the relevant discharge thresholds, associated with specific ecological or geomorphic objectives, are present in Table 10. The discharge values listed in the right-most column of the table indicate the median discharge in the reach at which the threshold is met or exceeded. With respect to some of the sediment transport thresholds both velocity and shear stress criteria are presented and there can be large differences between the threshold discharge required in each case (e.g. 55 – 537 ML/day to transport coarse sand). In part the difference arises due to differences in transport mechanisms being predicted, although much of the difference is simply down to uncertainty associated with the threshold. Such differences illustrate why expert judgement remains a vital step in interpreting the thresholds to define flow recommendations.

[2] This is a reach-averaged bankfull discharge where the marjority of the cross-sections were beginning to flood. Note that some cross-sections are not yet overbank due to flow capacity differences and the water surface slope.

Table 10.
List of indicative discharge thresholds computed to meet or exceed a depth (m), critical shear stress (N/m^2), or velocity (m/s) in order to meet an ecological or geomorphic requirement.

Process / Characteristics	Ecological/Geomorphic Requirement ID	Threshold	Median Discharge (ML/day)
depth of flow (sample of thresholds)			
hydraulic depth	2a.2, 2b.1	D_H = 0.1 m	2
max. flow depth	3e 2b.1	D = 0.3 m D = 0.5 m	3 9
in-channel bench	4a	site specific	212
bankfull	1d	site specific	6,700
erosion of consolidated sediment			
cohesive sediment (>45% clay)	1c, 1e	V_{max} = 0.7 m/s τ_c = 11 N/m^2	550 2,569
transport of unconsolidated sediments			
fine silt	1a	V_{max} = 1.0 m/s	602
coarse silt	1a	V_{max} = 0.7 m/s	550
medium sand (d = 0.5 mm)	1a	V_{max} = 0.2 m/s τ_c = 0.5 N/m^2	55 108
coarse sand (d = 1.0 mm)	1a	V_{max} = 0.2 m/s τ_c = 2.0 N/m^2	55 537
removal of vegetation			
bunch grass	1c	τ_c = 80 N/m^2	>40,000
macrophytes	1b, 2a.2, 2b.4	$D.V$ = 0.152 $D.V$ = 1.52	70 1,777

Table 11.
Roughness Coefficient Estimation at Darlot Creek drain downstream of Lake Condah

Method	Manning's n	Selected values		Description
Cowan's Method	0.032	n_b = 0.020 n_1 = 0.002 n_2 = 0.005	n_3 = 0.000 n_4 = 0.005 m = 1.00	Silt-clay (earth) substrate with negligible irregularity (very flat profiles) with occasional cross-section shape change. Obstructions are negligible with vegetation (low) important at lower flow stages. Meandering is considered minor in this context.
Chow's Table	0.030	Table Ref: C-b.2 (normal)		Excavated or dredged channel, earth, winding and sluggish with grass and some weeds.
Bathurst's Table	0.025 +veg = 0.005	Slope: <0.005%	D_{50}: 0.008mm	Slope characteristic of sand bed material. Select intermediate roughness and add vegetation increment (n_4).
Hicks and Mason	0.022 – 0.032 +veg = 0.005	id: 9140 (p.70)	Q = 1.51 m^3/sec S = 0.0002 Sand	Principal matched parameters: water slope at average discharge, channel type and mean daily flow all reasonable matches. Perhaps not as much vegetation in the stream so add vegetation increment (n_4).
Empirical Equations	0.027 – 0.030 0.031	Riggs (1976) Dingman and Sharma (1997)		
FINAL ESTIMATE:	0.030 ± 0.003	(mean ± 1 SD)		SD = standard deviation.

2.5 Site 3 – Darlot Creek at Wylies Road

2.5.1 Hydraulics

A MIKE11 model was constructed for this reach using nine surveyed cross-sections along a 729 m reach of Darlot Creek. The downstream cross-section was copied 771 m downstream and lowered by 0.143 m, consistent with the average channel slope, providing a suitable location for a downstream boundary.

A Q-H relationship was developed for the downstream boundary using Manning's Equation assuming uniform flow, a representative roughness and an average channel slope.

A detailed assessment of possible roughness coefficients was undertaken utilising a number of methods (Table 13). An average of the estimates was found to be 0.044 (standard deviation of 0.007), and this was adopted for the modelling.

A time-series of discharge was used for the upstream boundary, beginning with a low flow and ramping up to an overbank flow of 40,000 ML/day. This enabled a water surface profile to be estimated along the entire reach for a range of flows. To provide an indication of the nature of the water surface slope along the reach, a longitudinal profile is shown at approximately bankfull discharge[3] in Figure 5.

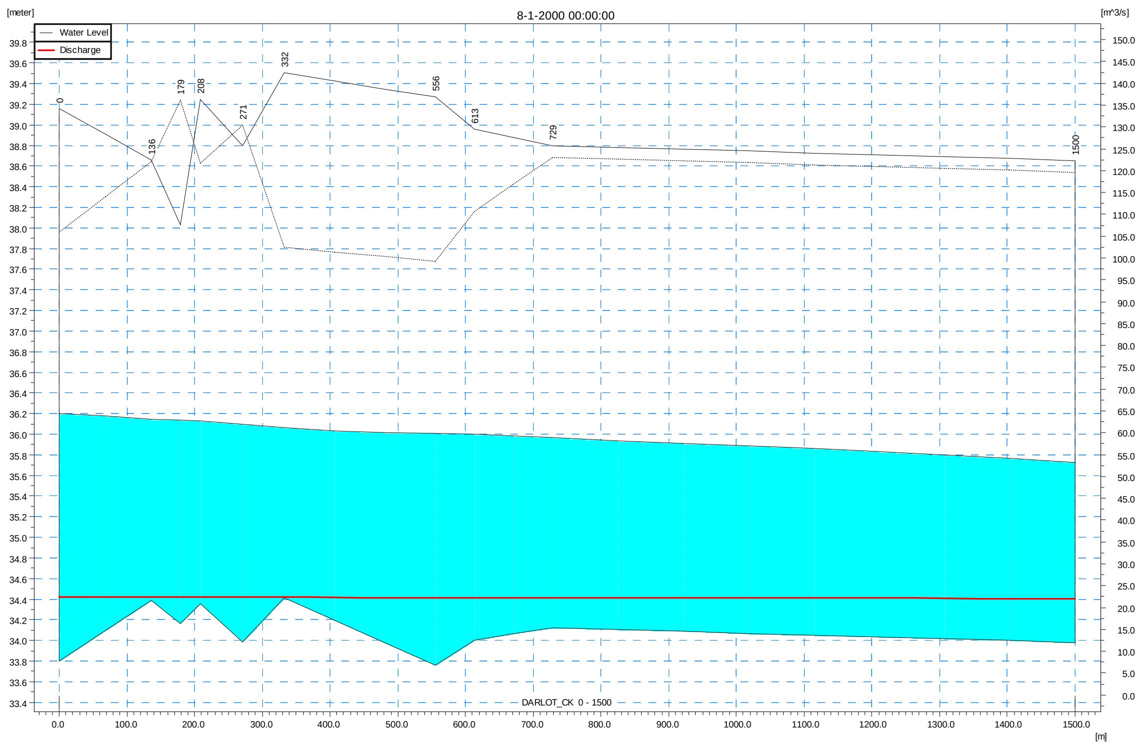

Figure 5. Longitudinal profile for Wylies Road reach at bankfull flow.

A summary of some of the relevant discharge thresholds, associated with specific ecological or geomorphic objectives, are present in Table 12. The discharge values listed in the right-most column of the table indicate the median discharge in the reach at which the threshold is met or exceeded.

[3] This is a reach-averaged bankfull discharge where the majority of the cross-sections were beginning to flood. Note that some cross-sections are not yet overbank due to flow capacity differences and the water surface slope.

Table 12.
List of indicative discharge thresholds computed to meet or exceed a depth (m), critical shear stress (N/m^2), or velocity (m/s) in order to meet an ecological or geomorphic requirement.

Process / Characteristics	Ecological/Geomorphic Requirement ID	Threshold	Median Discharge (ML/day)
depth of flow (sample of thresholds)			
hydraulic depth	2a.2, 2b.1	D_H = 0.1 m	1.3
max. flow depth	3e 2b.1	D = 0.3 m D = 0.5 m	4 21
in-channel bench	4a	site specific	17
bankfull	1d	site specific	850
erosion of consolidated sediment			
cohesive sediment (>45% clay)	1c, 1e	V_{max} = 0.7 m/s τ_c = 11 N/m^2	8,765 7,795
transport of unconsolidated sediments			
fine silt	1a	V_{max} = 1.0 m/s	18,125
coarse silt	1a	V_{max} = 0.7 m/s	8,765
medium sand (d = 0.5 mm)	1a	V_{max} = 0.2 m/s τ_c = 0.5 N/m^2	171 43
coarse sand (d = 1.0 mm)	1a	V_{max} = 0.2 m/s τ_c = 2.0 N/m^2	171 211
removal of vegetation			
bunch grass	1c	τ_c = 80 N/m^2	>40,000
macrophytes	1b, 2a.2, 2b.4	*D.V* = 0.152 *D.V* = 1.52	63 8,322

Table 13.
Roughness Coefficient Estimation at Wylies Road

Method	Manning's n	Selected values	Description
Cowan's Method	0.050	n_b = 0.020 n_3 = 0.000 n_1 = 0.005 n_4 = 0.020 n_2 = 0.005 m = 1.00	Silt-clay (earth) substrate with negligible irregularity (very flat profiles) with occasional cross-section shape change. Obstructions are negligible with vegetation (medium) important at lower flow stages. Meandering is considered minor in this context.
Chow's Table	0.045	Table Ref: D-1.a.4 (normal)	Small natural stream that meanders (winding) and has some vegetation growth (weeds).
Bathurst's Table	0.025 +veg = 0.02	Slope: = 0.02% D_{50}: 0.008mm	Slope characteristic of sand bed material. Add vegetation increment (n_4).
Hicks and Mason	0.022 - 0.032 +veg = 0.02	id: 9140 (p. 70) Q = 2 m^3/sec S = 0.0003 Silt/Clay	Principal matched parameters: water slope at average discharge a little lower than site 3, channel type and mean daily flow are reasonable matches. Perhaps not as much vegetation in the stream so add vegetation increment (n_4).
Empirical Equations	0.023 0.030 +veg = 0.02	Riggs (1976) Dingman and Sharma (1997)	
FINAL ESTIMATE:	0.044 ± 0.007	(mean ± 1 SD)	SD = standard deviation.

2.6 Site 4 – Darlot Creek at IPA Site

2.6.1 Hydraulics

A MIKE11 model was constructed for this reach using six surveyed cross-sections along a 456 m reach of Darlot Creek. The downstream cross-section was copied 344 m downstream and lowered by 0.442 m, consistent with the average channel slope, providing a suitable location for a downstream boundary.

A stage-discharge relationship was developed for the downstream boundary using Manning's Equation assuming uniform flow, a representative roughness and an average channel slope.

A detailed assessment of possible roughness coefficients was undertaken utilising a number of methods (Table 15). An average of the estimates was found to be 0.047 (standard deviation of 0.006), and this was adopted for the modelling.

A time-series of discharge was used for the upstream boundary, beginning with a low flow and ramping up to an overbank flow of 40,000 ML/day. This enabled a water surface profile to be estimated along the entire reach for a range of flows. To provide an indication of the nature of the water surface slope along the reach, a longitudinal profile is shown at approximately bankfull discharge[4] in Figure 5.

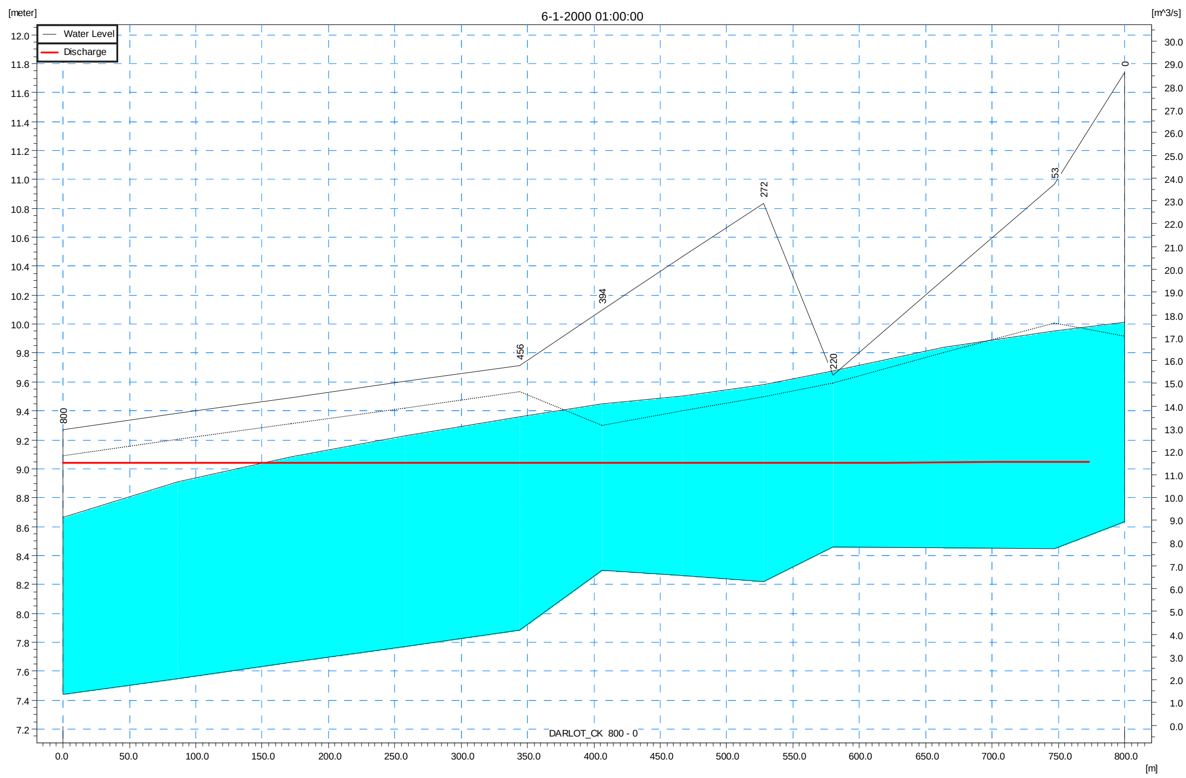

Figure 6. Longitudinal profile for IPA Site at bankfull flow.

A summary of some of the relevant discharge thresholds, associated with specific ecological or geomorphic objectives, are present in Table 14. The discharge values listed in the right-most column of the table indicate the median discharge in the reach at which the threshold is met or exceeded.

[4] This is a reach-averaged bankfull discharge where the marjority of the cross-sections were beginning to flood. Note that some cross-sections are not yet overbank due to flow capacity differences and the water surface slope.

Table 14.
List of indicative discharge thresholds computed to meet or exceed a depth (m), critical shear stress (N/m^2), or velocity (m/s) in order to meet an ecological or geomorphic requirement.

Process / Characteristics	Ecological/Geomorphic Requirement ID	Threshold	Median Discharge (ML/day)
depth of flow (sample of thresholds)			
hydraulic depth	2a.2, 2b.1	D_H = 0.1 m	7
max. flow depth	3e 2b.1	D = 0.3 m D = 0.5 m	28 87
in-channel bench	4a	site specific	29
bankfull	1d	site specific	702
erosion of consolidated sediment			
cohesive sediment (>45% clay)	1c, 1e	V_{max} = 0.7 m/s τ_c = 11 N/m^2	187 342
transport of unconsolidated sediments			
fine silt	1a	V_{max} = 1.0 m/s	313
coarse silt	1a	V_{max} = 0.7 m/s	187
medium sand (d = 0.5 mm)	1a	V_{max} = 0.2 m/s τ_c = 0.5 N/m^2	8 1
coarse sand (d = 1.0 mm)	1a	V_{max} = 0.2 m/s τ_c = 2.0 N/m^2	8 10
removal of vegetation			
bunch grass	1c	τ_c = 80 N/m^2	>40,000
macrophytes	1b, 2a.2, 2b.4	$D.V$ = 0.152 $D.V$ = 1.52	115 >40,000

Table 15.
Roughness Coefficient Estimation at IPA Site

Method	Manning's n	Selected values	Description
Cowan's Method	0.047	n_b = 0.020 n_3 = 0.000 n_1 = 0.002 n_4 = 0.020 n_2 = 0.005 m = 1.00	Silt-clay (earth) substrate with negligible irregularity (very flat profiles) with occasional cross-section shape change. Obstructions are negligible with vegetation (medium) important at lower flow stages. Meandering is considered minor in this context.
Chow's Table	0.045	Table Ref: D-1.a.4 (normal)	Small natural stream that meanders (winding) and has some vegetation growth (weeds).
Bathurst's Table	0.02 +veg = 0.020	Slope: = 0.12% D_{50}: 0.008mm	Slope slightly higher than that characteristic of sand bed material. Select lower roughness and add vegetation increment (n_4).
Hicks and Mason	0.022 - 0.032 +veg = 0.020	id: 9140 (p.70) Q = 2 m^3/sec S = 0.0018 id: 25902 (p.214) Sand	Principal matched parameters: Perhaps not as much vegetation in the first stream so add vegetation increment (n_4). First matched stream has more similar flow characteristics, the second matched stream has a more similar slope, and both streams are sandy bed material.
Empirical Equations	0.029 0.036 +veg = 0.020	Riggs (1976) Dingman and Sharma (1997)	
FINAL ESTIMATE:	0.047 ± 0.006	(mean ± 1 SD)	SD = standard deviation.

3 Flow Recommendations

This section presents the quantitative flow recommendations for Lake Condah and Darlot Creek. For each site the ecological and physical objectives addressed by the flow bands are identified, with indices linking this information to the flow components listed in Section 2. Summer is December to May inclusive and winter is June to November inclusive.

3.1 Site 1: Lake Condah

Lake Condah, looking north from sinuous lava ridge

3.1.1 Summary of Recommendations:

Component	Magnitude (elevation)	Required Summer (% of time)	Required Winter (% of time)	Key Indices
Essentially dry	<50.4 mAHD	0%	0%	all
% time exceeds 33% FSL (open water zone)	>51.1 mAHD	>80%	100%	2h
% time exceeds 66% FSL (submerged aquatic plant zone)	>51.7 mAHD	>60%	>80%	2c1, 2c2, 2c3, 2c4
% time fishway active	>52.2 mAHD	>20%	>20%	3e
% time less than 100% FSL (expose reed zone)	<52.4 mAHD	>60%	0%	2d1
% time exceeds 100% FSL (reed zone)	>52.4 mAHD	0%	>60%	2d2, 2d3, 2d4
% time exceeds 105% FSL (Silky Tea Tree zone)	>52.5 mAHD	0%	>20%	2g1

3.1.2 Open Water Zone

Largely permanent open water habitat is required to provide a reliable habitat for large fish and a variety of waterbirds, particularly deep-diving waterbirds, piscivorous waterbirds and dabbling ducks. Largely permanent flooding to depths of greater than 1 m will exclude most aquatic macrophytes. Dry periods are undesirable as they will promote submerged aquatic vegetation but up to one dry period in four years will not promote vegetation growth significantly.

3.1.3 Submerged Aquatic Plant Zone

Submerged aquatic plants will grow in shallow seasonally flooded or permanently flooded areas. Species likely to colonise Lake Condah include *Triglochin procera, Myriophyllum* spp. and *Potamogeton* spp. These plants support biofilms, zooplankton and aquatic macroinvertebrates and they provide a productive food source and sheltering habitat for small fish, large fish, dabbling ducks and waterfowl. Seasonal exposure of this zone will promote mineralisation of organic matter and wetland productivity.

3.1.4 Reed Zone

Reed beds will be promoted by annual flooding to a depth of up to 0.7 m. This habitat will be provided at the outer edge of the lake and will provide an important breeding site for waterbirds which build nest platforms from reeds, sedges and rushes. Shy and cryptic waterbirds will inhabit this zone and would include crakes, rails, bittern and Reed Warblers. Reed beds will also provide a productive feeding and sheltering habitat for large and small fish.

3.1.5 Silky Tea Tree Zone

Silky Tea Tree occupies permanently waterlogged habitats which may be inundated from time to time. This species is expected to colonise the area surrounding the lake above the full supply level, which will only be inundated when the lake spills. Waterlogging is essential to this species, but the degree to which this can be achieved through the management of lake water levels is not known.

3.1.6 Fishway Active

The fishway must be active for one or more one week periods each autumn and each spring. This is to meet the dispersal and migratory requirements of fish, particularly eels. It should be noted that the reed zone, which is above the fishway level, requires a greater inundation period than the fishway, and that by meeting the reed zone objective the fishway objective is exceeded.

3.2 Site 2: Darlot Creek drain downstream of Lake Condah

XS9 – longitudinal view of reach

XS6 – bank erosion and gap in spoil heap

3.2.1 Summary of Recommendations:

Component	Magnitude (ML/day)	Frequency	Duration	Key Indices	Other Indices
Cease To Flow	------------------- *not recommended* --------------			2b.1	2a.3
Summer Low Flow	≥2			2a.2, 2b.1	
Low Flow Fresh†	≤212 (no min.)	≥1 period per sum-aut	≥2 months	4a	
Winter High Flow*	≥9*			2a.1, 2b.2	
High Flow Fresh	≥288 (no max.)	≥2 per win-spr	≥3 days	4b	1a, 1b, 3d, 3f, 2a.4, 2b.4, 2b.5
Bankfull Flow*	not required			1e	
Overbank Flow*	not required				

† There is no requirement for a low flow fresh. This specification is for a period of ≥2 months over the summer period with flow ≤212 ML/d. So, low flow freshes can occur, provided they do not exceed this magnitude.

* The recommendations for these flow components are sufficient to support the ecological health of Reach 2. However, it is noted that higher discharges may need to be conveyed through Reach 2 to meet requirements in downstream reaches (Reach 3 Wylies Road and Reach 4 IPA site), depending on other inflows.

3.2.2 Cease-to-flow

A cease-to-flow period was not recommended for this reach to ensure that the base of the channel remains water logged throughout the low flow period to maintain seasonally growing submerged and semi-emergent aquatic vegetation [2b.1]. Cease-to-flow should only occur along this reach if catchment inflows cease as a result of climatic conditions and on the basis of 2007 landuse and development levels.

This cease-to-flow recommendation also protects flow-tolerant submerged aquatic macrophytes [2a.3].

3.2.3 Summer Low Flow

A minimum discharge through Reach 2 is required to support flow-tolerant submerged aquatic macrophytes [2a.2] and seasonally growing submerged and semi-emergent aquatic vegetation [2b.1]. A suitable flow to ensure the survival of these plants was one that maintains a minimum hydraulic depth[5] of 0.10 m at 50% of the cross-sections. At Reach 2 a discharge of **2 ML/day** achieves this condition.

Note that in this reach the following requirements do not apply: [3a.1] to maintain deep water refuge for fish (River Blackfish in particular); [4c] support perennial foraging habitat for resident fauna. Refuge and foraging habitat are presumed to be sought at places other than the relatively uniform channel that defines the drain.

3.2.4 Low Flow Fresh

Due to the absence of high value pool habitats in Reach 2 there is no requirement to provide a low flow fresh to maintain water quality in pools over summer and autumn [3b], nor a need to facilitate local fish passage [3e] (although longitudinal fish passage is required through winter and spring [3f]). Hence there is no ecological requirement for a low flow fresh. However, there is a need to expose instream benches in summer and autumn [4a] for at least a 2 month period. This sets a maximum discharge for the low flow fresh that can be allowed to pass (during the 2 month dry) of **212 ML/day**.

3.2.5 Winter High Flow

Over winter and spring flow-tolerant submerged aquatic macrophytes [2a.2] and seasonally growing submerged and semi-emergent aquatic vegetation [2b.1] require reliable flowing water with a minimum depth of 0.5 m to maintain productivity. It is recommended that such a depth be maintained over at least 50% of the cross-sections in Reach 2 to ensure these vegetation communities remain viable. This requires a minimum discharge of **9 ML/day** through winter and spring at Reach 2 site.

A baseflow of 9 ML/day is sufficient to support the ecological health of Reach 2. However, a higher winter base flow may be required in order to provide downstream reaches (Wylies Road and the IPA site) with sufficient water to support the winter base flow discharges recommended at these downstream sites. Thus, the winter baseflow discharge through Reach 2 may end up being larger than 9 ML/day (depending on how much flow is added downstream of Reach 2 by inflowing springs and tributaries).

3.2.6 High Flow Fresh

Flow events in winter or spring are required to inundate benches in the channel to a depth of at least 0.3 m to provide foraging habitat that will be exploited by birds and other local fauna [4b]. To achieve this objective a flow of **288 ML/day** is required to inundate at least 50% of the benches to this depth. It is recommended that such a flow occur at least twice over the winter-spring period for at least 3 days each time.

A number of other objectives depend on high flow freshes, these are:

- To provide conditions to initiate fish spawning [3d] by flooding stream margins (0.1 m of water over in-stream benches) achieved at 231 ML/day;
- To mobilise silt-sized floccs from the base of pools [1a] which should occur when the velocity in the deepest pool reaches around 0.2 m/s, requiring a discharge of around 73 ML/day at this site;

---

[5] Hydraulic depth is the areal average depth. It is computed as the flow area divided by the flow width.

- To provide a flow sufficient to rupture the stems of emergent macrophytes [1b, 2a.4, 2b.4] and clear the channel of dense *Myriophyllum sp.* and *Triglochin procera* [2b.5]. Sufficient discharge to achieve this objective requires a bending stress be applied to the macrophyte stems to cause rupture. Groenveld and French (1995) demonstrate that when the product of flow depth and mean channel velocity exceeds 0.152 there is a 95% chance of stem rupture. For 50% of the cross-sections this condition is met by a discharge of 70 ML/day.
- To facilitate longitudinal fish passage between the upper reaches of Darlot Creek and the estuary by ensuring the minimum depth in the reach is 0.3 m [3f], fulfilled at the site by a flow of 62 ML/day.

3.2.7 Bankfull Flow

Darlot Creek downstream of Lake Condah is an artificial channel and consequently the channel morphology does not reflect the antecedent discharge regime. Furthermore, the flow regime does not appear to have had a major impact on channel form in the 50 years since the drain was cut, probably explained by the highly cohesive clay soil through which the drain is cut. Consequently the only applicable geomorphic objective is to maintain downstream sediment transport [1e] (from the upper to the lower reaches). It was thought that this objective would be achieved if flow sufficient to move sediments up to medium grained sands from the deepest pool were provided. In fact, the system carries mostly clay and silt sized material, but this settles as floccs, so it was considered appropriate to assume a higher size threshold. The shear stress threshold required a discharge of 201 ML/day to achieve this, while the velocity threshold suggested 164 ML/day was needed. Both of these discharges are lower than the high flow fresh (288 ML/day) hence there is no need for a separate bankfull flow recommendation.

For the future flow regime, with a restored Lake Condah, the lake will trap a certain percentage of the inflowing suspended sediments. The sediment load in Darlot Creek is not high enough to threaten the functionality of the lake through sedimentation, and the outflow pipe and lake spills will transfer some of the sediment load downstream. As most of the sediment load is transported during high flow events, it is likely that most of the annual sediment load will be passed through the lake. Thus, the high flow fresh will be adequate to maintain the downstream transport of any sediment floccs that might settle in the deeper parts of Reach 2.

There are no ecological objectives for Reach 2 that require a bankfull flow.

3.2.8 Overbank Flow

There are no ecological or geomorphological objectives that require an overbank flow in Reach 2.

3.3 Site 3: Darlot Creek at Wylies Road

XS2 – upstream end of reach	XS9 – downstream end of reach

3.3.1 Summary of Recommendations:

Component	Magnitude (ML/day)	Frequency	Duration	Key Indices	Other Indices
Cease To Flow	------------------- *not recommended* --------------			2b.1	2a.3
Summer Low Flow	≥3			3a, 4c	2a.2, 2b.1
Low Flow Fresh - 1	≥66 (no max.)	≥2 per sum-aut	≥3 days	3e	3b
Low Flow Fresh - 2	≥240 (no max.)	≥1 per sum-aut	≥3 days	3f.2, 3e	4b, 3d, 3f.1
Low Flow Fresh - 3	≥97 (no max.)	Natural freq. or 1 per April-May (if natural >1)	Natural duration	3m	
Winter High Flow	≥108			2a.1, 2b.2; 3c.1, 3c.2	3a, 4c
High Flow Fresh - 1	≥428 (no max.)	≥1 per win-spr	≥1 day; recession 14 - 21 days	1b, 2a.4, 2b.4, 2a.5	1a
High Flow Fresh - 2	≥240 (no max.)	≥2, one each per win and spr	≥3 days	3f.2; 3e	4b, 3d, 3f.1
Bankfull Flow	≥850 (no max)	≥2 in 3 years	≥1 day <2 months	1c, d, e	2f
Overbank Flow	≥1,171	≥1 in 3 years	≥1 day	3h	3g

3.3.2 Cease-to-flow

A cease-to-flow period was not recommended for this reach. This will ensure that the base of the channel remains water logged throughout the low flow period in order to maintain seasonally growing submerged and semi-emergent aquatic vegetation [2b.1]. Cease-to-flow should only occur along this reach if catchment inflows cease as a result of climatic conditions and on the basis of 2007 landuse and development levels.

This cease-to-flow recommendation also protects flow-tolerant submerged aquatic macrophytes [2a.3].

3.3.3 Summer Low Flow

A minimum discharge through the Wylies Road reach is required over summer to maintain permanent deep water refuges for fish (River Blackfish in particular) [3a.1] and perennial foraging habitat for resident fauna [4c.2]. An adequate refuge for River Blackfish requires a minimum water depth of 0.5 m. The survey indicated the presence of a number of pools through the reach and thus a flow of only **3 ML/day** was required to provide suitable refuge depths in at least 2 pools.

The low flow recommendation also satisfies the requirements of flow-tolerant submerged aquatic macrophytes [2a.2] and seasonally growing submerged and semi-emergent aquatic vegetation [2b.1]. A suitable flow to ensure the survival of these plants was one that maintains a minimum hydraulic depth of 0.10 m at 50% of the cross-sections. In the Wylies Road reach a flow of 1.5 ML/day achieved this condition and hence the recommendation of 3 ML/day is sufficient.

3.3.4 Low Flow Fresh (1, 2 and 3)

Low flow freshes are required to cover low points on the bed, in-stream barriers or other obstructions to facilitate the local movement of fish (longitudinal fish passage [3e]). A suitable discharge was defined as one that provides a water depth of 0.30 m at most of the cross-sections at least twice over summer/autumn. Movement through the entire reach (i.e. 0.30 m at all cross-sections) was not considered necessary as the need is for local rather than regional movement. The discharge required to provide 0.30 m of water at all but two of the cross-sections (considered to provide local movement) is **66 ML/day**.

The natural rock barrier at the upstream end of this reach near the Condah Mission limits fish passage between Reach 3 and the upstream Reach 2 and Lake Condah. It is desirable to provide fish passage over this barrier, particularly for eels [3f.2], which is achieved by a flow of at least **240 ML/day**. A duration of at least 3 days and frequency of at least 1 per season are specified. Higher frequencies are desirable, but a minimum frequency of 1 per season was selected in recognition of the naturally lower frequency of these events in summer compared to winter.

Low flow fresh 3 is a special Grayling spawning flow. This event is valuable only in April or May. The hydraulic criterion was discharge required to provide 0.30 m of water at all cross-sections (considered to provide reach-wide movement) is **97 ML/day**. The frequency and duration required are according to the natural frequency and duration; the likelihood of Grayling in the river is based on only one anecdotal sighting so the Panel were not inclined to recommend this as an annual event unless this was the natural frequency.

Low flow freshes also have a function to ensure pool water quality is maintained [3b]. The fresh should ideally provide sufficient flow to maintain and mix the water in pools at least once every 3 to 4 weeks. A discharge that produces a measurable velocity (0.1 m/s) in the deepest pool was considered a suitable flow to perform this function. At Wylies Road a discharge of 64 ML/day is predicted to achieve this objective, hence the 66 ML/day required to achieve [3e] is sufficient. The frequency of Low Flow Fresh events was not set at every 3 – 4 weeks (equal to 6 – 8 events per season) in order to meet the ideal requirements for pool mixing events as examination of the flow time series revealed that such a frequency rarely occurred in the Unimpaired scenario. The reason for this inconsistency is that at this site, in nature, either the pools are mixed with flows <0.1 m/s, or the hydraulic model did not accurately characterise this condition.

3.3.5 Winter High Flow

Over winter flow-tolerant submerged aquatic macrophytes [2a.2] and seasonally growing submerged and semi-emergent aquatic vegetation [2b.1] require reliable flowing water with a minimum depth of 0.5 m to maintain productivity. It is recommended that such a depth be maintained over at least 50% of the cross-sections of the Wylies Road reach to ensure these vegetation communities remain viable. This requires a minimum discharge of **108 ML/day** through winter and spring.

Baseflow through winter and spring is also necessary to maintain permanent deep water refuges (0.5 m depth at one cross-section in the reach) for both fish [3a] and other resident fauna [4c]. These requirements are met by the 108 ML/day flow specified. The High Flow also provides conditions suitable for reproduction for a number of fish species through a long recession of 14 – 21 days from Aug – Nov [3c.1, 3c.2]. During these periods, maximum velocity in pools should be 0.1 m/s.

3.3.6 High Flow Fresh (1 and 2)

At Wylies Road the most stringent requirement for the high flow fresh is to provide a flow sufficient to rupture the stems of emergent macrophytes [1b, 2a.4, 2b.4] and clear the channel of dense *Myriophyllum sp.* and *Triglochin procera* [2a.5]. Sufficient discharge to achieve this objective requires a bending stress be applied to the macrophyte stems to cause rupture. Groenveld and French (1995) demonstrated that when the product of flow depth and mean channel velocity exceeds 0.152 there is a 95% chance of stem rupture. For 50% of the cross-sections this condition is met by a discharge of **428 ML/day** and this is the recommended minimum magnitude for a high flow fresh. Only one event per season is required.

A number of other objectives depend on high flow freshes, these are:

- To inundate benches in the channel to at least 0.3 m during winter and spring [4b] demands the highest discharge at 182 ML/day. This discharge inundates at least 50% of the benches and needs to occur at least twice, once in winter and once in spring, for at least 3 days each time.
- To mobilise silt-sized floccs from the base of pools [1a] which should occur when the velocity in the deepest pool reaches around 0.2 m/s, requiring a discharge of 235 ML/day at this site;
- To provide conditions to initiate fish spawning [3d] by flooding stream margins (0.1 m of water over in-stream benches) achieved at 109 ML/day; and
- To facilitate longitudinal fish passage between the upper reaches of Darlot Creek and the estuary by ensuring the minimum depth in the reach is 0.3 m [3f.1], fulfilled at the site by a flow of 97 ML/day.

A high flow fresh sufficient to rupture emergent macrophyte stems need only be provided once a year. However, it is necessary (according to [4b]) that benches be inundated at least twice a year. The requirement for this objective (182 ML/d) is met by the requirement to provide fish passage over the natural rock barrier near the Condah Mission [3f.2], which is achieved by a flow of at least **240 ML/day**.

Therefore, two high flow freshes are recommended: one large fresh of at least **428 ML/day**; and one smaller fresh of at least **240 ML/day**. This regime satisfies each of the objectives in a water efficient manner.

3.3.7 Bankfull Flow

Bankfull flows are geomorphologically important in order to maintain channel form and key habitats [1c], to maintain connectivity between the channel and important floodplain and wetland zones [1d], and to maintain downstream sediment transport [1e]. To achieve each of these geomorphic objectives a discharge that produces a water surface elevation equalling the morphologically-defined[6] bankfull elevation at 50% or more cross-sections was deemed necessary. At Wylies Road this was achieved by a flow of **850 ML/day**. These channel maintenance flows should occur as least twice every three years and this was used to define the frequency of the bankfull flow.

There are high value floodplain grasslands associated with Darlot Creek that require at least shallow inundation every couple of years during winter/spring [2f]. At the Wylies Road reach the requirement was evaluated for the grassland dissected by cross-section 7 (water surface elevation of 35.60 mAHD). A discharge of 837 ML/day was needed to inundate this region, a flow that the geomorphic requirements above would provide (i.e. 850 ML/day is sufficient).

3.3.8 Overbank Flow

Overbank flows provide a critical mechanism for the exchange of carbon and organic debris from the riparian zone into the main channel [3h]. An overbank flow suitable for this purpose was defined as the discharge having a depth 0.2 m above the morphological bankfull at 50% of cross-sections. The hydraulic model suggests a flow of **1,171 ML/day** will achieve this purpose. The flow was designed principally to facilitate organic material transport and therefore the overbank event having a flow peak of 1,171 ML/day maintained for at least 1 day is sufficient.

This overbank flow is also considered sufficient to activate the floodplains that flank the Wylies Road reach. Inundation of these areas provides extensive habitat spieces for fish and macroinvertebrates [3g]. The flow required to inundate this area was thought to be 837 ML/day which inundates the grassland dissected by cross-section 7 (see description for [2f] in the Bankfull Flow section above). As the recommended overbank flow is almost 40% greater than this, the inundation duration should be sufficient assuming the hydrographs follow the shape of natural events (i.e. from the historical record).

[6] Morphological bankfull point is judged by an expert fluvial geomorphologist who looks at the break-of-slope points in the channel cross-section. The selection of the bankfull elevation is also supported by the hydraulics and hydrology to ensure that the elevation chosen corresponds to a flow with an appropriate return interval (usually between 1 and 2 ARI) and consistent with the elevation at other cross-sections in the reach.

3.4 Site 4: Darlot Creek at the IPA

IPA 6B - main channel (overbank)	IPA8 - floodplain channel

3.4.1 Summary of Recommendations:

Component	Magnitude (ML/day)	Frequency	Duration	Key Indices	Other Indices
Cease To Flow	------------------ *not recommended* --------------			2b.1	2a.3
Summer Low Flow	≥26 (no max.)			3a.1, 4c	2a.2, 2b.1
Low Flow Fresh - 1	≥35 (no max.)	≥2 per sum-aut	≥3 days	3e	3b
Low Flow Fresh - 2	≥108 (no max.)	Natural freq. or 1 per April-May (if natural >1)	Natural duration	3m	
Winter High Flow	≥87 (no max.)			2a.1, 2b.2	3a, 4c
High Flow Fresh	≥115 (no max.)	≥2 per win-spr	≥3 days peak, recession 14 - 21 days	1b, 2b.4 2a.4, 2a.5, 3c.1, 3c.2	1a, 3d, 3f
Very High Flow Fresh	≥401 (no max.)	≥3 per win-spr	≥1 day	2e.2, 3g	1c, 1d, 1e
Bankfull Flow	≥702 (no max.)	2 in 3 years	≥1 day <2 months	2f	
Overbank Flow	≥845 (no max.)	1 in 3 years	≥1 day <60 days total	3h 2g.2	3g

3.4.2 Cease-to-flow

A cease-to-flow period was not recommended for this reach. This will ensure that the base of the channel remains water logged throughout the low flow period in order to maintain seasonally growing submerged and semi-emergent aquatic vegetation [2b.1]. Cease-to-flow should only occur along this reach if catchment inflows cease as a result of climatic conditions and on the basis of 2007 landuse and development levels.

This cease-to-flow recommendation also protects flow-tolerant submerged aquatic macrophytes [2a.3].

3.4.3 Summer Low Flow

A minimum discharge at the IPA site is required through summer to maintain permanent deep water refuges for fish (River Blackfish in particular) [3a.1] and perennial foraging habitat for resident fauna [4c]. An adequate refuge for River Blackfish requires a minimum water depth of 0.5 m. As the survey at this site did not indicate the presence of significant pools (Figure 6) this water depth must be maintained by flow. A discharge of **26 ML/day** was set on the basis that this provided 0.5 m of water over at least one of the cross-sections[7].

The low flow recommendation also satisfies the requirements of flow-tolerant submerged aquatic macrophytes [2a.2] and seasonally growing submerged and semi-emergent aquatic vegetation [2b.1]. It is suggested that a suitable flow to ensure the survival of these plants is a flow that maintains a minimum hydraulic depth of 0.10 m at 50% of the cross-sections. At the IPA site a flow of 7 ML/day is needed to meet this condition which is satisfied by the recommendation of 26 ML/day.

3.4.4 Low Flow Fresh (1 and 2)

Low flow freshes are required to cover low points on the bed, in-stream barriers or other obstructions to facilitate the local movement of fish (longitudinal fish passage [3e]). A suitable discharge was defined as one that provides a water depth of 0.30 m at most of the cross-sections at least twice over summer/autumn. Movement through the entire reach (i.e. 0.30 m at all cross-sections) was not considered necessary as the need is for local rather than regional movement. The discharge required to provide 0.30 m of water at all but two of the cross-sections (considered to provide local movement) is **35 ML/day**.

Low flow fresh-2 is a special Grayling spawning flow. This event is valuable only in April or May. The hydraulic criterion was discharge required to provide 0.30 m of water at all cross-sections (considered to provide reach-wide movement) is **108 ML/day**. The frequency and duration required are according to the natural frequency and duration; the likelihood of Grayling in the river is based on only one anecdotal sighting so the Panel were not inclined to recommend this as an annual event unless this was the natural frequency.

Low flow freshes also have a function to ensure pool water quality is maintained [3b]. The fresh should provide sufficient flow to maintain and mix the water in pools at least once every 3 to 4 weeks. A discharge that produces a measurable velocity (0.1 m/s) in the deepest pool was considered a suitable flow to perform this function. At the IPA a discharge of 6 ML/day is required to achieve this objective (a flow that is attained more often than every 3 to 4 weeks at this site in summer), hence 35 ML/day is adequate.

3.4.5 Winter High Flow

Over winter flow-tolerant submerged aquatic macrophytes [2a.2] and seasonally growing submerged and semi-emergent aquatic vegetation [2b.1] require reliable flowing water with a minimum depth of 0.50 m to maintain productivity. It is recommended that such a depth be maintained over at least 50% of the cross-sections at the IPA site to ensure these vegetation communities remain viable. This requires a minimum discharge of 87 ML/day through winter and spring at the IPA site.

Baseflow through winter and spring is also necessary to maintain permanent deep water refuges (0.50 m depth at one cross-section in the reach) for both fish [3a] and other resident fauna [4c]. These requirements are met by the **87 ML/day** flow specified.

3.4.6 High Flow Fresh

High flow freshes are required to meet a range of environmental objectives. At the IPA site the most stringent requirement is to provide flows that rupture the stems of emergent macrophytes [1b, 2a.4, 2b.4] and clear the channel of dense *Myriophyllum sp.* and *Triglochin procera* [2a.5]. Sufficient discharge to achieve this objective requires that sufficient bending stress be applied to the macrophyte stems to cause rupture. Groenveld and French (1995) demonstrate that when the product of flow depth and mean channel velocity exceeds 0.152 there is a 95% chance of stem rupture. For 50% of the IPA cross-sections this condition is met by a discharge of **115 ML/day** and this is the recommended minimum magnitude for a high flow fresh.

A number of other objectives depend on high flow freshes, these are:

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[7] Cross-section 1 at this site.

- the geomorphic requirement to mobilise silt-sized floccs from the base of pools [1a] which requires 26 ML/day at this site;
- provide conditions to initiate fish spawning [3d] by flooding stream margins (0.1 m of water over in-stream benches) achieved at 88 ML/day; and
- to facilitate longitudinal fish passage between the upper reaches of Darlot Creek and the estuary by ensuring the minimum depth in the reach is 0.3 m [3f], fulfilled at the IPA by a flow of 108 ML/day.
- To provide conditions suitable for reproduction for a number of fish species through a long recession of 14 – 21 days from Aug – Nov [3c.1, 3c.2]

3.4.7 Very High Flow Fresh

At the IPA site there is an additional requirement for flows that inundate the wetland complex on the floodplain. The wetland area is recognised as a high value asset for the environmental diversity it brings to Darlot Creek and, as a consequence, the cultural heritage that is associated with the site. The flow requirement, called a *very high flow fresh*, is designed to deliver water to refresh the floodplain wetlands regularly over winter and spring to support both wetland plant communities [2e.2] and for fish, eels and macroinvertebrates [3g]. It was estimated that a discharge of **401 ML/day** was required to connect one of the key, large wetland areas[8]. A frequency of three times per winter/spring was set as the minimum required to maintain the volume of water in the wetlands (low evaporation) and to refresh it with only a short duration (1 day) necessary to achieve such an exchange.

This flow recommendation was based on the assumption that the wetlands are not supported by groundwater but are filled by surface water. It is likely that groundwater interactions play a role and that the connectivity of these wetlands occurs at a different volume than that identified. Therefore, it is recommended that the magnitude of this flow threshold be refined through time by observation of the water levels (install a stage board at the bridge) that provide water to the wetland system.

3.4.8 Bankfull Flow

There are high value floodplain grasslands associated with Darlot Creek that require at least shallow inundation every couple of years during winter/spring [2f]. At the IPA site the requirement was evaluated for the grassland dissected by cross-section 3 (water surface elevation of 9.55 mAHD). A discharge of **702 ML/day** was needed to inundate this region.

Bankfull flows are also important for geomorphological functioning [1c, 1d, 1e]. To achieve the geomorphic objectives a discharge that produces a water surface elevation equalling the morphologically-defined bankfull elevation at 50% or more cross-section was deemed necessary. At the IPA site this was achieved by a flow of 572 ML/day, meaning that the grassland requirement (702 ML/day, above) defines this component. These channel maintenance flows should occur as least twice every three years and this was used to define the frequency of the bankfull flow.

3.4.9 Overbank Flow

Overbank flows provide a critical mechanism for the exchange of carbon and organic debris from the riparian zone into the main channel [3h] as well as providing a period of high productivity in fish and macroinvertebrate communities courtesy of the extensive habitat across the floodplain and wetland areas [3g]. An overbank flow suitable for this purpose was defined as the discharge having a depth 0.2 m above the morphological bankfull at 50% of cross-sections. The hydraulic model suggests a flow of **845 ML/day** will achieve this purpose. The flow was designed principally to facilitate organic material transport and therefore a duration of only 1 day was recommended. Such a flow is likely to ensure a significant duration of wetland connectivity [3g], which is provided at the lower, Very High Flow Fresh magnitude of 401 ML/day. The duration of the overbank flow should not exceed 60 days in any year to meet requirements for *Leptospermum lanigerum* [2g.2].

[8] It was not possible within the survey scope to identify with certainty the critical sills that control the filling and emptying of the wetland area, however the survey was designed to allow an estimate to be made. The wetland area is connected to the main Darlot Creek channel just downstream of the IPA site via a floodplain channel. The sill (low point) on the southern margin of the wetland lies at 8.66 mAHD. A flow depth of 8.88 mAHD at the most-downstream cross-section was selected to define the Very High Flow Fresh at the IPA site as this should provide approximately 0.2 m of water backing up over the wetland sill.

3.5 Site 5: Estuary of the Fitzroy River and Darlot Creek

3.5.1 Methodology

Due to a lack of information on the hydrodynamics of the estuary, it was not possible to make specific recommendations for flow components. As an alternative, a risk assessment was undertaken to determine the relative risk posed to ecological assets by reductions in three key hydrological indices (Table 16).

Table 16.
Three key estuarine hydrological indices and relevant flow objectives relating to assets potentially at risk from a reduction in the hydrological indices.

Estuarine hydrological index	Asset group			
	Geomorphic	Vegetation	Fish	Waterbirds
Summer baseflow magnitude (Low Flow)	-	2a, 2b	3b	4g
Winter baseflow magnitude (High Flow)	-	2a, 2b	3k, 3l	4g, 4h
Frequency of mouth opening and subsequent flushing events (% of years with potential for event)	1a, 1b, 1c, 1d, 1f	2f, 2g	3d, 3f, 3i, 3l	-

The change in the hydrological indices was calculated for six scenarios, relative to Unimpaired (Current with no development):

- Current
- Current land use and climate, with weir and 10 ML/d passing flow
- Current land use and climate, with weir and 20 ML/d passing flow
- Current land use and climate, with weir and 30 ML/d passing flow
- 2030 land use, current climate, with weir and 20 ML/d passing flow
- 2030 land use, dry climate, with weir and 20 ML/d passing flow

Change in baseflow index was calculated as the change in the flow exceeded 50% of the time for the summer and winter periods (from flow duration curves in Gippel et al., 2008b) and change in frequency of mouth opening and flushing was based on the percentage of years with an event thought to overcome this threshold (from analysis of threshold frequency in Gippel et al. 2008b).

A list was made of the ecological assets that were potentially at risk of impairment from a reduction in the three indices (Table 17). The assets were rated according to three conservation status classes, with the consequence of change (consequence) being higher the higher the conservation status (Table 18). Degree of change (likelihood of impairment due to hydrological change) was ranked into 4 classes (Table 18). The product of consequence and likelihood gives risk of impairment, which was grouped into 5 classes, ranging from very low (insignificant) to very high (Table 19).

Table 17.
Main hydrological changes likely from restoration of Lake Condah hydrology through installation and operation of a weir, and the ecological components potentially at risk. Common assets for each of the three hydrological change indices are colour coded and have the same alphabetic code designation.

Key hydrological change index	Ecological asset potentially at risk of impairment	Asset code
Reduction in summer baseflow	Estuarine dependent fish (freshwater) Eels and Australian Grayling: upstream migration could be limited by reduction in duration of mouth being open	1A
	Freshwater derived estuarine opportunists (Yarra pigmy perch, Blackfish)	1B
	Estuarine resident fish (Black bream, Estuary perch)	1C
	Frogs and water rats (n.b. *Pseudophryne semimarmorata*)	1D
	Freshwater dependent vegetation (e.g. *Phragmites australis*)	1E
Reduction in winter baseflow	Estuarine dependent fish (freshwater) (esp. Eels and Australian Grayling): migration could be limited by reduction in duration of mouth being open	2A
	Freshwater derived estaurine opportunists (Yarra pigmy perch, Blackfish)	2B
	Estaurine resident fish (Black bream, Estuary perch)	2C
	Frogs and water rats (n.b. *Pseudophryne semimarmorata*)	2D
	Freshwater dependent vegetation (e.g. *Phragmites australis*)	2E
	Freshwater dependent waterbirds (n.b. Great Egret, Australasian Bitterns, Bush Stone-curlew, Magpie Goose)	2F
Reduction in frequency of mouth opening and flushing flow	Estuarine dependent fish (freshwater) (esp. Eels and Australian Grayling): migration could be limited by reduction in frequency of mouth being open	3A
	Estuarine aquatic vegetation (Ruppia)	3B
	Estuarine opportunist fish (marine) - fishery species (e.g. Yellow eyed mullet)	3C
	Estuarine opportunist fish (freshwater) - fishery species (Australian Salmon)	3D
	Estuarine dependent fish (marine) - fishery species (e.g. congollis)	3E

Table 18.
Three key classes of ecological assets, and score for consequence to ecosystem if a change occurs. Also, score for likelihood of impairment due to hydrological change corresponding to four degrees of change.

Asset	Consequence score
National or state endangered or threatened or high cultural significance	3
National or state rare/icon value/economic value/key ecosystem habitat species	2
Native spp. with no particular conservation status	1
Degree of change	**Likelihood score**
No significant change in quality or extent of habitat / process	0
Minor change in quality or extent of habitat / process	1
Major change in quality or extent of habitat / process	2
Loss of habitat or process	3

Table 19.
Risk matrix, showing classes of risk of impairment for product of consequence and likelihood scores.

		Likelihood			
		0	1	2	3
Consequence	1	very low	low	moderate	moderate
	2	very low	moderate	high	high
	3	very low	moderate	high	very high

Consequence and likelihood scores were assigned to each ecological asset through an expert workshop process (Table 20 and Table 21). Risk scores were calculated for each asset for the Current and the 5 future scenarios (Table 20 and Table 21).

The degree of reduction in summer and winter baseflow increased from Current to 2030 land use to 2030 land use plus dry climate scenarios (Table 20), while the only scenario to have a significant impact on estuary opening frequency potential was the 2030 land use plus dry climate scenario (Table 21). Of the With Weir (current climate and land use) scenarios, the 10 ML/d passing flow option was hydrologically little different from the Current scenario (Table 20 and Table 21), while the 30 ML/d option reduced the impact on summer baseflows but increased the impact on winter baseflows (Table 21). This is explained by the 30 ML/d baseflow enhancing summer flows (by releasing water for longer into summer using water stored in the lake) but reducing winter baseflows because of trapping of some high flows in winter when the lake is low (the 30 L/d passing flow tends to create lower lake levels through faster draining). The impact of the 20 ML/d option fell between that of the 10 ML/d and 30 ML/d options (Table 21).

For the With Weir (current climate and land use) scenario (i.e. immediately upon restoring Lake Condah hydrology) the increased risk of impairment was significant only for winter baseflow, and for the 30 ML/d passing flow option (Table 21). The 20 ML/d passing flow option led to slightly increased risk for some estuarine fish assets and phragmites (Table 21). With the expected 2030 land use patterns there is a moderate risk to assets sensitive to changes in winter baseflows (Table 20) (with the hydrological change brought about principally by the land use change rather than the Lake Condah weir). A dry future climate scenario places most of the assets at high to very high risk of impairment

(Table 20). This risk has nothing to do with the Lake Condah weir, with the risk being associated with the climate change.

Table 20.
Risk of impairment to three key classes of ecological assets in Fitzroy estuary in response to hydrological changes associated with three future scenarios. Change is relative to Unimpaired (Current with no development) scenario. Common assets for each of the three hydrological change indices are colour coded.

			Current		2030 land use, current climate, with weir and 20 ML/d passing flow		2030 land use, dry climate, with weir and 20 ML/d passing flow	
Index	Asset code	Con-sequence	Likelihood	Risk	Likelihood	Risk	Likelihood	Risk
Reduction in summer baseflow	change		81 ↓ 67 ML/d (↓17%)		81 ↓ 62 ML/d (↓23%)		81 ↓ 47 ML/d (↓42%)	
	1A	3	2	6	2	6	2	6
	1B	3	2	6	2	6	2	6
	1C	2	1	2	2	4	2	4
	1D	2	2	4	2	4	2	4
	1E	1	1	1	1	1	1	1
Reduction in winter baseflow	change		283 ↓ 266 ML/d (↓6%)		283 ↓ 223 ML/d (↓21%)		283 ↓ 119 ML/d (↓58%)	
	2A	3	0	0	2	6	3	9
	2B	3	0	0	2	6	3	9
	2C	2	0	0	1	2	2	4
	2D	2	0	0	1	2	2	4
	2E	1	0	0	2	2	3	3
	2F	3	0	0	1	3	2	6
Reduction in flushing frequency	change		78% - 78% yrs (0%)		78% ↓ 78% yrs (0%)		78% ↓ 63% yrs (↓15%)	
	3A	3	0	0	0	0	2	6
	3B	1	0	0	0	0	1	1
	3C	2	0	0	0	0	1	2
	3D	2	0	0	0	0	1	2
	3E	2	0	0	0	0	2	4

3.5.2 Conclusion

The risk assessment suggested that the future scenario most similar to the Current scenario (i.e. least likely to create a change) was With Weir and 10 ML/d passing flow. This scenario carries a similar risk for processes reliant on summer baseflows as does the Current scenario. This risk is reduced for the scenario with a 30 ML/d passing flow, but this scenario carries a significant risk to processes reliant on winter baseflows. The 20 ML/d passing flow option with the weir offers a reasonable compromise. If land use and climate change as predicted, then the health of the estuary will be at risk from insufficient frequency of mouth opening and flushing.

Table 21.
Risk of impairment to three key classes of ecological assets in Fitzroy estuary in response to hydrological changes associated with three future scenarios. Change is relative to Unimpaired (Current with no development) scenario. Common assets for each of the three hydrological change indices are colour coded.

Index	Asset code	Con-sequence	Current with weir and 10 ML/d passing flow Likelihood	Risk	Current with weir and 20 ML/d passing flow Likelihood	Risk	Current with weir and 30 ML/d passing flow Likelihood	Risk
Reduction in summer baseflow	change		81 ↓ 63 ML/d (↓22%)		81 ↓ 67 ML/d (↓17%)		81 ↓ 74 ML/d (↓9%)	
	1A	3	2	6	2	6	1	3
	1B	3	2	6	2	6	1	3
	1C	2	2	4	1	2	0	0
	1D	1	2	4	2	4	1	1
	1E	2	1	1	1	1	1	2
Reduction in winter baseflow	change		283 ↓ 264 ML/d (↓7%)		283 ↓ 249 ML/d (↓12%)		283 ↓ 236 ML/d (↓17%)	
	2A	3	0	0	1	3	2	6
	2B	3	0	0	1	3	2	6
	2C	2	0	0	0	0	1	2
	2D	3	0	0	0	0	1	2
	2E	2	0	0	1	2	2	2
	2F	2	0	0	0	0	1	3
Reduction in flushing frequency	change		78% ↑ 85% yrs (↑7%)		78% - 80% yrs (↑2%)		78% - 83% yrs (↑5%)	
	3A	3	0	0	0	0	0	0
	3B	1	0	0	0	0	0	0
	3C	2	0	0	0	0	0	0
	3D	2	0	0	0	0	0	0
	3E	2	0	0	0	0	0	0

4 Compliance

4.1 *Introduction*

Compliance is whether or not, or the degree to which, the hydrology meets the targets specified in the FLOWS recommendations. For Lake Condah these targets were expressed as threshold lake heights to be achieved for a certain minimum percentage of the time (different durations were specified for summer and winter periods). For Darlot Creek the targets are Low Flow, High Flow, Fresh, Bankfull and Overbank flow components, specified in terms of season, magnitude, frequency, and duration. In most FLOWS studies it is reasonable to assume that the benchmark flow scenario (the Unimpaired scenario) should be 100% compliant. This does not necessarily mean that each FLOWS component has to occur as specified in each year, but rather that the pattern of compliance and non-compliance from year to year is the “natural” pattern, and is the benchmark pattern against which the recommended regime should be compared. The flow components are normally specified as applying to an “average” hydrological year, and they would not necessarily be expected to occur at the same frequency or duration in drought years.

4.2 Methodology

The compliance examined 7 modelled daily flow series for 5 sites over the period 1964 to 2004 (inclusive). The scenarios were coded as follows:

U	Unimpaired (Current with no diversions and farm dams)
C	Current hydrology (as impacted by existing diversions and farm dams; existing drain, but no weir at Lake Condah)
C10	Current hydrology with 52.4 mAHD weir at Lake Condah and 10 ML/d passing flow
C20	Current hydrology with 52.4 mAHD weir at Lake Condah and 20 ML/d passing flow
C30	Current hydrology with 52.4 mAHD weir at Lake Condah and 30 ML/d passing flow
F.a	Future 2030 land use and current climate impacted hydrology with 52.4 mAHD weir at Lake Condah and 20 ML/d passing flow
F.b	Future 2030 land use and future dry climate impacted hydrology with 52.4 mAHD weir at Lake Condah and 20 ML/d passing flow

The flow series' were analysed using a special program (copyright Fluvial Systems) that extracted the flow components as specified by the FLOWS recommendations. The program then calculated the frequency and duration of each component in each year of the record, with the records split into winter (*Wi*) and summer (*Su*) seasons, or for particular months if specified by the recommendations. The program output the results as a series of yearly time series plots, indicating for each year (separately for summer and winter), and each scenario, the frequency of events and the duration of events (with the option of mean or maximum duration if multiple events occurred). In identifying hydrological events, a number of assumptions were made:

1. The hydrological season was used, such that December was lumped in with the following year's summer.
2. Events were allocated to the month in which they finished, except where indicated.
3. Flow events (Freshes, Bankfull and Overbank) were deemed independent if separated from the next event by at least 7 days of lower flow.
4. In cases where an event contained days of flow that fell below the event threshold, but the event was still regarded as a continuous event (due to the drop being for less than the 7 day independence criterion) those days were not counted in the calculation of event duration.
5. Bankfull events were not regarded as independent from Overbank events, i.e. if an Overbank event occurred then it also qualified as a Bankfull event.
6. In making recommendations for freshes, they can be specified as being independent from higher magnitude events. The Panel would specify such freshes as having an upper, as well as a lower, magnitude threshold. For example, if a Low Flow Fresh rises above its upper threshold then it cannot be classed as Low Flow Fresh, but will be classed as a High Flow Fresh, Bankfull or Overbank event, depending on how high the peak goes, and whether it continues from the summer into the winter period. By definition then, these freshes that are specified with an upper threshold cannot be defined as comprising part of the rising and falling limbs of hydrographs of larger events. Freshes might be defined with an upper limit if the ecological or geomorphic objective that it is supposed to satisfy is compromised if the flow rises above a certain limit. For example, a fresh to cue fish spawning might have an upper limit, because if the flow rises too high there might be too much risk that the eggs will be washed away. In the case of Darlot Creek, the Panel did not specify any components with an upper limit, so this condition was not used.

Having established yearly time series' of frequency and duration for each flow component, for each season for each scenario, the compliance of each component can be assessed against a benchmark. In this project, two benchmarks were used:

1. The requirements as specified by the Panel for each FLOWS component, and
2. The degree to which the Panel's specifications for each FLOWS component are met in the Unimpaired scenario.

In the first method, compliance involves calculation of the percentage of years that satisfy the Panel's specification of the component. For example, if the recommendation for a particular Fresh component requires 3 events per season, with a minimum of 3 days duration, then years with only 1 or 2 events, or less than 3 events of at least 3 days duration would not be regarded as complying. It was found that in general this method of assessing compliance was too stringent, as for many of the flow components very few years in the record complied. As an alternative, years were classed as "partially complying" if at least one event above the threshold magnitude occurred, and regardless of duration. The baseflow components, Low Flows and High Flows, could not be assessed in this way (based on frequency) as they are not "events". In this case an arbitrary threshold for compliance was set at 50%, i.e. a year failed to comply if the baseflow fell below threshold for more than 50% of the time. The number of years either fully or partially complying was then calculated, and expressed as a percentage of the record length (41 years). This statistic allowed for comparison of event frequency and baseflow duration between scenarios.

The second method of assessment of compliance uses the Unimpaired scenario as the benchmark. In this method, the compliance of a test scenario was assessed for each year relative to the occurrence (or non-occurrence) of events in the Unimpaired scenario. In other words, if the event occurred in a particular year in the Unimpaired scenario, then if it also occurred in the test scenario then it would be deemed compliant for that year – if it did not then the test scenario was deemed non-compliant for that year. If, in a particular year, an event did not occur in the Unimpaired scenario, then the test scenario could not be deemed non-complaint for that year. For baseflow components the deviation in percent of time less than threshold from that of the Unimpaired scenario was calculated, and compliance was defined by an arbitrary upper limit of 10% change. The number of years complying was then calculated, and expressed as a percentage of the record length (41 years). This statistic allowed for comparison of event frequency and baseflow duration for scenarios relative to the Unimpaired scenario. The fundamental basis of this method of compliance testing is the assumption that the Unimpaired scenario represents low risk to the ecological health of the river. Thus, this method also acts as a risk assessment, with low compliance meaning high risk and high compliance meaning low risk. Note: for Lake Condah the Unimpaired scenario does not represent low risk, as Lake Condah is highly hydrologically disturbed, so this second method of compliance testing could not be applied.

4.3 Site 1: Lake Condah

The Unimpaired and Current water level regimes for Lake Condah were not suitable benchmarks for comparison of future scenarios, as these scenarios are represent a high degree of hydrological disturbance, while the future test scenarios with a weir represent a hydrological regime that is closer to natural. As an alternative, the compliance of each of the lake level FLOWS components was measured against targets established by the Panel as being suitable to satisfy the objectives established for lake restoration. These objectives related to establishment and maintenance of an open water zone, submerged aquatic plant zone, reed zone and Silky Tea Tree zone, avoidance of drying out, and allowance for fish passage over the weir.

4.3.1 Fish passage to the lake

With respect to fish passage, the set threshold was >52.2 mAHD, assuming a 0.2 m slot in the crest of the weir. However, this threshold would potentially provide only very shallow water through the slot, so the compliance analysis used the more conservative value of 52.4 mAHD. For the Unimpaired and Current scenarios, with no weir present, a threshold of 51 m was set as the height where fish can access the lake from the Drain running through the lake. The target for fish passage was set at a duration of >20% of the time, for summer and winter.

The compliance analysis revealed that under the Unimpaired and Current scenarios, fish passage was rarely available in summer, but was available for >20% of the time in more than 70% of years (Figure 7). In contrast, under all but one of the With Weir future scenarios, fish passage was available for >20% of the time in a much greater percentage of years, both in summer and winter. The exception was the 2030 land use and dry climate scenario, which provided similar fish access duration as the Current and Unimpaired scenarios (Figure 7).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	0%	0%	0%	0%	0%	0%	0%
1965	21%	20%	98%	81%	57%	59%	24%
1966	0%	0%	11%	10%	10%	10%	0%
1967	10%	7%	27%	21%	19%	19%	4%
1968	2%	2%	0%	0%	0%	0%	0%
1969	3%	2%	82%	47%	22%	30%	9%
1970	0%	0%	33%	24%	18%	18%	0%
1971	25%	20%	75%	63%	53%	54%	26%
1972	37%	30%	100%	100%	97%	94%	44%
1973	0%	0%	1%	0%	0%	0%	0%
1974	0%	0%	45%	24%	21%	19%	5%
1975	0%	0%	41%	18%	17%	17%	2%
1976	5%	4%	98%	75%	19%	19%	10%
1977	0%	0%	82%	59%	26%	25%	9%
1978	0%	0%	9%	7%	6%	6%	0%
1979	14%	13%	94%	64%	32%	30%	15%
1980	0%	0%	24%	14%	10%	11%	1%
1981	0%	0%	10%	9%	4%	5%	0%
1982	0%	0%	9%	7%	2%	3%	0%
1983	16%	17%	30%	29%	28%	29%	20%
1984	12%	10%	97%	82%	68%	75%	15%
1985	0%	0%	59%	22%	15%	18%	5%
1986	15%	13%	48%	35%	32%	32%	13%
1987	22%	17%	90%	58%	36%	37%	16%
1988	0%	0%	9%	8%	8%	8%	0%
1989	0%	0%	10%	9%	9%	9%	0%
1990	0%	0%	11%	9%	7%	9%	0%
1991	0%	0%	19%	13%	0%	3%	0%
1992	0%	0%	32%	4%	3%	4%	0%
1993	10%	8%	67%	49%	31%	36%	17%
1994	0%	0%	30%	25%	14%	16%	0%
1995	0%	0%	12%	1%	0%	0%	0%
1996	0%	0%	9%	6%	0%	2%	0%
1997	0%	0%	12%	10%	8%	9%	0%
1998	0%	0%	5%	3%	0%	0%	0%
1999	0%	0%	5%	4%	0%	4%	0%
2000	0%	0%	0%	0%	0%	0%	0%
2001	0%	0%	8%	5%	4%	4%	0%
2002	10%	9%	38%	29%	25%	28%	11%
2003	0%	0%	2%	0%	0%	0%	0%
2004	0%	0%	10%	9%	5%	8%	0%
%yrs	**10%**	**5%**	**51%**	**44%**	**32%**	**29%**	**10%**

Duration (% time passage available)

never available

1 to 20%

>20% (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	77%	77%	79%	76%	76%	75%	73%
1965	28%	28%	100%	99%	94%	96%	50%
1966	44%	39%	69%	66%	63%	63%	50%
1967	0%	0%	0%	0%	0%	0%	0%
1968	92%	90%	100%	100%	100%	100%	96%
1969	28%	24%	99%	89%	60%	62%	0%
1970	44%	43%	95%	77%	70%	72%	50%
1971	85%	84%	100%	100%	100%	100%	100%
1972	0%	0%	95%	83%	75%	77%	18%
1973	49%	41%	100%	76%	66%	71%	48%
1974	53%	51%	96%	90%	72%	72%	59%
1975	67%	67%	99%	79%	67%	70%	55%
1976	37%	36%	100%	100%	90%	92%	38%
1977	22%	19%	98%	89%	82%	84%	42%
1978	75%	70%	96%	81%	78%	79%	70%
1979	30%	25%	100%	100%	60%	61%	27%
1980	18%	14%	100%	78%	58%	66%	11%
1981	59%	57%	81%	79%	79%	78%	68%
1982	0%	0%	24%	0%	0%	0%	0%
1983	93%	90%	100%	100%	100%	100%	100%
1984	48%	41%	100%	100%	98%	99%	77%
1985	26%	20%	100%	100%	74%	86%	36%
1986	73%	70%	100%	100%	85%	90%	70%
1987	14%	10%	99%	93%	92%	92%	36%
1988	16%	14%	65%	50%	43%	45%	27%
1989	56%	53%	70%	66%	65%	65%	55%
1990	37%	34%	73%	60%	54%	58%	43%
1991	35%	34%	75%	62%	59%	60%	41%
1992	70%	65%	100%	93%	84%	87%	66%
1993	36%	30%	98%	75%	55%	58%	31%
1994	14%	12%	87%	61%	32%	51%	0%
1995	25%	24%	100%	87%	70%	79%	45%
1996	50%	49%	71%	67%	66%	66%	58%
1997	0%	0%	89%	39%	25%	33%	0%
1998	24%	20%	77%	66%	60%	65%	17%
1999	0%	0%	0%	0%	0%	0%	0%
2000	49%	46%	68%	67%	65%	66%	42%
2001	53%	52%	53%	52%	52%	51%	48%
2002	0%	0%	87%	67%	45%	58%	0%
2003	35%	27%	69%	54%	52%	53%	36%
2004	29%	19%	89%	84%	80%	83%	55%
%yrs	**76%**	**71%**	**95%**	**93%**	**93%**	**93%**	**76%**

Duration (% time passage available)

never available

1 to 20%

>20% (compliance)

Figure 7. Pattern of percent of time when fish passage threshold overcome at Lake Condah. Threshold for Unimpaired and Current is 51 mAHD and for the other scenarios (With Weir) it is 52.4 mAHD.

Probably of greater importance than achieving a percentage of time that fish passage is available is the need for a number of events per season (>7 days duration) that allow fish access to the lake. The analysis of these events revealed that for all scenarios, double and triple events per season were much less common than single events (Figure 8). Winter event frequency was similar for all scenarios, but summer event frequency was much higher for the future With Weir scenarios (except for the 2030 land use and dry climate scenario). Most events were >7 days duration, with the future With Weir scenarios tending to have longer events that the Unimpaired and Current scenarios, especially for winter (Figure 8).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	1	1	1	2	2	2	1
1966			1	1	1	1	
1967	1	1	1	1	1	1	1
1968	1	1					
1969	1	1	3	3	2	3	1
1970			2	2	2	2	
1971	4	3	3	2	2	2	3
1972	1	2	1	1	1	1	3
1973			1				
1974			3	2	1	1	1
1975			2	1	1	1	1
1976	1	1	1	4	1	1	1
1977			3	2	1	2	1
1978			1	1	1	1	
1979	1	1	1	2	1	1	1
1980			3	1	1	1	1
1981			1	1	1	1	
1982			1	1	1	2	
1983	1	2	1	1	1	1	1
1984	1	1	1	2	2	2	1
1985			2	2	1	1	1
1986	1	1	2	2	1	1	1
1987	1	1	1	3	2	2	1
1988			1	1	1	1	
1989			1	1	1	1	
1990			1	1	1	1	
1991			2	2		2	
1992			2	1	1	1	
1993	1	1	2	1	2	1	1
1994			1	1	2	1	
1995			2	1			
1996			1	1		1	
1997			1	1	1	1	
1998			1	1			
1999			1	1		1	
2000							
2001			1	1	1	1	
2002	1	1	1	1	1	1	1
2003			1				
2004			1	1	1	1	
%yrs	34%	34%	93%	88%	76%	83%	44%

Event frequency
1 day (compliance)
2 days (compliance
>2 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	1	1	1	1	1
1965	2	2	1	1	2	1	1
1966	2	2	1	1	1	1	1
1967							
1968	2	2	1	1	1	1	1
1969	2	2	1	2	1	1	
1970	2	2	2	1	1	1	2
1971	2	2	1	1	1	1	1
1972			1	2	1	1	1
1973	3	2	1	1	1	1	1
1974	1	1	2	2	1	1	1
1975	1	1	1	1	1	1	1
1976	1	1	1	1	1	1	1
1977	2	2	1	2	2	2	1
1978	1	1	1	1	1	1	1
1979	2	2	1	1	1	1	1
1980	1	2	1	1	1	1	1
1981	1	1	1	1	1	1	1
1982			1				
1983	2	2	1	1	1	1	1
1984	1	2	1	1	1	1	1
1985	2	2	1	1	1	1	2
1986	1	1	1	1	1	1	1
1987	2	2	1	1	1	1	1
1988	1	1	1	2	2	2	1
1989	1	1	1	1	1	1	1
1990	1	1	1	1	1	1	1
1991	1	1	1	1	1	1	2
1992	2	2	1	1	1	1	1
1993	1	1	1	2	1	1	1
1994	1	1	1	1	1	1	
1995	1	1	1	1	2	1	1
1996	1	1	1	1	1	1	1
1997			1	2	2	2	
1998	2	2	1	1	1	1	1
1999							
2000	2	2	1	1	1	1	1
2001	1	1	1	1	1	1	1
2002			2	1	1	1	
2003	2	2	1	1	1	1	1
2004	3	1	1	1	1	1	1
%yrs	85%	85%	95%	93%	93%	93%	83%

Event frequency
1 day (compliance)
2 days (compliance
>2 days (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	39	36	178	74	52	54	43
1966			20	19	18	19	
1967	18	13	50	39	35	35	8
1968	4	4					
1969	6	4	50	28	20	18	17
1970			31	22	17	17	
1971	11	12	45	58	48	50	16
1972	68	28	183	183	177	172	27
1973			2				
1974			28	22	39	34	10
1975			38	32	31	31	3
1976	10	8	178	34	34	34	19
1977			50	54	48	23	17
1978			16	13	11	11	
1979	26	23	172	58	58	55	28
1980			15	25	19	20	2
1981			19	16	8	10	
1982			17	13	4	3	
1983	29	16	54	53	51	53	37
1984	22	19	177	75	63	68	28
1985			54	21	28	32	9
1986	27	23	44	32	58	58	23
1987	40	31	164	35	33	34	30
1988			16	15	14	14	
1989			19	16	16	16	
1990			20	16	13	16	
1991			17	12		3	
1992			30	8	5	7	
1993	19	15	61	90	29	65	31
1994			54	46	13	30	
1995			11	2			
1996			16	11		4	
1997			21	18	15	16	
1998			10	5			
1999			10	8		8	
2000							
2001			15	9	7	8	
2002	19	16	70	53	46	52	20
2003			4				
2004			19	16	10	14	
%yrs	29%	29%	88%	83%	71%	76%	39%

Event duration
< 7 days
7 to 30 days (compliance)
>30 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	141	141	144	138	138	137	134
1965	26	26	183	181	86	176	92
1966	41	36	126	121	115	115	91
1967							
1968	84	83	183	183	182	182	176
1969	26	22	180	81	110	113	
1970	41	40	87	141	128	132	46
1971	78	77	183	183	183	183	183
1972			173	76	136	141	32
1973	30	37	183	139	120	130	87
1974	96	93	88	83	131	132	108
1975	123	123	181	144	123	128	100
1976	68	65	183	183	165	168	69
1977	20	18	178	82	75	77	77
1978	137	127	176	148	142	144	127
1979	27	23	183	182	109	111	49
1980	33	13	183	143	106	120	20
1981	108	104	148	145	144	143	124
1982			43				
1983	85	82	183	183	183	183	183
1984	88	37	183	182	178	181	140
1985	24	19	183	183	135	157	33
1986	134	128	183	183	156	164	128
1987	13	9	181	170	167	167	66
1988	29	26	118	46	39	41	49
1989	103	96	128	120	118	118	100
1990	67	62	133	110	99	105	78
1991	64	62	136	113	107	110	38
1992	64	60	183	169	153	158	121
1993	65	54	178	68	100	106	57
1994	25	21	158	112	58	93	
1995	45	43	182	158	64	144	83
1996	91	89	129	122	120	120	106
1997			162	36	23	31	
1998	22	19	141	121	109	118	31
1999							
2000	45	42	124	122	119	121	77
2001	96	95	97	94	94	93	88
2002			80	122	82	106	
2003	32	25	126	99	95	97	65
2004	18	34	162	153	146	151	100
%yrs	85%	85%	95%	93%	93%	93%	83%

Event duration
< 7 days
7 to 30 days (compliance)
>30 days (compliance)

Figure 8. Pattern of frequency and duration of fish passage events at Lake Condah. Duration for each year is mean event duration. Threshold for Unimpaired and Current is 51 mAHD and for the other scenarios (With Weir) it is 52.4 mAHD.

4.3.2 Avoidance of lake drying

At levels less than 50.4 mAHD the coverage of water in Lake Condah is sparse, with only the deep pools containing water. It is considered undesirable for the lake to fall to this level, so the target for this objective was set at zero% of the time for both winter and summer.

Analysis of the lake drying spells revealed that under the Unimpaired and Current scenarios the lake level fell below 50.4 m for the majority of the time in summer in most years (Figure 9). No years occurred when the level was always higher than 50.4 m throughout summer. In winter the lake levels were higher, but only 7% of years occurred when lake levels were always higher than 50.4 m throughout winter (Figure 9). The future With Weir scenarios dramatically altered this pattern, with the compliance being high for summer and winter (Figure 9). The 30 ML/d passing flow scenario did not achieve the same degree of compliance as the 10 ML/d and 20 ML/d passing flow scenarios because the higher passing flow drains the lake faster. The 2030 land use and dry climate scenario had lower levels of compliance than the other future scenarios, but was still vastly superior to the Unimpaired and Current scenarios (Figure 9).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	100%	100%	17%	17%	58%	39%	81%
1965	63%	65%	0%	0%	0%	0%	0%
1966	100%	100%	0%	0%	8%	0%	46%
1967	71%	76%	0%	0%	3%	0%	35%
1968	97%	97%	12%	62%	78%	74%	80%
1969	80%	82%	0%	0%	0%	0%	0%
1970	78%	82%	0%	0%	0%	0%	34%
1971	45%	52%	0%	0%	0%	0%	0%
1972	42%	45%	0%	0%	0%	0%	0%
1973	99%	99%	0%	0%	0%	0%	44%
1974	82%	84%	0%	0%	0%	0%	4%
1975	95%	99%	0%	0%	0%	0%	18%
1976	78%	80%	0%	0%	0%	0%	0%
1977	83%	84%	0%	0%	0%	0%	0%
1978	97%	97%	0%	0%	7%	0%	27%
1979	70%	73%	0%	0%	0%	0%	0%
1980	84%	86%	0%	0%	0%	0%	34%
1981	93%	97%	0%	0%	29%	18%	52%
1982	100%	100%	0%	0%	0%	0%	41%
1983	62%	62%	13%	47%	62%	62%	62%
1984	72%	75%	0%	0%	0%	0%	0%
1985	83%	85%	0%	0%	0%	0%	0%
1986	65%	67%	0%	0%	0%	0%	13%
1987	60%	63%	0%	0%	0%	0%	0%
1988	98%	98%	0%	0%	33%	18%	48%
1989	100%	100%	0%	0%	34%	20%	55%
1990	94%	95%	0%	0%	0%	0%	25%
1991	93%	93%	0%	0%	1%	0%	18%
1992	97%	97%	0%	0%	0%	0%	11%
1993	72%	75%	0%	0%	0%	0%	0%
1994	88%	91%	0%	0%	0%	0%	38%
1995	99%	100%	0%	0%	2%	0%	35%
1996	100%	100%	0%	0%	30%	6%	56%
1997	100%	100%	0%	0%	0%	0%	21%
1998	100%	100%	0%	11%	28%	18%	79%
1999	100%	100%	0%	4%	35%	18%	57%
2000	100%	100%	24%	75%	88%	77%	98%
2001	91%	93%	0%	0%	0%	0%	45%
2002	73%	75%	0%	0%	0%	0%	24%
2003	98%	98%	0%	0%	18%	0%	65%
2004	87%	91%	0%	0%	0%	0%	40%
%yrs	0%	0%	90%	85%	63%	76%	27%

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	18%	22%	0%	0%	4%	0%	15%
1965	35%	44%	0%	0%	0%	0%	0%
1966	30%	30%	0%	0%	23%	0%	25%
1967	100%	100%	0%	0%	50%	19%	79%
1968	0%	0%	0%	0%	0%	0%	0%
1969	53%	53%	0%	0%	0%	0%	0%
1970	29%	31%	0%	0%	0%	0%	0%
1971	0%	0%	0%	0%	0%	0%	0%
1972	100%	100%	0%	0%	0%	0%	0%
1973	36%	36%	0%	0%	0%	0%	0%
1974	26%	26%	0%	0%	0%	0%	6%
1975	32%	33%	0%	0%	0%	0%	10%
1976	40%	40%	0%	0%	0%	0%	0%
1977	45%	47%	0%	0%	0%	0%	0%
1978	18%	19%	0%	0%	0%	0%	0%
1979	65%	65%	0%	0%	0%	0%	0%
1980	59%	59%	0%	0%	0%	0%	6%
1981	19%	21%	0%	0%	0%	0%	15%
1982	100%	100%	0%	0%	39%	0%	100%
1983	0%	0%	0%	0%	0%	0%	0%
1984	39%	42%	0%	0%	0%	0%	0%
1985	37%	44%	0%	0%	0%	0%	0%
1986	16%	18%	0%	0%	0%	0%	0%
1987	53%	57%	0%	0%	0%	0%	0%
1988	64%	66%	0%	0%	4%	4%	8%
1989	33%	33%	0%	0%	8%	8%	10%
1990	38%	39%	0%	0%	12%	0%	18%
1991	45%	45%	0%	0%	14%	0%	14%
1992	12%	12%	0%	0%	0%	0%	0%
1993	54%	54%	0%	0%	0%	0%	0%
1994	67%	68%	0%	0%	0%	0%	13%
1995	50%	51%	0%	0%	0%	0%	0%
1996	28%	30%	0%	0%	12%	12%	13%
1997	89%	97%	0%	0%	0%	0%	15%
1998	38%	42%	0%	0%	2%	0%	11%
1999	100%	100%	0%	12%	44%	17%	93%
2000	27%	28%	0%	0%	0%	0%	0%
2001	45%	45%	0%	0%	25%	0%	44%
2002	100%	100%	0%	0%	0%	0%	16%
2003	46%	46%	0%	0%	3%	0%	4%
2004	25%	27%	0%	0%	0%	0%	9%
%yrs	7%	7%	100%	98%	68%	88%	49%

Duration (% time less than 50.4 m)

- never less than (compliance)
- 1 to 30%
- 30 to 60%
- >60%

Duration (% time less than 50.4 m)

- never less than (compliance)
- 1 to 30%
- 30 to 60%
- >60%

Figure 9. Pattern of duration of Lake Condah essentially dry (<50.4 m) in summer and winter. Compliance is set at zero% of time for each year.

4.3.3 Open water zone

At levels higher than 51.1 mAHD the various sections of Lake Condah become a contiguous body of water. The target for this objective was set at 100% of the time for winter and >80% of the time for summer.

Analysis of the open water threshold revealed that under the Unimpaired and Current scenarios no years complied with the targets (Figure 10). This is consistent with the historical observations of short duration lake inundation events. The future With Weir scenarios dramatically altered this pattern, with the compliance being high for summer and winter (Figure 10). The 30 ML/d passing flow scenario did not achieve the same degree of compliance as the 10 ML/d and 20 ML/d passing flow scenarios because the higher passing flow drains the lake faster. The 2030 land use and dry climate scenario had lower levels of compliance than the other future scenarios, but was still vastly superior to the Unimpaired and Current scenarios (Figure 10).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	0%	0%	83%	52%	20%	39%	10%
1965	20%	16%	100%	100%	100%	100%	100%
1966	0%	0%	100%	100%	68%	87%	44%
1967	8%	4%	100%	100%	82%	96%	54%
1968	2%	2%	54%	4%	3%	9%	2%
1969	1%	0%	100%	100%	100%	100%	100%
1970	0%	0%	100%	100%	100%	100%	38%
1971	19%	17%	100%	100%	100%	100%	100%
1972	31%	25%	100%	100%	100%	100%	100%
1973	0%	0%	100%	100%	53%	100%	19%
1974	0%	0%	100%	100%	100%	100%	60%
1975	0%	0%	100%	100%	100%	100%	51%
1976	4%	3%	100%	100%	100%	100%	100%
1977	0%	0%	100%	100%	100%	100%	99%
1978	0%	0%	100%	100%	54%	67%	41%
1979	13%	10%	100%	100%	100%	100%	97%
1980	0%	0%	100%	100%	100%	100%	51%
1981	0%	0%	100%	76%	59%	67%	36%
1982	0%	0%	100%	100%	73%	100%	46%
1983	16%	15%	73%	43%	38%	38%	38%
1984	10%	9%	100%	100%	100%	100%	100%
1985	0%	0%	100%	100%	100%	100%	89%
1986	13%	11%	100%	100%	100%	100%	65%
1987	19%	14%	100%	100%	100%	100%	100%
1988	0%	0%	100%	78%	55%	62%	41%
1989	0%	0%	100%	73%	50%	64%	35%
1990	0%	0%	100%	100%	86%	100%	55%
1991	0%	0%	100%	100%	85%	100%	70%
1992	0%	0%	100%	100%	98%	100%	71%
1993	7%	6%	100%	100%	100%	100%	89%
1994	0%	0%	100%	100%	100%	100%	52%
1995	0%	0%	100%	100%	72%	98%	37%
1996	0%	0%	100%	87%	56%	69%	32%
1997	0%	0%	100%	100%	84%	100%	52%
1998	0%	0%	100%	55%	42%	50%	2%
1999	0%	0%	100%	74%	50%	66%	31%
2000	0%	0%	47%	14%	0%	13%	0%
2001	0%	0%	100%	100%	52%	100%	37%
2002	9%	7%	100%	100%	100%	100%	65%
2003	0%	0%	100%	100%	49%	90%	0%
2004	0%	0%	100%	100%	76%	100%	46%
%yrs	0%	0%	93%	78%	56%	73%	27%

Duration (% time 51.1 m exceeded)

- not exceeded
- 1 to 40%
- 40 - 80%
- >80% (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	77%	77%	100%	86%	82%	84%	77%
1965	23%	21%	100%	100%	100%	100%	100%
1966	32%	25%	100%	100%	70%	72%	68%
1967	0%	0%	100%	69%	16%	34%	0%
1968	87%	85%	100%	100%	100%	100%	100%
1969	20%	14%	100%	100%	100%	100%	100%
1970	41%	41%	100%	100%	100%	100%	72%
1971	77%	77%	100%	100%	100%	100%	100%
1972	0%	0%	100%	100%	100%	100%	100%
1973	38%	36%	100%	100%	100%	100%	87%
1974	46%	41%	100%	100%	100%	100%	71%
1975	67%	67%	100%	100%	100%	100%	67%
1976	35%	34%	100%	100%	100%	100%	99%
1977	16%	13%	100%	100%	100%	100%	100%
1978	65%	64%	100%	100%	100%	100%	94%
1979	20%	20%	100%	100%	100%	100%	51%
1980	10%	7%	100%	100%	100%	100%	68%
1981	54%	52%	100%	86%	82%	84%	81%
1982	0%	0%	100%	100%	0%	82%	0%
1983	84%	76%	100%	100%	100%	100%	100%
1984	38%	31%	100%	100%	100%	100%	100%
1985	18%	16%	100%	100%	100%	100%	92%
1986	69%	63%	100%	100%	100%	100%	100%
1987	2%	1%	100%	100%	100%	100%	100%
1988	14%	13%	100%	92%	77%	86%	64%
1989	49%	45%	100%	88%	84%	86%	69%
1990	32%	28%	100%	100%	73%	89%	64%
1991	31%	26%	100%	100%	81%	89%	76%
1992	64%	59%	100%	100%	100%	100%	100%
1993	27%	25%	100%	100%	100%	100%	58%
1994	12%	10%	100%	100%	100%	100%	58%
1995	22%	21%	100%	100%	100%	100%	100%
1996	47%	44%	100%	80%	76%	78%	73%
1997	0%	0%	100%	100%	100%	100%	42%
1998	18%	14%	100%	89%	85%	89%	79%
1999	0%	0%	100%	44%	0%	43%	0%
2000	45%	42%	99%	95%	84%	96%	70%
2001	51%	49%	100%	100%	54%	92%	52%
2002	0%	0%	100%	100%	100%	100%	69%
2003	26%	21%	100%	99%	82%	92%	65%
2004	18%	18%	100%	100%	89%	100%	86%
%yrs	0%	0%	98%	76%	61%	63%	27%

Duration (% time 51.1 m exceeded)

- not exceeded
- 1 to 50%
- 50 - 99%
- 100% (compliance)

Figure 10. Pattern of duration of open water zone inundated in summer (>51.1 m) and inundated in winter (>51.1 m) at Lake Condah. Compliance is set at >80% of time for each year for summer and 100% of the time each year for winter.

4.3.4 Submerged aquatic plant zone

At levels higher than 51.7 mAHD habitat is available in the submerged aquatic plant zone. The target for this objective was set at >80% of the time for winter and >60% of the time for summer.

Analysis of the spells of submerged aquatic plant zone threshold revealed that under the Unimpaired and Current scenarios no years complied with the targets (Figure 11). The future With Weir scenarios dramatically altered this pattern, with the compliance being high for summer and winter (Figure 11). The 30 ML/d passing flow scenario did not achieve the same degree of compliance as the 10 ML/d and 20 ML/d passing flow scenarios because the higher passing flow drains the lake faster. The 2030 land use and dry climate scenario had lower levels of compliance than the other future scenarios, but was still vastly superior to the Unimpaired and Current scenarios (Figure 11).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	0%	0%	48%	12%	5%	9%	0%
1965	0%	0%	100%	100%	100%	100%	100%
1966	0%	0%	100%	57%	45%	50%	26%
1967	0%	0%	100%	76%	60%	67%	37%
1968	0%	0%	22%	2%	2%	2%	0%
1969	0%	0%	100%	100%	100%	100%	74%
1970	0%	0%	100%	100%	62%	89%	19%
1971	1%	1%	100%	100%	100%	100%	77%
1972	9%	8%	100%	100%	100%	100%	100%
1973	0%	0%	100%	41%	20%	23%	7%
1974	0%	0%	100%	100%	95%	100%	43%
1975	0%	0%	100%	100%	93%	100%	36%
1976	0%	0%	100%	100%	100%	100%	57%
1977	0%	0%	100%	100%	100%	100%	49%
1978	0%	0%	96%	45%	35%	38%	25%
1979	0%	0%	100%	100%	100%	100%	59%
1980	0%	0%	100%	100%	59%	62%	35%
1981	0%	0%	71%	52%	41%	45%	21%
1982	0%	0%	100%	58%	43%	48%	28%
1983	7%	6%	54%	38%	38%	38%	37%
1984	0%	0%	100%	100%	100%	100%	100%
1985	0%	0%	100%	100%	100%	100%	40%
1986	0%	0%	100%	100%	82%	100%	49%
1987	5%	4%	100%	100%	100%	100%	63%
1988	0%	0%	67%	48%	36%	42%	24%
1989	0%	0%	64%	43%	36%	39%	21%
1990	0%	0%	100%	87%	53%	61%	30%
1991	0%	0%	100%	81%	65%	74%	47%
1992	0%	0%	100%	94%	64%	83%	26%
1993	0%	0%	100%	100%	100%	100%	64%
1994	0%	0%	100%	98%	61%	66%	35%
1995	0%	0%	100%	66%	35%	53%	10%
1996	0%	0%	90%	50%	40%	45%	17%
1997	0%	0%	100%	79%	48%	54%	32%
1998	0%	0%	47%	33%	26%	30%	0%
1999	0%	0%	70%	36%	28%	33%	19%
2000	0%	0%	29%	0%	0%	0%	0%
2001	0%	0%	100%	44%	34%	38%	23%
2002	0%	0%	100%	100%	76%	100%	48%
2003	0%	0%	100%	30%	23%	27%	0%
2004	0%	0%	100%	72%	49%	61%	27%
%yrs	0%	0%	88%	61%	49%	56%	17%

Duration (% time 51.7 m exceeded)

- not exceeded
- 1 to 30%
- 30 to 60%
- >60% (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	39%	37%	99%	80%	77%	77%	75%
1965	0%	0%	100%	100%	100%	100%	100%
1966	3%	1%	100%	70%	67%	68%	61%
1967	0%	0%	100%	0%	0%	0%	0%
1968	22%	20%	100%	100%	100%	100%	100%
1969	0%	0%	100%	100%	100%	100%	41%
1970	19%	19%	100%	100%	90%	100%	65%
1971	23%	21%	100%	100%	100%	100%	100%
1972	0%	0%	100%	100%	100%	100%	100%
1973	8%	8%	100%	100%	85%	93%	62%
1974	7%	6%	100%	100%	100%	100%	67%
1975	35%	33%	100%	100%	100%	100%	64%
1976	18%	17%	100%	100%	100%	100%	56%
1977	0%	0%	100%	100%	100%	100%	84%
1978	25%	24%	100%	100%	89%	94%	77%
1979	7%	7%	100%	100%	100%	100%	35%
1980	0%	0%	100%	100%	82%	100%	41%
1981	11%	11%	95%	82%	81%	81%	79%
1982	0%	0%	100%	73%	0%	0%	0%
1983	26%	26%	100%	100%	100%	100%	100%
1984	12%	12%	100%	100%	100%	100%	100%
1985	5%	4%	100%	100%	100%	100%	65%
1986	13%	11%	100%	100%	100%	100%	79%
1987	0%	0%	100%	100%	100%	100%	98%
1988	2%	2%	96%	70%	64%	67%	49%
1989	8%	7%	92%	73%	67%	70%	64%
1990	0%	0%	100%	76%	61%	64%	56%
1991	4%	3%	100%	81%	65%	75%	60%
1992	31%	28%	100%	100%	100%	100%	82%
1993	4%	3%	100%	100%	100%	100%	43%
1994	4%	3%	100%	100%	65%	86%	27%
1995	5%	5%	100%	100%	94%	100%	76%
1996	17%	14%	86%	71%	70%	71%	67%
1997	0%	0%	100%	100%	47%	60%	0%
1998	3%	2%	92%	82%	76%	81%	65%
1999	0%	0%	59%	0%	0%	0%	0%
2000	4%	3%	72%	70%	69%	70%	66%
2001	18%	13%	100%	53%	52%	52%	51%
2002	0%	0%	100%	100%	81%	97%	0%
2003	0%	0%	100%	73%	59%	67%	52%
2004	10%	10%	100%	92%	85%	89%	80%
%yrs	0%	0%	95%	71%	61%	66%	22%

Duration (% time 51.7 m exceeded)

- not exceeded
- 1 to 40%
- 40 - 80%
- >80% (compliance)

Figure 11. Pattern of duration of submerged aquatic plant zone inundated in summer (>51.7 m) and inundated in winter (>51.7 m) at Lake Condah. Compliance is set at >60% of time for each year for summer and >80% of the time each year for winter.

4.3.5 Reed zone

The requirements of the reed zone are for winter levels to exceed 52.4 mAHD for >60% of the time, and for summer levels to be less than 52.4 for >60% of the time.

Analysis of the reed zone threshold revealed that under the Unimpaired and Current scenarios all years complied with the summer target (Figure 12), but this would be of little use, as the winter target was not met in any year (Figure 12). The future With Weir scenarios dramatically altered this pattern, by maintaining compliance in the majority of years in summer, and also providing compliance in the majority of years in winter (Figure 12). The 10 ML/d passing flow scenario did not achieve the same degree of summer compliance as the 10 ML/d and 20 ML/d passing flow scenarios because the lower passing flow slows the rate of lake draining. The 2030 land use and dry climate scenario had a lower level of winter compliance than the other future scenarios, but was still vastly superior to the Unimpaired and Current scenarios (Figure 12).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	100%	100%	100%	100%	100%	100%	100%
1965	100%	100%	2%	19%	43%	41%	76%
1966	100%	100%	89%	90%	90%	90%	100%
1967	100%	100%	73%	79%	81%	81%	96%
1968	100%	100%	99%	100%	100%	100%	100%
1969	100%	100%	18%	53%	78%	70%	91%
1970	100%	100%	67%	76%	82%	82%	100%
1971	100%	100%	25%	37%	47%	46%	74%
1972	100%	100%	0%	0%	3%	6%	56%
1973	100%	100%	99%	100%	100%	100%	100%
1974	100%	100%	55%	76%	79%	81%	95%
1975	100%	100%	59%	82%	83%	83%	98%
1976	100%	100%	2%	25%	81%	81%	90%
1977	100%	100%	18%	41%	74%	75%	91%
1978	100%	100%	91%	93%	94%	94%	100%
1979	100%	100%	6%	36%	68%	70%	85%
1980	100%	100%	76%	86%	90%	89%	99%
1981	100%	100%	90%	91%	96%	95%	100%
1982	100%	100%	91%	93%	98%	97%	100%
1983	100%	100%	70%	71%	72%	71%	80%
1984	100%	100%	3%	18%	32%	25%	85%
1985	100%	100%	41%	78%	85%	82%	95%
1986	100%	100%	52%	65%	68%	68%	87%
1987	100%	100%	10%	42%	64%	63%	84%
1988	100%	100%	91%	92%	92%	92%	100%
1989	100%	100%	90%	91%	91%	91%	100%
1990	100%	100%	89%	91%	93%	91%	100%
1991	100%	100%	81%	87%	100%	97%	100%
1992	100%	100%	68%	95%	97%	96%	100%
1993	100%	100%	33%	51%	69%	64%	83%
1994	100%	100%	70%	75%	86%	84%	100%
1995	100%	100%	88%	99%	100%	99%	100%
1996	100%	100%	91%	94%	100%	98%	100%
1997	100%	100%	88%	90%	92%	91%	100%
1998	100%	100%	95%	97%	100%	100%	100%
1999	100%	100%	95%	96%	99%	96%	100%
2000	100%	100%	100%	100%	100%	100%	100%
2001	100%	100%	92%	95%	96%	96%	100%
2002	100%	100%	62%	71%	75%	72%	89%
2003	100%	100%	98%	100%	100%	100%	100%
2004	100%	100%	90%	91%	95%	92%	100%
%yrs	100%	100%	66%	76%	90%	90%	98%

Duration (% time less than 52.4 m)

(white)	never less than
(light grey)	1 to 30%
(mid grey)	30 to 60%
(dark grey)	>60% (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	6%	5%	79%	76%	76%	75%	73%
1965	0%	0%	100%	99%	94%	96%	50%
1966	0%	0%	69%	66%	63%	63%	50%
1967	0%	0%	0%	0%	0%	0%	0%
1968	0%	0%	100%	100%	100%	100%	96%
1969	0%	0%	99%	89%	60%	62%	0%
1970	2%	2%	95%	77%	70%	72%	50%
1971	0%	0%	100%	100%	100%	100%	100%
1972	0%	0%	95%	83%	75%	77%	18%
1973	3%	3%	100%	76%	66%	71%	48%
1974	0%	0%	96%	90%	72%	72%	59%
1975	3%	1%	99%	79%	67%	70%	55%
1976	4%	3%	100%	100%	90%	92%	38%
1977	0%	0%	98%	89%	82%	84%	42%
1978	5%	5%	96%	81%	78%	79%	70%
1979	0%	0%	100%	100%	60%	61%	27%
1980	0%	0%	100%	78%	58%	66%	11%
1981	1%	1%	81%	79%	79%	78%	68%
1982	0%	0%	24%	0%	0%	0%	0%
1983	7%	7%	100%	100%	100%	100%	100%
1984	0%	0%	100%	100%	98%	99%	77%
1985	0%	0%	100%	100%	74%	86%	36%
1986	0%	0%	100%	100%	85%	90%	70%
1987	0%	0%	99%	94%	92%	92%	36%
1988	0%	0%	65%	50%	43%	45%	27%
1989	0%	0%	70%	66%	65%	65%	55%
1990	0%	0%	73%	60%	54%	58%	43%
1991	0%	0%	75%	62%	59%	60%	41%
1992	2%	2%	100%	93%	84%	87%	66%
1993	0%	0%	98%	75%	55%	58%	31%
1994	0%	0%	87%	61%	32%	51%	0%
1995	0%	0%	100%	87%	70%	79%	45%
1996	0%	0%	71%	67%	66%	66%	58%
1997	0%	0%	89%	39%	25%	33%	0%
1998	0%	0%	77%	66%	60%	65%	17%
1999	0%	0%	0%	0%	0%	0%	0%
2000	0%	0%	68%	67%	65%	66%	42%
2001	0%	0%	53%	52%	52%	51%	48%
2002	0%	0%	87%	67%	45%	58%	0%
2003	0%	0%	69%	54%	52%	53%	36%
2004	1%	0%	89%	84%	80%	83%	55%
%yrs	0%	0%	90%	83%	63%	73%	22%

Duration (% time 52.4 m exceeded)

(white)	not exceeded
(light grey)	1 to 30%
(mid grey)	30 to 60%
(dark grey)	>60% (compliance)

Figure 12. Pattern of duration of reed zone exposed in summer (<52.4 m) and inundated in winter (>52.4 m) at Lake Condah. Compliance is set at >60% of time for each year.

4.3.6 Silky Tea Tree zone

The requirements of the Silky Tea Tree zone are for winter levels to exceed 52.5 mAHD for >20% of the time. There is no requirement for summer levels.

Analysis of the Silky Tea Tree zone threshold revealed that under the Unimpaired and Current scenarios no years complied with the winter target (Figure 13). The future With Weir scenarios dramatically altered this pattern, by maintaining compliance in the majority of years (Figure 13). The passing flow had no impact on degree of compliance as these events rely on significant high flow events to overtop the weir and create an afflux, lifting the lake level at least 0.1 m higher than the crest. The 2030 land use and dry climate scenario had a lower level of compliance than the other future scenarios, but was still vastly superior to the Unimpaired and Current scenarios (Figure 12).

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	4%	3%	78%	76%	76%	75%	66%
1965	0%	0%	30%	30%	30%	25%	3%
1966	0%	0%	44%	39%	37%	31%	5%
1967	0%	0%	0%	0%	0%	0%	0%
1968	0%	0%	95%	95%	95%	88%	64%
1969	0%	0%	26%	26%	26%	21%	0%
1970	0%	0%	61%	61%	58%	54%	32%
1971	0%	0%	93%	93%	93%	87%	60%
1972	0%	0%	0%	0%	0%	0%	0%
1973	2%	1%	47%	47%	47%	44%	18%
1974	0%	0%	54%	54%	52%	45%	16%
1975	0%	0%	68%	68%	67%	67%	50%
1976	3%	3%	49%	49%	49%	45%	30%
1977	0%	0%	22%	22%	22%	16%	5%
1978	3%	1%	79%	79%	76%	76%	55%
1979	0%	0%	35%	35%	35%	30%	5%
1980	0%	0%	19%	19%	19%	14%	0%
1981	0%	0%	61%	59%	59%	54%	34%
1982	0%	0%	0%	0%	0%	0%	0%
1983	6%	6%	100%	100%	100%	100%	83%
1984	0%	0%	53%	53%	53%	49%	24%
1985	0%	0%	31%	31%	31%	25%	1%
1986	0%	0%	81%	81%	80%	73%	32%
1987	0%	0%	14%	14%	14%	9%	0%
1988	0%	0%	20%	20%	20%	14%	1%
1989	0%	0%	58%	56%	55%	49%	21%
1990	0%	0%	37%	36%	33%	30%	3%
1991	0%	0%	41%	39%	37%	32%	14%
1992	1%	0%	70%	70%	67%	67%	53%
1993	0%	0%	36%	36%	36%	29%	2%
1994	0%	0%	23%	23%	22%	20%	0%
1995	0%	0%	33%	33%	33%	29%	15%
1996	0%	0%	65%	61%	60%	54%	36%
1997	0%	0%	0%	0%	0%	0%	0%
1998	0%	0%	26%	25%	22%	16%	0%
1999	0%	0%	0%	0%	0%	0%	0%
2000	0%	0%	45%	44%	42%	41%	9%
2001	0%	0%	53%	52%	52%	49%	20%
2002	0%	0%	0%	0%	0%	0%	0%
2003	0%	0%	29%	29%	27%	25%	0%
2004	0%	0%	49%	47%	43%	38%	44%
%yrs	**0%**	**0%**	**80%**	**80%**	**80%**	**71%**	**37%**

Duration (% time 52.5 m exceeded)

(white)	not exceeded
(light grey)	1 to 20%
(dark grey)	>20% (compliance)

Figure 13. Pattern of duration of Silky Tea Tree zone inundated in winter (>52.5 m) at Lake Condah. Compliance is set at >20% of time for each year.

4.4 Site 2: Darlot Creek drain downstream of Lake Condah

The compliance of each of the FLOWS components for Reach 2 was measured against the achievement of the component for the Unimpacted scenario. The specifications of components made by the Panel were such that they were not necessarily met, or met in their entirety, in each year.

4.4.1 Cease-to-flow

Cease to flow was not recommended for Reach 2. This means that any year with a cease to flow event is non-compliant. Cease to flow did not occur in winter, but a few events occurred in summer during the drought years of 1968, 1983, 1998, 2000 and 2003 (Figure 14). Apart from 1983, these were short events with little consequence. The 1983 events were longer duration, of about one month. Overall, there is a very high level of compliance with the cease to flow recommendation.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965							
1966							
1967							
1968						1	3
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983		1		1	1	1	1
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							1
1999							
2000		2		1	1	1	3
2001							
2002							
2003							1
2004							
%yrs	0%	5%	0%	5%	5%	7%	12%

Event frequency
- 1 event per year
- 2 events per year
- >2 events per year

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965							
1966							
1967							
1968						1	9
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983		26		17	25	30	30
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							18
1999							
2000		4		1	6	4	11
2001							
2002							
2003							24
2004							

Event mean duration
- 1 to 7 days
- 7 to 14 days
- >14 days

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		0%	0%	0%	0%	0%	0%
1965		0%	0%	0%	0%	0%	0%
1966		0%	0%	0%	0%	0%	0%
1967		0%	0%	0%	0%	0%	0%
1968		0%	0%	0%	0%	1%	14%
1969		0%	0%	0%	0%	0%	0%
1970		0%	0%	0%	0%	0%	0%
1971		0%	0%	0%	0%	0%	0%
1972		0%	0%	0%	0%	0%	0%
1973		0%	0%	0%	0%	0%	0%
1974		0%	0%	0%	0%	0%	0%
1975		0%	0%	0%	0%	0%	0%
1976		0%	0%	0%	0%	0%	0%
1977		0%	0%	0%	0%	0%	0%
1978		0%	0%	0%	0%	0%	0%
1979		0%	0%	0%	0%	0%	0%
1980		0%	0%	0%	0%	0%	0%
1981		0%	0%	0%	0%	0%	0%
1982		0%	0%	0%	0%	0%	0%
1983		14%	0%	9%	14%	16%	16%
1984		0%	0%	0%	0%	0%	0%
1985		0%	0%	0%	0%	0%	0%
1986		0%	0%	0%	0%	0%	0%
1987		0%	0%	0%	0%	0%	0%
1988		0%	0%	0%	0%	0%	0%
1989		0%	0%	0%	0%	0%	0%
1990		0%	0%	0%	0%	0%	0%
1991		0%	0%	0%	0%	0%	0%
1992		0%	0%	0%	0%	0%	0%
1993		0%	0%	0%	0%	0%	0%
1994		0%	0%	0%	0%	0%	0%
1995		0%	0%	0%	0%	0%	0%
1996		0%	0%	0%	0%	0%	0%
1997		0%	0%	0%	0%	0%	0%
1998		0%	0%	0%	0%	0%	10%
1999		0%	0%	0%	0%	0%	0%
2000		4%	0%	1%	3%	2%	19%
2001		0%	0%	0%	0%	0%	0%
2002		0%	0%	0%	0%	0%	0%
2003		0%	0%	0%	0%	0%	13%
2004		0%	0%	0%	0%	0%	0%
%yrs		95%	100%	95%	95%	93%	88%

Difference in Duration (relative to U)
- zero (compliance)
- >zero (non-compliance)

Figure 14. Pattern of frequency and duration of cease to flow events at Reach 2. Duration is mean event duration for each year.

4.4.2 Summer Low Flow

The Low Flow threshold of 2 ML/d is exceeded all of the time in every summer in the Unimpaired and With Weir and 10 ML/d passing flow scenarios (Figure 15). These scenarios could be said to be 100% compliant with the recommendation. For the other scenarios, in some years the flow falls below 2 ML/d for a percentage of the time. These years cannot be said to be non-compliant, because for most of the time in those months the flow is compliant (Figure 15). A threshold for compliance was set at 50%, i.e. a year failed to comply if the flow fell below 2 ML/d for more than 50% of the time. This criterion created only one non-compliant year in one scenario (year 2000, for the 2030 land use and dry climate scenario) (Figure 15). An alternative way of assessing compliance is to measure, for each year, the deviation (in percent of time <2 ML/d) from that of the Unimpaired scenario, and then place an upper limit on this deviation. Applying an upper limit of 10% change created only a few non-compliant years, with 5 occurring in the 2030 land use and dry climate scenario (Figure 15). Overall, there is a very high level of compliance with the Low Flow recommendation across the scenarios.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	0%	0%	0%	0%	0%	0%	0%
1965	0%	0%	0%	0%	0%	0%	0%
1966	0%	0%	0%	0%	0%	0%	0%
1967	0%	0%	0%	0%	0%	0%	0%
1968	0%	2%	0%	1%	1%	4%	47%
1969	0%	0%	0%	0%	0%	0%	0%
1970	0%	0%	0%	0%	0%	0%	0%
1971	0%	0%	0%	0%	0%	0%	0%
1972	0%	0%	0%	0%	0%	0%	0%
1973	0%	0%	0%	0%	0%	0%	0%
1974	0%	0%	0%	0%	1%	0%	0%
1975	0%	0%	0%	0%	0%	0%	0%
1976	0%	0%	0%	0%	0%	0%	0%
1977	0%	0%	0%	0%	0%	0%	0%
1978	0%	0%	0%	0%	0%	0%	0%
1979	0%	0%	0%	0%	0%	0%	0%
1980	0%	0%	0%	0%	0%	0%	0%
1981	0%	0%	0%	0%	0%	0%	0%
1982	0%	0%	0%	0%	0%	0%	0%
1983	0%	17%	0%	9%	16%	16%	36%
1984	0%	0%	0%	0%	0%	0%	0%
1985	0%	0%	0%	0%	0%	0%	0%
1986	0%	0%	0%	0%	0%	0%	0%
1987	0%	0%	0%	0%	0%	0%	0%
1988	0%	0%	0%	0%	0%	0%	0%
1989	0%	0%	0%	0%	0%	0%	0%
1990	0%	0%	0%	0%	0%	0%	0%
1991	0%	0%	0%	0%	0%	0%	0%
1992	0%	0%	0%	0%	0%	0%	0%
1993	0%	0%	0%	0%	0%	0%	0%
1994	0%	0%	0%	0%	0%	0%	0%
1995	0%	0%	0%	0%	0%	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%
1997	0%	0%	0%	0%	0%	0%	0%
1998	0%	0%	0%	0%	0%	0%	11%
1999	0%	0%	0%	0%	0%	0%	0%
2000	0%	12%	0%	1%	12%	3%	52%
2001	0%	0%	0%	0%	0%	0%	0%
2002	0%	0%	0%	0%	0%	0%	0%
2003	0%	0%	0%	0%	0%	0%	13%
2004	0%	0%	0%	0%	0%	0%	0%
%yrs	100%	100%	100%	100%	100%	100%	98%

Duration (% time less than 2 ML/d)

- 0 to 25% (compliance)
- 25 to 50% (compliance)
- 50 to 75%
- 75 to 100%

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		0%	0%	0%	0%	0%	0%
1965		0%	0%	0%	0%	0%	0%
1966		0%	0%	0%	0%	0%	0%
1967		0%	0%	0%	0%	0%	0%
1968		2%	0%	1%	1%	4%	47%
1969		0%	0%	0%	0%	0%	0%
1970		0%	0%	0%	0%	0%	0%
1971		0%	0%	0%	0%	0%	0%
1972		0%	0%	0%	0%	0%	0%
1973		0%	0%	0%	0%	0%	0%
1974		0%	0%	0%	1%	0%	0%
1975		0%	0%	0%	0%	0%	0%
1976		0%	0%	0%	0%	0%	0%
1977		0%	0%	0%	0%	0%	0%
1978		0%	0%	0%	0%	0%	0%
1979		0%	0%	0%	0%	0%	0%
1980		0%	0%	0%	0%	0%	0%
1981		0%	0%	0%	0%	0%	0%
1982		0%	0%	0%	0%	0%	0%
1983		17%	0%	9%	16%	16%	36%
1984		0%	0%	0%	0%	0%	0%
1985		0%	0%	0%	0%	0%	0%
1986		0%	0%	0%	0%	0%	0%
1987		0%	0%	0%	0%	0%	0%
1988		0%	0%	0%	0%	0%	0%
1989		0%	0%	0%	0%	0%	0%
1990		0%	0%	0%	0%	0%	0%
1991		0%	0%	0%	0%	0%	0%
1992		0%	0%	0%	0%	0%	0%
1993		0%	0%	0%	0%	0%	0%
1994		0%	0%	0%	0%	0%	0%
1995		0%	0%	0%	0%	0%	0%
1996		0%	0%	0%	0%	0%	0%
1997		0%	0%	0%	0%	0%	0%
1998		0%	0%	0%	0%	0%	11%
1999		0%	0%	0%	0%	0%	0%
2000		12%	0%	1%	12%	3%	52%
2001		0%	0%	0%	0%	0%	0%
2002		0%	0%	0%	0%	0%	0%
2003		0%	0%	0%	0%	0%	13%
2004		0%	0%	0%	0%	0%	0%
%yrs		95%	100%	100%	95%	98%	88%

Difference in Duration (relative to U)

- <10% (compliance)
- 10 to 20%
- 20 to 40%
- >40%

Figure 15. Pattern of duration of time less than summer Low Flow threshold (2 ML/d) at Reach 2, with compliance set at <50% of the time; and, pattern of difference in duration compared to that of the Unimpaired scenario with compliance set at <10% difference in duration.

4.4.3 Low Flow Fresh

There is no requirement for a Low Flow Fresh in Reach 2, but they are permitted, on the condition that the flow remain below 212 ML/d for a period of two months or more (1 event minimum). These events occurred at least once in every year for all scenarios. In most years the flow was lower than this threshold for the entire season (giving 1 event) (Figure 16). Some years had more events, but these events were shorter in duration, although the longest of these multiple events was typically 4 months long or longer (Figure 16). Overall, every year of each scenario was 100% compliant with this recommendation.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	1	1	1	1	1
1965	6	2	3	3	2	2	1
1966	1	1	1	1	1	1	1
1967	1	1	1	1	1	1	1
1968	1	2	1	1	1	1	1
1969	1	1	1	1	1	1	1
1970	1	1	2	2	1	1	1
1971	2	2	4	4	2	3	1
1972	5	3	5	3	3	3	3
1973	1	1	1	1	1	1	1
1974	1	1	1	1	1	1	1
1975	1	1	1	1	1	1	1
1976	1	1	1	1	1	1	1
1977	1	1	1	1	1	1	1
1978	1	1	1	1	1	1	1
1979	2	2	4	4	4	3	1
1980	1	1	1	1	1	1	1
1981	1	1	1	1	1	1	1
1982	1	1	1	1	1	1	1
1983	4	5	3	3	2	3	2
1984	1	1	1	1	1	1	1
1985	1	1	2	1	1	1	1
1986	2	3	2	2	2	2	1
1987	2	3	4	3	3	4	1
1988	1	1	2	2	1	1	1
1989	1	1	1	1	1	1	1
1990	1	1	1	1	1	1	1
1991	1	1	1	1	1	1	1
1992	1	1	1	1	1	1	1
1993	2	2	2	2	3	3	1
1994	1	1	1	1	1	1	1
1995	1	1	1	1	1	1	1
1996	1	1	1	1	1	1	1
1997	1	1	1	1	1	1	1
1998	1	1	1	1	1	1	1
1999	1	1	1	1	1	1	1
2000	1	1	1	1	1	1	1
2001	1	1	1	1	1	1	1
2002	2	1	2	2	2	2	1
2003	1	1	1	1	1	1	1
2004	1	1	1	1	1	1	1
%yrs	100%	100%	100%	100%	100%	100%	100%

Event <212 ML/d frequency

- 1 event
- 2 events
- >2 events

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	152	152	152	152	152	152	152
1965	148	153	153	153	153	157	182
1966	182	182	182	182	182	182	182
1967	182	182	182	182	182	182	182
1968	179	179	182	183	183	183	183
1969	182	182	182	182	182	182	182
1970	182	182	148	148	182	182	182
1971	154	154	146	146	153	148	180
1972	133	137	67	136	136	138	140
1973	182	182	182	182	182	182	182
1974	182	182	182	182	182	182	182
1975	182	182	182	182	182	182	182
1976	175	175	180	180	182	182	183
1977	182	182	182	182	182	182	182
1978	182	182	182	182	182	182	182
1979	156	163	164	166	166	169	182
1980	183	183	183	183	183	183	183
1981	182	182	182	182	182	182	182
1982	182	182	182	182	182	182	182
1983	144	112	144	144	153	144	153
1984	173	180	177	177	177	180	183
1985	182	182	122	182	182	182	182
1986	148	151	154	154	155	156	182
1987	155	162	156	162	163	163	182
1988	183	183	181	181	183	183	183
1989	182	182	182	182	182	182	182
1990	182	182	182	182	182	182	182
1991	182	182	182	182	182	182	182
1992	183	183	183	183	183	183	183
1993	165	168	175	176	176	176	182
1994	182	182	182	182	182	182	182
1995	182	182	182	182	182	182	182
1996	183	183	183	183	183	183	183
1997	182	182	182	182	182	182	182
1998	182	182	182	182	182	182	182
1999	182	182	182	182	182	182	182
2000	183	183	183	183	183	183	183
2001	182	182	182	182	182	182	182
2002	166	172	172	173	173	174	182
2003	182	182	182	182	182	182	182
2004	183	183	183	183	183	183	183
%yrs	100%	100%	100%	100%	100%	100%	100%

Event <212 ML/d maximum duration

- 1 to 60 days
- 60 to 120 days (compliance)
- >120 days (compliance)

Figure 16. Pattern of frequency and maximum duration of events of uninterrupted discharge <212 ML/d at Reach 2. Compliance requires at least one event per year of at least 60 days duration.

4.4.4 Winter High Flow

The High Flow threshold of 9 ML/d is exceeded all of the time in every summer in the Unimpaired and the With Weir and 10 ML/d and 20 ML/d passing flow scenarios (Figure 17). These scenarios could be said to be 100% compliant with the recommendation. For the other scenarios, in some years the flow falls below 9 ML/d for a percentage of the time. These years cannot be said to be non-compliant, because for most of the time in those months the flow is compliant (Figure 17). A threshold for compliance was set at 50%, i.e. a year failed to comply if the flow fell below 9 ML/d for more than 50% of the time. This criterion still resulted in all years being compliant (Figure 17). An alternative way of assessing compliance is to measure, for each year, the deviation (in percent of time <9 ML/d) from that of the Unimpaired scenario, and then place an upper limit on this deviation. Applying an upper limit of 10% change created only one non-compliant year, 1967 in the 2030 land use and dry climate scenario (Figure 17). Overall, there is a very high level of compliance with the High Flow recommendation across the scenarios.

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	0%	0%	0%	0%	0%	0%	0%
1965	0%	0%	0%	0%	0%	1%	0%
1966	0%	0%	0%	0%	0%	0%	0%
1967	0%	0%	0%	0%	0%	0%	41%
1968	0%	0%	0%	0%	0%	0%	0%
1969	0%	0%	0%	0%	0%	0%	0%
1970	0%	0%	0%	0%	0%	0%	0%
1971	0%	0%	0%	0%	0%	0%	0%
1972	0%	0%	0%	0%	0%	0%	0%
1973	0%	0%	0%	0%	0%	0%	0%
1974	0%	0%	0%	0%	0%	0%	0%
1975	0%	0%	0%	0%	0%	0%	0%
1976	0%	0%	0%	0%	0%	0%	0%
1977	0%	0%	0%	0%	0%	0%	0%
1978	0%	0%	0%	0%	0%	0%	0%
1979	0%	0%	0%	0%	0%	0%	0%
1980	0%	0%	0%	0%	0%	0%	0%
1981	0%	0%	0%	0%	0%	0%	0%
1982	0%	4%	0%	0%	0%	0%	3%
1983	0%	0%	0%	0%	0%	0%	0%
1984	0%	0%	0%	0%	0%	0%	0%
1985	0%	0%	0%	0%	0%	0%	0%
1986	0%	0%	0%	0%	0%	0%	0%
1987	0%	0%	0%	0%	0%	0%	0%
1988	0%	0%	0%	0%	0%	0%	0%
1989	0%	0%	0%	0%	0%	0%	0%
1990	0%	0%	0%	0%	0%	0%	0%
1991	0%	0%	0%	0%	0%	0%	6%
1992	0%	0%	0%	0%	0%	0%	0%
1993	0%	0%	0%	0%	0%	0%	0%
1994	0%	0%	0%	0%	0%	0%	0%
1995	0%	0%	0%	0%	0%	0%	0%
1996	0%	0%	0%	0%	0%	0%	1%
1997	0%	0%	0%	0%	0%	0%	0%
1998	0%	0%	0%	0%	0%	0%	0%
1999	0%	0%	0%	0%	0%	0%	0%
2000	0%	0%	0%	0%	0%	0%	0%
2001	0%	9%	0%	0%	9%	0%	9%
2002	0%	0%	0%	0%	0%	0%	0%
2003	0%	0%	0%	0%	0%	0%	2%
2004	0%	0%	0%	0%	0%	0%	4%
%yrs	100%	100%	100%	100%	100%	100%	100%

Duration (% time less than 9 ML/d)

- 0 to 25% (compliance)
- 25 to 50% (compliance)
- 50 to 75%
- 75 to 100%

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		0%	0%	0%	0%	0%	0%
1965		0%	0%	0%	0%	1%	0%
1966		0%	0%	0%	0%	0%	0%
1967		0%	0%	0%	0%	0%	41%
1968		0%	0%	0%	0%	0%	0%
1969		0%	0%	0%	0%	0%	0%
1970		0%	0%	0%	0%	0%	0%
1971		0%	0%	0%	0%	0%	0%
1972		0%	0%	0%	0%	0%	0%
1973		0%	0%	0%	0%	0%	0%
1974		0%	0%	0%	0%	0%	0%
1975		0%	0%	0%	0%	0%	0%
1976		0%	0%	0%	0%	0%	0%
1977		0%	0%	0%	0%	0%	0%
1978		0%	0%	0%	0%	0%	0%
1979		0%	0%	0%	0%	0%	0%
1980		0%	0%	0%	0%	0%	0%
1981		0%	0%	0%	0%	0%	0%
1982		4%	0%	0%	0%	0%	3%
1983		0%	0%	0%	0%	0%	0%
1984		0%	0%	0%	0%	0%	0%
1985		0%	0%	0%	0%	0%	0%
1986		0%	0%	0%	0%	0%	0%
1987		0%	0%	0%	0%	0%	0%
1988		0%	0%	0%	0%	0%	0%
1989		0%	0%	0%	0%	0%	0%
1990		0%	0%	0%	0%	0%	0%
1991		0%	0%	0%	0%	0%	6%
1992		0%	0%	0%	0%	0%	0%
1993		0%	0%	0%	0%	0%	0%
1994		0%	0%	0%	0%	0%	0%
1995		0%	0%	0%	0%	0%	0%
1996		0%	0%	0%	0%	0%	1%
1997		0%	0%	0%	0%	0%	0%
1998		0%	0%	0%	0%	0%	0%
1999		0%	0%	0%	0%	0%	0%
2000		0%	0%	0%	0%	0%	0%
2001		9%	0%	0%	9%	0%	9%
2002		0%	0%	0%	0%	0%	0%
2003		0%	0%	0%	0%	0%	2%
2004		0%	0%	0%	0%	0%	4%
%yrs		100%	100%	100%	100%	100%	98%

Difference in Duration (relative to U)

- <10% (compliance)
- 10 to 20%
- 20 to 40%
- >40%

Figure 17. Pattern of duration of time less than winter High Flow threshold (9 ML/d) at Reach 2, with compliance set at <50% of the time; and, pattern of difference in duration compared to that of the Unimpaired scenario with compliance set at <10% difference in duration.

4.4.5 High Flow Fresh

The High Flow Fresh was defined in terms of magnitude (≥288 ML/d), duration and frequency. Recommended frequency of events was set at 2 per year, but it is recognised that even in the Unimpaired scenario the frequency will be less than this in dry years. Similarly, the recommended minimum duration of events was set at 3 days, but it is recognized that the duration of some events satisfying the magnitude requirement may be lower than 3 days. Thus, years with one event were classed as partially compliant on frequency, and years with an event with a duration of one day were classed as partially compliant (Figure 18). The future With Weir scenarios had slightly more years with at least one High Flow Fresh event compared to the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface. Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario, and provided the maximum duration exceeded 3 days (unless the Unimpaired maximum duration was less than 3 days). These criteria resulted in an overall high level of compliance for all but the 2030 land use and dry climate scenario (Figure 18).

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	2	2	2	2	3
1965	1	1	2	2	2	1	
1966	1	1	3	2	1	1	
1967							
1968	4	4	5	5	5	5	3
1969	1	1	1	1	1	1	
1970	2	1	2	2	2	2	1
1971	3	3	3	3	3	4	5
1972							
1973	2	2	3	3	3	2	1
1974	2	2	2	2	2	2	2
1975	1	1	1	1	1	2	2
1976	1	1	1	1	1	1	2
1977	1	1	3	2	2	2	1
1978	3	3	4	3	4	4	3
1979	1	1	2	2	2	2	
1980			1	1	1		
1981	2	3	4	4	4	3	1
1982							
1983	1	1	2	2	2	3	3
1984	1	1	2	2	1	1	2
1985	2	1	3	3	3	2	
1986	3	1	3	3	4	4	4
1987			2	2	2		
1988	1	1	1	1	1	1	
1989	2	2	3	3	3	3	2
1990	1	1	2	2	2	1	
1991	1	1	3	3	2	2	2
1992	1	2	3	3	3	2	1
1993	2	2	2	2	2	2	
1994	1	1	1	1	1	1	
1995	1	1	1	1	1	1	1
1996	2	2	2	2	2	2	3
1997							
1998			2	2	1	1	
1999							
2000	2	1	3	3	2	2	
2001	2	2	2	2	2	3	
2002							
2003	1		1				
2004	1	1	1	1	1	1	1
%yrs	78%	76%	85%	83%	83%	78%	49%

High Flow Fresh event frequency

- No events
- 1 event (partial compliance)
- 2 events (compliance)
- >2 events (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	124	116	112	109	106	104	38
1965	23	23	22	20	19	11	
1966	23	20	19	18	17	16	
1967							
1968	45	43	47	47	46	42	26
1969	16	14	16	14	11	7	
1970	55	53	53	51	51	50	29
1971	65	65	64	63	59	57	15
1972							
1973	21	18	18	17	16	13	5
1974	40	40	39	39	37	29	3
1975	120	115	113	107	104	88	29
1976	57	56	55	54	54	52	13
1977	15	15	13	13	12	11	3
1978	44	43	42	41	38	34	20
1979	25	24	24	23	22	20	
1980			1	1	1		
1981	55	37	34	34	33	31	23
1982							
1983	117	113	109	56	56	54	45
1984	53	51	52	51	50	46	12
1985	2	2	4	4	4	4	
1986	53	86	38	37	33	28	7
1987			4	3	3		
1988	20	19	18	17	17	15	
1989	51	46	30	30	28	26	7
1990	37	24	25	25	22	17	
1991	44	38	18	17	16	15	6
1992	99	90	90	89	89	88	57
1993	6	5	7	7	7	6	
1994	5	4	5	5	5	4	
1995	36	34	33	31	30	27	12
1996	38	37	35	35	35	34	12
1997							
1998			3	3	3	1	
1999							
2000	30	25	24	21	20	7	
2001	24	22	22	19	19	16	
2002							
2003	1		1				
2004	29	27	26	26	26	24	19

High Flow Fresh event max. duration

- No events
- 1 - 2 days (partial compliance)
- 3 days (compliance)
- >3 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	0%
1966		100%	100%	100%	100%	100%	0%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	0%
1969		100%	100%	100%	100%	100%	0%
1970		0%	100%	100%	100%	100%	0%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	0%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	0%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	0%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		0%	100%	100%	100%	100%	0%
1986		0%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	0%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	0%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	100%	0%
1994		100%	100%	100%	100%	100%	0%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		0%	100%	100%	100%	100%	0%
2001		100%	100%	100%	100%	100%	0%
2002		100%	100%	100%	100%	100%	100%
2003		0%	100%	0%	0%	0%	0%
2004		100%	100%	100%	100%	100%	100%
%yrs		88%	100%	98%	98%	98%	61%

HF Fresh occurrence (relative to U)

- Compliance
- Non-compliance

Figure 18. Pattern of frequency and duration of High Flow Freshes (≥288 ML/d) at Reach 2. Duration is maximum event duration for each year.

4.5 Site 3: Darlot Creek at Wylies Road

The compliance of each of the FLOWS components for Reach 3 was measured against the achievement of the component for the Unimpacted scenario. The specifications of components made by the Panel were such that they were not necessarily met, or met in their entirety, in each year.

4.5.1 Cease-to-flow

Cease to flow was not recommended for Reach 3. This means that any year with a cease to flow event is non-compliant. Cease to flow did not occur in winter, but a few events occurred in summer during the drought years of 1968, 1983, 1988, 2000 and 2003 (Figure 19). Apart from 1983, these were short events with little consequence. The 1983 events were longer duration, of about three weeks. Overall, there is a very high level of compliance with the cease to flow recommendation.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965							
1966							
1967							
1968						1	4
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983		1		1	1	1	1
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							1
1999							
2000		1			1		4
2001							
2002							
2003							2
2004							
%yrs	0%	5%	0%	2%	5%	5%	12%

Event frequency
- 1 event per year
- 2 events per year
- >2 events per year

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965							
1966							
1967							
1968						1	4
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983		20		6	19	25	25
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							13
1999							
2000		4			3		2
2001							
2002							
2003							5
2004							

Event mean duration
- 1 to 7 days
- 7 to 14 days
- >14 days

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		0%	0%	0%	0%	0%	0%
1965		0%	0%	0%	0%	0%	0%
1966		0%	0%	0%	0%	0%	0%
1967		0%	0%	0%	0%	0%	0%
1968		0%	0%	0%	0%	1%	8%
1969		0%	0%	0%	0%	0%	0%
1970		0%	0%	0%	0%	0%	0%
1971		0%	0%	0%	0%	0%	0%
1972		0%	0%	0%	0%	0%	0%
1973		0%	0%	0%	0%	0%	0%
1974		0%	0%	0%	0%	0%	0%
1975		0%	0%	0%	0%	0%	0%
1976		0%	0%	0%	0%	0%	0%
1977		0%	0%	0%	0%	0%	0%
1978		0%	0%	0%	0%	0%	0%
1979		0%	0%	0%	0%	0%	0%
1980		0%	0%	0%	0%	0%	0%
1981		0%	0%	0%	0%	0%	0%
1982		0%	0%	0%	0%	0%	0%
1983		11%	0%	3%	10%	14%	14%
1984		0%	0%	0%	0%	0%	0%
1985		0%	0%	0%	0%	0%	0%
1986		0%	0%	0%	0%	0%	0%
1987		0%	0%	0%	0%	0%	0%
1988		0%	0%	0%	0%	0%	0%
1989		0%	0%	0%	0%	0%	0%
1990		0%	0%	0%	0%	0%	0%
1991		0%	0%	0%	0%	0%	0%
1992		0%	0%	0%	0%	0%	0%
1993		0%	0%	0%	0%	0%	0%
1994		0%	0%	0%	0%	0%	0%
1995		0%	0%	0%	0%	0%	0%
1996		0%	0%	0%	0%	0%	0%
1997		0%	0%	0%	0%	0%	0%
1998		0%	0%	0%	0%	0%	7%
1999		0%	0%	0%	0%	0%	0%
2000		2%	0%	0%	2%	0%	4%
2001		0%	0%	0%	0%	0%	0%
2002		0%	0%	0%	0%	0%	0%
2003		0%	0%	0%	0%	0%	5%
2004		0%	0%	0%	0%	0%	0%
%yrs		95%	100%	98%	95%	95%	88%

Difference in Duration (relative to U)
- zero (compliance)
- >zero (non-compliance)

Figure 19. Pattern of frequency and duration of cease to flow events at Reach 3. Duration is mean event duration for each year.

4.5.2 Summer Low Flow

The Low Flow threshold of 3 ML/d is exceeded all of the time in every summer in the Unimpaired and With Weir and 10 ML/d passing flow scenarios (Figure 20). These scenarios could be said to be 100% compliant with the recommendation. For the other scenarios, in some years the flow falls below 3 ML/d for a percentage of the time. These years cannot be said to be non-compliant, because for most of the time in those months the flow is compliant (Figure 20). A threshold for compliance was set at 50%, i.e. a year failed to comply if the flow fell below 3 ML/d for more than 50% of the time. This criterion did not create any non-compliant years (Figure 20). An alternative way of assessing compliance is to measure, for each year, the deviation (in percent of time <3 ML/d) from that of the Unimpaired scenario, and then place an upper limit on this deviation. Applying an upper limit of 10% change created only a few non-compliant years, with 3 occurring in the 2030 land use and dry climate scenario (Figure 20). Overall, there is a very high level of compliance with the Low Flow recommendation across the scenarios.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	0%	0%	0%	0%	0%	0%	0%
1965	0%	0%	0%	0%	0%	0%	0%
1966	0%	0%	0%	0%	0%	0%	0%
1967	0%	0%	0%	0%	0%	0%	0%
1968	0%	2%	0%	2%	2%	4%	47%
1969	0%	0%	0%	0%	0%	0%	0%
1970	0%	0%	0%	0%	0%	0%	0%
1971	0%	0%	0%	0%	0%	0%	0%
1972	0%	0%	0%	0%	0%	0%	0%
1973	0%	0%	0%	0%	0%	0%	0%
1974	0%	0%	0%	0%	0%	0%	0%
1975	0%	0%	0%	0%	0%	0%	0%
1976	0%	0%	0%	0%	0%	0%	0%
1977	0%	0%	0%	0%	0%	0%	0%
1978	0%	0%	0%	0%	0%	0%	0%
1979	0%	0%	0%	0%	0%	0%	0%
1980	0%	0%	0%	0%	0%	0%	0%
1981	0%	0%	0%	0%	0%	0%	0%
1982	0%	0%	0%	0%	0%	0%	0%
1983	0%	17%	0%	7%	16%	16%	36%
1984	0%	0%	0%	0%	0%	0%	0%
1985	0%	0%	0%	0%	0%	0%	0%
1986	0%	0%	0%	0%	0%	0%	0%
1987	0%	0%	0%	0%	0%	0%	0%
1988	0%	1%	0%	0%	0%	0%	0%
1989	0%	0%	0%	0%	0%	0%	1%
1990	0%	0%	0%	0%	0%	0%	0%
1991	0%	0%	0%	0%	0%	0%	0%
1992	0%	0%	0%	0%	0%	0%	0%
1993	0%	0%	0%	0%	0%	0%	0%
1994	0%	0%	0%	0%	0%	0%	0%
1995	0%	0%	0%	0%	0%	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%
1997	0%	0%	0%	0%	0%	0%	0%
1998	0%	1%	0%	0%	0%	0%	9%
1999	0%	0%	0%	0%	0%	0%	0%
2000	0%	13%	0%	1%	3%	1%	45%
2001	0%	0%	0%	0%	0%	0%	0%
2002	0%	0%	0%	0%	0%	0%	0%
2003	0%	1%	0%	0%	0%	0%	7%
2004	0%	0%	0%	0%	0%	0%	0%
%yrs	100%	100%	100%	100%	100%	100%	100%

Duration (% time less than 3 ML/d)
- 0 to 25% (compliance)
- 25 to 50% (compliance)
- 50 to 75%
- 75 to 100%

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		0%	0%	0%	0%	0%	0%
1965		0%	0%	0%	0%	0%	0%
1966		0%	0%	0%	0%	0%	0%
1967		0%	0%	0%	0%	0%	0%
1968		2%	0%	2%	2%	4%	47%
1969		0%	0%	0%	0%	0%	0%
1970		0%	0%	0%	0%	0%	0%
1971		0%	0%	0%	0%	0%	0%
1972		0%	0%	0%	0%	0%	0%
1973		0%	0%	0%	0%	0%	0%
1974		0%	0%	0%	0%	0%	0%
1975		0%	0%	0%	0%	0%	0%
1976		0%	0%	0%	0%	0%	0%
1977		0%	0%	0%	0%	0%	0%
1978		0%	0%	0%	0%	0%	0%
1979		0%	0%	0%	0%	0%	0%
1980		0%	0%	0%	0%	0%	0%
1981		0%	0%	0%	0%	0%	0%
1982		0%	0%	0%	0%	0%	0%
1983		17%	0%	7%	16%	16%	36%
1984		0%	0%	0%	0%	0%	0%
1985		0%	0%	0%	0%	0%	0%
1986		0%	0%	0%	0%	0%	0%
1987		0%	0%	0%	0%	0%	0%
1988		1%	0%	0%	0%	0%	0%
1989		0%	0%	0%	0%	0%	1%
1990		0%	0%	0%	0%	0%	0%
1991		0%	0%	0%	0%	0%	0%
1992		0%	0%	0%	0%	0%	0%
1993		0%	0%	0%	0%	0%	0%
1994		0%	0%	0%	0%	0%	0%
1995		0%	0%	0%	0%	0%	0%
1996		0%	0%	0%	0%	0%	0%
1997		0%	0%	0%	0%	0%	0%
1998		1%	0%	0%	0%	0%	9%
1999		0%	0%	0%	0%	0%	0%
2000		13%	0%	1%	3%	1%	45%
2001		0%	0%	0%	0%	0%	0%
2002		0%	0%	0%	0%	0%	0%
2003		1%	0%	0%	0%	0%	7%
2004		0%	0%	0%	0%	0%	0%
%yrs		95%	100%	100%	98%	98%	93%

Difference in Duration (relative to U)
- <10% (compliance)
- 10 to 20%
- 20 to 40%
- >40%

Figure 20. Pattern of duration of time less than summer Low Flow threshold (3 ML/d) at Reach 3, with compliance set at <50% of the time; and, pattern of difference in duration compared to that of the Unimpaired scenario with compliance set at <10% difference in duration.

4.5.3 Low Flow Fresh - 1

The Low Flow Fresh - 1was defined in terms of magnitude (≥66 ML/d), duration and frequency. Recommended frequency of events was set at 2 per year, but it is recognised that even in the Unimpaired scenario the frequency will be less than this in dry years. Similarly, the recommended minimum duration of events was set at 3 days, but it is recognized that the duration of some events satisfying the magnitude requirement may be lower than 3 days. Thus, years with one event were classed as partially compliant on frequency, and years with an event with a duration of one day were classed as partially compliant (Figure 21). The future With Weir scenarios tended to have less years with freshes compared to the Current and Unimpaired scenarios. This is due to the effect of the lake absorbing some small events when it is below the crest level. Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario, and provided the maximum duration exceeded 3 days (unless the Unimpaired maximum duration was less than 3 days). These criteria resulted in an overall moderate level of compliance for all but the 2030 land use and dry climate scenario, which had a low level of compliance (Figure 21).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	2	3	4	4	2	2	1
1966	1	1	1	1	1	1	
1967	1	1	2	1	1	1	
1968	1	2	1				
1969	3	2	7	4	2	2	1
1970	2	4	3	2	2	2	
1971	3	3	4	3	3	3	3
1972	1	1	1	2	3	3	2
1973	1						
1974	2	4	2	1	1	1	1
1975	3	3	3	1	1	1	
1976	3	3	8	6	1	1	1
1977	3	3	4	5	1	2	1
1978	3	4	1	1	1	1	
1979	2	1	6	4	2	2	1
1980	3	2	3	1	1	1	
1981	1		1	1	1		
1982	2	1	1	1			
1983	1	1	2	2	2	2	2
1984	1	2	3	4	4	5	1
1985	2	2	6	1	1	1	
1986	2	3	2	2	1	1	1
1987	3	2	6	2	2	2	1
1988	1	1	1	1	1	1	
1989	1	1	1	1	1	1	
1990	2	1	1	1	1	2	
1991	3	2	2	1			
1992	3	2	4				1
1993	1	2	3	3	2	2	1
1994	1	1	1	2	2	3	
1995	2	2	1				
1996	1		1				
1997	2	2	1	1	1	1	
1998							
1999							
2000	1	1					
2001	1	1	1				
2002	1	1	1	1	1	1	1
2003							
2004	2	1			1		
%yrs	90%	83%	83%	71%	68%	63%	37%

Low Flow Fresh event frequency

- No events
- 1 event (partial compliance)
- 2 events (compliance)
- >2 events (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	120	75	68	57	53	53	35
1966	33	17	17	17	16	17	
1967	58	39	34	31	28	27	
1968	26	8	1				
1969	116	48	38	26	17	23	10
1970	60	22	19	18	16	16	
1971	86	71	62	51	50	49	20
1972	183	176	171	114	109	108	49
1973	12						
1974	68	35	30	27	17	22	1
1975	55	29	30	21	16	17	
1976	118	46	31	26	23	24	14
1977	82	50	35	29	27	27	9
1978	28	12	10	8	7	7	
1979	100	66	50	41	35	35	21
1980	53	23	18	17	11	14	
1981	11		1	1	3		
1982	19	5	2	1			
1983	71	71	54	51	46	52	35
1984	179	70	66	47	34	36	17
1985	53	35	27	26	25	26	
1986	72	61	56	52	51	51	16
1987	102	79	62	59	53	54	8
1988	27	12	11	10	9	9	
1989	25	15	16	13	13	13	
1990	29	15	11	8	3	5	
1991	21	14	8	6			
1992	23	18	13				1
1993	104	71	56	42	41	41	27
1994	57	31	23	7	3	4	
1995	34	24	13				
1996	12		4				
1997	25	15	15	5	3	3	
1998							
1999							
2000	2	2					
2001	16	11	5				
2002	63	53	46	41	36	38	16
2003							
2004	13	1			1		

Low Flow Fresh event max. duration

- No events
- 1 - 2 days (partial compliance)
- 3 days (compliance)
- >3 days (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	0%
1966		100%	100%	100%	100%	100%	0%
1967		100%	100%	100%	100%	100%	0%
1968		100%	0%	0%	0%	0%	0%
1969		0%	100%	100%	0%	0%	0%
1970		100%	100%	100%	100%	100%	0%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	100%
1973		0%	0%	0%	0%	0%	0%
1974		100%	100%	0%	0%	0%	0%
1975		100%	100%	0%	0%	0%	0%
1976		100%	100%	100%	0%	0%	0%
1977		100%	100%	100%	0%	0%	0%
1978		100%	0%	0%	0%	0%	0%
1979		0%	100%	100%	100%	100%	0%
1980		0%	100%	0%	0%	0%	0%
1981		0%	0%	0%	100%	0%	0%
1982		0%	0%	0%	0%	0%	0%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	0%	0%	0%	0%
1986		100%	100%	100%	0%	0%	0%
1987		0%	100%	0%	0%	0%	0%
1988		100%	100%	100%	100%	100%	0%
1989		100%	100%	100%	100%	100%	0%
1990		0%	0%	0%	0%	100%	0%
1991		0%	0%	0%	0%	0%	0%
1992		0%	100%	0%	0%	0%	0%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	0%
1995		100%	0%	0%	0%	0%	0%
1996		0%	100%	0%	0%	0%	0%
1997		100%	0%	0%	0%	0%	0%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	0%	0%	0%	0%	0%
2001		100%	100%	0%	0%	0%	0%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		0%	0%	0%	0%	0%	0%
%yrs		71%	73%	54%	46%	46%	24%

LF Fresh occurrence (relative to U)

- Compliance
- Non-compliance

Figure 21. Pattern of frequency and duration of Low Flow Fresh - 1 (≥66 ML/d) at Reach 3. Duration is maximum event duration for each year.

4.5.4 Low Flow Fresh - 2

The Low Flow Fresh - 2 (allows fish passage over the natural rock barrier near Condah Mission) was defined in terms of magnitude (≥240 ML/d), duration and frequency. Recommended frequency of events was set at 2 per year, but it is recognised that even in the Unimpaired scenario the frequency will be less than this in dry years. Similarly, the recommended minimum duration of events was set at 3 days, but it is recognized that the duration of some events satisfying the magnitude requirement may be lower than 3 days. Thus, years with one event, which constituted 67% of years with events, were classed as partially compliant on frequency, and years with an event with a duration of 1 or 2 days were classed as partially compliant (Figure 22). Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario, and provided the maximum duration exceeded 3 days (unless the Unimpaired maximum duration was less than 3 days). These events were not common in summer, occurring in only around 30% of years for most scenarios (only 7% of years for the future 2030 land use and dry climate scenario). The compliance criteria resulted in an overall high level of compliance with the pattern of events in the Unimpaired scenario for all scenarios (Figure 22).

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	2	1	2	1	1	1	
1966							
1967							
1968	1	1	1				
1969							
1970			1				
1971	2	2	2	2	2	2	1
1972	2	2	3	2	2	2	2
1973							
1974							
1975							
1976	1	1	1	1	1	1	
1977							
1978							
1979	1	1	1	1	2	2	
1980							
1981							
1982							
1983	2	4	3	3	2	3	1
1984	1	1	1	1	1	1	
1985							
1986	1	1	1	1	1	1	
1987	1	1	2	1	1	1	
1988			1	1			
1989							
1990							
1991							
1992							
1993	1	1	1	1	1	1	
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002	1	1	1	1	1	1	
2003							
2004							
%yrs	29%	29%	34%	29%	27%	27%	7%

LF Fresh-2 event frequency

(white)	No events
(light grey)	1 event (compliance)
(grey)	2 events (compliance)
(dark grey)	>2 events (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	11	3	5	3	2	1	
1966							
1967							
1968	3	2	1				
1969							
1970			1				
1971	4	2	12	12	8	8	2
1972	24	15	11	11	9	9	3
1973							
1974							
1975							
1976	8	5	3	2	1	1	
1977							
1978							
1979	22	13	6	4	1	1	
1980							
1981							
1982							
1983	7	4	5	5	5	4	3
1984	8	2	5	4	4	3	
1985							
1986	27	22	19	19	18	17	
1987	14	12	11	10	10	7	
1988			1	1			
1989							
1990							
1991							
1992							
1993	14	8	4	2	1	1	
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002	12	8	7	6	6	6	
2003							
2004							

LF Fresh-2 event max. duration

(white)	No events
(yellow)	1 - 2 days (partial compliance)
(grey)	3 days (compliance)
(dark grey)	>3 days (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		0%	100%	0%	0%	0%	0%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		0%	0%	0%	0%	0%	0%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		0%	100%	100%	100%	100%	0%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	0%	0%	0%	0%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	0%	0%	0%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	0%
1984		0%	100%	100%	100%	100%	0%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	0%
1987		100%	100%	100%	100%	100%	0%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	0%	0%	0%	0%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	0%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		90%	98%	90%	88%	88%	73%

LF-2 Fresh occurrence (relative to U)

(grey)	Compliance
(white)	Non-compliance

Figure 22. Pattern of frequency and duration of Low Flow Fresh - 2 (≥240 ML/d) at Reach 3. Duration is maximum event duration for each year.

4.5.5 Low Flow Fresh - 3

The low Flow Fresh - 3 is specifically for Australian Grayling spawning. The compliance test for this flow was limited to the months of April and May, when the Grayling spawn in response to an event. The threshold of 97 ML/d allows fish passage through the entire surveyed reach. As Grayling have been sighted on only one occasion in the river, there is no certainty that they are currently found there. The natural duration and frequency was recommended. It is apparent that this flow component has not occurred in Darlot Creek over the past 15 years, which perhaps explains the lack of sightings of the fish. Years were regarded as compliant as long as they had an event in the same year that one was present in the unimpaired scenario. This criterion resulted in an overall high level of compliance (Figure 23).

A-M	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	1	1	2	1	1	1	
1966							
1967							
1968	1	1	1				
1969			1				
1970							
1971	1	1	1	1	1	1	1
1972	2	1	3	3	1	1	
1973							
1974			1				
1975			2				
1976							
1977	1	1	2	1			
1978							
1979			1	1			
1980							
1981							
1982							
1983	1	2	2	2	1	2	2
1984	1		3	1		1	
1985			2				
1986	1	1	1	1			
1987	1	1	1	1	1	1	
1988							
1989							
1990							
1991							
1992	1	1					
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							
%yrs	24%	22%	34%	22%	12%	15%	5%

LF Fresh-3 event frequency
- No events
- 1 event (compliance)
- 2 events (compliance)
- >2 events (compliance)

A-M	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	12	9	14	12	10	10	
1966							
1967							
1968	8	8	1				
1969			1				
1970							
1971	37	36	38	37	33	34	10
1972	12	12	12	6	3	3	
1973							
1974			3				
1975			2				
1976							
1977	1	1	4	4			
1978							
1979			1	1			
1980							
1981							
1982							
1983	52	35	39	37	37	37	18
1984	2		2	1		1	
1985			1				
1986	12	10	14	3			
1987	11	6	11	9	5	6	
1988							
1989							
1990							
1991							
1992	7	5					
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

LF Fresh-3 event max. duration
- No events
- 1 - 2 days (compliance)
- 3 days (compliance)
- >3 days (compliance)

A-M	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	0%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	0%	0%	0%	0%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	0%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	0%	0%	0%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	100%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		0%	100%	100%	0%	100%	0%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	0%	0%	0%
1987		100%	100%	100%	100%	100%	0%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	0%	0%	0%	0%	0%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		98%	98%	95%	88%	90%	80%

LF-3 Fresh occurrence (relative to U)
- Compliance
- Non-compliance

Figure 23. Pattern of frequency and duration of Low Flow Fresh - 3 (≥97 ML/d in April - May) at Reach 3. Duration is maximum event duration for each year.

4.5.6 Winter High Flow

Flow is less than the High Flow threshold of 108 ML/d for a variable percentage of the time in all scenarios (Figure 24). These years cannot be said to be non-compliant, because for some of the time in those months the flow is compliant (Figure 24). A threshold for compliance was set at 50%, i.e. a year failed to comply if the flow fell below 108 ML/d for more than 50% of the time. This criterion resulted in 76% of years being compliant in the Unimpaired scenario, with lower levels of compliance in the other scenarios (Figure 24). An alternative way of assessing compliance is to measure, for each year, the deviation (in percent of time <108 ML/d) from that of the Unimpaired scenario, and then place an upper limit on this deviation. Applying this method with an upper limit of 10% change produced a different pattern of compliance, with compliance being high only for the Current and the With Weir with 10 ML/d passing flow scenarios (Figure 24). Overall, the level of compliance with the High Flow recommendation was moderate to low across the scenarios.

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	15%	22%	21%	25%	25%	25%	27%
1965	21%	45%	39%	49%	52%	53%	72%
1966	33%	37%	39%	45%	50%	51%	89%
1967	100%	100%	100%	100%	100%	100%	100%
1968	0%	0%	0%	0%	1%	1%	19%
1969	55%	58%	55%	62%	64%	66%	100%
1970	31%	36%	37%	38%	44%	41%	70%
1971	0%	0%	0%	0%	0%	0%	5%
1972	75%	77%	71%	76%	83%	83%	100%
1973	25%	27%	26%	26%	41%	37%	77%
1974	26%	26%	26%	26%	30%	30%	66%
1975	24%	25%	24%	25%	33%	30%	45%
1976	36%	37%	36%	38%	41%	41%	68%
1977	28%	39%	33%	39%	54%	54%	88%
1978	18%	18%	18%	19%	22%	21%	42%
1979	48%	56%	55%	57%	59%	60%	94%
1980	59%	77%	66%	76%	85%	85%	100%
1981	22%	32%	39%	41%	42%	43%	58%
1982	100%	100%	100%	100%	100%	100%	100%
1983	0%	0%	0%	0%	0%	0%	6%
1984	18%	20%	19%	21%	26%	28%	67%
1985	30%	37%	40%	45%	50%	51%	96%
1986	10%	14%	15%	16%	18%	17%	38%
1987	38%	45%	43%	54%	58%	57%	94%
1988	41%	45%	47%	61%	72%	70%	93%
1989	32%	35%	36%	41%	43%	42%	57%
1990	41%	43%	46%	53%	59%	57%	84%
1991	43%	48%	50%	54%	60%	59%	75%
1992	12%	12%	12%	14%	22%	18%	41%
1993	41%	53%	53%	54%	63%	65%	96%
1994	65%	80%	75%	89%	90%	92%	100%
1995	37%	48%	41%	48%	55%	55%	80%
1996	30%	37%	42%	47%	49%	49%	56%
1997	88%	94%	90%	93%	100%	100%	100%
1998	54%	72%	77%	81%	85%	89%	100%
1999	100%	100%	100%	100%	100%	100%	100%
2000	27%	30%	37%	50%	53%	51%	83%
2001	44%	44%	47%	49%	49%	49%	78%
2002	93%	100%	100%	100%	100%	100%	100%
2003	41%	55%	59%	66%	70%	69%	100%
2004	15%	25%	27%	44%	48%	45%	83%
%yrs	**76%**	**68%**	**66%**	**59%**	**46%**	**44%**	**20%**

Duration (% time less than 108 ML/d)

- 0 to 25% (compliance)
- 25 to 50% (compliance)
- 50 to 75%
- 75 to 100%

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		7%	6%	9%	9%	10%	12%
1965		24%	18%	27%	30%	31%	51%
1966		4%	6%	12%	17%	18%	55%
1967		0%	0%	0%	0%	0%	0%
1968		0%	0%	0%	1%	1%	19%
1969		3%	1%	7%	9%	11%	45%
1970		5%	6%	7%	13%	9%	38%
1971		0%	0%	0%	0%	0%	5%
1972		2%	-4%	1%	8%	8%	25%
1973		3%	1%	2%	16%	12%	53%
1974		0%	0%	1%	4%	4%	40%
1975		2%	0%	1%	9%	7%	22%
1976		1%	0%	2%	4%	4%	32%
1977		12%	5%	11%	26%	26%	60%
1978		0%	0%	2%	5%	4%	24%
1979		9%	7%	9%	12%	13%	46%
1980		19%	7%	18%	26%	27%	42%
1981		9%	16%	18%	20%	20%	36%
1982		0%	0%	0%	0%	0%	0%
1983		0%	0%	0%	0%	0%	6%
1984		2%	1%	3%	8%	10%	49%
1985		7%	10%	15%	20%	21%	66%
1986		3%	4%	5%	8%	7%	28%
1987		8%	5%	16%	20%	19%	56%
1988		4%	5%	20%	31%	28%	52%
1989		3%	4%	9%	11%	10%	25%
1990		2%	5%	12%	18%	16%	43%
1991		5%	7%	11%	17%	16%	32%
1992		0%	0%	2%	10%	5%	29%
1993		12%	12%	13%	22%	24%	55%
1994		15%	10%	24%	26%	27%	36%
1995		11%	4%	12%	19%	19%	43%
1996		7%	12%	16%	19%	19%	26%
1997		6%	2%	5%	12%	12%	12%
1998		18%	23%	27%	31%	35%	46%
1999		0%	0%	0%	0%	0%	0%
2000		3%	9%	22%	25%	24%	55%
2001		1%	3%	5%	5%	5%	35%
2002		7%	7%	7%	7%	7%	7%
2003		14%	18%	25%	29%	28%	60%
2004		10%	12%	29%	33%	31%	68%
%yrs		**78%**	**83%**	**56%**	**44%**	**44%**	**15%**

Difference in Duration (relative to U)

- <10% (compliance)
- 10 to 20%
- 20 to 40%
- >40%

Figure 24. Pattern of duration of time less than winter High Flow threshold (108 ML/d) at Reach 3, with compliance set at <50% of the time; and, pattern of difference in duration compared to that of the Unimpaired scenario with compliance set at <10% difference in duration.

4.5.7 High Flow Fresh - 1

The High Flow Fresh - 1 was defined in terms of magnitude (≥428 ML/d), duration and frequency. Recommended frequency of events was set at 2 per year and the recommended minimum duration of events was set at 1 day. The future With Weir scenarios had slightly more years with at least one High Flow Fresh event compared to the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface. Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario. This criterion resulted in an overall high level of compliance for all but the 2030 land use and dry climate scenario (Figure 25).

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	2	3	3	3	3
1965	1		1	1	1	1	
1966	1	1	1	1	1	1	
1967							
1968	4	4	5	5	5	5	1
1969			1	1	1		
1970	1	1	2	2	2	2	1
1971	5	5	5	5	5	5	4
1972							
1973	2	2	2	2	2	2	1
1974	3	3	3	3	3	3	
1975	3	3	3	3	3	3	4
1976	1	1	1	1	1	1	2
1977	1	1	1	1	1	1	
1978	4	5	5	5	5	5	2
1979	1	1	1	1	1	2	
1980							
1981	1	1	2	1	1	1	1
1982							
1983	3	3	3	3	3	3	4
1984	1	1	1	1	1	1	1
1985			1	1	1	1	
1986	4	4	4	4	4	4	3
1987							
1988	1	1	1	1	1	1	
1989	3	3	3	3	3	2	1
1990	1	1	2	2	2	2	
1991	2	2	2	2	2	2	
1992	1	1	1	1	1	1	1
1993	2	2	2	2	2	1	
1994	1	1	1	1	1	1	
1995	1	1	2	2	2	2	1
1996	2	2	2	2	2	2	1
1997							
1998			1	1	1		
1999							
2000	1		1	1	1	1	
2001	2	2	2	2	2	3	
2002							
2003							
2004	1	1	1	1	1	1	1
%yrs	71%	66%	78%	78%	78%	73%	41%

HF Fresh-1 event frequency

- No events
- 1 event (compliance)
- 2 events (compliance)
- >2 events (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	90	88	90	43	42	40	34
1965	5		7	6	6	2	
1966	12	5	8	8	6	2	
1967							
1968	31	31	32	29	27	26	3
1969			1	1	1		
1970	40	39	42	40	39	35	18
1971	21	21	22	20	19	19	10
1972							
1973	9	8	9	9	9	7	1
1974	18	18	17	17	16	14	
1975	41	39	39	38	38	36	15
1976	48	48	44	44	41	35	11
1977	9	8	9	8	8	5	
1978	32	23	22	22	22	20	14
1979	12	11	13	13	13	9	
1980							
1981	28	25	27	27	27	24	19
1982							
1983	47	45	46	45	45	45	23
1984	44	42	43	42	41	36	8
1985			4	4	4	2	
1986	12	12	12	11	10	10	1
1987							
1988	13	13	14	14	14	7	
1989	23	19	22	21	18	11	1
1990	8	2	8	5	5	2	
1991	14	13	13	11	11	10	
1992	74	74	77	75	71	65	26
1993	3	3	5	5	5	3	
1994	1	1	4	4	4	3	
1995	23	15	15	15	15	13	3
1996	33	32	29	29	28	25	9
1997							
1998			1	1	1		
1999							
2000	1		5	5	4	3	
2001	18	17	16	13	13	2	
2002							
2003							
2004	24	23	23	22	22	20	6

HF Fresh-1 event max. duration

- No events
- 1 - 2 days (compliance)
- 3 days (compliance)
- >3 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		0%	100%	100%	100%	100%	0%
1966		100%	100%	100%	100%	100%	0%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	0%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	0%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	0%
1974		100%	100%	100%	100%	100%	0%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	0%
1978		100%	100%	100%	100%	100%	0%
1979		100%	100%	100%	100%	100%	0%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	0%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	0%
1989		100%	100%	100%	100%	0%	0%
1990		100%	100%	100%	100%	100%	0%
1991		100%	100%	100%	100%	100%	0%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	0%	0%
1994		100%	100%	100%	100%	100%	0%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	0%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		0%	100%	100%	100%	100%	0%
2001		100%	100%	100%	100%	100%	0%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		95%	100%	100%	100%	95%	54%

HF Fresh-1 occurrence (relative to U)

- Compliance
- Non-compliance

Figure 25. Pattern of frequency and duration of High Flow Fresh - 1 (≥428 ML/d) at Reach 3. Duration is maximum event duration for each year.

4.5.8 High Flow Fresh - 2

The High Flow Fresh - 2 (allows fish passage over the natural rock barrier near Condah Mission) was defined in terms of magnitude (≥240 ML/d), duration and frequency. Recommended frequency of events was set at 2 per season (1 in winter and 1 in spring), but it is recognised that even in the Unimpaired scenario the frequency will be less than this in dry years. Similarly, the recommended minimum duration of events was set at 3 days, but it is recognized that the duration of some events satisfying the magnitude requirement may be lower than 3 days. Thus, years with one event, which constituted 37% of years with events, were classed as partially compliant on frequency, and years with an event with a duration of 1 or 2 days were classed as partially compliant (Figure 26). In some years the future With Weir scenarios had marginally more events per year compared to the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface. Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario, and provided the maximum duration exceeded 3 days (unless the Unimpaired maximum duration was less than 3 days). These criteria resulted in an overall high level of compliance for all but the 2030 land use and dry climate scenario (Figure 26).

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	1	1	1	1	2
1965	2	2	2	2	2	2	1
1966	2	2	3	2	2	2	1
1967							
1968	3	4	4	4	4	4	4
1969	1	1	2	2	2	1	
1970	2	2	2	2	2	2	1
1971	3	3	2	3	3	3	5
1972							
1973	3	3	3	3	3	3	2
1974	2	1	1	1	1	2	2
1975	1	1	1	1	1	1	2
1976	2	2	2	2	2	2	2
1977	2	2	4	3	3	3	1
1978	2	2	2	2	2	4	5
1979	2	2	2	2	2	2	
1980	1	1	1	1	1	1	
1981	1	1	2	2	2	2	1
1982							
1983	2	3	3	3	2	3	3
1984	2	2	2	2	2	3	1
1985	3	3	4	4	3	3	
1986	1	1	1	1	1	1	4
1987	2	2	2	2	2	2	
1988	1	1	1	1	1	1	1
1989	1	1	1	2	2	3	2
1990	2	2	2	2	2	2	1
1991	1	1	1	1	1	1	2
1992	2	2	2	2	2	2	1
1993	1	1	2	1	1	2	
1994	1	1	1	1	1	1	
1995	2	1	1	1	1	1	1
1996	1	1	1	1	1	1	2
1997							
1998	2	1	2	2	1	2	
1999							
2000	2	2	3	2	2	3	1
2001	2	3	2	2	3	3	2
2002							
2003	1	1	3	3	2	2	
2004	3	3	4	4	4	3	1
%yrs	**85%**	**85%**	**85%**	**85%**	**85%**	**85%**	**63%**

HF Fresh-2 event frequency

- No events
- 1 event (partial compliance)
- 2 events (compliance)
- >2 events (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	140	137	135	131	128	125	91
1965	40	37	38	37	35	30	2
1966	30	29	25	24	22	21	2
1967							
1968	84	58	55	54	54	54	42
1969	24	22	25	24	22	19	
1970	64	63	69	65	59	58	35
1971	98	98	117	97	96	94	22
1972							
1973	27	26	24	24	23	20	6
1974	90	87	86	80	73	39	13
1975	122	122	123	122	122	120	38
1976	71	63	68	65	63	59	19
1977	23	22	19	18	18	16	8
1978	100	89	93	88	78	45	23
1979	34	33	32	31	30	26	
1980	2	2	4	4	4	3	
1981	86	79	67	60	57	48	30
1982							
1983	146	140	138	137	133	129	54
1984	63	62	62	61	60	59	35
1985	9	7	9	7	6	5	
1986	132	125	123	120	116	106	14
1987	9	9	10	9	8	6	
1988	25	24	22	22	22	20	2
1989	96	90	82	51	48	33	20
1990	43	41	43	41	37	30	1
1991	65	58	58	55	48	45	11
1992	110	110	108	105	105	104	75
1993	18	18	20	19	17	7	
1994	8	6	10	9	8	6	
1995	43	42	41	38	37	36	16
1996	89	86	86	79	75	73	27
1997							
1998	3	2	4	3	3	4	
1999							
2000	62	53	34	34	33	28	3
2001	43	29	33	31	23	20	1
2002							
2003	5	3	4	4	4	3	
2004	34	33	30	29	29	28	22

HF Fresh-2 event max. duration

- No events
- 1 - 2 days (partial compliance)
- 3 days (compliance)
- >3 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	0%
1966		100%	100%	100%	100%	100%	0%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	0%
1970		100%	100%	100%	100%	100%	0%
1971		100%	0%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	0%
1974		0%	0%	0%	0%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	0%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	0%
1980		100%	100%	100%	100%	100%	0%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	0%
1985		100%	100%	100%	100%	100%	0%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	0%
1988		100%	100%	100%	100%	100%	0%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	0%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	0%
1993		100%	100%	100%	100%	100%	0%
1994		100%	100%	100%	100%	100%	0%
1995		0%	0%	0%	0%	0%	0%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		0%	100%	100%	0%	100%	0%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	0%
2001		100%	100%	100%	100%	100%	0%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	0%
2004		100%	100%	100%	100%	100%	0%
%yrs		**93%**	**93%**	**95%**	**93%**	**98%**	**46%**

HF-2 Fresh occurrence (relative to U)

- Compliance
- Non-compliance

Figure 26. Pattern of frequency and duration of High Flow Fresh - 2 (≥240 ML/d) at Reach 3. Duration is maximum event duration for each year.

4.5.9 Bankfull

The Bankfull Flow component was defined in terms of magnitude (≥850 ML/d), duration and frequency. Recommended frequency of events was set at 2 in 3 years, but this should be interpreted a general long-term frequency target, as Bankfull events do not naturally occur with such regularity. Thus, the 2 in every 3 year frequency recommendation was not used as part of the compliance testing. The recommended minimum duration of events was set at 1 day, so this was not a determinant of compliance. Also, the maximum duration target of 2 months was not exceeded in any event, so this was not a determinant of compliance. Years were classed as compliant if at least one Bankfull event occurred in the same year as one or more occurred in the Unimpaired scenario. This criterion resulted in 100% compliance for all but two of the scenarios (Figure 27). Overall, long-term frequency of Bankfull was lower than the recommended target, being 2 in 5 to 2 in 6 years, and 2 in 12 for the 2030 land use and dry climate scenario. Bankfull events occurred regularly in the 17-year period 1970 – 1986, but were sporadic in the rest of the 41-year record from 1964 - 2004. The future With Weir) scenarios had slightly more years with at least one Bankfull event compared to the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface.

	U	C	C.10	C.20	C.30	F.a	F.b
1964	3	3	3	3	3	3	1
1965							
1966							
1967							
1968							
1969							
1970	2	2	1	1	1	2	1
1971	2	3	3	3	3	2	
1972							
1973		1	1	1	1	1	
1974							
1975	3	4	4	4	4	2	
1976	2	2	2	2	2	2	1
1977							
1978	2	2	2	2	2	2	1
1979			1	1	1	1	
1980							
1981	1	1	1	1	1	1	1
1982							
1983	1	1	1	1	1	1	1
1984	1	1	1	1	1	1	
1985							
1986	1	1	1	1	1		
1987							
1988							
1989			1	1	1		
1990							
1991							
1992	1	1	1	1	1	2	1
1993							
1994							
1995							
1996	1	1	1	1	1	1	
1997							
1998							
1999							
2000							
2001			1	1	1		
2002							
2003							
2004			1	1	1	1	
%yrs	29%	32%	41%	41%	41%	34%	17%

Bankfull event frequency
- 1 event per year
- 2 events per year
- >2 events per year

	U	C	C.10	C.20	C.30	F.a	F.b
1964	9	9	9	9	9	7	6
1965							
1966							
1967							
1968							
1969							
1970	6	6	13	12	12	5	1
1971	8	5	7	6	6	6	
1972							
1973		1	3	3	3	2	
1974							
1975	10	8	8	8	8	8	
1976	8	8	8	8	8	7	2
1977							
1978	11	11	11	11	10	8	6
1979			1	1	1	1	
1980							
1981	10	10	10	10	10	8	1
1982							
1983	16	18	18	18	18	17	13
1984	8	8	8	8	8	6	
1985							
1986	2	2	4	4	3		
1987							
1988							
1989			1	1	1		
1990							
1991							
1992	19	20	19	18	17	5	1
1993							
1994							
1995							
1996	4	4	3	2	1	1	
1997							
1998							
1999							
2000							
2001			2	1	1		
2002							
2003							
2004			2	2	2	2	

Bankfull event duration
- 1 to 2 days
- 2 to 7 days
- >7 days

	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	0%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	0%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	100%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	0%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	0%	0%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	0%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		100%	100%	100%	100%	98%	88%

Bankfull occurrence (relative to U)
- Compliance
- Non-compliance

Figure 27. Pattern of frequency and duration of Bankfull (850 ML/d) at Reach 3. Duration is mean duration for the events occurring in each year.

4.5.10 Overbank

The Overbank Flow component was defined in terms of magnitude (≥1,171 ML/d), duration and frequency. Recommended frequency of events was set at 1 in 3 years, but this should be interpreted a general long-term frequency target, as Overbank events do not naturally occur with such regularity. Thus, the 1 in every 3 year frequency recommendation was not used as part of the compliance testing. The recommended minimum duration of events was set at 1 day, so this was not a determinant of compliance. Years were classed as compliant if at least one Overbank event occurred in the same year as one or more occurred in the Unimpaired scenario. This criterion resulted in a high level of compliance for all scenarios except the 2030 land use and dry climate scenario (Figure 28). Overall, long-term frequency of Overbank was lower than the recommended target, being 1 in 4 to 1 in 4.5 years, and occurring only once in 41 years in the 2030 land use and dry climate scenario. Overbank events occurred regularly in the 15-year period 1970 – 1984, but were sporadic in the rest of the 41-year record from 1964 - 2004.

	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	1	1	1	1	
1965							
1966							
1967							
1968							
1969							
1970	1	1	1	1	1	1	
1971	1	1	1	1	1	1	
1972							
1973			1	1	1		
1974							
1975	1	1	1	1	1	1	
1976	1	1	2	2	2	1	
1977							
1978	2	2	2	2	2	2	
1979							
1980							
1981	1	1	1	1	1	1	
1982							
1983	1	1	1	1	1	1	1
1984	1	1	1	1	1		
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992	1	1	1	1	1	1	
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							
%yrs	24%	24%	27%	27%	27%	22%	2%

Overbank event frequency
- 1 event per year
- 2 events per year
- >2 events per year

	U	C	C.10	C.20	C.30	F.a	F.b
1964	13	12	12	12	12	7	
1965							
1966							
1967							
1968							
1969							
1970	4	5	5	5	5	2	
1971	3	3	2	2	2	1	
1972							
1973			1	1	1		
1974							
1975	8	8	7	7	7	3	
1976	9	8	5	5	5	6	
1977							
1978	6	6	7	7	7	4	
1979							
1980							
1981	4	5	6	6	6	1	
1982							
1983	13	14	14	14	14	13	9
1984	4	3	4	4	4		
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992	6	4	5	5	5	3	
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

Overbank event duration
- 1 to 2 days
- 2 to 7 days
- >7 days

	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	0%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	0%
1971		100%	100%	100%	100%	100%	0%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	0%
1976		100%	100%	100%	100%	100%	0%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	0%
1979		100%	100%	100%	100%	100%	100%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	0%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	0%	0%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	0%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		100%	100%	100%	100%	98%	78%

Overbank occurrence (relative to U)
- Compliance
- Non-compliance

Figure 28. Pattern of frequency and duration of Overbank (1,171 ML/d) at Reach 3. Duration is mean duration for the events occurring in each year.

4.6 Site 4: Darlot Creek at the IPA

The compliance of each of the FLOWS components for Reach 4 was measured against the achievement of the component for the Unimpacted scenario. The specifications of components made by the Panel were such that they were not necessarily met, or met in their entirety, in each year.

4.6.1 Cease-to-flow

Cease to flow was not recommended for Reach 4. This means that any year with a cease to flow event is non-compliant. Cease to flow did not occur in winter, and in summer occurred only in the 2030 land use and dry climate scenario. Cease to flow events occurred during the drought years of 1968, 1983, 1998, 2000 and 2003. The 1983 event had a 3-week duration, the 1998 event had a 2-week duration, and the other 7 events were less than 1-week duration. Overall, all but one scenario had 100% compliance with the cease to flow recommendation; the 2030 land use and dry climate scenario had 88% compliance.

4.6.2 Summer Low Flow

The flow falls below the Low Flow threshold of 26 ML/d for some of the time for all scenarios (Figure 29). A threshold for compliance was set at 50%, i.e. a year failed to comply if the flow fell below 26 ML/d for more than 50% of the time. This criterion resulted in a high level of compliance for all scenarios, except the 2030 land use and dry climate scenario, which had a compliance of 80% (Figure 29). An alternative way of assessing compliance is to measure, for each year, the deviation (in percent of time <26 ML/d) from that of the Unimpaired scenario, and then place an upper limit on this deviation. Applying an upper limit of 10% change created some non-compliant years in the Current, and in particular, the 2030 land use and dry climate scenario. The other scenarios had a high level of compliance (Figure 29). Overall, there is a high level of compliance with the Low Flow recommendation across the scenarios.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	1%	12%	0%	0%	0%	0%	60%
1965	0%	0%	0%	0%	0%	0%	0%
1966	4%	28%	0%	0%	0%	0%	33%
1967	0%	12%	0%	0%	0%	0%	32%
1968	49%	70%	31%	50%	66%	56%	75%
1969	0%	0%	0%	0%	0%	0%	0%
1970	0%	0%	0%	0%	0%	0%	15%
1971	0%	0%	0%	0%	0%	0%	0%
1972	0%	0%	0%	0%	0%	0%	0%
1973	0%	0%	0%	0%	0%	0%	15%
1974	0%	0%	0%	0%	0%	0%	0%
1975	0%	0%	0%	0%	0%	0%	0%
1976	0%	0%	0%	0%	0%	0%	0%
1977	0%	0%	0%	0%	0%	0%	0%
1978	0%	0%	0%	0%	0%	0%	18%
1979	0%	0%	0%	0%	0%	0%	0%
1980	0%	0%	0%	0%	0%	0%	15%
1981	0%	1%	0%	0%	0%	0%	47%
1982	0%	0%	0%	0%	0%	0%	15%
1983	43%	61%	19%	47%	61%	58%	63%
1984	0%	0%	0%	0%	0%	0%	0%
1985	0%	0%	0%	0%	0%	0%	0%
1986	0%	0%	0%	0%	0%	0%	0%
1987	0%	0%	0%	0%	0%	0%	0%
1988	0%	0%	0%	0%	0%	0%	26%
1989	0%	0%	0%	0%	0%	0%	29%
1990	0%	0%	0%	0%	0%	0%	0%
1991	0%	0%	0%	0%	0%	0%	0%
1992	0%	0%	0%	0%	0%	0%	5%
1993	0%	0%	0%	0%	0%	0%	0%
1994	0%	0%	0%	0%	0%	0%	21%
1995	0%	0%	0%	0%	0%	0%	32%
1996	0%	0%	0%	0%	0%	0%	53%
1997	0%	0%	0%	0%	0%	0%	14%
1998	1%	49%	4%	0%	10%	0%	63%
1999	13%	43%	0%	0%	0%	0%	53%
2000	60%	80%	27%	59%	70%	50%	93%
2001	0%	0%	0%	0%	0%	0%	24%
2002	0%	0%	0%	0%	0%	0%	17%
2003	4%	35%	0%	0%	0%	0%	58%
2004	1%	0%	0%	0%	0%	0%	21%
%yrs	98%	93%	100%	95%	93%	93%	80%

Duration (% time less than 26 ML/d)
- 0 to 25% (compliance)
- 25 to 50% (compliance)
- 50 to 75%
- 75 to 100%

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		10%	-1%	-1%	-1%	-1%	59%
1965		0%	0%	0%	0%	0%	0%
1966		24%	-4%	-4%	-4%	-4%	29%
1967		12%	0%	0%	0%	0%	32%
1968		20%	-18%	1%	17%	7%	25%
1969		0%	0%	0%	0%	0%	0%
1970		0%	0%	0%	0%	0%	15%
1971		0%	0%	0%	0%	0%	0%
1972		0%	0%	0%	0%	0%	0%
1973		0%	0%	0%	0%	0%	15%
1974		0%	0%	0%	0%	0%	0%
1975		0%	0%	0%	0%	0%	0%
1976		0%	0%	0%	0%	0%	0%
1977		0%	0%	0%	0%	0%	0%
1978		0%	0%	0%	0%	0%	18%
1979		0%	0%	0%	0%	0%	0%
1980		0%	0%	0%	0%	0%	15%
1981		1%	0%	0%	0%	0%	47%
1982		0%	0%	0%	0%	0%	15%
1983		18%	-24%	3%	18%	14%	20%
1984		0%	0%	0%	0%	0%	0%
1985		0%	0%	0%	0%	0%	0%
1986		0%	0%	0%	0%	0%	0%
1987		0%	0%	0%	0%	0%	0%
1988		0%	0%	0%	0%	0%	26%
1989		0%	0%	0%	0%	0%	29%
1990		0%	0%	0%	0%	0%	0%
1991		0%	0%	0%	0%	0%	0%
1992		0%	0%	0%	0%	0%	5%
1993		0%	0%	0%	0%	0%	0%
1994		0%	0%	0%	0%	0%	21%
1995		0%	0%	0%	0%	0%	32%
1996		0%	0%	0%	0%	0%	53%
1997		0%	0%	0%	0%	0%	14%
1998		48%	3%	-1%	9%	-1%	62%
1999		30%	-13%	-13%	-13%	-13%	40%
2000		20%	-33%	-1%	10%	-10%	33%
2001		0%	0%	0%	0%	0%	24%
2002		0%	0%	0%	0%	0%	17%
2003		31%	-4%	-4%	-4%	-4%	54%
2004		-1%	-1%	-1%	-1%	-1%	21%
%yrs		78%	100%	100%	95%	98%	41%

Difference in Duration (relative to U)
- <10% (compliance)
- 10 to 20%
- 20 to 40%
- >40%

Figure 29. Pattern of duration of time less than summer Low Flow threshold (26 ML/d) at Reach 4, with compliance set at <50% of the time; and, pattern of difference in duration compared to that of the Unimpaired scenario with compliance set at <10% difference in duration.

4.6.3 Low Flow Fresh - 1

The Low Flow Fresh - 1was defined in terms of magnitude (≥35 ML/d), duration and frequency. Recommended frequency of events was set at 2 per year, but it is recognised that even in the Unimpaired scenario the frequency can be less than this. Similarly, the recommended minimum duration of events was set at 3 days, but it is recognized that the duration of some events satisfying the magnitude requirement may be lower than 3 days. Thus, years with one event were classed as partially compliant on frequency, and years with an event with a duration of 1 - 2 days were classed as partially compliant.

Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario, and provided the maximum duration exceeded 3 days (unless the Unimpaired maximum duration was less than 3 days). Assessing the compliance of the Low Flow Fresh component was problematic for this site because the magnitude of the component was set lower than the normal summer baseflow, even for the future 2030 land use and dry climate scenario. Thus, for most years this component consisted of a single event, which was little different to the Low Flow component (Figure 30). The future scenarios with the weir in place tended to enhance the baseflow, hence giving more years where flow was>35 ML/d for the entire summer season. This had the effect of producing a pattern of more single event frequency years in the future scenarios than under the Unimpaired scenario, producing less than 100% compliance (Figure 30). The FLOWS method requires the Panel to set the minimum flow regime to maintain ecological integrity, and for this reach the Low Flow was 26 ML/d, in which case the Low Flow Fresh of 35 ML/d represents a rise over the baseflow. In practice though, most of the time the summer baseflow is currently, and in the future will be, above 35 ML/d in this reach. Strictly speaking, the Low Flow Fresh should be a rise above the Low Flow, but because the FLOWS method is based on achieving hydraulic thresholds, it was specified as an absolute magnitude (which just happened to be below the current summer baseflow). The conclusion to be drawn from this analysis is that the ecological functions of the Low Flow Fresh – 1, as defined (provide longitudinal fish passage and maintain pool water quality), are currently, and will into the future, be performed by summer baseflows.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	2	4	3	1	2	1	1
1965	1	1	1	1	1	1	1
1966	2	3	4	1	1	1	2
1967	1	3	3	1	1	1	1
1968	3	2	6	3	5	1	1
1969	1	1	1	1	1	1	1
1970	1	1	1	1	1	1	3
1971	1	1	1	1	1	1	1
1972	1	1	1	1	1	1	1
1973	1	3	2	1	1	1	5
1974	1	1	1	1	1	1	3
1975	1	1	1	1	1	1	1
1976	1	1	1	1	1	1	1
1977	1	1	1	1	1	1	1
1978	1	1	1	1	1	1	3
1979	1	1	1	1	1	1	1
1980	1	1	2	1	1	1	2
1981	1	3	2	1	1	1	1
1982	1	2	5	1	1	1	2
1983	2	1	3	2	2	2	1
1984	1	1	1	1	1	1	1
1985	1	1	1	1	1	1	1
1986	1	1	1	1	1	1	1
1987	1	1	1	1	1	1	1
1988	1	1	1	1	1	1	5
1989	1	1	1	1	1	1	4
1990	1	1	1	1	1	1	3
1991	1	1	1	1	1	1	1
1992	1	1	2	1	1	1	2
1993	1	1	1	1	1	1	1
1994	1	1	1	1	1	1	2
1995	1	2	4	1	1	1	3
1996	1	1	1	1	1	1	1
1997	1	1	2	1	1	1	3
1998	4	2	3	3	3	1	3
1999	4	2	3	1	3	1	1
2000	2	1	2	2	7	2	
2001	1	2	4	1	1	1	3
2002	1	1	2	1	1	1	1
2003	4	3	5	1	2	1	3
2004	1	2	5	1	1	1	1
%yrs	100%	100%	100%	100%	100%	100%	98%

LF Fresh-1 event frequency
- No events
- 1 event (partial compliance)
- 2 events (compliance)
- >2 events (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964	69	42	40	150	88	151	38
1965	182	182	182	182	182	182	182
1966	97	65	60	182	182	182	102
1967	176	85	85	182	182	182	122
1968	41	41	17	34	39	34	23
1969	182	182	179	182	182	182	182
1970	182	182	181	182	182	182	90
1971	182	182	180	182	182	182	182
1972	183	183	183	183	183	183	183
1973	181	115	89	182	182	182	53
1974	182	176	170	182	181	182	149
1975	182	182	179	182	182	182	178
1976	183	183	183	183	183	183	183
1977	182	182	182	182	182	182	182
1978	182	182	181	182	182	182	97
1979	182	182	182	182	182	182	182
1980	183	183	142	183	183	183	117
1981	181	78	105	180	181	181	91
1982	180	69	50	182	181	181	109
1983	71	71	53	66	71	66	66
1984	183	183	183	183	183	183	183
1985	182	182	176	182	182	182	182
1986	182	182	182	182	182	182	180
1987	182	182	182	182	182	182	182
1988	183	179	182	183	183	183	98
1989	182	182	181	182	182	182	84
1990	182	182	181	182	182	182	154
1991	182	182	182	182	182	182	179
1992	183	183	129	183	183	183	117
1993	182	182	182	182	182	182	182
1994	182	176	180	182	182	182	119
1995	181	87	124	182	182	182	70
1996	183	179	182	183	183	183	84
1997	182	182	157	182	182	182	123
1998	53	43	65	127	99	175	27
1999	52	15	54	182	126	182	79
2000	47	17	70	46	24	47	
2001	180	95	109	182	182	182	88
2002	182	182	146	182	182	182	142
2003	47	12	43	182	157	182	23
2004	180	74	57	182	182	183	114

LF Fresh-1 event max. duration
- No events
- 1 - 2 days (partial compliance)
- 3 days (compliance)
- >3 days (compliance)

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	0%	100%	0%	0%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	0%	0%	0%	100%
1967		100%	100%	100%	100%	100%	100%
1968		0%	100%	100%	100%	0%	0%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	100%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		0%	100%	100%	100%	100%	0%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		0%	0%	0%	0%	0%	0%
1999		0%	0%	0%	0%	0%	0%
2000		0%	100%	100%	100%	100%	0%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		0%	100%	0%	0%	0%	0%
2004		100%	100%	100%	100%	100%	100%
%yrs		85%	95%	88%	90%	85%	83%

LF Fresh-1 occurrence (relative to U)
- Compliance
- Non-compliance

Figure 30. Pattern of frequency and duration of Low Flow Fresh - 1 (≥35 ML/d) at Reach 4. Duration is maximum event duration for each year.

4.6.4 Low Flow Fresh - 2

The low Flow Fresh - 2 is specifically for Australian Grayling spawning. The compliance tests for this flow was limited to the months of April and May, when the Grayling spawn in response to an event. The threshold of 108 ML/d allows fish passage through the entire surveyed reach. As Grayling have been sighted on only one occasion in the river, there is no certainty that they are currently found there. The natural duration and frequency was recommended. It is apparent that this flow component has not occurred in Darlot Creek over the past 15 years, which perhaps explains the lack of sightings of the fish. Years were regarded as compliant as long as they had an event in the same year that one was present in the unimpaired scenario. This criterion resulted in an overall high level of compliance (Figure 31).

A-M	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	1	1	2	1	1	1	
1966							
1967							
1968	1	1	1	1	1	1	1
1969			1				
1970			1				
1971	1	1	1	1	1	1	1
1972	2	2	3	3	1	1	
1973							
1974			1				
1975	1	1	1				
1976	2	2	3	3	1		
1977	2	2	3	2	1	1	1
1978	2	1					
1979			2	2			
1980							
1981							
1982							
1983	1	1	2	2	1	2	2
1984			2	2	1	1	
1985			4				
1986	1	1	1	1	1	1	
1987	3	1	2	1	1	1	1
1988							
1989							
1990							
1991							
1992	1	1	2				1
1993			1				
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							
%yrs	29%	29%	44%	27%	24%	22%	15%

LF Fresh-2 event frequency

- No events
- 1 event (compliance)
- 2 events (compliance)
- >2 events (compliance)

A-M	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	8	7	12	10	9	9	
1966							
1967							
1968	8	7	3	3	3	2	1
1969			1				
1970			2				
1971	36	35	36	36	32	33	10
1972	25	9	10	6	4	4	
1973							
1974			2				
1975	2	1	6				
1976	23	2	7	3	2		
1977	5	4	8	6	3	2	2
1978	2	2					
1979			2	2			
1980							
1981							
1982							
1983	52	34	37	37	37	36	16
1984			1	1	1	1	
1985			1				
1986	16	15	15	7	5	3	
1987	18	17	18	16	9	5	3
1988							
1989							
1990							
1991							
1992	6	4	5				1
1993			1				
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

LF Fresh-2 event max. duration

- No events
- 1 - 2 days (compliance)
- 3 days (compliance)
- >3 days (compliance)

A-M	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	0%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	0%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	0%	0%	0%	0%
1976		100%	100%	100%	100%	0%	0%
1977		100%	100%	100%	100%	100%	100%
1978		100%	0%	0%	0%	0%	0%
1979		100%	100%	100%	100%	100%	100%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	0%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	0%	0%	0%	100%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		100%	98%	93%	93%	90%	85%

LF Fresh-2 occurrence (relative to U)

- Compliance
- Non-compliance

Figure 31. Pattern of frequency and duration of Low Flow Fresh - 2 (≥108 ML/d in April - May) at Reach 4. Duration is maximum event duration for each year.

4.6.5 Winter High Flow

Flow is less than the High Flow threshold of 87 ML/d for a variable percentage of the time in all scenarios (Figure 32). These years cannot be said to be non-compliant, because for most of the time in those months the flow is compliant (Figure 32). A threshold for compliance was set at 50%, i.e. a year failed to comply if the flow fell below 87 ML/d for more than 50% of the time. This criterion resulted in 90% of years being compliant in the Unimpaired scenario, with evels of compliance in the other scenarios being between 90% and 34% (Figure 32). An alternative way of assessing compliance is to measure, for each year, the deviation (in percent of time <87 ML/d) from that of the Unimpaired scenario, and then place an upper limit on this deviation. Applying this method with an upper limit of

10% change produced a different pattern of compliance, with compliance being high only for the Current and the With Weir with 10 ML/d passing flow scenarios (Figure 32). Overall, the level of compliance with the High Flow recommendation was moderate to low across the scenarios.

Duration (% time less than 87 ML/d)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	13%	13%	22%	22%	22%	23%	23%
1965	0%	0%	7%	10%	13%	17%	60%
1966	17%	19%	35%	41%	38%	44%	72%
1967	93%	96%	100%	100%	100%	100%	100%
1968	0%	0%	0%	1%	1%	1%	4%
1969	23%	35%	18%	35%	43%	39%	100%
1970	0%	9%	5%	8%	1%	16%	57%
1971	0%	0%	0%	0%	0%	0%	0%
1972	0%	20%	20%	26%	39%	39%	79%
1973	0%	2%	0%	22%	17%	23%	65%
1974	17%	21%	20%	17%	17%	21%	47%
1975	0%	1%	0%	12%	7%	14%	38%
1976	0%	0%	0%	1%	1%	6%	52%
1977	0%	10%	11%	15%	9%	18%	42%
1978	0%	0%	1%	2%	0%	3%	18%
1979	0%	30%	4%	31%	36%	39%	91%
1980	18%	31%	26%	42%	66%	60%	100%
1981	13%	17%	23%	34%	35%	35%	55%
1982	100%	100%	100%	100%	100%	100%	100%
1983	0%	0%	0%	0%	0%	0%	0%
1984	0%	18%	5%	17%	17%	18%	36%
1985	1%	2%	0%	2%	9%	13%	79%
1986	0%	0%	0%	0%	0%	1%	24%
1987	8%	16%	16%	19%	28%	28%	67%
1988	3%	8%	32%	20%	7%	37%	78%
1989	4%	4%	23%	13%	8%	17%	49%
1990	14%	14%	28%	25%	32%	36%	71%
1991	12%	13%	16%	12%	17%	18%	52%
1992	1%	1%	0%	1%	4%	7%	28%
1993	1%	14%	7%	17%	28%	44%	95%
1994	18%	40%	37%	62%	82%	81%	100%
1995	3%	9%	5%	23%	36%	30%	70%
1996	13%	13%	30%	33%	23%	33%	48%
1997	55%	82%	67%	89%	100%	95%	100%
1998	22%	39%	52%	66%	72%	73%	100%
1999	95%	100%	100%	100%	100%	100%	100%
2000	10%	23%	33%	34%	25%	25%	56%
2001	34%	43%	37%	37%	48%	39%	62%
2002	28%	44%	39%	67%	82%	76%	100%
2003	26%	32%	33%	58%	61%	61%	100%
2004	8%	8%	12%	17%	19%	18%	45%
%yrs	**90%**	**90%**	**88%**	**80%**	**78%**	**78%**	**34%**

Shading	Duration (% time less than 87 ML/d)
Dark grey	0 to 25% (compliance)
Mid grey	25 to 50% (compliance)
Light grey	50 to 75%
White	75 to 100%

Difference in Duration (relative to U)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		0%	9%	10%	10%	10%	10%
1965		0%	7%	10%	13%	17%	60%
1966		2%	18%	24%	21%	27%	55%
1967		3%	7%	7%	7%	7%	7%
1968		0%	0%	1%	1%	1%	4%
1969		12%	-5%	12%	20%	16%	77%
1970		9%	5%	8%	1%	16%	57%
1971		0%	0%	0%	0%	0%	0%
1972		20%	20%	26%	39%	39%	79%
1973		2%	0%	22%	17%	23%	65%
1974		4%	3%	0%	0%	4%	30%
1975		1%	0%	12%	7%	14%	38%
1976		0%	0%	1%	1%	6%	52%
1977		10%	11%	15%	9%	18%	42%
1978		0%	1%	2%	0%	3%	18%
1979		30%	4%	31%	36%	39%	91%
1980		14%	8%	24%	48%	43%	83%
1981		4%	10%	21%	21%	22%	42%
1982		0%	0%	0%	0%	0%	0%
1983		0%	0%	0%	0%	0%	0%
1984		18%	5%	17%	17%	18%	36%
1985		2%	-1%	2%	9%	13%	78%
1986		0%	0%	0%	0%	1%	24%
1987		9%	9%	11%	20%	21%	60%
1988		4%	29%	17%	3%	34%	75%
1989		0%	19%	9%	4%	13%	45%
1990		0%	14%	11%	18%	21%	56%
1991		1%	4%	0%	5%	5%	40%
1992		1%	-1%	0%	3%	7%	28%
1993		14%	6%	16%	27%	43%	94%
1994		22%	19%	44%	64%	63%	82%
1995		7%	3%	20%	33%	27%	67%
1996		1%	18%	21%	10%	21%	36%
1997		27%	12%	34%	45%	41%	45%
1998		17%	30%	43%	50%	51%	78%
1999		5%	5%	5%	5%	5%	5%
2000		13%	22%	24%	15%	14%	46%
2001		9%	3%	3%	14%	5%	28%
2002		16%	12%	39%	54%	48%	72%
2003		6%	7%	31%	35%	35%	74%
2004		1%	4%	9%	12%	10%	37%
%yrs		**73%**	**71%**	**44%**	**46%**	**32%**	**15%**

Shading	Difference in Duration (relative to U)
Dark grey	<10% (compliance)
Mid grey	10 to 20%
Light grey	20 to 40%
White	>40%

Figure 32. Pattern of duration of time less than winter High Flow threshold (87 ML/d) at Reach 4, with compliance set at <50% of the time; and, pattern of difference in duration compared to that of the Unimpaired scenario with compliance set at <10% difference in duration.

4.6.6 High Flow Fresh

The High Flow Fresh was defined in terms of magnitude (≥115 ML/d), duration and frequency. Recommended frequency of events was set at 2 per year. It is recognised that even in the Unimpaired scenario the frequency can be less than this. Similarly, the recommended minimum duration of events was set at 3 days, but it is recognized that the duration of some events satisfying the magnitude requirement may be lower than 3 days. Thus, years with one event were classed as partially compliant on frequency, and years with an event with a duration of 1 - 2 days were classed as partially compliant. Most years had high flow fresh events in all scenarios. The future With Weir scenarios tended to have more events per year than the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface. While the Unimpaired scenario tended to have less frequent events, the events had longer durations (as there was more water in the system).

Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario, and provided the maximum duration exceeded 3 days (unless the Unimpaired maximum duration was less than 3 days). This criterion resulted in an overall high level of compliance for all scenarios (Figure 33).

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	1	1	2	1	1
1965	1	2	2	2	2	2	1
1966	1	1	1	1	2	1	1
1967							
1968	1	1	1	1	1	1	1
1969	2	2	3	4	3	3	
1970	1	1	1	1	1	1	3
1971	1	1	1	1	1	1	1
1972	1	1	1	1	2	2	2
1973	1	2	2	2	3	1	3
1974	1	1	3	1	1	1	2
1975	2	2	2	1	1	1	2
1976	1	2	1	2	3	3	3
1977	2	2	3	2	2	2	2
1978	1	1	1	2	2	2	2
1979	2	1	2	2	1	2	3
1980	1	2	2	2	2	1	
1981	1	1	2	2	1	2	2
1982			1				
1983	1	1	1	1	1	1	1
1984	1	1	3	3	2	3	3
1985	1	2	1	2	3	3	4
1986	1	1	1	1	1	1	2
1987	1	3	2	3	2	2	2
1988	1	3	4	4	3	4	2
1989	1	1	2	3	3	2	2
1990	1	1	2	4	2	2	2
1991	1	1	2	2	2	2	2
1992	1	1	1	1	2	1	1
1993	4	4	4	3	4	3	2
1994	3	4	5	4	3	2	1
1995	2	2	2	2	2	1	1
1996	1	1	1	1	1	1	1
1997	2	1	4	1		1	
1998	2	3	2	2	2	4	
1999							
2000	1	1	2	2	3	3	1
2001	1	1	1	1	1	2	2
2002	2	1	2	3	4	3	
2003	1	3	2	2	2	3	1
2004	1	1	1	1	1	1	1
%yrs	**93%**	**93%**	**95%**	**93%**	**90%**	**93%**	**80%**

HF Fresh event frequency
- No events
- 1 event (partial compliance)
- 2 events (compliance)
- >2 events (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	156	156	143	141	141	141	140
1965	175	145	143	139	130	130	67
1966	136	127	111	103	94	93	34
1967							
1968	183	183	183	182	181	181	157
1969	94	91	105	53	51	51	
1970	163	152	156	147	147	137	74
1971	183	183	183	183	183	183	183
1972	113	103	110	100	87	87	14
1973	173	140	141	138	117	130	26
1974	148	136	136	138	138	136	92
1975	154	151	153	154	154	151	101
1976	178	124	175	124	124	123	66
1977	157	149	148	146	142	139	80
1978	183	182	177	153	155	151	140
1979	114	102	110	105	96	61	13
1980	127	59	99	68	39	40	
1981	142	124	120	115	110	109	79
1982			1				
1983	183	183	183	183	183	183	180
1984	152	150	151	151	151	150	81
1985	178	132	164	118	79	77	31
1986	183	179	183	180	163	164	125
1987	147	118	122	116	114	112	28
1988	156	109	101	87	89	73	19
1989	173	166	127	122	118	119	86
1990	151	131	118	99	98	96	41
1991	159	149	125	117	111	110	59
1992	180	173	178	168	154	157	120
1993	117	78	92	86	74	69	9
1994	46	25	27	22	20	17	1
1995	136	116	123	107	89	98	50
1996	153	152	128	116	114	114	82
1997	27	16	26	13		3	
1998	62	26	31	23	20	12	
1999							
2000	133	133	119	107	93	92	41
2001	108	102	96	96	96	95	27
2002	62	49	64	40	9	27	
2003	123	63	76	49	43	46	2
2004	168	167	158	144	129	134	88

HF Fresh event max. duration
- No events
- 1 - 2 days (partial compliance)
- 3 days (compliance)
- >3 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	0%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	0%	0%	0%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		0%	100%	100%	0%	100%	100%
1980		100%	100%	100%	100%	100%	0%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	0%	100%	0%	0%
1994		100%	100%	100%	100%	0%	0%
1995		100%	100%	100%	100%	0%	0%
1996		100%	100%	100%	100%	100%	100%
1997		0%	100%	0%	0%	0%	0%
1998		100%	100%	100%	100%	100%	0%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		0%	100%	100%	100%	100%	0%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		**93%**	**100%**	**93%**	**93%**	**88%**	**80%**

HF Fresh occurrence (relative to U)
- Compliance
- Non-compliance

Figure 33. Pattern of frequency and duration of High Flow Freshes (≥115 ML/d) at Reach 4. Duration is maximum event duration for each year.

4.6.7 Very High Flow Fresh

The High Flow Fresh was defined in terms of magnitude (≥401 ML/d), duration and frequency. Recommended frequency of events was set at 3 per year. It is recognised that even in the Unimpaired scenario the frequency can be less than this. Thus, years with 1 – 2 events were classed as partially compliant on frequency. At least 80% of years had a Very High Flow Fresh events in all scenarios (except the 2030 land use and dry climate scenario), but the period after 1996 was noticeably drier in this respect. The recommended frequency of 3 per season was clearly unrealistic, as this is very rare, even in the Unimpaired scenario (Figure 34).

Overall, compliance was assigned to any year where the fresh/es occurred with at least the same frequency as for the Unimpaired scenario. This criterion resulted in an overall high level of compliance for all scenarios except the 2030 land use and dry climate scenario (Figure 34).

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	2	2	2	2	3
1965	3	3	3	3	3	2	
1966	1	1	1	1	1	1	
1967							
1968	5	4	5	5	5	5	3
1969	1	1	1	1	1	2	
1970	1	1	2	2	2	2	1
1971	2	2	2	2	2	3	6
1972	1	1	1	1	1	1	
1973	3	3	3	3	3	3	1
1974	2	2	2	2	2	3	2
1975	1	1	1	1	1	2	3
1976	2	3	2	2	2	2	2
1977	3	4	4	4	4	4	1
1978	2	2	2	3	3	3	3
1979	1	2	1	1	1	1	
1980							
1981	2	2	3	1	1	1	1
1982							
1983	1	1	1	1	2	2	2
1984	2	2	2	2	2	2	2
1985	2	2	4	3	3	2	
1986	2	2	2	2	2	3	4
1987	2	2	2	2	2	2	
1988	1	1	1	1	1	1	
1989	3	3	3	3	3	3	2
1990	2	2	1	1	1	1	
1991	1	1	1	1	1	1	2
1992	2	2	2	2	2	1	1
1993	2	2	2	2	2	2	
1994	1	1	1	1	1	1	
1995	1	1	1	1	1	2	1
1996	1	1	1	1	1	1	2
1997							
1998			1	1	1		
1999							
2000	2	1	2	1	1	1	
2001	2	2	3	2	2	2	
2002							
2003							
2004	1	1	2	1	1	1	1
%yrs	80%	80%	83%	83%	83%	80%	49%

VHF Fresh event frequency

- No events
- 1 - 2 event (partial compliance)
- 3 events (compliance)
- >3 events (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	110	107	108	107	107	97	36
1965	18	18	16	13	13	8	
1966	20	14	16	14	12	7	
1967							
1968	49	49	47	47	45	44	36
1969	4	3	10	7	7	1	
1970	66	65	63	63	63	58	34
1971	125	120	119	116	112	110	21
1972	4	4	4	4	4	4	
1973	15	13	16	13	13	11	2
1974	35	35	33	30	27	18	4
1975	122	119	114	112	109	94	26
1976	57	54	54	52	52	45	13
1977	39	24	22	20	20	16	8
1978	116	110	106	96	88	79	22
1979	19	13	18	18	17	15	
1980							
1981	38	35	34	34	34	31	24
1982							
1983	132	125	124	120	101	100	82
1984	64	64	62	62	61	57	18
1985	7	3	7	7	6	4	
1986	94	91	84	79	77	34	10
1987	7	7	8	7	7	5	
1988	17	17	16	16	16	15	
1989	36	34	33	32	31	30	15
1990	24	21	25	23	19	17	
1991	51	46	48	46	41	37	12
1992	90	88	88	88	87	85	66
1993	6	6	6	6	6	5	
1994	5	4	5	5	5	4	
1995	29	26	26	26	25	16	12
1996	78	75	72	72	69	63	12
1997							
1998			1	1	1		
1999							
2000	10	3	8	7	7	6	
2001	22	21	20	19	19	12	
2002							
2003							
2004	70	66	64	64	63	59	21

VHF Fresh event max. duration

- No events
- 1 day (compliance)
- 2 - 3 days (compliance)
- >3 days (compliance)

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	0%	0%
1966		100%	100%	100%	100%	100%	0%
1967		100%	100%	100%	100%	100%	100%
1968		0%	100%	100%	100%	100%	0%
1969		100%	100%	100%	100%	100%	0%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	0%
1973		100%	100%	100%	100%	100%	0%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	0%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	0%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	0%	0%	0%	0%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	0%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	0%
1988		100%	100%	100%	100%	100%	0%
1989		100%	100%	100%	100%	100%	0%
1990		100%	0%	0%	0%	0%	0%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	0%	0%
1993		100%	100%	100%	100%	100%	0%
1994		100%	100%	100%	100%	100%	0%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		0%	100%	0%	0%	0%	0%
2001		100%	100%	100%	100%	100%	0%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		95%	98%	93%	93%	88%	54%

VHF Fresh occurrence (relative to U)

- Compliance
- Non-compliance

Figure 34. Pattern of frequency and duration of Very High Flow Freshes (≥401 ML/d) at Reach 4. Duration is maximum event duration for each year.

4.6.8 Bankfull

The Bankfull Flow component was defined in terms of magnitude (≥702 ML/d), duration and frequency. Recommended frequency of events was set at 2 in 3 years. The 2 in every 3 year frequency recommendation was not used as part of the compliance testing, although the period 1968 – 1997 clearly satisfied this requirement. The recommended minimum duration of events was set at 1 day, so this was not a determinant of compliance. Also, the maximum duration target of 2 months was not exceeded in any event, so this was not a determinant of compliance. Years were classed as compliant if at least one Bankfull event occurred in the same year as one or more events occurred in the Unimpaired scenario. This criterion resulted in a high level of compliance for all scenarios, except the future 2030 land use and dry climate scenario (Figure 27). The future With Weir scenarios had slightly more years with Bankfull events compared to the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface. Overall, long-term frequency of Bankfull was close to 2 in 3 for the scenarios (as recommended), except for the 2030 land use and dry climate scenario which had a frequency of 2 in 5 years. Bankfull events occurred regularly up to 1996.

	U	C	C.10	C.20	C.30	F.a	F.b
1964	3	3	3	3	3	3	2
1965							
1966							
1967							
1968	1	1	4	4	3	3	1
1969							
1970	2	2	3	3	3	1	2
1971	5	5	6	6	6	5	4
1972	1	1	2	2	2	2	
1973	1	1	2	2	2	1	1
1974	3	3	3	3	3	2	
1975	3	4	4	4	4	4	2
1976	2	2	3	3	3	2	1
1977	2	2	2	2	2	2	
1978	4	4	6	6	5	4	2
1979	2	2	2	2	2	2	
1980							
1981	1	1	1	1	1	1	1
1982							
1983	4	4	5	5	5	5	4
1984	1	1	1	1	1	1	1
1985			1	1	1		
1986	4	4	4	4	4	4	1
1987							
1988	1	1	1	1	1	1	
1989	2	2	3	2	2	2	1
1990	2	1	1	1	1		
1991	3	3	3	3	3	3	
1992	1	1	1	1	1	1	2
1993			1	1	1		
1994	1		1	1	1	1	
1995	1	1	1	1	1	1	
1996	2	2	3	3	3	2	1
1997							
1998							
1999							
2000							
2001	1	1	1	1	1		
2002							
2003							
2004	1	1	1	1	1	2	1
%yrs	63%	61%	68%	68%	68%	59%	39%

Bankfull event frequency
- 1 event per year
- 2 events per year
- >2 events per year

	U	C	C.10	C.20	C.30	F.a	F.b
1964	23	22	22	21	21	18	12
1965							
1966							
1967							
1968	30	30	9	8	11	8	6
1969							
1970	18	17	11	11	11	23	5
1971	12	11	10	10	10	10	5
1972	2	2	2	2	2	1	
1973	6	5	3	3	3	3	1
1974	4	3	6	5	5	3	
1975	23	16	16	15	15	13	10
1976	14	12	8	8	8	11	10
1977	7	7	7	7	7	5	
1978	11	11	7	7	8	8	11
1979	5	5	5	5	5	3	
1980							
1981	23	23	23	23	23	16	10
1982							
1983	16	15	12	12	12	10	9
1984	34	34	35	35	34	24	10
1985			1	1	1		
1986	11	10	10	10	10	8	1
1987							
1988	7	6	8	8	7	6	
1989	14	12	9	13	11	8	1
1990	2	2	7	7	6		
1991	9	8	8	8	8	5	
1992	65	65	66	65	64	53	8
1993			4	4	3		
1994	1		3	3	3	2	
1995	10	8	11	10	10	3	
1996	10	9	8	7	7	7	1
1997							
1998							
1999							
2000							
2001	4	3	4	2	2		
2002							
2003							
2004	25	21	18	14	12	2	1

Bankfull event duration
- 1 to 2 days
- 2 to 7 days
- >7 days

	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	0%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	0%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	0%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	0%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	0%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	0%	0%
1991		100%	100%	100%	100%	100%	0%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	100%	100%
1994		0%	100%	100%	100%	100%	0%
1995		100%	100%	100%	100%	100%	0%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	0%	0%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		98%	100%	100%	100%	95%	76%

Bankfull occurrence (relative to U)
- Compliance
- Non-compliance

Figure 35. Pattern of frequency and duration of Bankfull (702 ML/d) at Reach 4. Duration is mean duration for the events occurring in each year.

4.6.9 Overbank

The Overbank Flow component was defined in terms of magnitude (≥845 ML/d), duration and frequency. Recommended frequency of events was set at 1 in 3 years. The 1 in every 3 year frequency recommendation was not used as part of the compliance testing. The recommended minimum duration of events was set at 1 day, so this was not a determinant of compliance. Maximum seasonal duration was 60 days (equivalent to 33% of the time). Years were classed as compliant if at least one Overbank event occurred in the same year as one or more occurred in the Unimpaired scenario, and the total seasonal duration >845 ML/d did not exceed 33% of the time. The latter criterion was met in every year in every scenario. These criteria resulted in a high level of compliance for all scenarios except the 2030 land use and dry climate scenario (Figure 36). The future With Weir scenarios tended to have more events per year than the Unimpaired and Current scenarios. This is explained by the additional water contributed to Darlot Creek from direct rainfall on the lake surface. Overall, long-term frequency of Overbank was higher than the recommended target, being 1 in 1.6 to 1 in 2 years, and 1 in 3.4 for the 2030 land use and dry climate scenario. Overbank events occurred regularly up to 1996.

	U	C	C.10	C.20	C.30	F.a	F.b
1964	3	3	3	3	3	3	2
1965							
1966							
1967							
1968	1	1	3	3	3	1	1
1969							
1970	1	1	1	1	1	1	1
1971	5	5	5	5	5	5	3
1972			1	1	1		
1973	1	1	1	1	1	1	1
1974	1	1	2	2	2		
1975	4	4	5	5	5	5	2
1976	2	2	2	2	2	2	1
1977	2	1	2	2	2	1	
1978	2	2	4	4	3	2	2
1979	1	1	2	2	2	1	
1980							
1981	1	1	1	1	1	1	1
1982							
1983	3	3	5	5	5	4	3
1984	2	2	2	2	2	2	1
1985							
1986	4	4	4	4	4	4	
1987							
1988	1	1	1	1	1	1	
1989	2	1	2	2	2	2	
1990							
1991	2	2	2	2	2	1	
1992	1	1	1	1	1	1	2
1993							
1994			1	1	1		
1995	1	1	1	1	1		
1996	1	1	2	2	2	1	
1997							
1998							
1999							
2000							
2001	1	1	1	1	1		
2002							
2003							
2004	1		1	1	1	1	
%yrs	**56%**	**54%**	**61%**	**61%**	**61%**	**49%**	**29%**

Overbank event frequency
1 event per year
2 events per year
>2 events per year

	U	C	C.10	C.20	C.30	F.a	F.b
1964	16	15	17	16	15	11	10
1965							
1966							
1967							
1968	17	17	7	6	6	13	1
1969							
1970	22	22	22	22	22	17	6
1971	9	9	9	9	9	7	3
1972			1	1	1		
1973	3	2	3	3	3	2	1
1974	2	1	3	3	3		
1975	11	11	10	9	9	8	4
1976	11	11	11	11	10	10	9
1977	5	9	5	5	4	5	
1978	14	15	8	8	10	13	10
1979	2	1	3	3	3	2	
1980							
1981	14	13	13	13	13	11	8
1982							
1983	16	16	10	10	10	11	7
1984	10	10	11	10	9	8	4
1985							
1986	8	7	8	8	7	5	
1987							
1988	1	1	6	6	6	1	
1989	7	11	8	8	8	5	
1990							
1991	7	7	7	7	7	6	
1992	53	51	52	52	51	42	6
1993							
1994			2	2	2		
1995	1	1	2	2	2		
1996	9	8	5	5	5	3	
1997							
1998							
1999							
2000							
2001	1	1	3	1	1		
2002							
2003							
2004	1		5	5	5	3	

Overbank event duration
1 to 2 days
2 to 7 days
>7 days

	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	100%	100%	100%	100%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	100%	100%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	0%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	0%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	100%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	0%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	0%	0%
1987		100%	100%	100%	100%	100%	100%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	100%	100%
1994		100%	100%	100%	100%	100%	100%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	0%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	100%
2004		100%	100%	100%	100%	100%	100%
%yrs		**100%**	**100%**	**100%**	**100%**	**98%**	**88%**

Overbank occurrence (relative to U)
Compliance
Non-compliance

Figure 36. Pattern of frequency and duration of Overbank (845 ML/d) at Reach 4. Duration is mean duration for the events occurring in each year.

4.7 Site 5: Estuary of the Fitzroy River and Darlot Creek

Due to a lack of information on the hydrodynamics of the estuary, it was not possible to make specific recommendations for flow components. As an alternative, a risk assessment was undertaken to determine the relative risk posed to ecological assets by reductions in three key hydrological indices (Table 16). The time series of the estuary opening and flushing index is analysed below in more detail.

4.7.1 Potential mouth opening and flushing flow

The potential mouth opening and flushing flow component was defined as a peak flow of 1,000 ML/d for one day minimum, to open the estuary, followed by flows of 660 ML/d to maintain freshwater conditions. The distribution of opening-flushing events through time was examined for the Unimpaired, Current and the 5 future scenarios. Years were classed as compliant if at least one opening-flushing event occurred in the same year as one or more occurred in the Unimpaired scenario. This criterion resulted in a high level of compliance for all scenarios (Figure 37). Overall, long-term frequency of potential mouth opening and flushing was 80% of years. Duration of events was highly variable, but mean duration for each year was often longer than 30 days.

	U	C	C.10	C.20	C.30	F.a	F.b
1964	1	1	1	1	1	1	3
1965	2	2	2	2	2	2	1
1966	2	2	2	2	2	2	
1967							
1968	4	4	4	4	4	4	2
1969	1	1	1	1	1		
1970	1	1	1	1	1	1	2
1971	2	2	2	2	2	3	5
1972	2	2	3	3	3	2	2
1973	3	3	3	3	3	3	2
1974	2	2	2	2	2	2	2
1975					1		2
1976	3	3	3	3	3	3	2
1977	2	2	2	2	2	3	1
1978	2	2	3	3	3	4	2
1979	2	1	2	1	1	1	
1980			1				
1981	1	1	1	1	1	1	1
1982							
1983	2	2	3	3	3	3	2
1984	2	2	2	2	2	2	2
1985			1	1	1	1	
1986	2	2	2	2	2	3	4
1987	3	3	3	3	3	3	
1988	1	1	1	1	1	1	1
1989	3	3	3	3	3	3	1
1990	1	1	1	1	1	1	2
1991	2	2	2	2	2	1	1
1992	1	1	2	2	2	1	1
1993	1	1	1	1	1	1	
1994	1	1	1	1	1	1	
1995	1	1	1	1	1	1	1
1996	1	1	1	1	1	2	3
1997							
1998			1				
1999							
2000	2	3	3	3	3	3	1
2001	1	1	1	1	2	2	1
2002							
2003	1	1	2	2	2	1	
2004	1	1	1	1	1	1	2
%yrs	78%	78%	85%	80%	83%	78%	63%

Flushing event frequency
- 1 event per year
- 2 events per year
- >2 events per year

	U	C	C.10	C.20	C.30	F.a	F.b
1964	106	106	106	105	105	105	25
1965	23	19	23	19	19	19	2
1966	12	11	11	10	10	10	
1967							
1968	31	31	31	30	30	24	21
1969	4	3	12	12	12		
1970	79	79	78	78	77	77	25
1971	97	96	96	96	96	59	22
1972	7	7	5	5	5	7	3
1973	17	17	16	16	16	14	12
1974	32	33	32	32	32	31	10
1975					10		44
1976	76	75	76	75	69	73	15
1977	20	20	21	20	20	9	11
1978	49	49	33	33	33	19	14
1979	14	24	13	23	23	23	
1980			4				
1981	68	68	67	67	67	31	29
1982							
1983	60	54	37	36	36	35	48
1984	31	30	30	30	30	28	21
1985			4	3	3	3	
1986	66	66	65	65	65	29	11
1987	8	7	8	8	8	6	
1988	18	16	16	16	16	15	2
1989	21	20	20	20	20	18	20
1990	44	44	44	44	44	43	9
1991	30	30	30	30	30	56	37
1992	135	135	64	64	64	123	72
1993	5	5	5	5	5	4	
1994	6	6	6	6	6	5	
1995	31	31	30	30	30	30	11
1996	76	75	75	74	74	32	14
1997							
1998			3				
1999							
2000	18	7	6	6	6	5	2
2001	18	18	19	19	5	3	2
2002							
2003	4	3	3	3	3	2	
2004	93	93	91	86	86	83	11

Flushing event mean duration
- 1 to 30 days
- 30 to 60 days
- >60 days

	U	C	C.10	C.20	C.30	F.a	F.b
1964		100%	100%	100%	100%	100%	100%
1965		100%	100%	100%	100%	100%	100%
1966		100%	100%	100%	100%	100%	0%
1967		100%	100%	100%	100%	100%	100%
1968		100%	100%	100%	100%	100%	100%
1969		100%	100%	100%	100%	0%	0%
1970		100%	100%	100%	100%	100%	100%
1971		100%	100%	100%	100%	100%	100%
1972		100%	100%	100%	100%	100%	100%
1973		100%	100%	100%	100%	100%	100%
1974		100%	100%	100%	100%	100%	100%
1975		100%	100%	100%	100%	100%	100%
1976		100%	100%	100%	100%	100%	100%
1977		100%	100%	100%	100%	100%	100%
1978		100%	100%	100%	100%	100%	100%
1979		100%	100%	100%	100%	100%	0%
1980		100%	100%	100%	100%	100%	100%
1981		100%	100%	100%	100%	100%	100%
1982		100%	100%	100%	100%	100%	100%
1983		100%	100%	100%	100%	100%	100%
1984		100%	100%	100%	100%	100%	100%
1985		100%	100%	100%	100%	100%	100%
1986		100%	100%	100%	100%	100%	100%
1987		100%	100%	100%	100%	100%	0%
1988		100%	100%	100%	100%	100%	100%
1989		100%	100%	100%	100%	100%	100%
1990		100%	100%	100%	100%	100%	100%
1991		100%	100%	100%	100%	100%	100%
1992		100%	100%	100%	100%	100%	100%
1993		100%	100%	100%	100%	100%	0%
1994		100%	100%	100%	100%	100%	0%
1995		100%	100%	100%	100%	100%	100%
1996		100%	100%	100%	100%	100%	100%
1997		100%	100%	100%	100%	100%	100%
1998		100%	100%	100%	100%	100%	100%
1999		100%	100%	100%	100%	100%	100%
2000		100%	100%	100%	100%	100%	100%
2001		100%	100%	100%	100%	100%	100%
2002		100%	100%	100%	100%	100%	100%
2003		100%	100%	100%	100%	100%	0%
2004		100%	100%	100%	100%	100%	100%
%yrs		100%	100%	100%	100%	98%	83%

Flushing occurrence (relative to U)
- Compliance
- Non-compliance

Figure 37. Pattern of frequency and duration of potential estuary mouth opening and flushing events (1,000 ML/d peak followed by minimum flow of 660 ML/d) at Reach 5. Duration is mean duration for the events occurring in each year.

4.8 Impact of a weir at Lake Condah on frequency of freshes in the April – July period

The compliance testing revealed that, in general, winter events were more common under the future With Weir scenarios compared to the Current scenario. This is explained by direct rainfall on the lake water surface being transferred directly to outflows when the lake is full. This volume of water can be substantial under intense rainfall and high lake levels, such that over 100 ML of additional spill could be generated from the lake surface alone over a day of 50 mm rainfall (Figure 38). The highest daily rainfall at Lake Condah between 1964 and 2004 was 72 mm.

Under the future With Weir scenarios the lake water surface is usually much larger compared to the Unimpaired and Current (no weir) scenarios, so there is a higher direct contribution. Under the Current (no weir) scenario, with the rain usually falling on the dry lake bed, a smaller proportion of the rain is transferred to runoff (Figure 39). The Lake Condah water balance model uses the entire surface area of Lake Condah and Condah swamp to calculate local surface runoff. The difference between the no weir and With Weir scenarios in volume of water generated in this manner can be up to 700 ML/d, but was often in the order of 50 – 100 ML/d (Figure 39). These contributions are attenuated by the lake, but still manifest as higher peaks in freshes and floods downstream of Lake Condah under the future With Weir scenario compared to the Current (no weir) scenario. Under the future With Weir scenario, the larger lake surface area gives rise to higher evaporation and seepage losses (Figure 39), so over the entire year, under the future With Weir scenario there is more water lost at Lake Condah compared with the Current (no weir) scenario.

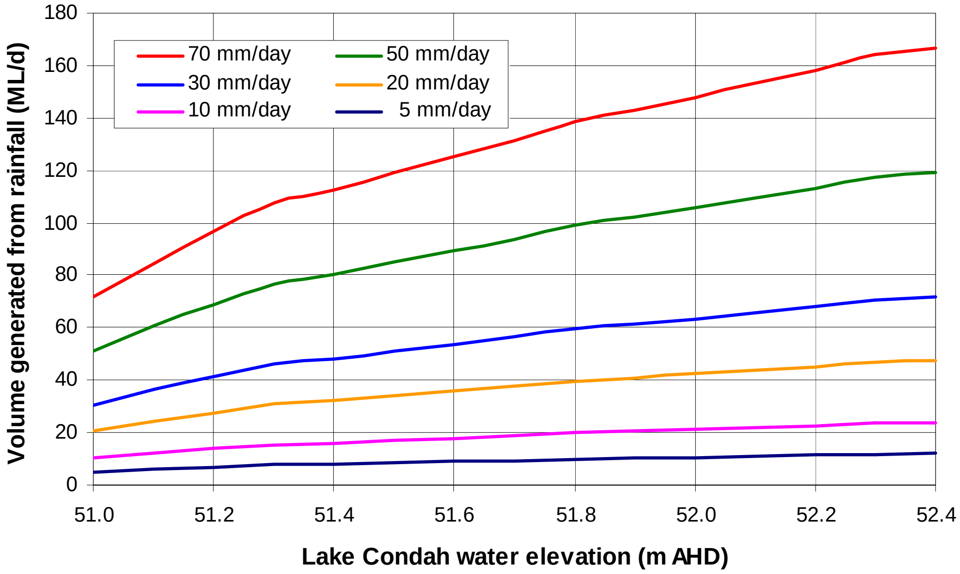


Figure 38. Model of volume of water generated by rainfall on the lake surface as a function of the lake water level (surface area increases with level) and rainfall intensity.

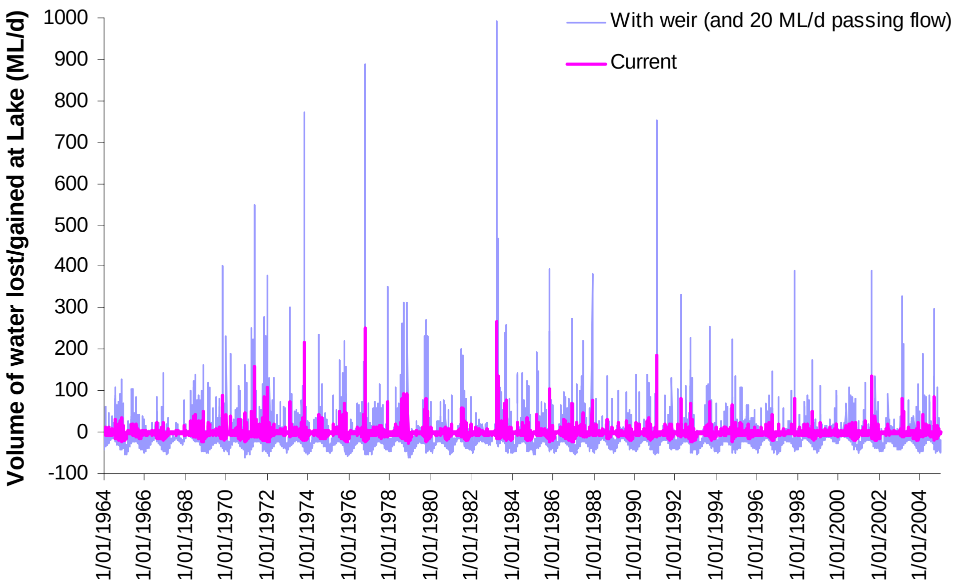


Figure 39. Modelled time series of volume of water lost/gained (due to direct rainfall, evaporation, local runoff from the dry part of the lake bed and Condah Swamp, and seepage) to Darlot Creek at Lake Condah from 1964-2004. The scenarios are Current (no weir) and With Weir at 52.4 mAHD and with a 20 ML/d passing flow.

The volume of the passing flow has an impact on the volume of water gained by direct rainfall on the lake and lost through evaporation and seepage, as the passing flow affects the lake surface area. The lower the passing flow, the higher the lake levels tends to be, so the lower the passing flow the greater the winter gains through direct rainfall, and the higher the summer losses due to evaporation. The difference in the volume gained at the lake, between the 10 ML/d and 30 ML/d passing flow options, was generally less than 40 ML/d, but was 115 ML/d on a day of intense rainfall in August 2001 (Figure

40). The difference between these options in the volume lost at the lake through evaporation and seepage was up to 40 ML/d, with the highest losses tending to occur in summer (Figure 40). Overall, this process leads to a higher probability of winter lake spills under the 10 ML/d passing flow option compared to the 30 ML/d passing flow option.

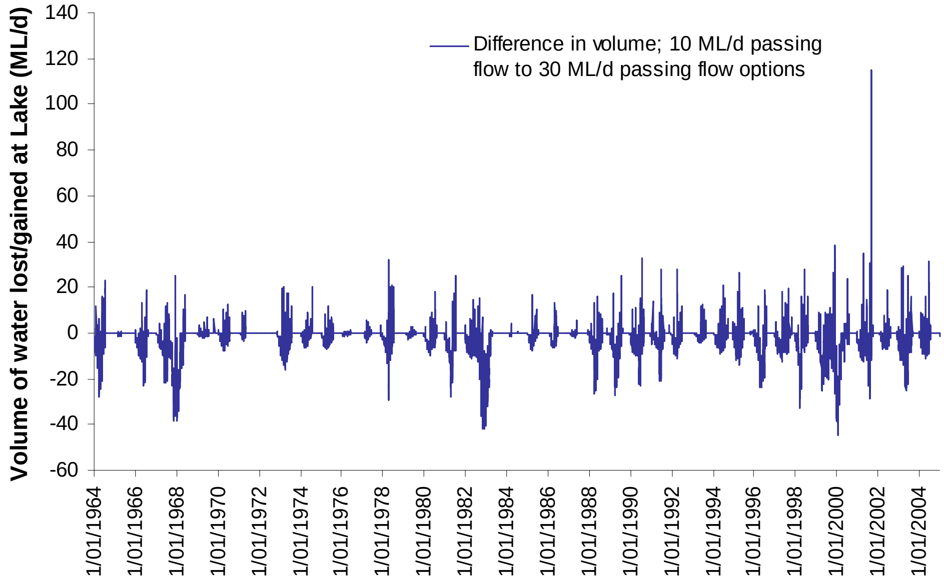


Figure 40. Modelled time series of difference in volume of water lost/gained (due to direct rainfall, evaporation, local runoff from the dry part of the lake bed and Condah Swamp, and seepage) to Darlot Creek at Lake Condah, 10 ML/d passing flow compared to 30 ML/d passing flow.

A weir at Lake Condah creates a lake with a variable water level. The level tends to be high in winter/spring, and lower through seepage evaporation (and lower inflows) during summer/autumn. When the lake level falls below the crest it has “air space” available to absorb incoming freshes. This effect would be most likely at the end of the FLOWS summer season (i.e. April-May) and the beginning of the FLOWS winter season (i.e. June-July). While the compliance testing did show a reduced occurrence of Low Flow Freshes at Reach 3 (Wylies Rd) and Reach 4 (IPA) under the With Weir scenarios, the effect of the lake absorbing freshes was not fully revealed by this analysis as it included the early summer season when the lake was often full.

An analysis was undertaken to investigate the capacity of the lake (with weir) to absorb freshes, by focusing on the months April to July inclusive, when the lake level was most likely to be low. This period crosses the boundary of the FLOWS summer and winter periods. Flows exceeding the magnitudes of FLOWS fresh components were extracted from the time series’. For April and May the Low Flow Fresh threshold was used, and for June and July the High Flow Fresh was used (Table 22). For each time series, the total number of the specified events occurring in the defined period (April – July) was counted.

Table 22.
FLOWS component thresholds used in analysis of the effect of Lake Condah on frequency of freshes in the period April to July.

Reach	April-May		June-July	
	Threshold (ML/d)	Component	Threshold (ML/d)	Component
Reach 2	66	Reach 3 LFF-1†	288	HFF
Reach 3	97	LFF-2	240	HFF-2
Reach 4	108	LFF-2	401	VHFF
Reach 5	1,000	Mouth opening¥	1,000	Mouth opening

† No Low Flow Fresh was specified for Reach 2, so the LFF-1 specified for Reach 3 was used.
¥ No hydraulic analysis was undertaken for Reach 5 (so no FLOWS components were recommended), so the potential mouth opening threshold was used for both April-May and June-July

The analysis indicated that there were generally slightly fewer events in the Current compared to the Unimpaired scenario; this was due to less overall water in the system in the Current scenario (Figure 41). There were more events in the With Weir and 10 ML/d passing flow scenario than the current and Unimpaired scenarios; this is explained by the effect of the lake contributing additional water to Darlot Creek from direct rainfall on the lake surface. For the 10 ML/d passing flow scenario this effect overrode the effect of the lake absorbing freshes (the lake level tended to be higher for longer under the 10 ML/d passing flow option) (Figure 41). The number of freshes was less under the 20 ML/d passing flow option, and less still under the 30 ML/d option. The 20 ML/d passing flow option produced a frequency of events similar to the Unimpaired and Current scenarios. As expected, the 2030 land use and the 2030 land use and dry climate scenarios led to further reductions in frequency of freshes in this period (Figure 41). The effect of the lake absorbing freshes was apparent in reaches 2, 3 and 4, but not in Reach 5 (Figure 41), which is most distant from Lake Condah and is influenced by inflows from the Fitzroy River.

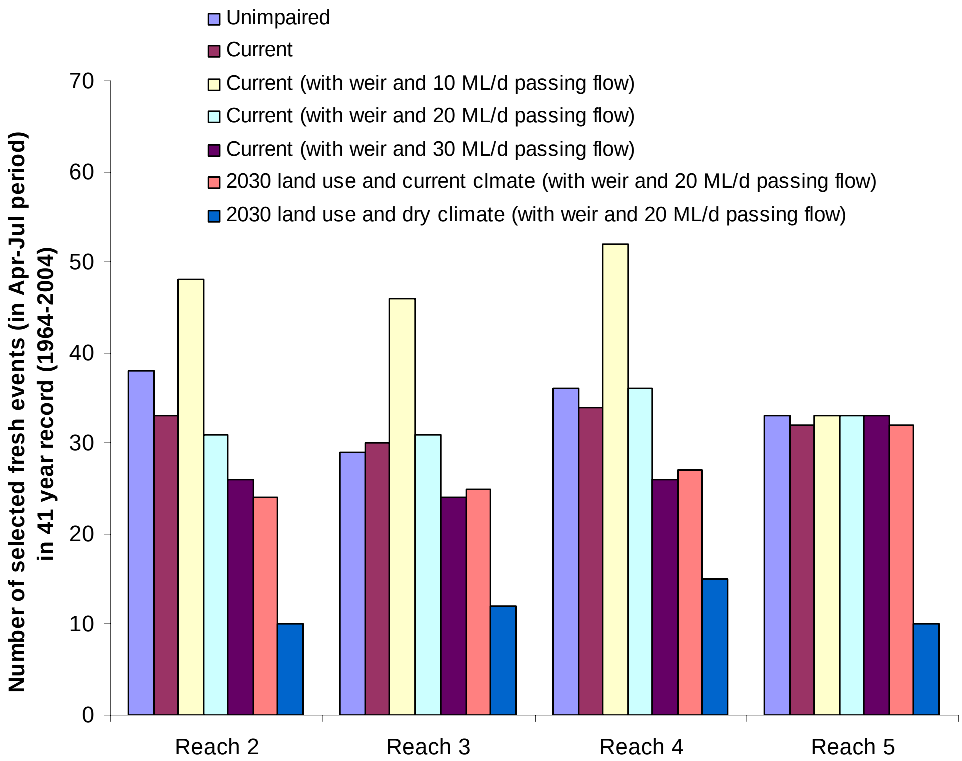


Figure 41. Frequency (number of events over 41 year time series) of selected FLOWS components (Freshes) in the period April to July when the lake level is more likely to be low.

The Lake Condah water balance model contains two main assumptions regarding contributions from local runoff. The first assumption is that the local contributing area includes Condah Swamp, as well as the dry parts of Lake Condah. The second assumption concerns the runoff ratio; the model has a variable runoff ratio with a higher percentage of rainfall becoming runoff under higher rainfall intensities. For example, for 30 mm per day rainfall the ratio is 0.25, and for 10 mm per day rainfall the ratio is 0.08. This is an oversimplification of reality, but given the available knowledge, there was no point in attempting to make this part of the model more sophisticated. However, it is possible that the model over-estimates the impact of local rainfall and runoff, which would lead to an over-estimate of the enhancement of the freshes leaving the lake. Regardless, the pattern of more freshes being created by the 10 ML/d passing flow option compared to the 30 ML/d passing flow option (Figure 41) would still hold.

4.9 Summary of compliance

The compliance data for the various FLOWS components were compiled and classified from very high risk (complies <25% of years) to low risk (complies >75% of years) (Table 23). For Lake Condah the compliance was not expressed against that of a benchmark scenario; rather it was based on the number of years on record when the lake achieved target durations at certain lake levels (corresponding to plant association zones) (Table 23). For each scenario, the number of flow components in the low risk category was expressed as a percentage of all components and the scenarios were ranked for each season on that basis (Table 23).

It is clear that from the perspective of lowering risks to ecological degradation (and enhancing rehabilitation potential), for both Lake Condah and Darlot Creek, the two preferred scenarios were with a weir at Lake Condah and a passing flow of 10 ML/d or 20 ML/d. The 10 ML/d passing flow was marginally lower risk than the 20 ML/d passing flow (Table 23). The Current scenario also ranked highly (for low risk) for Darlot Creek, but it was high risk for Lake Condah (Table 23). These findings are consistent with ecological observations that Lake Condah is currently in relatively poor health while Darlot Creek is currently in relatively good health.

Examination of the modelled Darlot Creek flow series revealed that under normal steady summer conditions a 10 ML/d passing flow at Lake Condah (with a 52.4 mAHD weir in place) is associated with a minimum flow of 15 - 20 ML/d at the IPA, and a 20 ML/d passing flow is associated with a minimum flow of 25 - 30 ML/d at the IPA. On this basis, a 20 ML/d passing flow has an advantage over the 10 ML/d option in offering a lower risk of not meeting the Low Flow environmental flow requirement at the Reach 4 IPA site (i.e. >26 ML/d).

The 10 ML/d passing flow offers the lowest risk to Lake Condah, as it maintains water levels for longer, which is one of the goals of hydrological rehabilitation. Holding the lake close to full supply level for longer also helps maintain conditions in Darlot Creek, as the lake more readily spills. The 30 ML/d passing flow probably presents too much risk, as it draws the lake down faster, creating air space that can trap freshes. **The 20 ML/d passing flow offers low environmental risk to the lake and creek and has the advantage of more often meeting the Low Flow requirement of Reach 4, so is the recommended passing flow option.**

Future land use and climate change will cause large hydrological changes at Lake Condah and in Darlot Creek. The Dry climate plus predicted 2030 land use change scenario in particular will lead to lower and more variable lake levels and less frequent freshes and lower baseflows in Darlot Creek. The land use change and climate change impacts on the lake and creek are independent of the effects of constructing a weir at Lake Condah. A weir at Lake Condah on its own presents low risk to Darlot Creek and the Fitzroy estuary, while it has the potential to create large benefits at Lake Condah.

Table 23.
Summary of compliance of FLOWS components for Lake Condah and Darlot Creek. Risk categories are risk to maintenance of aspects of lake and creek ecological health related to the flow components.

Reach 1: Lake Condah	Summer							Winter						
Component	U	C	C10	C20	C30	F.a	F.b	U	C	C10	C20	C30	F.a	F.b
Fish passage to lake														
Percent of time	10%	5%	51%	44%	32%	29%	19%	76%	71%	95%	93%	93%	93%	76%
Event frequency	34%	34%	93%	88%	76%	83%	44%	85%	85%	95%	93%	93%	93%	83%
Event duration	29%	29%	88%	83%	71%	76%	39%	85%	5%	95%	93%	93%	93%	83%
Avoidance of lake drying														
Duration	0%	0%	90%	85%	63%	76%	27%	7%	7%	100%	98%	68%	88%	49%
Open water zone														
Duration	0%	0%	93%	78%	56%	73%	27%	0%	0%	98%	76%	61%	63%	27%
Submerged aquatic plant zone														
Duration	0%	0%	88%	61%	49%	56%	17%	0%	0%	95%	71%	61%	66%	22%
Reed zone														
Duration	100%	100%	66%	76%	90%	90%	98%	0%	0%	90%	83%	63%	73%	22%
Silky Tea Tree zone														
Duration								0%	0%	80%	80%	80%	71%	37%
Percentage of components low risk (>75% compliance)	14%	14%	71%	71%	29%	57%	14%	38%	13%	100%	88%	50%	50%	38%
Rank for low risk			1	2		3				1	2	3		

Reach 2: D/S of Lake Condah	Summer							Winter						
Component	U	C	C10	C20	C30	F.a	F.b	U	C	C10	C20	C30	F.a	F.b
Cease To Flow	Benchmark	95%	100%	95%	95%	93%	88%	Benchmark	100%	100%	100%	100%	100%	100%
Summer Low Flow		95%	100%	100%	95%	98%	88%							
Low Flow Fresh		100%	100%	100%	100%	100%	100%							
Winter High Flow									100%	100%	100%	100%	100%	98%
High Flow Fresh									88%	100%	98%	98%	98%	61%
Percentage of components low risk (>75% compliance)		100%	100%	100%	100%	100%	100%		100%	100%	100%	100%	100%	67%
Rank for low risk			1	2	3					1	2	2		

Reach 3: Wylies Road	Summer							Winter						
Component	U	C	C10	C20	C30	F.a	F.b	U	C	C10	C20	C30	F.a	F.b
Cease To Flow	Benchmark	95%	100%	98%	95%	95%	88%	Benchmark	100%	100%	100%	100%	100%	100%
Summer Low Flow		95%	100%	100%	98%	98%	93%							
Low Flow Fresh - 1		71%	73%	54%	46%	46%	24%							
Low Flow Fresh - 2		90%	98%	90%	88%	88%	73%							
Low Flow Fresh - 3		98%	98%	95%	88%	90%	80%							
Winter High Flow									78%	83%	56%	44%	44%	15%
High Flow Fresh - 1									95%	100%	100%	100%	95%	54%
High Flow Fresh - 2									93%	93%	95%	93%	98%	46%
Bankfull (calc. entire year)									100%	100%	100%	100%	98%	88%
Overbank (calc. entire year)									100%	100%	100%	100%	98%	78%
Percentage of components low risk (>75% compliance)		80%	80%	80%	80%	80%	60%		100%	100%	83%	83%	83%	50%
Rank for low risk			1	2	3				2	1	3			

Reach 4: IPA	Summer							Winter						
Component	U	C	C10	C20	C30	F.a	F.b	U	C	C10	C20	C30	F.a	F.b
Cease To Flow	Benchmark	100%	100%	100%	100%	100%	88%	Benchmark	100%	100%	100%	100%	100%	100%
Summer Low Flow		78%	100%	100%	95%	98%	41%							
Low Flow Fresh - 1		85%	95%	88%	90%	85%	83%							
Low Flow Fresh - 2		100%	98%	93%	93%	90%	85%							
Winter High Flow									73%	71%	44%	46%	32%	15%
High Flow Fresh									93%	100%	93%	93%	88%	80%
Very High Flow Fresh									95%	98%	93%	93%	88%	54%
Bankfull (calc. entire year)									98%	100%	100%	100%	95%	76%
Overbank (calc. entire year)									100%	100%	100%	100%	98%	88%
Percentage of components low risk (>75% compliance)		100%	100%	100%	100%	100%	75%		83%	83%	83%	83%	83%	67%
Rank for low risk			1	2	3				2	1	3			

Very high risk: 0 - 25% compliance
High risk: 25 - 50% compliance
Moderate risk: 50 - 75% compliance
Low risk: 75 - 100% compliance

4.10 Implementation of flow recommendations

The flow recommendations made by the Panel are based on the minimum requirements to achieve a healthy ecosystem, with the recommendations being somewhat ideal in two respects:

1. The specified minimum frequencies and durations are for average hydrological conditions, and these frequencies and durations would not necessarily be expected in drought years.
2. Most of the flow components address the needs of multiple objectives, with the final recommendations based on satisfying the magnitude requirement of the objective with the highest flow magnitude requirement. Frequency and duration are specified following a similar philosophy. In other words, satisfying the neediest objective will ensure that the rest are satisfied.

This means that not providing the flow recommendations strictly as specified in dry years will not necessarily pose a major threat to long-term stream health. That issue aside, there is a need to devise a way of implementing the flow recommendations. For sites located immediately downstream of dams this appears at first glance to be a relatively straightforward exercise, as a dam allows a high degree of control over the downstream flows. In these cases it is customary in FLOWS studies to specify baseflows as a lower threshold with an "or natural" clause (i.e. if the flows would naturally be below the threshold, then they can fall below threshold). The "or natural" refers to the unimpaired flow, which in the case of a site immediately downstream of a dam with no development in the catchment, is the dam inflows. In all other locations it is difficult to implement the "or natural" rule unless there is a real time model of unimpaired flows for each FLOWS site. FLOWS studies can also specify Freshes with an "or natural" rule, meaning that the Fresh must meet the magnitude threshold, but can be of a lower duration, equivalent to the duration of the event under unimpaired conditions. A major problem with implementing Fresh recommendations (which also applies to Bankfull and Overbank components) is that a river operator cannot not know if a particular event will reach the flow threshold until the event is over, so as they observe a flow event rising they would not know whether to allow the event to pass through the dam or not. It may be possible to overcome this problem by developing predictive relationships based on catchment rainfall and/or flows at upstream gauges, so that operators would have some notice regarding whether or not a fresh should be allowed through a dam. At sites distant from dams, implementation of Fresh recommendations will be even more problematic. It is important to release a controlled Fresh at the time it is naturally occurring, rather than store it in a dam and release it with a delay, or at some other time. The reason for this is that as the Fresh travels downstream, under natural event conditions there is a high likelihood that the flow will be augmented by inflows from tributaries, building the magnitude of the Fresh to the level required at downstream locations.

In the case of Darlot Creek there is no dam to control flows, but under the Current scenario the baseflows flows can be partly controlled through the restrictions and roster system for diversions upstream of Lake Condah. Currently the compliance point is Darlot Creek @ Homerton gauge, where 30 ML/d is the trigger point for starting the restrictions. There is no control possible over Bankfull or Overbank flows, and control of Freshes (exercised by controlling the boards in the diversion weirs) would be difficult and only partial. Given the lack of knowledge of real time unimpaired flows in the system, this FLOWS study did not include the "or natural" clause, because such a clause could not be utilized in implementation of the recommendations. In the Darlot Creek system, for baseflows, all that can be done is to monitor flows at gauges, and if flow falls below the recommended thresholds (adjusted for difference in location of the gauge and the FLOWS site) then a restrictions and roster system on upstream diversions should be initiated. If development of farm dams and water resource extraction (i.e. plantation forestry, stock and domestic, winterfill dams, and other abstractions) continues in the catchment upstream of Lake Condah the result will be increasing periods of time when flow falls below threshold (as was demonstrated by the compliance testing in this report). Under the current system, little can be done to manage Freshes, but the distribution of Freshes currently shows a high degree of compliance with the Unimpaired scenario (Table 23), so at the present time they do not require to be controlled.

If a weir is constructed at Lake Condah, an opportunity will exist for controlling flows in order to meet the environmental flow recommendations made for Darlot Creek. However, this opportunity is likely to be very limited, as the current proposal is for a simple structure with no control valves, gates or boards. The only control can be exerted through the outlet pipe, and this is likely to be of a fixed capacity (i.e. fixed after initial adjustment). The Lake Condah Facilitation Group has given the design issue considerable thought, and the group has good reasons for recommending a relatively simple structure.

One critical issue for implementation of the recommended environmental flows that will impact on weir design is the need to satisfy baseflow requirements. In winter this is not a major issue, because the lake will most often be full and spilling so the outflows will equal the inflows (minus seepage loss). If inflows fall below the capacity of the passing flow pipe, then provided seepage is not excessive, outflows will usually be higher than the inflows (so downstream of the lake, baseflows will be more favourable than they would be with no weir). There will be a period of time in early winter when the lake is filling when outflows from the lake will be lower than inflows. In summer, inflows will usually fall below the combined losses from the passing flow pipe and seepage, so the lake will often be below the crest. In this case outflows will be set by the capacity of the passing flow pipe and baseflows will usually be more favourable than they would be with no weir. This explains why the summer Low Flow components show high compliance under the With Weir scenarios (Table 23). Most of the time, the critical limitation on meeting the Low Flow requirements in Darlot Creek is the recommendation for Reach 4 (IPA). This can be achieved with a low risk by the 20 ML/d passing flow option.

With a weir in place, the current system of restrictions and rostering can continue to operate. A conservative approach would be to retain the current trigger level of 30 ML/d at Homerton gauge, but in the long term it may be possible to reduce this to 25 ML/d and still meet the environmental flow recommendations specified in this report.

Monitoring compliance of the FLOWS recommendations would be improved by installation of a gauge downstream of Lake Condah and reactivation of the water level gauge in Lake Condah. These gauges would complement the gauge at Myamyn and Homerton to provide a fairly complete picture of inflows and outflows, and lake seepage losses, and these gauges could be used to monitor the recommendations made for the FLOWS sites (by factoring the recommended flow thresholds). Also the water balance of Lake Condah could be refined with this gauge information.

5 Condah Weir Design Considerations

5.1 Passing flow release from weir

The design concept for a weir at Lake Condah includes a passing flow to allow water to flow from the lake at times when the lake is lower than the full supply level. This flow is required to meet ecological requirements in Darlot Creek and also to satisfy the requirements of licenced diversions.

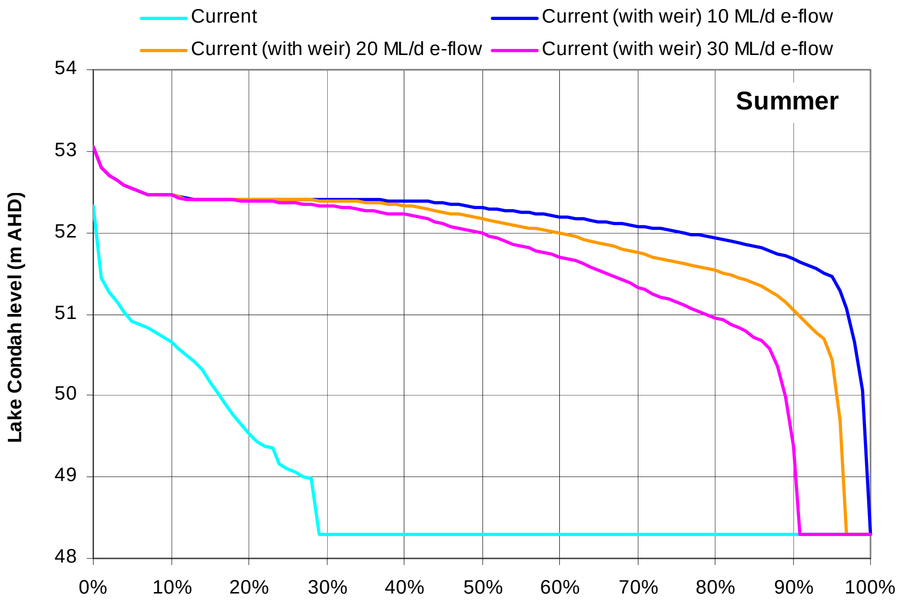
The effect of increasing the passing flow is to reduce lake levels (Figure 42). For a passing flow of 10 ML/d the lake is >51 mAHD for 100% of the time in winter and 98% of the time in summer; for a passing flow of 30 ML/d the lake is >51 mAHD for 88% of the time in winter and 79% of the time in summer (Figure 42). The most marked effect of increasing the passing flow is to reduce the length of time that fish passage is open (Table 23).

Lake Condah develops a more strongly seasonal water level cycle as the passing flow increases from 10 ML/d to 30 ML/d. A more strongly seasonal water regime will promote a more diverse aquatic plant community and will increase overall lake productivity by promoting the mineralisation of organic matter when exposed areas of the lake are re-flooded. Many of the conservation values associated with the lake under natural conditions (Gippel et al., 2008b) depend on a seasonal water level regime. However a seasonal cycle with a high amplitude introduces risks to eel and waterbird habitat, even though both of these values require a productive lake and diverse plant communities. Overall, compliance testing of the lake FLOWS components (which are grounded in ecological objectives) suggested that the 10 ML/d option was slightly superior to the 20 ML/d option (Table 23).

The volume of the passing flow made a significant difference to the flow duration curves for Darlot Creek downstream of Lake Condah (Sites 2 and 3) (Gippel et al., 2008b). The weir with passing flow tends to extend the baseflow period compared to current by releasing stored water during spring and summer. The lower is the passing flow the longer is this effect, but the lower are the flows in the creek. Overall, with the weir and passing flow in place, summer baseflows are higher for longer at Sites 3, 4 and 5. For example, at Site 4 (at the IPA, downstream of Homerton), under current conditions summer flows exceed 50 ML/d for 63% of the time, while with a weir and a 20 ML/d passing flow in place, this flow is exceeded for 73% of the time. Compliance testing of the Darlot Creek FLOWS components consistently showed the 10 ML/d passing flow to be preferable over the 20 ML/d and 30 ML/d options (Table 23).

The relative difference in the duration curves between Current and future scenarios was more marked for water level at Lake Condah than for discharge at Darlot Creek. In winter, the difference between the flow duration curves in Darlot Creek was less marked, but the marked difference between the Lake Condah water level duration curves remained stark. This was reflected in the results of the compliance testing, with the current flow regime presenting a high risk to the lake, but a low risk to the creek, while the future scenarios with a weir at Lake Condah presented a low risk to both lake and creek (Table 23). Of the three passing flow options tested, the 10 ML/d option offered the lowest overall risk to the health of the lake and creek, but the 20 ML/d option is also low risk; the 30 ML/d option significantly increases the risk level for the lake, and also increases risk for a few flow components in Darlot Creek (Table 23).

The 30 ML/d passing flow option is not recommended, but the 10 ML/d and 20 ML/d options are acceptable.



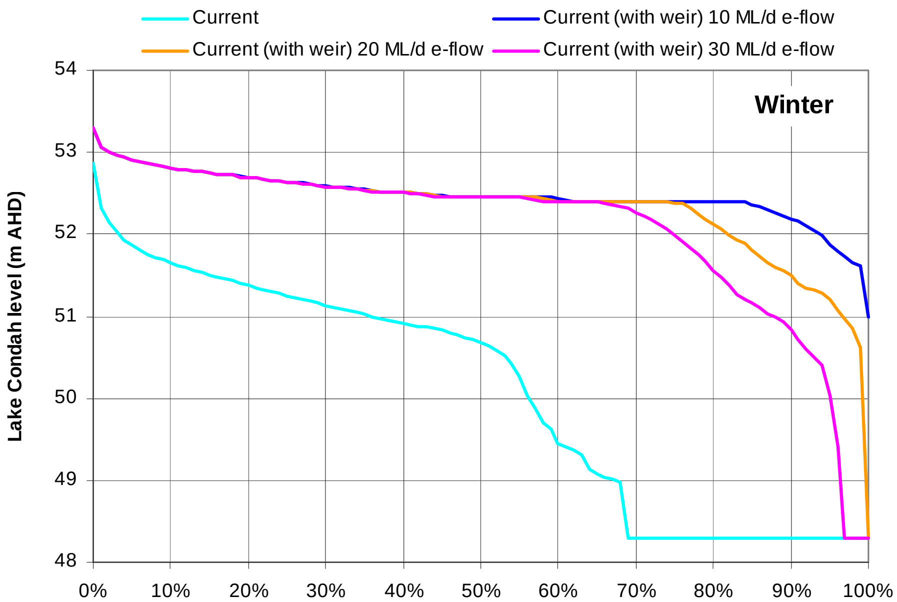


Figure 42. Summer (Dec – May) and winter (Jun – Nov) water level duration curves for Lake Condah for for three passing flow scenarios (With Weir) compared with Current scenario. X-axis is percent of time level is exceeded.

5.2 Weir height

The level of the weir will affect the water regime of the lake. The higher the weir crest, the closer the water regime will be to the pre-drain natural regime (Gippel et al, 2006). However, the higher the crest, the greater the impact on flows to Darlot Creek downstream, as the lake will have a greater potential to absorb inflowing freshes. A higher crest will maintain lake levels longer, but will also result in shorter and less frequent periods of spill and shorter and less frequent periods when the fish passage is active.

After consideration of a range of factors, Gippel et al. (2006) recommended a weir crest height of 52.4 m. This aligns with previous recommendations made in respect to potential weir height. A weir of 52.4 m is a good balance between the need to: maintain generally high water levels in the Lake for ecological restoration (i.e. provide fish habitat and conditions suitable for wetland vegetation); activate existing eel trap systems; maintain a large surface area of inundated Lake bed; provide seasonal spills over the crest to Darlot Creek (also allowing open fish passage); and minimize the impact on uncontrolled flooding of Condah Swamp. It was also suggested that after the weir has been constructed that the performance of the weir in achieving the objectives for Lake Condah be periodically reviewed (say every 5 to 10 years), and the desirability, or otherwise, of raising the weir crest height be reviewed.

The compliance testing undertaken here of the future scenarios based on the proposed weir height of 52.4 m AHD indicated that, compared to the Unimpaired and Current scenarios, this option did not present significant risks to the Darlot Creek ecosystem downstream of the lake, and significantly lowered the risks at the lake itself.

5.3 Fish passage

Fish will require to pass the proposed Lake Condah weir, both upstream and downstream, to complete their life cycles and allow fish access to Lake Condah and the downstream reaches.

Eels require downstream migration in summer and autumn to reach the sea to breed and young eels return upstream during spring and summer to allow eels to colonise freshwater habitats and, in particular, a hydrologically restored Lake Condah, for growth and survival. Without upstream and downstream access, an eel fishery in the Lake will not be possible.

Other migratory fish species such as Congolli (tupong) and galaxiids are common above the weir and therefore also require access to the estuary to breed and freshwater habitats for their juveniles to grow and mature. These fish require to migrate downstream in autumn and return in spring and early summer. Most other fish species would be opportunistic about movement requirements past any structure built to create Lake conditions in Lake Condah.

Under a rehabilitated Lake Condah situation, the weir wall would not be the only potential barrier to fish reaching the lake from the sea, and moving from the lake to the sea. There are two other known potential barriers: the mouth of the estuary and the natural rock barrier near Condah Mission (there would undoubtedly be other smaller barriers present, and perhaps some other large barriers of which the Panel was unaware). A preliminary assessment of the hydraulics of the rock barrier suggested that passage is available in summer in only around 30% of years for the Current scenario, and also for a future scenario with a weir at Lake Condah. Passage was available in 85% of years in winter, but the duration of passage each year was variable, from just 2 days to 4 months. A preliminary assessment of the estuary mouth suggested that hydrologic conditions with the potential to open the mouth occur in around 80% of years (vast majority occurring in winter). For a weir at 52.4 m and a 10 ML/d passing flow, it was estimated that water will flow over the weir (i.e. allowing for fish passage) in over 90% of years in both summer and winter, with the duration of winter events usually exceeding 4 months (a 20 ML/d passing flow provides similar frequency of passage). Thus, fish passage will be more limited by the estuary mouth and the natural rock barrier at Condah Mission than by the weir at Lake Condah.

General Lake Condah weir fishway design requirements include:

- allowing passage for periods of several days to a few weeks in most years in autumn and spring as a minimum, and preferably for longer periods and in all years (the latter being impossible to achieve due to the reality of drought years occurring);
- a low slope fish passage channel (about 1:20) across the face of the weir;
- the channel would have a roughened surface perhaps with rocks placed along its path to create resting locations and slow flow areas;
- the flow in the channel would be less than 0.5 m/s for most of the time;
- an entrance slot to the fish passage channel is required to be at least 30 cm deep and baffled to prevent high velocities through the slot and to regulate water leaving the lake; and,

- in high flows, the grouted-rock face of the structure would act as a rock-ramp fishway and allow both upstream and downstream movement of eels (and other fish) as well as delivery of water downstream.

Fishway design to suit eels at Lake Condah was discussed in a preliminary way by McKinnon (2007b). It was suggested that a ramp and substrate style fishway was the most suitable design, but it was also noted that eels can use pipes (through weir walls) that are below the water level of the impoundment, preferably with a rough substrate on the pipe. McKinnon (2007).

5.4 Non-ecological issues for weir design

FLOWS studies are concerned only with ecological/geomorphological aspects of flows – the recommendations are based on satisfying the ecological objectives for the waterway. Of course, river management is concerned with other cultural, social, legal and economic issues as well, such as minimizing inconvenience flooding of private land, and providing sufficient water for licenced diverters to extract their allocations at suitable times. In the case of Lake Condah there are cultural requirements, such as providing a lake and creek hydrological and ecological environment that will enable rehabilitation of the traditional eel aquaculture. This FLOWS study did not address any of these issues in detail, but some brief discussion is possible on the basis of information generated by the study.

5.4.1 Frequency and duration of inundation of private land near the Fitzroy estuary

The historical frequency and duration of inundation of private land near the Fitzroy estuary is undocumented. No hydraulic modelling has ever been undertaken on the Fitzroy estuary so it is not possible to model the frequency and duration of inundation of private land under Current or future scenarios.

The issue of inundation of private land near the estuary relates to mouth closing. When the mouth is closed and a significant flow event occurs, then there is an increased likelihood of flooding. The dynamics of mouth closure and opening are complex, and several factors additional to freshwater inflows are involved. Modelling undertaken for this study demonstrated that the frequency of flow events with the potential to open the mouth and flush the estuary is unchanged by the presence of a weir at Lake Condah. Thus, it can be concluded that a weir at Lake Condah will not impact on the frequency and duration of inundation of private land in the vicinity of the Fitzroy estuary.

5.4.2 Frequency and duration of inundation of private land on the bed of Lake Condah

The northwestern corner of Lake Condah lies on privately owned land – T.A.H. Morton, Block 4[D] (Figure 43). Although there are areas as low as 50.8 mAHD on the property, a sill prevents entry of water until the Lake level reaches 51.1 mAHD. The area of land inundated varies according to the Lake level, with a predicted maximum being 41 ha at the assumed 1946 flood (largest post-European settlement flood) level of 55 mAHD (Table 24 and Figure 44). The total area of the property was measured from the Cadastral Plan to be 98 ha (Note: this is approximate – the true area can only be measured by a registered surveyor through field survey).

The duration of inundation of the private land was calculated from the modelled Lake Condah water level time series' (Figure 45). Under the 52.4 m weir situation 22 ha will be inundated for 50% of the time, regardless of passing flow; with a 20 ML/d passing flow, at least some private land is inundated for 93% of the time; 30 ha or greater is inundated for <1% of the time. The 2030 land use and the 2030 land use and dry climate scenarios reduce the duration of inundation of private land. The 1 in 1 year inundation event is currently 12 ha, and under a 52.4 m weir (20 ML/d passing flow) scenario with increases to 25 ha (Figure 46). Under the 2030 land use and 2030 land use and dry climate scenario this reduces to 23 ha. Less frequent events involve inundation of larger areas of land.

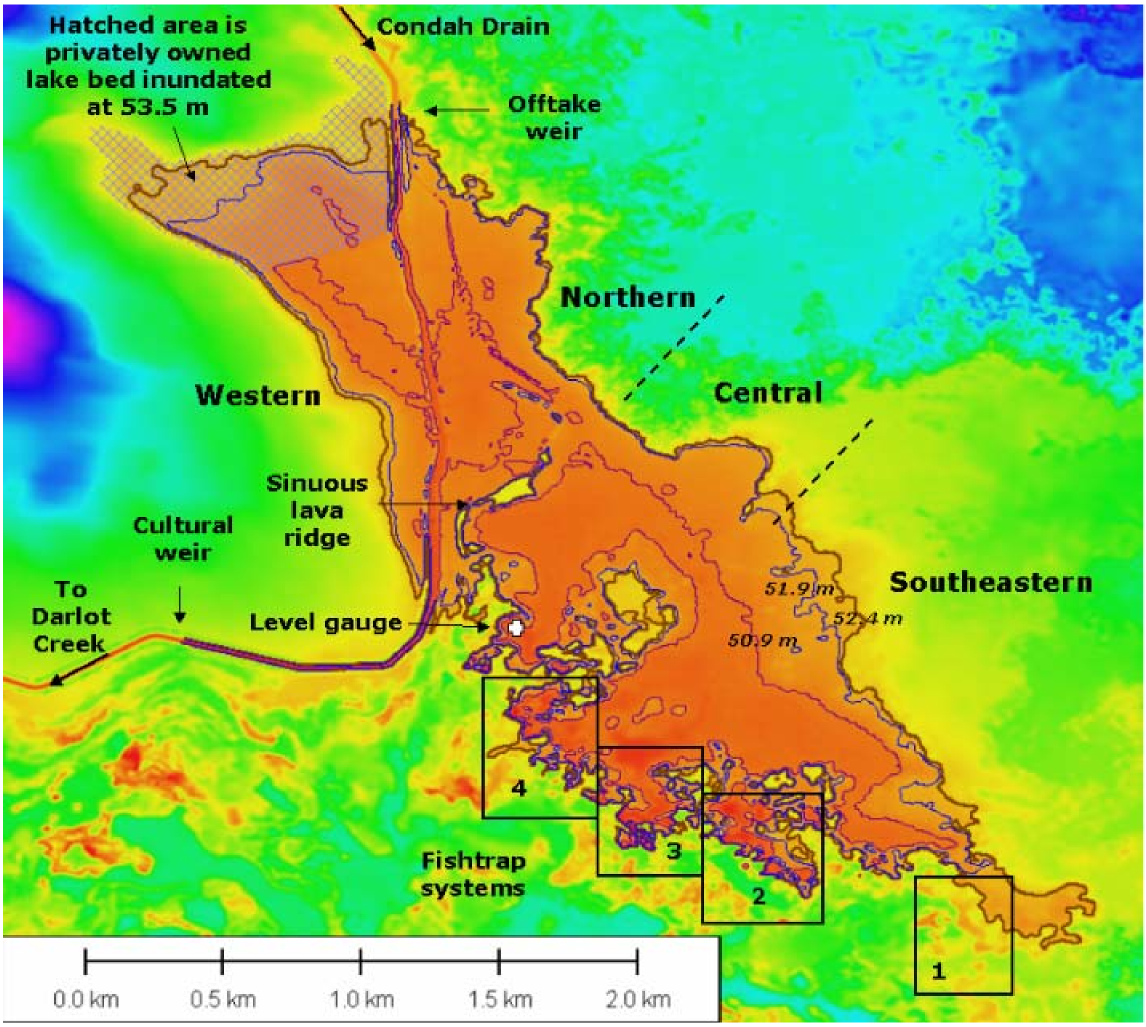


Figure 43. Lake Condah showing 50.9 m, 51.9 m and 52.4 m contours, and main features of the Lake. In this report, the Lake was divided into four main sections. The fishtrap systems indicated are those defined by Coutts et al. (1978), but structures also exist in other locations. North is vertical. Colour shading represents elevation gradient.

Table 24.
Estimated area of Morton's property inundated for a range of flood frequencies (Current conditions).

ARI (years)	Elevation (mAHD)	Area inundated (ha)
1	51.9	15.4
2	52.2	19.0
5	52.5	23.4
10	52.7	25.6
50	53.5	32.2
100	54.0	36.0
1946 flood	55.0	41.2

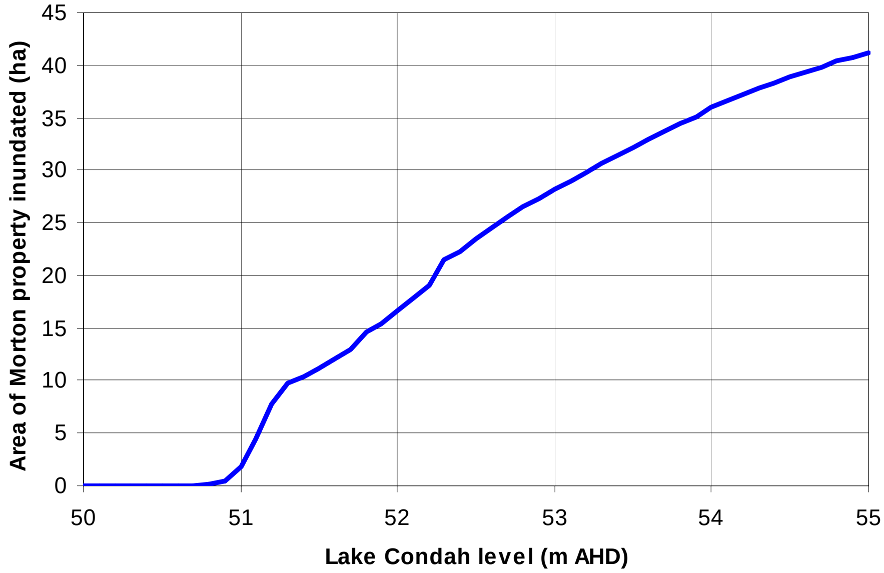
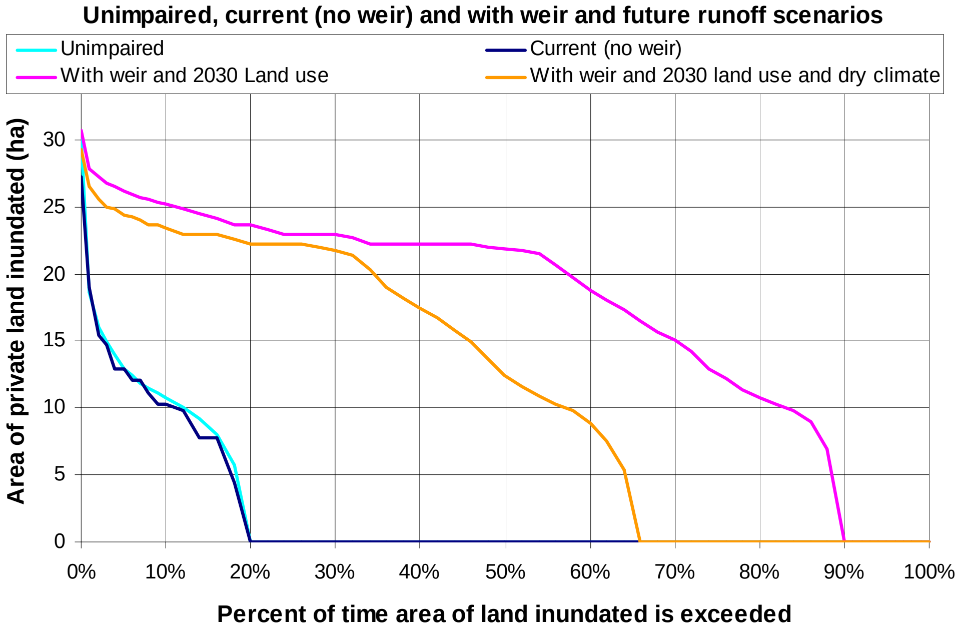


Figure 44. Area of Morton's property inundated for Lake Condah levels up to 55 mAHD (corresponding to the record 1946 flood).



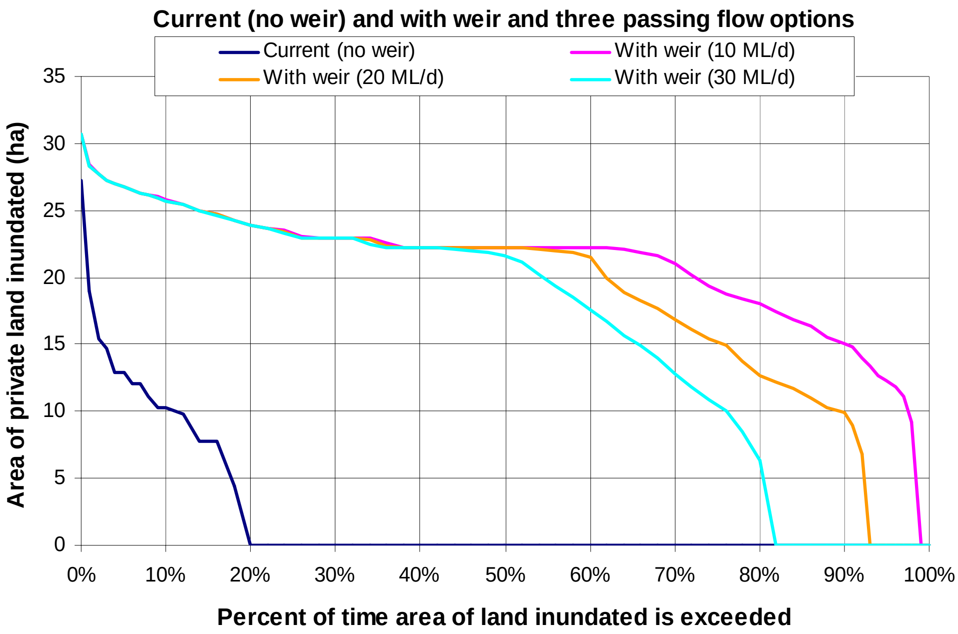


Figure 45. Duration of inundation of private land under tested scenarios. Top graph shows effect for future runoff scenarios (With Weir and 20 ML/d passing flow) and lower graphs shows effect for passing flow options. Current scenario shown in both graphs for reference.

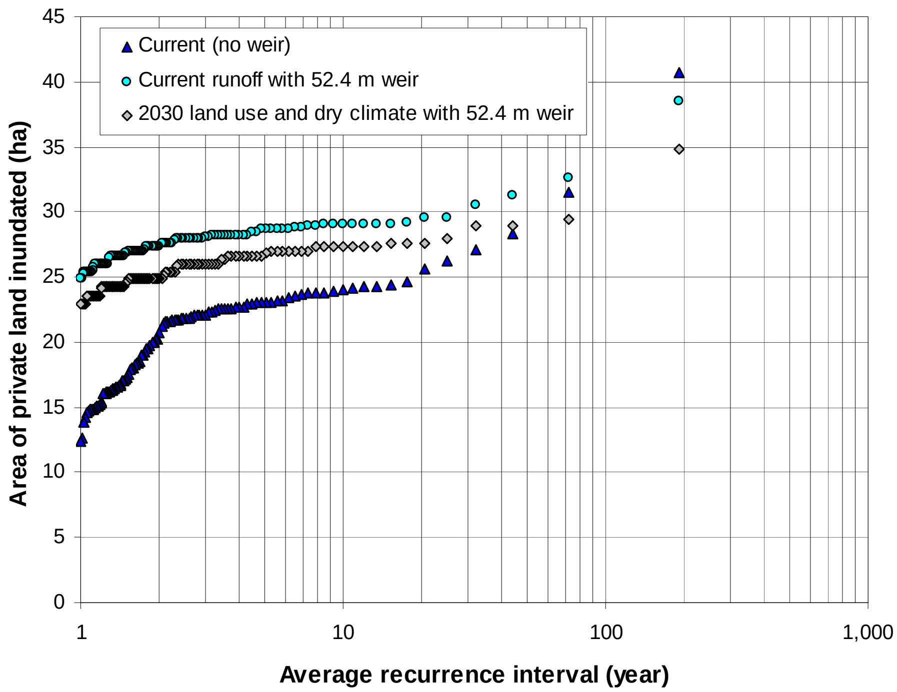


Figure 46. Average recurrence interval of area of inundated private land under current climate and land use scenario, for no weir situation (Current), and With Weir with 52.4 m weir with 20 ML/d passing flow. Impact of 2030 land use and 2030 land use and dry climate scenarios on inundation frequency also shown.

5.4.3 Frequency and duration of inundation of Condah Swamp

Condah Swamp is located upstream of Lake Condah. Parts of the Swamp are potentially inundated at levels above 52 m AHD (Figure 47). Parts of the Swamp are low-lying, and it is all below 53 m AHD. Gibbons and Downes (1964) cited local landholders reporting that the surface level in the centre of the main Condah Swamp lowered by one metre since draining (in 1954).

Unexpectedly, the more northerly sections (most upstream) are the lowest in elevation, which highlights the flatness of this landscape feature (Figure 47). Although parts of Condah Swamp are lower in elevation than 52 m, this does not necessarily mean that water levels above 52 m in Lake Condah will cause inundation in Condah Swamp – if water is contained within the Condah Drain, then the Swamp will not be flooded. Cross-sections through the Swamp (Figure 47) indicated that the Condah Drain has a distinct levee, although its height is variable (Gippel et al., 2006). The cross-sections indicated that the levees protect the Swamp against inundation for levels below 52.28 m AHD. This value is based on a DEM, not ground survey. A ground survey is the only way to know the actual sill level for inundation of the Swamp.

There are two ways that a weir at Lake Condah will possibly affect the flooding pattern of Condah Swamp. The first is if the sill that allows water to flow into the Swamp is lower than the level of the weir crest. In this case, water will inundate the Swamp very often. As the sill level is currently unknown, the likelihood of this cannot be assessed. However, it would be a relatively straightforward exercise to fill in any low points in the Condah Drain levees (and provide some freeboard) to prevent this form of inundation from happening. The second way that Condah Swamp could inundate is through a flood event. Flood events currently inundate the Swamp, but the afflux created by a weir at Lake Condah could increase the frequency of inundation.

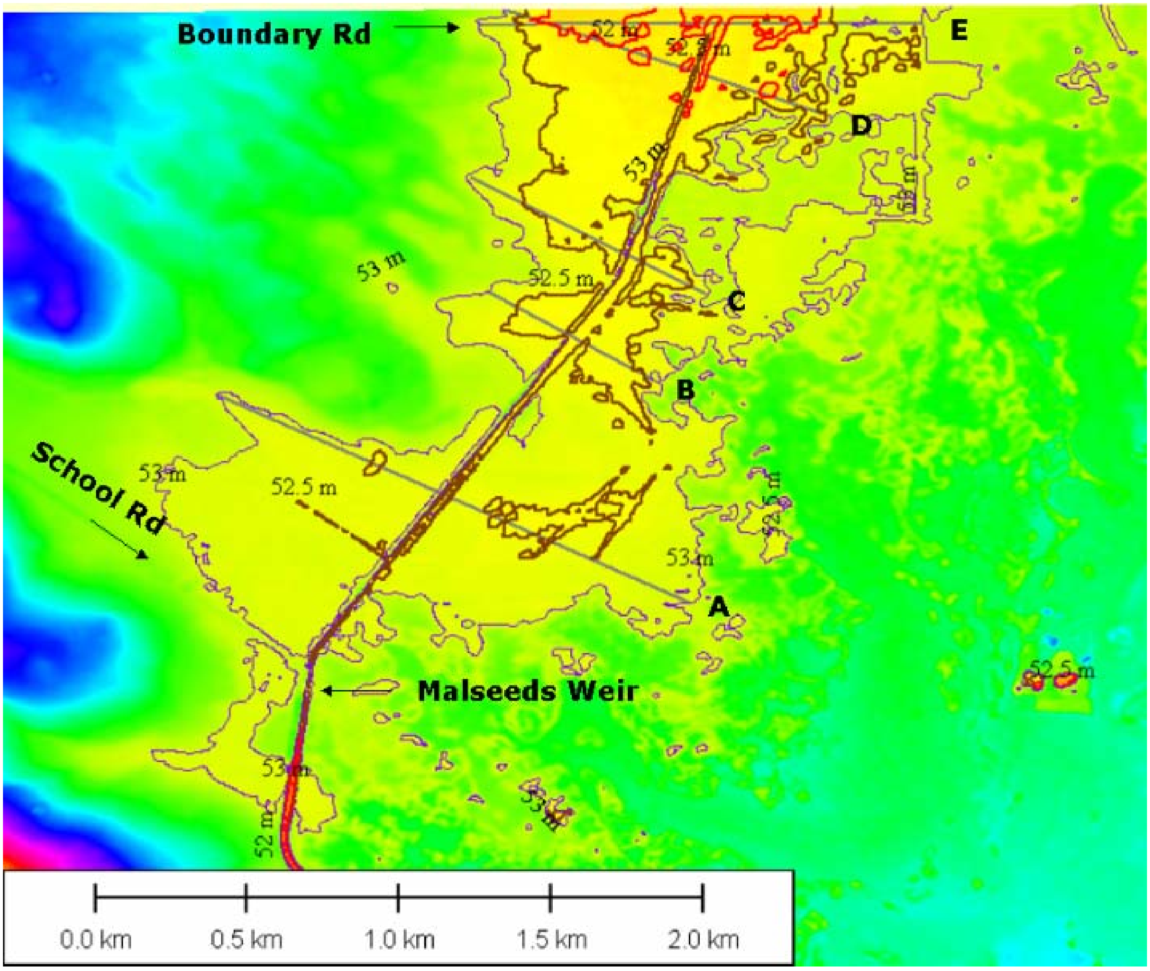


Figure 47. Southern section of Condah Swamp, showing 52 m (red), 52.5 m (brown) and 53 m (purple) contours derived from 2005 DEM. The five labelled lines are transects used to determine the drain overtopping elevations. North is vertical. Colour shading represents elevation gradient. Northern extent of map is limit of DEM data. From Gippel et al. (2006).

Hydraulic modelling undertaken by Gippel et al. (2006) indicated that under the current situation, the water level in the middle of Condah Swamp (chainage 6,662 m, midway between Malseeds Weir and Boundary Road) for the 1 in 1 year flood event (850 ML/d) was 53.25 mAHD, and if there was a 52.4 mAHD weir at Lake Condah the level was 53.37 mAHD (Figure 48). These levels are a metre above the possible sill level for inundation, suggesting that the Swamp readily floods most years. For the 50 year ARI event (3,150 ML/d) and above, a weir at Lake Condah is totally drowned out, regardless of the weir height. Thus, it can be concluded that a weir will only affect flood events of a magnitude lower than this.

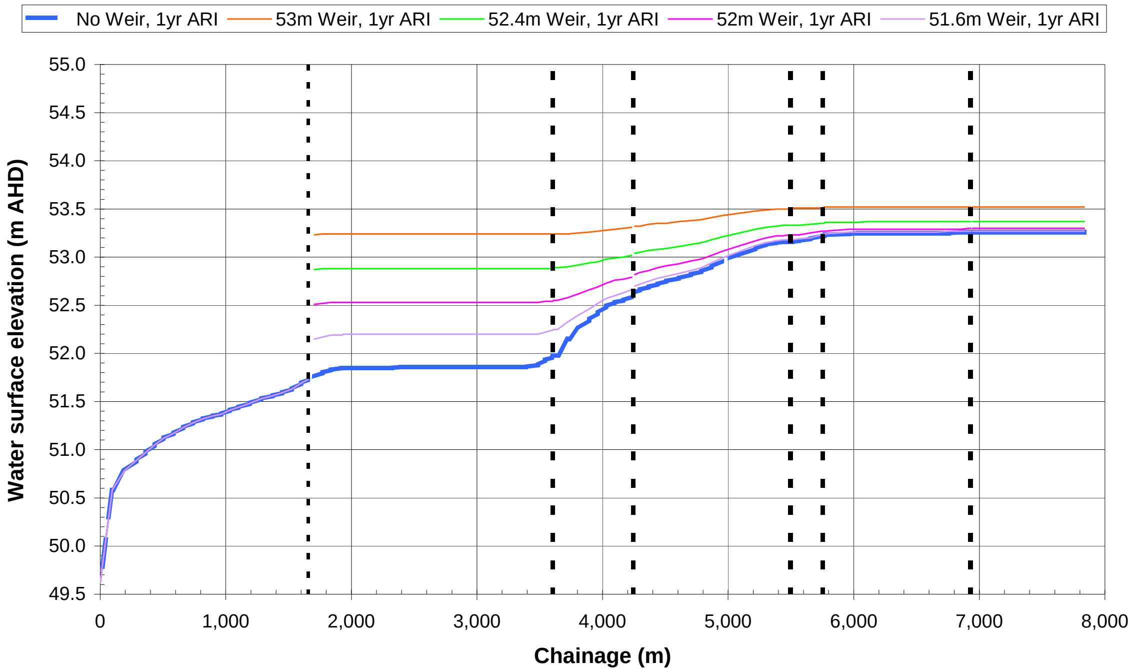


Figure 48. HEC-RAS predicted water surface profiles for Condah Drain for the 1 year event (850 ML/d) for a range of proposed weir heights. Weir at 1,656 m; Lake Condah at 1,656 to 3,600 m; Condah Swamp upstream of 5,800 m. Dashed lines indicate position of structures. From Gippel et al. (2006).

The hydraulic model of the Lake and Swamp derived by Gippel et al. (2006) was used to predict the time series of water levels in Condah Swamp under a range of scenarios. The lowest level modelled by Gippel et al. (2006) was 53.25 mAHD, which corresponded to the 1 in 1 year flood (850 ML/d). It is generally unwise to extrapolate/interpolate very far beyond modelled data points; for this analysis an arbitrary lower elevation limit of 52.9 mAHD was used, which is 0.35 m lower than the lowest modelled water height. Interpolation indicated that the level of 52.9 mAHD at Condah Swamp was associated with an event of 523 ML/d. The interpolation was based on derived relationships between levels at Lake Condah and levels at Condah Swamp for the “no weir” and With Weir situation; these relationships had R^2 values higher than 0.999.

Water level duration curves demonstrate that Condah Swamp inundation is unlikely in summer, but the water level is >52.9 mAHD for 16-17% of the time for the Unimpaired, Current and Current With Weir (at 52.4 mAHD) scenarios (Figure 49). The 2030 land use and 2030 land use and dry climate scenarios reduced the duration of time that water levels were above 52.9 mAHD (Figure 49). The volume of the passing flow had an insignificant effect on the duration of Condah Swamp levels >52.9 mAHD (these scenarios are not plotted in Figure 49).

The distribution of events >52.9 mAHD at Condah Swamp was examined by calculating the frequency and duration of independent events for each year of record for each modelled scenario (Figure 50). As expected, the events were rare in summer but common in winter. After 1987 there were no summer events recorded for any scenario (Figure 50). Prior to that, summer events occurred at a frequency of around one event every third year, and for a duration of a few days to two weeks. There was no significant difference in the distribution of these summer events for the Lake Condah weir (current climate and land use) scenarios. In winter the events occurred in 78% of years in the Unimpaired and scenario (76% for the Current), dropping slightly to 71% of years for the Lake Condah weir (current climate and land use) scenarios (Figure 50). The wetter years had more than one event, Mean event duration varied from a few days to a few months, with duration highly variable within scenarios. Total number of days in each year higher than 52.9 mAHD was slightly higher in the With Weir (current climate and land use) scenarios compared to Current and Unimpaired. The 2030 land use and 2030 land use and dry climate scenario significantly decreased the event frequency and duration for both summer and winter (Figure 50).

It can be concluded from this analysis that a weir at Lake Condah has a comparatively small effect on raising flood event water levels at Condah Swamp (i.e. compared to Lake Condah). For the same event, a weir will raise the water level, but this was insufficient to significantly affect the frequency of inundation events exceeding 52.9 mAHD. However, the actual impact of the weir on frequency and duration of all flooding events cannot be determined until the level of the sill that controls the flooding of the Swamp is determined.

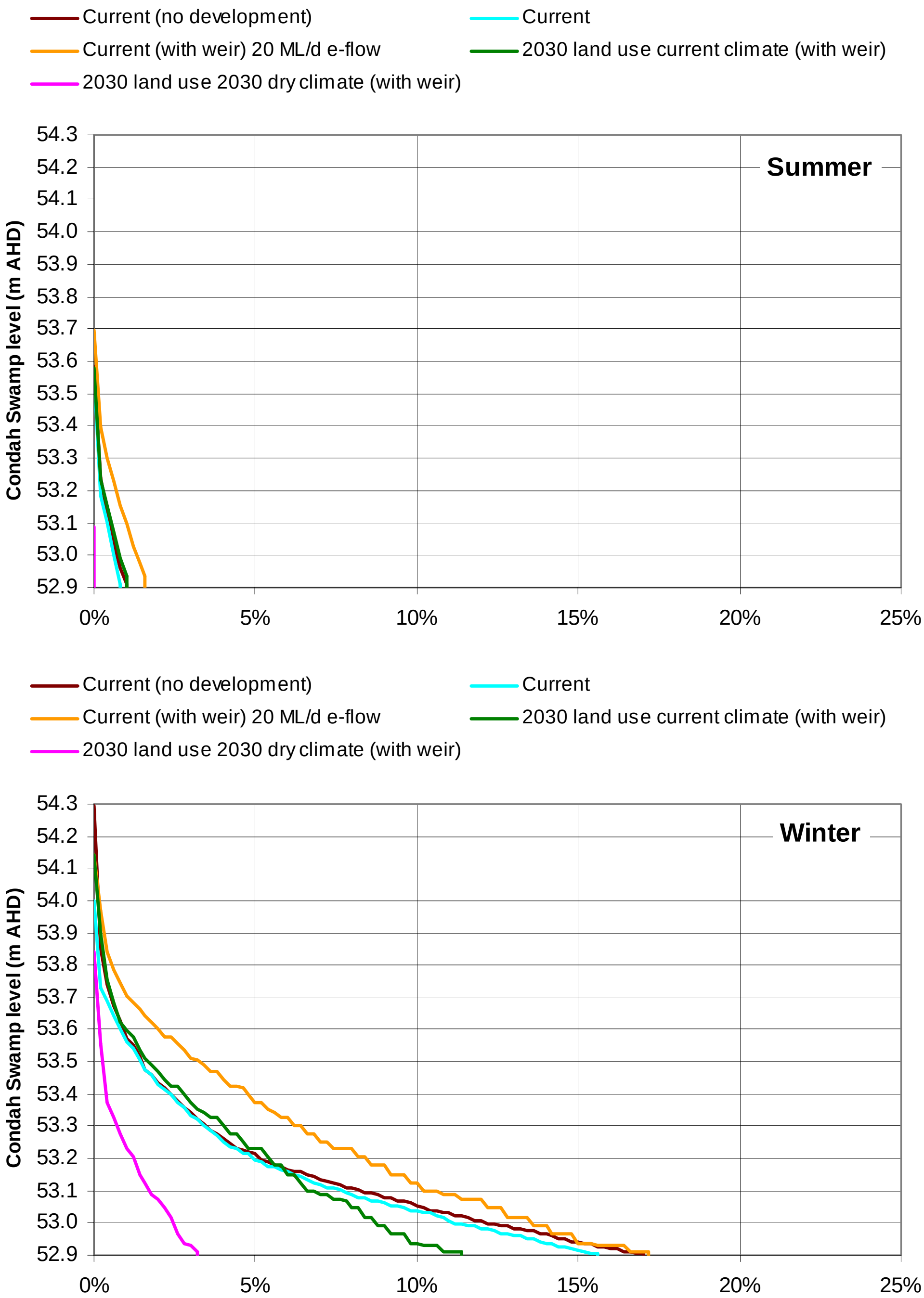


Figure 49. Summer and winter duration of water levels at Condah Swamp (at chainage 6,662 m). The With Weir scenarios are for a 52.4 mAHD weir height. X-axis is percent of time level is exceeded.

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	1						
1966							
1967							
1968	1	1					
1969							
1970							
1971	1	1	2	2	2	2	
1972	2	2	2	2	2	2	
1973							
1974			1	1	1		
1975							
1976							
1977			1	1	1		
1978							
1979	1		1	1	1	1	
1980							
1981							
1982							
1983	1	1	1	1	1	1	1
1984	1	1					
1985							
1986	1						
1987	1	1	1	1	1	1	
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							
%yrs	22%	15%	17%	17%	17%	12%	2%

Event >52.9 m frequency
- 1 event per year
- 2 events per year
- >2 events per year

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	4	4	3	3	3	4	2
1965	1						
1966	1	1	1	1	1		
1967							
1968	3	3	4	4	4	3	
1969							
1970	2	2	3	3	3	2	1
1971	5	5	3	3	3	3	2
1972							
1973	2	2	1	1	1	1	1
1974	2	2	2	2	2	1	
1975	3	3	2	2	2	3	1
1976	1	1	1	1	1	1	1
1977	1	1	1	1	1		
1978	4	5	3	3	3	3	2
1979	1	1	2	2	2	1	
1980							
1981	3	3	1	1	1	1	1
1982							
1983	3	4	4	4	4	4	1
1984	1	1	1	1	1	1	1
1985	1	1	1	1	1	1	
1986	4	4	4	4	4	4	
1987							
1988	1	1	1	1	1	1	
1989	3	2	2	2	2	2	
1990	2	1					
1991	2	2	2	2	2	1	
1992	1	1	1	1	1	2	1
1993	1	1	1	1	1	1	
1994	1	1	1	1	1	1	
1995	1	1	2	2	2	1	
1996	2	2	2	2	2	3	1
1997							
1998	1	1	1	1	1	1	
1999							
2000	3	2	1	1	1	1	
2001	2	2	2	2	2	3	
2002							
2003	1	1					
2004	1	1	1	1	1	1	1
%yrs	78%	76%	71%	71%	71%	66%	32%

Event >52.9 m frequency
- 1 event per year
- 2 events per year
- >2 events per year

Su	U	C	C.10	C.20	C.30	F.a	F.b
1964							
1965	2						
1966							
1967							
1968	2	5					
1969							
1970							
1971	1	4	8	8	8	4	
1972	13	12	21	21	21	13	
1973							
1974			6	6	6		
1975							
1976							
1977			6	6	6		
1978							
1979	4		20	20	20	13	
1980							
1981							
1982							
1983	19	17	29	29	29	28	9
1984	6	2					
1985							
1986	2						
1987	17	15	14	14	14	8	
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

Event >52.9 m mean duration
- 1 to 2 days
- 2 to 7 days
- >7 days

Wi	U	C	C.10	C.20	C.30	F.a	F.b
1964	27	25	34	33	33	19	17
1965	3						
1966	17	15	5	5	5		
1967							
1968	30	28	17	17	17	12	
1969							
1970	27	26	22	22	22	28	15
1971	15	13	30	30	30	23	6
1972							
1973	17	14	35	35	35	33	5
1974	21	18	8	8	8	4	
1975	29	29	53	53	53	28	13
1976	52	50	70	70	70	62	18
1977	8	7	3	3	3		
1978	18	14	34	34	34	27	19
1979	26	24	16	16	16	21	
1980							
1981	15	12	36	36	36	29	22
1982							
1983	25	18	26	26	26	21	45
1984	42	41	50	50	50	34	3
1985	20	19	19	19	19	8	
1986	12	11	13	13	13	6	
1987							
1988	14	13	14	14	14	3	
1989	12	13	13	13	13	6	
1990	4	4					
1991	13	11	7	7	7	3	
1992	79	73	75	75	75	29	18
1993	21	19	17	17	17	3	
1994	11	10	14	14	14	9	
1995	28	23	9	9	9	3	
1996	26	22	28	28	28	9	8
1997							
1998	10	10	13	13	13	3	
1999							
2000	8	8	15	15	15	3	
2001	32	30	28	25	25	6	
2002							
2003	6	4					
2004	24	23	38	38	38	31	21

Event >52.9 m mean duration
- 1 to 7 days
- 7 to 14 days
- >14 days

Figure 50. Pattern of frequency and duration of Condah Swamp inundation events >52.9 mAHD elevation. Duration for each year is mean event duration.

5.4.4 Reliability of supply for water licence holders

Southern Rural Water (SRW) manages annual licences to take and use water in the Condah Drain and Darlot Creek catchment. Weirs on Condah Drain are operated according to rosters and restrictions. When flows are greater than 30 ML/d at the Darlot Creek @ Homerton gauge there are no restrictions on how individual landholders operate the boards, but they are generally operated to allow stock access for drinking without causing bank erosion problems (O'Brien, 2006). A restriction roster commences when flow falls to 30 ML/d at the gauge (Southern Rural Water, 2006). This has the outcome of a reduction in the diversions from the drains/streams. The roster has five stages, with Stage 1 being no restrictions, and Stage 2 being implemented when the 30 ML/d at Homerton gauge threshold is reached. The restrictions are eased one stage at a time when the flows increase to 35 ML/d at Homerton gauge after one complete cycle of the diversion roster period. The threshold of 30 ML/d was based on Hall's (1991) recommendation for minimum environmental flows downstream of Lake Condah. There are two diverters downstream of Homerton, and the roster system helps to maintain sufficient flow in the creek to allow them to meet their needs. Under very dry conditions it is possible for flow to drop below 30 ML/d at Homerton, even with no diversions upstream of Lake Condah.

The complexity of the system of rosters and restrictions, plus a number of unknowns, means that this aspect of the creek's water balance cannot be easily modelled. A simple model of diversions was incorporated into the Lake Condah water balance model, but this model cannot accurately represent what flows might actually be in the creek at times of very low flow, because the flows will be partly dependent on human decision making at the time.

While Hall (1991) recommended a minimum flow of 30 ML/d downstream of Lake Condah, this FLOWS study recommended minimum summer baseflows of 2 ML/d immediately downstream of the lake, 3 ML/d at Wylies Road and 26 ML/d at the IPA. Obviously, the threshold at the IPA will be the limiting flow, as in order to satisfy this flow requirement, the flow downstream of Lake Condah will generally have to exceed 2 - 3 ML/d. A flow of 26 ML/d at the IPA will require a flow of around 24 – 25 ML/d at Homerton (factored according to the difference in catchment area). Thus, the controlling minimum summer flow recommendation from this study is similar to that recommended by Hall (1991).

If the threshold for beginning restrictions on diversions is altered from the current 30 ML/d at Homerton to 25 ML/d (a decision that would be consistent with the recommendations of this FLOWS study), this will have the effect of slightly increasing reliability of supply for licence holders upstream of Lake Condah. Licence holders downstream may be slightly worse off, depending on how much they need to pump in a single day. If it is expected to operate 3 pumps at a rate of 15 ML/d each, then a threshold of 25 ML/d may slightly reduce their reliability of supply. However, countering this is the tendency for a weir at Lake Condah to extend the length of the spring recession. The lake will act as a buffer, trapping winter/spring inflows and slowly releasing the stored water over summer through a passing flow. For example, at Site 4 (IPA, downstream of Homerton) flows currently fall below 26 ML/d for 9% of the time in summer, on average. With a 52.4 mAHD weir at the lake, and a passing flow of 20 ML/d the flow at the IPA is predicted to fall below 26 ML/d for only 3.5% of the time in summer, on average; with a passing flow of 10 ML/d this falls to 2% of the time. This effect can be seen in the flow duration curves in Gippel et al. (2008b) and also in a plot of monthly median flows (Figure 51).

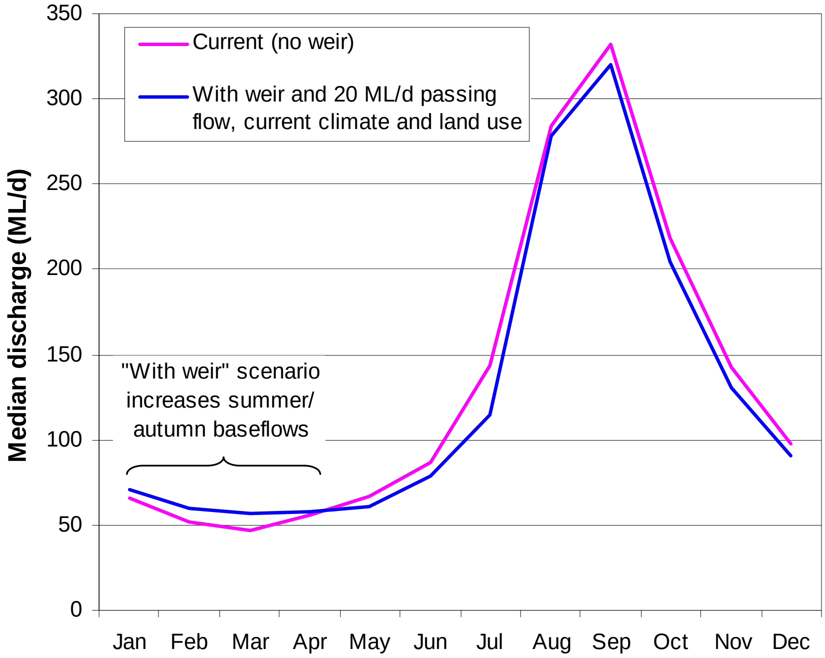


Figure 51. Pattern of monthly median flows for IPA Site 4.

With a weir in place, Lake Condah will have higher summer evaporation loss than currently, but the loss will be from stored water. Evaporation from the lake will not reduce the outflows from the lake, as outflows will be controlled by a fixed capacity pipe. If the lake level falls to the point where the lake becomes effectively “dry” (with water remaining only in the central drain), the evaporation losses will be no higher than for the Current ‘no weir’ situation. Thus, with a weir in place, evaporation will affect reliability of supply in exactly the same way as it does currently.

This FLOWS study considered the ecological merits of releasing passing flows of 10 ML/d, 20 ML/d and 30 ML/d from the Lake Condah Weir. A risk assessment to determine the lowest risk to the health of the creek and lake found that the 10 ML/d option was slightly preferred over the 20 ML/d option, and the 30 ML/d option was not recommended. Examination of the modelled Darlot Creek flow series revealed that under normal steady summer conditions a 10 ML/d passing flow at Lake Condah (i.e. with a 52.4 mAHD weir in place) is associated with a minimum flow of 15 - 20 ML/d at the IPA, and a 20 ML/d passing flow is associated with a minimum flow of 25 - 30 ML/d at the IPA. On this basis, a 20 ML/d passing flow is the lowest risk option to meet the Low Flow environmental flow requirements at the IPA (i.e. >26 ML/d).

Overall, the effect of a weir increasing the duration of summer/autumn low flows will tend to improve reliability of supply for users upstream and downstream of the lake. This is because the flows at Homerton gauge (the current compliance point for controlling restrictions on upstream diversions) will tend to be above the limit that initiates restrictions for longer in the season. Also, downstream users will benefit from an extended baseflow season.

6 Complementary Recommendations

A number of complementary recommendations are made here regarding aspects of stream and catchment management that need to be addressed in order to achieve the objectives set out in this FLOWS assessment:

a. Implement the River Health Strategy (Glenelg Hopkins CMA, 2004).
This strategy has identified most of the non-flow related issues, such as stock access to streams, willow and other weed control, catchment clearing and barriers to fish movement. The creek is in reasonably good condition, and failure to improve these aspects will not prevent achievement of benefits from environmental flows. However, the benefits of environmental flows will be enhanced if these complementary management activities are carried out.

b. Manage water quality.
Elevated nitrogen concentrations and low dissolved oxygen levels are perhaps the greatest water quality issues along Darlot Creek. While these factors would normally represent a high risk of eutrophication (blue green algae blooms in particular), the risk is mitigated somewhat in this system by low water temperatures and very low phosphorus concentrations. Nutrient levels in the Fitzroy estuary are considered to be too high. Total phosphorus in the Fitzroy is considerably higher than in Darlot Creek. Thus, water from Darlot Creek plays an important role in diluting phosphorus loads in the Fitzroy River.

c. Manage catchment flows.
Future land use change can potentially reduce flows in Darlot Creek, which will tend to cause lower water levels in Lake Condah and reduce the level of compliance of flows in Darlot Creek. It is particularly important that forestry plantations be carefully planned and managed to minimise impacts on runoff.

d. Develop a monitoring program.
Ecological/geomorphological monitoring will be required to assess whether the environmental flow regime is achieving the objectives. If the monitoring program indicates that objectives are not being achieved over time, the flow regime will require review. Monitoring should initially include gauging of flows along the length of Darlot Creek from Lake Condah to Homerton to establish the pattern of seepage inflows.

e. Undertake further investigations of the estuary.
While some good initial data exist for the Fitzroy estuary, the processes of mouth opening and flushing are not well understood. Further measurements of salinity, water levels, and degree of mouth opening will assist in development of an improved estuary model.

7 Summary and Conclusions

Following the requirements of the FLOWS methodology, a comprehensive set of objectives for the ecological values and physical condition of Lake Condah and Darlot Creek was developed. For each objective, one or more hydraulic or hydrological thresholds identified the flows required to achieve them, and the degree to which they were met by the current flow regime. For Darlot Creek, most of the flow objectives are currently met with a high level of compliance, while for Lake Condah the lake water level regime objectives are rarely met.

A characteristic of this system is the persistent baseflow that maintains permanent pools with high quality habitat for fish, vegetation and waterbirds. The preservation of baseflow is an important feature of the recommended flow regime. So too are the flow components associated with permanent pools such as passage of fish between pools and between reaches, and quality of habitat for waterbirds and other permanent residents at each reach.

Flood flows are particularly important in Reach 4 (IPA site) due to the extent and quality of floodplain habitat. The floodplain at this site includes wetlands which supports diverse plant communities and diverse habitat for frogs and waterbirds. The floodplain also provides habitat for fish, particularly eels, and flood flows are required activate floodplain channels and fill floodplain wetlands.

The conservation values of the excavated channel downstream of Lake Condah (Reach 1) are relatively poor. This reach has a simple channel form that provides little scope for aquatic plant community complexity or for fauna habitat. Consequently the flow objectives at this site are relatively simple.

The general flow requirements of Lake Condah were established in the previous Lake Condah study (Gippel et al., 2006). That study recommended a weir be constructed to a height of 52.4 mAHD, with a passing flow somewhere in the range 10 – 30 ML/d (the lower the passing flow, the longer the lake levels will be maintained). Based on the proposed depth of the lake, this FLOWS study suggested that a range of habitat structures would be expected to develop from the deepest areas to the overflow area around the lake. The water regime of the lake will be governed by principally by inflows from the unregulated catchment, but also affected by local rainfall, evaporation, seepage, and the volume of the passing flow. It is anticipated that with a weir in place, the water regime will restore the principal habitat structures present before the lake was drained. **This FLOWS study confirmed that a weir height of 52.4 mAHD is appropriate for ecological rehabilitation of the lake, and this structure presents low risk to the ecology of Darlot Creek**. This height is relative to the Mt Eccles Lava Flow 5 x 5 m grid photogrammetric DEM. There is a suggestion that this DEM contains a systematic and possibly a variable height error relative to AHD, so construction of any structure will need to take this into account.

The water regime of the lake is sensitive to the passing flow the weir incorporates. The water regime becomes more seasonal when higher passing flows are incorporated, although the permanent central lake area is preserved. The more strongly seasonal is the inundation of the lake perimeter the better the conditions for the intended plant communities. However a seasonal cycle with a high amplitude introduces risks to eel and waterbird habitat, even though both of these values require a productive lake and diverse plant communities. The risk assessment framework applied here determined that a passing flow of 10 ML/d or 20 ML/d had the lowest overall risk. **Taking into account the need to meet the summer baseflow requirement in Reach 4, the 20 ML/d passing flow becomes the preferred option**.

The case for making special provision for passing freshes is not strong, because the requirements are still met with a high degree of compliance even though a weir will trap some early season freshes. For the current land use and climate, the only flow component that is significantly negatively affected by a weir is Low Flow Fresh at Site 3 (Wylies Rd), and only for passing flow higher than 10 ML/d. The weir does not eliminate Low Flow Freshes but it does reduce their frequency compared to the Unimpaired scenario.

The weir will require a suitable fish passage device. Suggestions for an appropriate fishway design were made in previous reports (Gippel et al., 2006; McKinnon, 2007), and reiterated here. It would be difficult to justify an expensive fishway at Lake Condah weir that would remain open for 100% of the time, as migration through the Darlot Creek system is more often limited by the natural rock barrier near Condah Mission, and possibly closure of the estuary mouth. A simple fishway, as proposed for the weir at Lake Condah, will be open for an adequate length of time during the months most important for migration.

Hydrological objectives downstream of the lake are sensitive to possible future climate scenarios. A drier climate will impact on summer and winter baseflow and on early season winter freshes. However, the proposed weir does not significantly exacerbate these risks.

With a weir in place, the current system of restrictions and rostering for licenced diverters can continue to operate. A conservative approach would be to retain the current trigger level of 30 ML/d at Homerton gauge, but in the long term it may be possible to reduce this to 25 ML/d and still meet the environmental flow recommendations specified in this report.

A limitation of this study, as with any FLOWS study, is associated with the use of a single site to represent the water requirements of entire reaches. The surveyed reaches provide a limited appreciation of the size and extent of pools, riffles and benches. All of these morphological features are used to make flow recommendations and limited or unrepresentative survey data will result in unrepresentative flow recommendations. There is little scope to address this limitation without re-analysing the data on the basis of more extensive survey or by monitoring specific objectives to test their relationship with flow. Neither is feasible within the scope of the FLOWS assessment methodology. The recommendations of this report should therefore be interpreted with these limitations in mind.

The limitations of modelling potentially affected this project. As with most FLOWS studies, uncalibrated hydraulic models were used to define the FLOWS thresholds; even with the best professional judgment used to estimate the hydraulic roughness, the output of such models involves error (we reported the impact of uncertainty in roughness estimation). The flows in the creek upstream of

Homerton were modelled on the basis of outputs from the Lake Condah water balance model, which in turn was based on modelled inflows, and various other assumptions about the hydrological and hydraulic behaviour of the lake. These models were fairly sophisticated, but were still liable to error. The process with the greatest uncertainty was seepage from the lake and the return of this water to Darlot Creek. Improved knowledge of this process will only come from monitoring the hydrology of the lake and the creek. It is critical that should the lake's hydrology be restored, the lake's water level and the creek's discharge be monitored.

The most convenient location for a lake level gauge is probably on the upstream side of the proposed weir. At this point the majority of the surface area of the lake surface will be gauged when the lake falls to low levels, and access to the gauge for maintenance will be straightforward. The outflow pipe will have a nominally fixed flow rate, but this rate will actually vary according to the head (i.e. lake level). Repeated gauging of the flow from the pipe relative to the lake level will allow establishment of a rating curve to predict outflows from the pipe. A new flow gauge located in the vicinity of Wylies Rd (Coustleys Rd might be a suitable site) will allow gauging of the seepage inflows downstream of the lake, and be a compliance point for Reach 3 recommendations. This gauge should not hinder fish passage.

The ecological objectives, thresholds and hydrological objectives developed in this report provide valuable guidance for any future ecological and hydrological monitoring program for the creek. By focusing on critical flow-dependent processes, the objectives represent important values that would readily indicate any flow-related stresses in the system.

This study also briefly considered the major local "non-ecological" issues associated with a weir at Lake Condah. It was concluded that a 52.4 mAHD weir at Lake Condah with a 20 ML/d passing flow would offer benefits in terms of slightly increased reliability of supply for licence holders upstream and downstream of the lake; would possibly lead to slightly increased chance of flooding at Condah Swamp (this cannot be properly assessed until the sill level for flooding is known); would not increase the risk of flooding of private land in the Fitzroy estuary; and would cause much higher frequency of inundation of private land on the bed of Lake Condah.

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9 Appendix A – Hydraulic Analysis and Selected Results

This report describes the hydraulic analysis conducted for the Darlot Creek and Lake Condah FLOWS study, 2007. The first section of the report details the methodology and software tools applied in the study to develop one-dimensional hydraulic models for each of the three surveyed reaches. In particular, this section focuses on the rigorous approach taken to estimate the roughness coefficient of each reach. The second section then presents a detailed description of the input parameters (reach geometry, downstream boundary condition and hydraulic roughness coefficient) used to construct Mike11 (www.dhigroup.com) models of each reach.

Environmental flow recommendations were made by defining a series of quantitative ecological and geomorphological thresholds (e.g. shear stress required to initiate sediment motion). These thresholds were evaluated at each cross-section in each site and used as a tool for selecting the most appropriate discharge to meet all criteria relevant to a given flow component.

9.1.1 Reach geometry

The channel shape was measured by surveying between 6 and 9 lateral transects for each reach (transects are lines that cut across the stream perpendicular to the flow direction). Surveys provided the geometric data required to define a reach within Mike 11. Transects were located so as to capture the principal features of each reach, particularly geomorphic features such as pools, riffles and runs, and hydraulic features including channel constrictions, expansions and hydraulic controls. Overbank features were also included in the survey, with a series of specific surveys conducted at the IPA site of floodplain wetlands and channels.

Cross-section surveys were completed by Reed & Reed Surveying. They supplied data in both text file format (comma separated values) and as ESRI format shape files (included on the data CD). The principal parameters provided were:

- Co-ordinates in Zone 54 MGA.94 (Easting and Northing to +-0.01 metres);
- Reduced levels to Australian Height Datum (AHD, +-0.02 metres);
- Lateral position (in East-North plane) measured from zero at the most extreme point on the left hand bank (left side facing downstream) and increasing toward the right bank.

The surveyors also noted water surface levels on the day of the survey, as were other features such as the elevation of gauging station boards.

Cross-section data was used to develop geometry files in Mike 11 which define each of the three reaches to be simulated. Cross-section data was also analysed to:

- Compute the dimensional properties of each cross-section, including the variation with flow depth of wet perimeter, hydraulic radius, water surface top width and flow area.
- Estimate Manning's n roughness values using the empirical equations of Riggs (1976) and Dingman and Sharma (1997).
- Post-process flow results exported from Mike 11 by evaluating quantitative discharge thresholds (see Section 9.3) with output written to a text file.

9.1.2 Downstream boundary condition

The flow scenarios examined during this analysis were restricted to sub-critical flows, hence only a downstream boundary condition was required (Chow, 1959). Given the information available, normal depth was specified as the downstream boundary condition, applying the so-called 'Slope-Area Method'. Under this condition the flow depth at the outlet is determined by the geometry of the outlet cross-section, the roughness coefficient, and the local water surface slope. The strengths and weaknesses of this method were examined in detail by Fenton and Keller (2001). As the outlet geometry is known with high accuracy from survey data, the fidelity of the boundary condition depends on the values given to the roughness coefficient and the water surface slope. Fenton and Keller's (2001) analysis demonstrates that the impact of errors in the water surface slope specified "is dwarfed by the inaccuracy of knowledge of the friction factor" (Fenton and Keller, 2001, p. 15). Therefore, while the impact of uncertainty in Manning's n is reported explicitly, the impact of uncertainty associated with the downstream boundary condition is established by reference to the results of previous investigations.

The impact of an error in the slope assigned to the normal depth boundary condition was investigated for a similar project to establish the environmental water needs of the Werribee River (Ecological Associates and Fluvial Systems Pty Ltd et al., 2005). In that project the sensitivity to slope was assessed by perturbing the mean slope assigned to the normal depth boundary condition by ±10% of the reach average slope. This perturbation impacts the water surface profile most in the vicinity of the outlet cross-section, and the magnitude of any error declines in an upstream direction. Flow profiles were computed for the 25 year ARI flow[9] for a steep upstream site (Werribee Site 1: Werribee River downstream of the Upper Diversion Weir having a bed slope of 0.0018) and at a lowland reach (Werribee Site 4: Werribee River downstream of Cobbledicks Ford having a bed slope of 0.00017).

The sensitivity of the water surface profiles at Werribee Site 1 to the assigned water surface slope was limited to the 80m of the reach immediately upstream of the outlet (Figure 52). Water surface profiles were much more sensitive to an error in slope at Werribee Site 4. Here the profiles remain divergent for the entire reach length (Figure 53). However, as predicted by Fenton and Keller (2001), the error due to uncertainty in the friction factor (Manning's n) has a significantly larger impact. It is important to bear in mind that error due to slope declines for smaller flows, whereas errors due to roughness remain significant across the entire flow range.

This analysis demonstrated two key points:

- reaches of low slope are more sensitive to errors in the downstream boundary condition than reaches of higher slope; and
- uncertainty in the value of the friction factor is the key determining factor in the accuracy of predicted water surface profiles.

In order to minimise the impact of an error in the specification of slope the modelled reach was extended by adding extra cross-sections beyond the most downstream cross-section surveyed ('the outlet'). These artificial cross-sections were copies of the outlet cross-section extrapolated downstream along a vector perpendicular to the plane of the outlet and depressed at an angle equal to the average reach slope. The addition of such cross-sections is described for each reach later in this report.

9.2 Hydraulic Roughness

Hydraulic resistance (also called 'stream roughness') is a measure of the friction generated between flowing water and the channel boundary. Higher values of resistance are associated with rough-textured boundaries, with highly sinuous channels, and with turbulent flows down rapids and through vegetation. Flows through high resistance channels move more slowly and at a higher stage than through lower resistance channels at the same discharge. The magnitude of resistance determines the discharge at which different channel features are inundated, for example the bankfull flow at which flooding commences, and the speed at which flows are conveyed and accumulate down the network.

The overall value of flow resistance in a natural river comprises contributions from many interdependent sources, including: bed and bank roughness, bend losses, secondary flow resistance as well as the contribution of vegetation (Bathurst, 1993). There are four standard approaches used to estimate the various contributions to resistance in natural rivers and streams; they are: (i) procedural approaches; (ii) roughness tables; (iii) using roughness handbooks; and (iv) empirical or theoretical equations.

A procedural method that builds on the recommendations of Coon (1998) was developed for assessing the roughness of each of the seven reaches assessed for in the Barwon River FLOWS study. Coon's (1998) procedure is recommended by the United States Geological Survey and therefore is relevant for North American conditions that are somewhat different from those in Australia. Southern hemisphere data and techniques, for example Hicks and Mason's (1991) work, were therefore adopted in place of some of the references recommended by Coon (1998). There is no single best approach for the estimation of hydraulic resistance. In the absence of calibration data (measured discharge and stage), it is best practice to employ a range of methods (Coon, 1998; Lang et al., 2004). For this project, each of the four approaches (listed earlier) were employed, with the specific methods described in the following sections.

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[9] The 25 year flood was selected as being about the largest flow of interest to the FLOWS analysis, and adopted as a floodplain forming flow (e.g. Pickup and Marks, 2001).

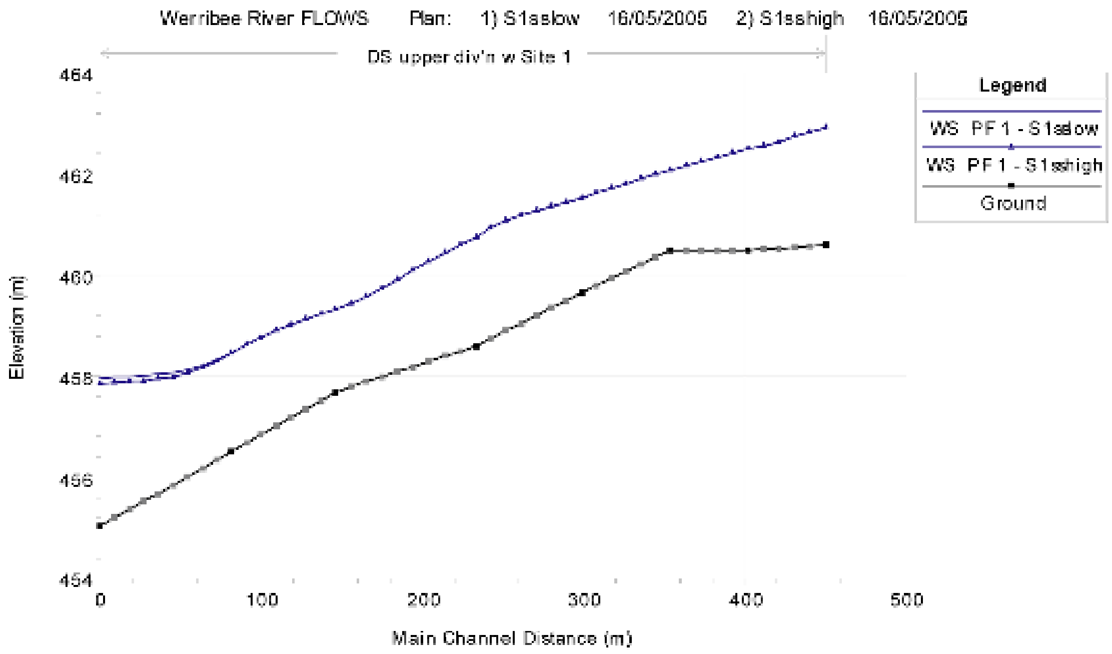

Figure 52. Water surface profiles resulting from slope sensitivity analysis at Site 1 reported as Elevation in metres relative to the Australian Height Datum (AHD). S1sslow and S1sshigh are for water surface slopes at the downstream boundary of 0.00159 and 0.00195 respectively. The convergence of the two profiles is complete at around 80m upstream of the outlet (i.e. Main Channel Distance).

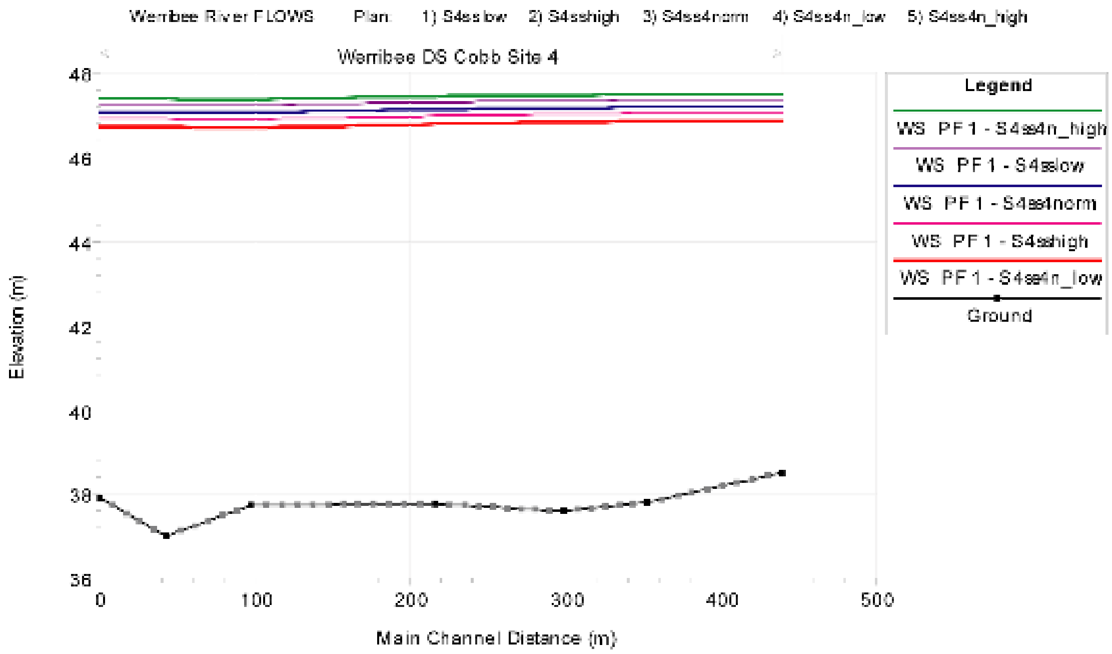

Figure 53. Flow profiles resulting from slope sensitivity analysis at Site 4. Profiles resulting from changing the water surface slope specified at the downstream boundary are denoted by S4sslow and S4sshigh. Profiles were also computed for the uncertainty in channel roughness, with three Manning's n cases reported: a best estimate (S4ss4norm); a low estimate (S4ss4n_low); and a high estimate (S4ss4n_high). (Refer to Site 4 in Section 2 for the values assigned for water surface slope and roughness coefficient).

A note on the spatial variation of hydraulic roughness

In reality hydraulic roughness varies with both lateral position over a cross-section and longitudinally down a reach. However, the determination of roughness with available estimation techniques is imprecise. Therefore, roughness coefficients are estimated to find a reach-average value, with most of the effort expended defining in-channel roughness characteristics. As a result, for this modelling roughness coefficients are in general held constant in the longitudinal and lateral directions. The only exception to this rule is where well-defined floodplains exist. Floodplains are known to exhibit very different roughness to the channel, hence these zones are assigned roughness values independently to the main channel. Floodplain flows are however less critical in the FLOWS assessment, hence values were estimated using only Chow's (1959) table.

9.2.1 Procedural Approach – Cowan's Method

Cowan's (1956) method attempts to capture the essence of professional judgement in a procedural method. Cowan notes that while the value of resistance could depend on 8 or 10 factors, he suggests the five most important channel features to be: surface irregularity; cross-section variability; obstructions; vegetation resistance; and channel sinuosity. Using his approach a base value of Manning's n is selected according the bed and bank material (n_b), with corrections for each factor (n_1, n_2, n_3, n_4, and m). Once the correction factors are selected, an estimation for the net section resistance can be computed using (0.1) (in Table 25). An indication of the relative importance of the correction factors is implied by the maximum recommended adjustment increment (Table 25).

Table 25.
Cowan's Method: Equation and Correction Factors

Equation: $n = (n_b + n_1 + n_2 + n_3 + n_4) \times m$ (0.1)

Factor	Description	Maximum Values channel[a]	floodplain[b]
n_b	base value of n for a straight and uniform channel	0.070	
n_1	correction for surface irregularity	+0.020	+0.020
n_2	correction for cross-section size and shape	+0.015	n/a
n_3	correction for obstructions	+0.015	+0.030
n_4	correction for vegetation	+0.100	+0.200
m	correction for sinuosity	× 1.3	n/a

Table Notes:
a - Values recommended by Cowan (1956) b - Values listed by Arcement and Schneider (1989)

Cowan's (1956) approach has attracted some criticism. Cowan described two limitations: firstly, the method is not applicable to streams with mobile beds; and secondly, the data set from which recommended corrections were derived does not include large channels. In addition, the theoretical basis of the method has been questioned, as the assumption that the resistance corrections may be applied independently implies that the principal of superposition applies, a proposition examined and rejected by numerous subsequent fluvial studies (see pages 77-103 of review by Yen, 1991). However, despite these detractions, Cowan's method provides a useful tool for approximation. Indeed, it is a core component of the approach to roughness selection recommended by the USGS (Coon, 1998).

Estimates of roughness using Cowan's method are made in this project by reference to the tabulation provided by Chow (Chow, 1959, Table 5-5, p. 109).

9.2.2 Roughness Tables - Chow

Roughness coefficients are also estimated by reference to tables, most reproducing the table produced by Chow (1959), although a similar tabulation has also been produced in South African by Rooseboom et al. (1986). Chow's table provides indicative low, medium, and maximum Manning's n values for open channel types ranging from constructed drains (lined or built-up) to flows down natural streams and across floodplains. Chow constructed the table using the best available experimental data from published and unpublished studies (Horton, 1916; Ramser, 1929; USDA, 1955 in Chow, 1959, p.114).

Values of Manning's n are selected by matching the properties of the reach under investigation with the type of channel and description provided by Chow (1959).

9.2.3 Roughness Tables - Bathurst

More recently, Bathurst (1993) proposed a method for bracketing channel roughness based on differentiating streams according to the calibre of bed material and the prevailing channel slope. His method is founded on the presumption that the dominant factors controlling flow resistance vary along the channel network, and in many cases with discharge. He identified four principal channel types based on hydraulic considerations:

- In sand-bed channels resistance varies principally with bedform types, although suspended sediment concentration may also have an effect.
- In gravel-bed rivers bed material relative roughness and ponding in pool-riffle sequences are the important factors.
- In boulder-bed rivers flow resistance is determined by form drag of boulders.
- In step pool/fall channels, ponding is the critical factor.

It is worth noting that while changes in resistance mechanisms and coefficients occur along the river system, resistance at a site is also variable. For example with increased discharge, ponding effects may be drowned out while bank vegetation may come into play. Data compiled by Bathurst (1993) shows the typical parameter values and ranges for each of his stream types (Table 26).

Table 26.
Typical physical properties of different channel types and characteristic values of their flow resistance characteristics (source: Bathurst, 1993).

	Approximate range of:		
Stream Type	Channel Slope (%)	Bed Material D_{50}^{*} (mm)	Manning's n
Sand bed	≤ 0.1	≤ 2	0.01 – 0.04
Gravel / Cobble bed	0.05 – 0.5	10 - 100	0.02 – 0.07
Boulder bed	0.05 – 5	≥ 100	0.05 – 5
Step pool / fall	≥ 5	variable	0.1 – 5

* D_{50} = bed material particle size for which 50% of the material is finer.

9.2.4 Roughness Handbook – Hicks and Mason

Fluvial researchers routinely measure the hydraulic properties of study reaches, sometimes as core data, in other cases simply to provide background or context. The majority of publications in this area focus on the streams in North America, although in the Australasian region Hicks and Mason (1991) authoritative guide for New Zealand streams is arguably the most relevant. An effort was made to replicate this work and to produce an Australian guide (Anderson et al., 2001; Ladson et al., 2003), however, to date information on only four reaches has been submitted.

The guide produced by Hicks and Mason (1991) for New Zealand streams is substantially more detailed than previous studies, covering a greater number of streams (78), and more importantly including measurements for a wide range of in-channel discharges. This seems to have set the standard for subsequent publications. Roughness is estimated using the guide by selecting a reference reach that is similar to the one being investigated. Reach similarity is established by matching, as far as possible, channel size and shape, bed material, channel slope, and bank vegetation characteristics. A first order match is obtained by matching the mean annual discharge

(m^3/sec), water slope at the mean discharge (approximated herein by the mean bed slope), and bed surface material size (specifically, the median diameter statistic for the bed surface material, D_{50}).

9.2.5 Empirical and Theoretical Equations – Dingman and Sharma

There are tens of empirical equations in the scientific and engineering literature that can be used to estimate stream roughness coefficients such as Manning's n (Anderson et al., 2001; Duncan and Smart, 1999; Lang et al., 2004). Collections of these were compiled and their performance assessed against directly computed roughness measurements for four reaches in Victoria by Lang et al. (2004). This investigation demonstrated that the empirical equations suggested by Dingman and Sharma (1997) and by Riggs (1976) produced the best results, while also noting that overall one should be sceptical when using empirical equations to estimate Manning's n. The two empirical equations are defined in Table 27.

Table 27.
Empirical equations for predicting Manning's n (after Lang et al., 2004), where A is flow cross-sectional area (m^2); R is hydraulic radius (m); S_w is water-surface slope (m/m); and S is the channel bed slope (m/m, assumed to equal S_w).

Author	Equation	Description / Conditions for use
Riggs (1976)	$n = 0.210\ A^{-0.33}\ R^{0.667}\ S_w^{0.095}$	Uniform cross-sectional area (preferably not converging); nearly full natural channel. Calibrated to 62 data points, comprising areas and slopes from Barnes (1967), and unpublished data from the USA; not thoroughly validated according to Dingman and Sharma (1997)
Dingman and Sharma (1997)	$n = 0.217\ A^{-0.173}\ R^{0.267}\ S^{0.156}$	Calibrated to 520 data points from Barnes (1967) and Hicks and Mason (1991); verified using 100 data points from Barnes (1967) and Hicks and Mason (1991).

9.2.6 Identification of morphologic features

Morphologic features of the stream channels were utilised in two respects that relate to the hydraulic analysis. First, a bankfull stage was required in order to compute the geometric parameters required to evaluate the empirical equations of Dingman and Sharma (1997) and Riggs (1976), and were also central to selecting an appropriate reach from Hicks and Mason's (1991) guide. Second, to construct an appropriate environmental flow regime it was important to establish (for ecological and geomorphological reasons) the discharge required to inundate particular channel features, in particular inset benches, high flow channels, and to simply wet the wetted perimeter of the low flow channel. These later surfaces were identified during the workshop at which the technical panel worked through the process of quantifying the environmental flow requirements.

9.2.6.1 Defining Bankfull Discharge

The bankfull stage is an important hydraulic parameter. It's most obvious use is used to demarcate in-channel flows from overbank flows. However, the more important aspect of bankfull stage is that, in alluvial channels especially, it is a good indicator of the dominant discharge and the sediment regime in the stream. For the hydraulic analysis, bankfull channel properties were important as they are widely employed in the literature, and are required in order to draw comparisons with properties of other channels. For example, the relationships presented by Riggs (1976) and Dingman and Sharma (1997) are applicable only to flows less than bankfull stage.

For many channels, bankfull stage is a difficult feature to identify with great accuracy. Gordon et al. (2004) list a range of criteria that can be applied to assist in the determination of bankfull stage. It is a property best estimated by a qualified geomorphologist (Dr. Chris Gippel for this study) using a combination of field inspection and analysis of the return interval (from the hydrology) of the discharge required to produce a given water surface elevation.

9.2.6.2 Computations involving parameters at bankfull stage

An average in-channel geometry was computed for each reach by averaging the in-channel (sub-bankfull) characteristics of each cross-section. The empirical relationships of Riggs (1976) and

Dingman and Sharma (1997) were then applied using the average geometric values at four values of stage: 25%, 50%, 75% and 100% of bankfull. The range of roughness values computed are reported in the summary tables of Manning's n values for each reach, with the average of the roughness at each stage used to estimate overall reach roughness.

9.2.7 Parameter uncertainty and model sensitivity

River channels are highly complex physical systems and the hydraulic models constructed in Mike 11 represent an approximation of this system. Parameter values were defined with the greatest accuracy possible given the constraints of time, resources and available technology. The hydraulic analysis followed the FLOWS method (SKM et al., 2002), with models of the river reaches constructed around at least 5 survey cross-sections (6 – 9 for this project) with best professional judgment used to establish Manning's n roughness coefficients. The two principal sources of uncertainty in the hydraulic model are associated with the value assigned to the roughness coefficient (Manning's n), and with the downstream boundary condition.

9.2.7.1 Manning's n uncertainty

It is generally accepted that the greatest parameter uncertainty in one-dimensional hydraulic modelling is associated with the value assigned to roughness coefficients (Aronica et al., 1998; Burnham and Davis, 1986; Coon, 1998; Western, 1994). There is no single 'best' tool, technique or equation, as numerous studies have demonstrated (Coon, 1998; Lang et al., 2004; Phillips and Ingersoll, 1998). The accuracy of the estimate hinges is thought to hinge on the experience of the practitioner, aided by the application of multiple methods of roughness estimation. Hence for this project six different tools were employed to estimate hydraulic roughness, giving six Manning's n values (n^1, n^2 … n^6). The average of these estimates was selected as the 'best' estimate of reach roughness.

The standard deviation of the estimates also provided an indication of the uncertainty associated with the value selected. Uncertainty bounds for a sampled parameter are usually set at two standard deviations either side of the mean (where, for normally distributed, data 95% of values fall within these bounds). However, as well as sample error, the estimation of roughness may also be inaccurate simply due to the tool used, i.e. every technique is not expected to supply an accurate estimate for every reach. Therefore, it is more likely that the actual value of roughness lies closer to the mean than two standard deviations would suggest. The uncertainty associated with the roughness coefficient was therefore set to one standard deviation rather than two in recognition of these two error sources.

Note: Floodplain roughness values suffer from similar uncertainty. Floodplain roughness values were perturbed in proportion to the perturbation of in-channel roughness.

9.3 Discharge Thresholds

In order to quantify the flow required to meet each ecological and geomorphological objective a specific flow criterion was established. For example, in order to entrain medium-grained sand a certain minimum shear stress must be applied. For each of the ecology-flow and geomorphology-flow relationships (listed in Section 2.2) a quantitative threshold, such as the shear stress threshold for sand, was established. Each of these thresholds was defined in terms of one or more of the following flow properties computed by the hydraulic model: shear stress, flow velocity or flow depth. Many of the thresholds simply require a certain flow depth to be achieved, either at all cross-sections in the reach or at a specific cross-section. These criteria and the reasoning for them have been described in the Issues Paper (Gippel et al., 2007) for this study.

The scientific basis for two objectives has not yet been established:

- the discharge required to move or erode bed and bank sediments; and
- the discharge required to bend or remove vegetation.

The relevant thresholds for these two cases are described in the following sections.

9.3.1 Bed and Bank Erosion (cohesive sediment)

Chow (1959, p. 164) noted that:

> "*The behavior of flow in an erodible channel is influenced by so many physical factors and by field conditions so complex and uncertain that precise design of such channels at the present stage of knowledge is beyond the realm of theory*."

Since that time there have been developments in the level of sophistication of river channel modeling capacity, but there have been no major advancements in relevant theory. The mobilization and transport of unconsolidated material (such as sand, gravel, cobbles etc) can be predicted reasonably well on the basis of shear stress, and there are numerous methodologies in the literature based on this approach. Prediction of the mobilization (i.e. scour) of consolidated sediments (i.e. clay-rich bed and banks) is not so amenable to a physical modelling approach, and most methods rely on empirical data from long-standing field and experimental studies. Thus, the methodology used in this study is the traditional one, as described in Chow (1959, pp. 164 - 191) and other popular channel hydraulics texts. The two methods that have been most commonly applied to this type of problem are the:

- method of maximum permissible velocity, and
- method of maximum permissible tractive force.

The tractive force (shear stress) method is preferable to the velocity method, as shear stress is more fundamentally related to particle mobilization than is velocity. The velocity method is appropriate in cases when shear stress cannot be modelled. It is important to realize that while these approaches have been applied extensively in the river engineering industry throughout the world for decades, like all empirically based approaches, they remain subject to uncertainty.

Method of maximum permissible velocity

The maximum permissible velocity (V_{max}) is the greatest mean channel velocity (V) that will not cause erosion of the channel body. A channel is stable when:

$$V < V_{max} \quad (1)$$

Chow (1959, p. 165) noted that maximum permissible velocity is 'very uncertain and variable'. When other conditions are the same, a deeper channel will convey water at a higher mean velocity than a shallow one. This is because the scouring is related to bottom velocities, which for the same mean velocity, are higher in the shallow channel. Tables of maximum permissible velocity appear in many channel design, engineering and hydraulics publications (e.g. Chang, 1988), and they are all based on values for canals given by Fortier and Scoby (1926), and from the USSR (Anon, 1936), although some agencies have adjusted these standard values on the basis of local empirical knowledge (e.g. Stallings, 1999). The values assume a bare channel surface (i.e. no grass or other lining or vegetation).

The soils in Darlot Creek and Lake Condah are clay rich with very low, to negligible sand content. For channels in "Stiff clay, very colloidal", which refers to "Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36%" (Stallings, 1999), the maximum permissible velocity for water depth of 1 m and water transporting fine suspended solids (which applies to Darlot Creek) is 1.5 ms^{-1} (Fortier and Scoby, 1926).

Flows with long durations often have a more significant effect on erosion than short-lived flows of higher magnitude. Fischenich and Allen (2000) and Fischenich (2001) recommended application of a factor of safety to V_{max} when flow duration exceeds a couple of hours (which is the case for Darlot Creek). A graph is provided in Fischenich (2001) for this purpose. The graph shows a value of V_{max} of 1.85 ms^{-1} for "bare soil (clay)" for very short duration flows, and for flow durations >50 hours this drops to, and appears to level out at, 0.7 ms^{-1}.

Anon (1936) gave correction factors for V_{max} for channels greater than 1 m deep (factor >1), and less than 1 m deep (factor <1). For Darlot Creek, where the depth ranges between 2 and 4 m, the correction factor ranges from 1.15 to 1.3.

Tabulated values of V_{max} are for straight channels, and for sinuous channels V_{max} should be reduced. Lane (1955) recommended reductions in V_{max} of 5% for slightly sinuous channels, 13% for moderately sinuous channels, and 22% for very sinuous channels. The sinuosity of Darlot Creek falls into the moderate category.

Allowing for these various adjustments, an appropriate value of maximum permissible velocity for Darlot Creek is ~0.7 ms^{-1}.

Method of maximum permissible tractive force

Tractive force is the force that acts in the direction of flow on the channel bed, and is also known as bed shear force or stress. Unit bed shear stress (or unit tractive force), τ_b, is calculated by:

$\tau_b = \gamma RS$ (2)

where

τ_b = bed shear stress (N m^{-2})

γ = the weight of water (9806 $N.ms^{-1}$)

R = hydraulic radius (m)

S = the slope of the energy grade line.

Maximum permissible shear stress (τ_{max}) is the maximum unit shear stress that will not cause serious erosion of the channel. Values of shear stress close to the maximum permissible value to prevent bed scour will obviously be sufficient to maintain the fine-grained sediment load in suspension and prevent siltation of the bed (i.e. tractive force just below the maximum permissible magnitude will maintain the channel morphology). Tables of maximum permissible shear stress appear in many channel design, engineering and hydraulics publications (e.g. Chang, 1988), and they are all based on values given by the U.S. Bureau of Reclamation (Lane, 1955; Carter, 1953).

A channel is stable when:

$\tau_b < \tau_{max}$ (3)

For channels in "Stiff clay, very colloidal", which refers to "Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36%" (Stallings, 1999), the maximum permissible shear stress for water depth of 1 m and water transporting fine suspended solids (which applies to Darlot Creek) is 22 Nm^{-2} (Chow, 1959, p. 165).

Tabulated values of maximum permissible shear stress are for straight channels, and for sinuous channels the maximum permissible shear stress should be reduced. Lane (1955) recommended reductions of 10% for slightly sinuous channels, 25% for moderately sinuous channels, and 40% for very sinuous channels. Allowing for this adjustment, an appropriate value of maximum permissible shear stress for the bed of Darlot Creek is 16.5 Nm^{-2}.

It should be noted that unit bed shear stress is not uniformly distributed along the wetted perimeter. Computed values of shear stress based on average cross-section conditions may be adjusted to account for local variability and instantaneous values higher than mean (Fischenich, 2001). A number of procedures exist for this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. According to Chow (1959, p. 170), for trapezoidal channels, the maximum shear stress on the bed is close to γRS, and on the sides it is close to $0.76\tau_b$. Fischenich (2001) recommended that for straight channels, the local maximum shear stress can be assumed to be 1.5 τ_b. Thus, on Darlot Creek the maximum permissible shear stress assuming at the point of local maximum shear is 16.5 / 1.5 = 11 Nm^{-2}.

9.3.2 Entrainment of bed material (unconsolidated sediment)

Sediment-entrainment theories predict the mobilisation of unconsolidated sediments (silts, sands, gravels, cobbles etc). It is normally assumed that particles will be flushed out when the threshold of motion for some percentage of the particles is reached. One method of predicting when particles will become entrained in the flow is based on the Hjulstrom curves, which relate particle size to mean velocity required for erosion, deposition and transportation (Gordon et al., 2004, p.192). The critical velocity (in m/s) for initiation of sediment movement (for particles >1 mm diameter) is $V_c = 0.155\sqrt{d}$, where d is the average particle diameter in millimetres. The Hjulstrom curve also predicts the limits for erosion of fine sands down to clay size sediment, and these values can be read from the curve (Gordon et al., 2004, p.192). The velocity near the bed is predicted by $V_b = 0.7\ V$, where V is the mean channel velocity (Gordon et al., 2004, p. 193). The bed material will become unstable when $V_b > V_c$.

Estimates of the mean channel velocity required to initiate movement of sediment across the range found in Darlot Creek were made based on these relationships with critical velocities listed in Table 28 (Note the higher of the two velocity thresholds was evaluated for this work).

Table 28
Mean channel velocities required to initiate sediment transport, for range of bed material particle sizes found in Darlot Creek.

Size class (Wentworth)	Diameter range (mm)	Mean channel velocity to initiate sediment movement (m/s)	
		Lower size range	Upper size range
Fine silt	0.0156 – 0.0078	0.7	1.0
Coarse silt	0.0625 – 0.0312	0.3	0.5
Medium sand	0.5 – 0.25	0.2	0.2
Coarse sand	1.0 – 0.5	0.2	0.2

The Shields equation (see Gordon et al., 2004) is commonly used to predict sediment mobilization (e.g. Reiser et al., 1985; Pitlick, 1994). Gordon et al. (2004, p.194) explained that a useful “rule of thumb” is that the critical shear (designated by τ_c and measured in N/m^2) is approximately equivalent to the diameter of the particle (measured in millimetres) (i.e. $\tau_c = 0.97\ d$, where d is median particle diameter). One difficulty is selecting an appropriate coefficient, as the method was developed for uniform sands, not mixed gravels. The above rule of thumb relationship applies to round particles, with flat-shaped particles requiring half the tractive force to initiate movement (Newbury and Gaboury, 1993, p. 68). Smaller particles can hide in the wake of large particles. The theory of ‘equal mobility’, based on empirical observations, states that nearly all grain sizes begin moving at nearly the same discharge (Gordon et al, 2004, p.190). This theory predicts that, rather than the entire bed becoming mobile at a particular threshold discharge, the bed selectively and progressively unravels from different locations as discharge increases. The amount of shielding, packing or imbrication, or armouring must be taken into account as well as the particle size to be mobilized (Gordon et al, 2004, p.190-1). Wilkinson and Rutherfurd (2001) found that the Shields function “rule of thumb” considerably underestimated the shear required to mobilise fine sediment (silts) based on field testing of a flushing flow for the cobble bed Upper Yarra River. This could have been related to imbrication of the sediments (whereby particles are stacked nose down into the current), which may be a position of maximum resistance to movement (Gordon et al., 2004, p.191). They recommended a shear stress of 15 N/m^2 to mobilise surficial fine sediment. To flush fine material from sand beds, LYDEFTP (2004) adopted an arbitrary value of 8 N/m^2 for the Little Yarra River.

The Shields equation only applies to bed material of sand size and coarser. Although the bed and bank material of Darlot Creek is essentially clay-rich silts, field observations also identified the presence of sand in places (e.g. the red clays of the Darlot Creek drain downstream of Lake Condah have a high sand content – Harry Reed, pers. comm., 6 July 2007). Two critical shear stress values were adopted to indicate the threshold for transport of sands (Table 29): 0.5 N/m^2 for medium sand (up to 0.5 mm diameter) and 2.0 N/m^2 for very coarse sand (up to 1 mm diameter).

Table 29
Critical shear stress required to initiate sediment transport in unconsolidated sediments found in Darlot Creek.

Size class (Wentworth)	Shields critical shear stress for mobilisation (N/m^2)
Very fine – medium sand	0.06 – 0.5
Medium – very coarse sand	0.5 – 2.0

9.3.3 Thresholds for vegetation removal

It is well established that in-channel and riparian vegetation has a mediating influence on channel morphology, principally via the impact of plants on sediment dynamics (Ikeda and Izumi, 1990; Marston et al., 1995; Rutherfurd et al., 1999; Trimble, 1997; Zimmerman et al., 1967). In general, the behaviour of vegetation is to colonise and exploit the fertility of the riparian zone and surfaces within the stream channel, behaviour that favours encroachment and channel narrowing (Hupp and Osterkamp, 1996; Tabacchi et al., 1998). However, the hydrologic regime holds encroachment in check, with periods of inundation and the destructive power of floods acting to inhibit growth or to clear the channel by force (Nakamura et al., 2000). This dynamic balance can be adversely affected by regulated flow regimes (e.g. Nilsson and Svedmark, 2002), although in Darlot Creek the present hydrologic regime includes long periods of high in-channel flows that inhibit macrophyte encroachment into the channel.

Thresholds for grasses

Fluvial scour depends on the erosion resistance offered by the substrates forming the wetted perimeter, with vegetation increasing erosion resistance substantially. A field study by Prosser and Slade (1994) of grasslands in southeastern Australia examined gully erosion. They reported that widespread gully erosion could be explained solely by degradation of valley floor vegetation. Using a high-discharge flume, Blackham (2006) identified two key mechanisms by which herbaceous vegetation reduces scour. Firstly the sward (plant stems above the ground surface) acts as roughness elements, reducing the velocity and hence the erosive potential of overland flows. Secondly shear stress is partitioned between soil particles and the root system, with the dense root mats of grass species absorbing the bulk of the shear (Blackham, 2006).

Blackham's (2006) flume data confirmed the work of other investigators (Table 30) in showing that a critical shear stress in the range 80 – 200 N/m^2 is required to strip grass swards from stream beds. Blackham (2006) went on to demonstrate hydraulic conditions (shear stress and duration) in small to medium sized streams are rarely sufficient to scour well-grassed surfaces. The minimum shear stress required to impact the least hardy of grasses (i.e. poorly established bunch grass) is 80 N/m^2. This was adopted as an indicative threshold of when grass-lined banks or benches in the channel may start to be adversely affected by flow. This is a very high threshold and it is recognised that the distribution of grass in the channel is likely to be influenced by other factors (such as inundation duration). This threshold simply provides one part of the picture, indicating the likelihood that a given flow has sufficient energy to remove grass coverings.

Table 30.
Summary table of threshold shear stress for erosion from various studies (source: Blackham, 2006).

Vegetation type	Erosion threshold
Aquatic (swampy) vegetation (Prosser and Slade, 1994)	105 N/m^2
Tussock and sedge (Prosser and Slade, 1994)	240 N/m^2
Disturbed tussock and sedge (Prosser and Slade, 1994)	180 N/m^2
Bunch grass† 20-25 cm high (Prosser et al., 1995)	184 N/m^2
Bunch grass† 2-4 cm high (Prosser et al., 1995)	104 N/m^2
Bunch grass† (Hudson, 1971)	80-170 N/m^2*
Bunch grass† [Ree, 1949 in (Reid, 1989)]	80-90 N/m^2*
Bermuda grass (Hudson, 1971)	110-200 N/m^2*
Bermuda grass [Ree, 1949 in (Reid, 1989)]	120-180 N/m^2*
Buffalo grass, Kentucky bluegrass (Hudson, 1971)	110-200 N/m^2*
Buffalo grass [Ree, 1949 in (Reid, 1989)]	110-180 N/m^2*

† Any of various grasses of many genera that grow in tufts or clumps rather than forming a sod or mat.

* These ranges summarise data for a variety of soil types/hillslopes. See Reid (1989) and Hudson (1971) for more details

Thresholds for macrophytes

Emergent macrophytes are a second ubiquitous vegetation agent in stream channels. Intra-annual resistance variations of around one order of magnitude are attributed to seasonal stem density changes by Shih and Rahi (1982). Similarly, Mierau and Trible's (1988, in Kadlec and Knight, 1996) measurements in Boney Marsh show a four-fold increase in the annual average Manning's n, which is primarily attributed to the increases in stem density associated with the maturation of the marsh over the ten year study period. Cases of extreme resistance occur where the channel is choked, with Guscio et al. (1965) reporting reductions in the design channel capacity of up to 97%. Chemical and mechanical control methods are often deployed to prevent infestations, however natural hydrodynamic controls can obviate the need for such interventions (Duan et al., 2002). Groeneveld and French (1995) found that colonisation by macrophytes could be prevented if flow events of sufficient water velocity and depth were delivered. They show that sufficient bending stress induced by hydrodynamic drag on the macrophyte stem caused stem rupture (lodging); failure involving permanent deformation and loss of plant function. They quantified the depth-velocity envelope required to induce rupture, providing a means to estimate the flow required to provide hydrodynamic protection against encroachment. The discharge required to rupture macrophyte stems was computed by application of Groeneveld and French's (1995) relationship. The diameter of the macrophyte stems tested was set, as recommended by Groenveld and French (1995), to 0.0119 m (11.9 mm). Two thresholds were then evaluated to give a 95% and 99.9% chance of stem rupture respectively. The thresholds are reported as a discharge required for the product of flow depth and velocity to exceed either 0.152 ($Q_m^{95\%}$) or 1.52 ($Q_m^{99.9\%}$).