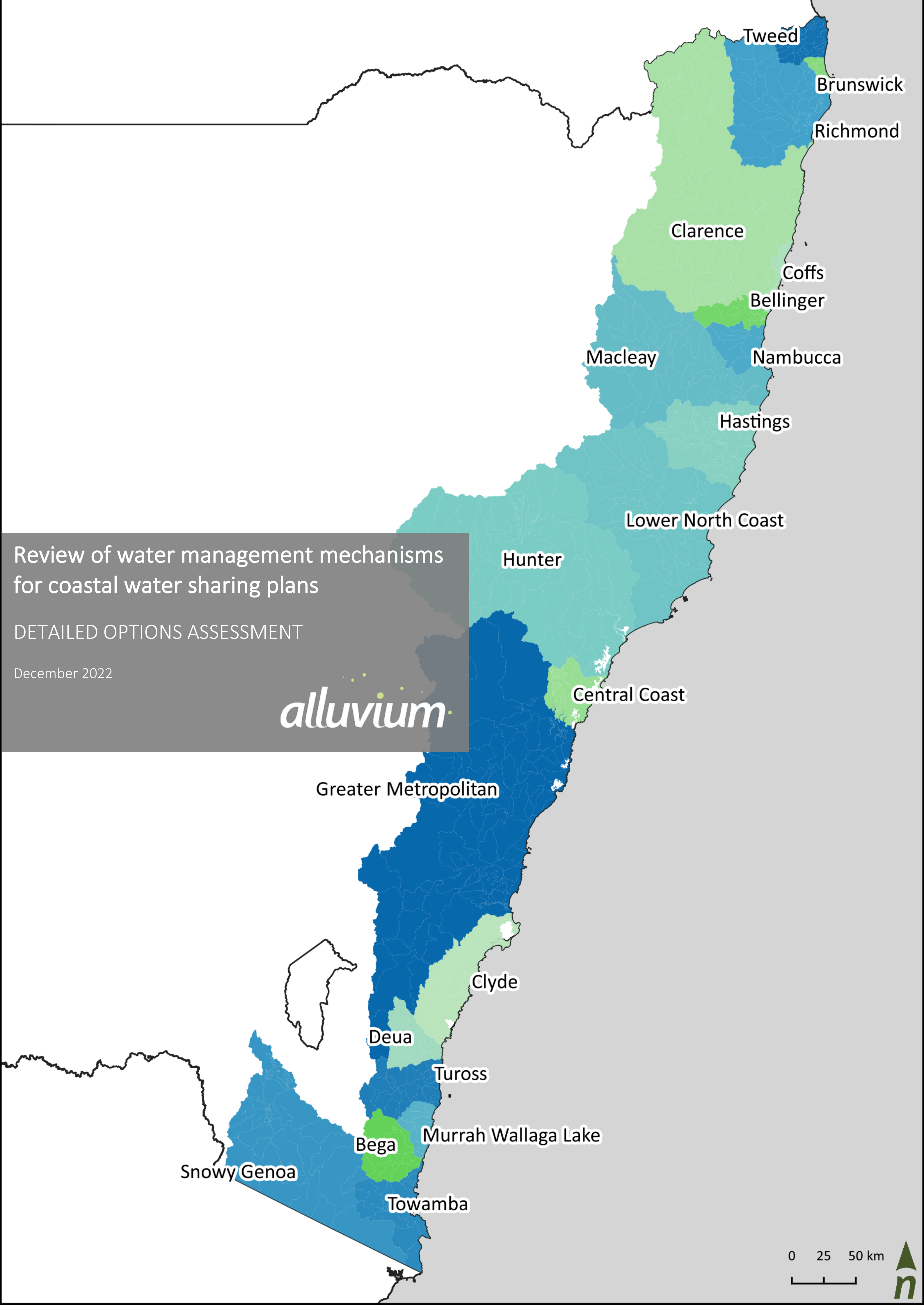
Review of water management mechanisms for coastal water sharing plans

DETAILED OPTIONS ASSESSMENT

December 2022

alluvium



Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Vicki Golding. This piece was commissioned by Alluvium and has told our story of water across Country, from catchment to coast, with people from all cultures learning, understanding, sharing stories, walking to and talking at the meeting places as one nation.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for the NSW Department of Climate Change, Energy, the Environment and Water under the contract titled PROC 1465 "Review of water management mechanisms used by other jurisdictions to protect the environment and achieve legislative outcomes".

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Contents

Figures

Tables

1 Introduction

1.1 Background

Extraction, diversion, and development of NSW water resources is regulated under the *Water Management Act 2000* (the Act). Water sharing plans (WSPs) are prepared under the Act to provide water management arrangements for specific catchments or water resources.

Clause 8 of the Act requires WSPs to commit water to fundamental ecosystem health that cannot be taken or used for any other purpose. This 'planned environmental water' is largely provided through defining a long-term average annual extraction limit (LTAAEL) on consumptive take.

The LTAAEL specifies the total volume that can be taken from the water source over the long term and is intended to provide for the long-term environmental objectives of WSPs and meet the objects of the Act. In addition to the LTAAEL, WSPs also commit planned environmental water through other rules such as access rules that restrict extraction during various flow conditions.

In the inland regulated WSPs, the LTAAEL is set at the level of long-term annual extraction that would have occurred under historical conditions, effectively freezing total take at a point in time. Inland WSPs are also subject to compliance with Sustainable Diversion Limits as specified in the *Basin Plan 2012*.

In many coastal WSP areas, the LTAAEL has been set at the total volume of licenced entitlement and an estimate for basic landholder rights. The limit on take in a water source is essentially the total potential volume of water that can be taken from the water source under an entitlement plus basic landholder right. In recent reviews of coastal WSPs the Natural Resources Commission (NRC) recommended the review of coastal LTAAELs and the development of an extraction limit that better aligns with the objects and principles of the Act.

The Water Group in the Department of Climate Change, Energy, Environment and Water has initiated a work program to review and improve LTAAELs in coastal WSPs. This work program will consider NRC recommendations and how to better give effect to the objects and principles of the Act.

The first component of this work program is a review of methods currently implemented in other Australian states as well as internationally to define limits on surface water extraction. The review will focus on how a given jurisdiction's extraction limit was set to consider the specific needs of local water-dependent environmental assets and extractive use.

1.2 This report

Alluvium was engaged by the Water Group to conduct a review of water management mechanisms implemented in other Australian states as well as internationally to assist it in identifying:

- methods for determining limits to extraction
- how the limit helps meet a jurisdiction's legislative requirement to protect the environment and provide water for licence holders and basic rights users
- any relevant mechanisms that complement the limit including access rules, water allocations etc
- the applicability of the method within NSW water management legislation
- Additional legislative and policy context around the methods to better understand both the overall process and critical policy decision points

To support this report, a broad literature search of publicly available documents was conducted to identify a long list of case studies, from which a short list has been selected to support more detailed analysis.

2 Project methodology

A broad literature search of publicly available documents was conducted to identify Australian and international case studies for how extraction limits that consider environmental assets were set. The focus of the search was to identify well-documented examples of the methods that a range of jurisdictions used to identify and understand the watering requirements of environmental assets and how those requirements were balanced against extractive use in water sharing plans.

From the literature search, a long list of 10 examples were identified that was later expanded to 11 Assessment questions were provided by the Water Group staff to assist in refining the examples to short list. A Water Group project advisory group selected six examples to be further assessed and reported on in detail. Those examples constitute the shortlist in section 3, where the full management hierarchy is described.

2.1 Literature review - Developing a long list of examples

Publicly available information was reviewed, using search engines to identify academic and public sector literature. Search terms included:

- Water sharing plans
- Water allocation plans
- Allocation limits
- Environmental water requirements
- Environmental water provisions
- Ecological limits of hydrological alteration

As well as search engine results, the websites of governments and non-profit organisations such as the Nature Conservancy and Worldwide Fund for Nature were reviewed to provide context for reports, plans and regulations.

Several geographical jurisdictions were focussed on to identify examples for which sufficient literature was considered to be available. To ensure adequate accessible documentation, comparable hydrology and issues with supply limitations and a similar level of focus on managing those limitations, geographical areas that we focused on included:

- All Australian mainland states
- English speaking countries: USA, England, New Zealand
- Southern Europe: Spain and Italy
- South Africa
- Mekong River

European examples were investigated as it was assumed that there would be a large amount of comparative literature available under the European Framework Directive for Water that would be accessible in English.

The search focused on southern Europe as it was thought that the water resources are more likely to be supply limited in this region, justifying the application of a limit to share water between consumptive users and the environment. A greater quantity and quality of Spanish literature was available, and that country was chosen as the focus. The Douro and Ebro River basins are the largest two basins in Spain and literature for both was reviewed before the Ebro was chosen due to more accessible regulatory literature.

Of the English-speaking countries, Canada was not a focus for research as it was assumed that water quantity is less likely to be limited in its humid environment.

There is a great deal of published literature on the Mekong River, including on environmental flows. However, the huge range of issues including multiple, difficult-to-translate languages and lack of an overarching management framework excluded it from the long list.

2.2 Long list

From the initial literature search, a long list of 10 examples was developed, later expanded to 11 (Table 1). Examples were selected to reflect a wide range of regulatory environments and different levels of the management hierarchy, from high level policy through regulatory plans, management mechanisms and environmental flow methods. Some examples were selected because they illustrated interesting policy approaches and others for well-documented technical assessment approaches.

The assessment questions in the first column of Table 1 were provided by Water Group staff. The examples were described in terms of how well they could address each question and were ranked from one to three in terms of how well it answered the question. Descriptions of each of the long list examples are provided in section 4.

2.3 Refining examples to a shortlist

A Water Group project advisory group was presented with the long list of 10 examples. Each example was discussed in relation to its applicability to the NSW context in terms of the regulatory environment, the hydrology and physical pressures on the water resource, and the quality of available information. In response to feedback from the meeting, another example from New Zealand was included to make a total of 11 examples on the long list.

An assessment report with the scores (as set out in Table 1) and descriptions (as described in section 4) was provided to the advisory group, which selected seven examples to be assessed in detail. Preliminary scores were assigned by the Alluvium project team based on how well the example answered the assessment questions:

- A score of three meant that the example could be used to directly address the question
- A score of two meant that the example could potentially be interpreted in ways that addressed the question
- A score of one meant that the example was not relevant or could not be used to address the question.

Scores were further refined after discussion with the advisory group.

The scoring was used as a guide by the advisory group but not the final determinant of selection for the shortlist. Some examples were chosen for their technical approaches, some for their policy and management framework and some for specific issues relating to water sharing.

The shortlisted examples are described in detail in section 3 of this report. For each shortlisted example, the full management hierarchy is described, from legislative requirements through to environmental objectives in plans to environmental flow methods used to set an extraction limit, quantitatively express objectives and develop rules that give effect to the objectives.

Table 1 Long list of examples considered by the Water Group's Advisory Group

	South Australia, Storage management	Queensland, fully allocated system	Western Australia, fully and under-allocated systems	Victoria, LTWRA	Spain, methods and governance	USA, methods	New Zealand, water resource consents	Vic. and WA, Statistical methods for setting limits	California, tribal rights	South Africa, water resource management	England, Groundwater-surfacewater interactions
What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes, share water between extractive users etc…	2	3	3	3	3	3	3	1	1	2	3
What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdiction's legislative requirements?	3	3	3	3	2	2	3	3	1	2	3
What types of information/data are used as the basis for establishing the limit? Is a model required?	3	3	2	2	2	3	2	2	1	2	2
How applicable is this method to the NSW context?	2	2	3	2	2	2	1	2	2	1	1
Does the example describe a volumetric limit?	2	3	2	3	2	2	2	3	1	2	2
Does the example attempt to achieve specific environmental objectives?	2	3	3	1	2	3	2	1	2	2	3
Is the legislative and governance context in the example relevant to NSW?	3	2	3	3	2	1	3	3	1	2	2
Is the hydrology that the mechanism applies to similar to NSW coastal catchments?	1	2	2	2	2	2	1	1	2	2	1
Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?	2	3	3	2	2	1	3	3	1	2	2
Is the example suitable for application to data-poor catchments?	2	1	2	1	1	1	1	3	1	2	1
Is the example suitable for application to data-rich catchments?	3	3	2	3	3	3	3	1	3	2	3
Does the example provide lessons regarding methodologies for determining environmental water requirements?	3	2	3	2	3	3	2	1	2	2	2
Total score	28	30	31	27	26	26	26	24	18	23	25

3 Detailed water sharing examples

3.1 Environmental Water Provisions in Water Allocation Plans - South Australia

Summary • A three-stage assessment process is required within Water Allocation Plans to determine environmental water requirements and, if they are being met under current conditions, set provisions that help meet those requirements. • The 'natural' or baseline scenario was defined as 'flow with the impacts of the 2005 level of dam development removed'. • Environmental water requirements were described by assigning functional biotic groups, identifying the flow-dependent ecological processes required by those groups and translating the water regime components required to support those processes into measurable hydrological metrics. • Limits for how far these metrics can deviate from its value whilst still maintaining a "low risk" to ecological processes were set by an expert panel and expected to be refined through on-ground monitoring. • Current development failed the initial "low risk" metrics for almost all model nodes. The expert panel subsequently established an "acceptable level of risk" metric as meeting 85% of EWRs for at least 50% of model nodes. • The success rate of meeting the "acceptable level of risk" was tested under different management scenarios with changes to extraction volumes, cease to pump thresholds and storage size tested. • It was found that limiting harvesting to 20% of catchment runoff and imposing passing flow requirements on all dams over 5ML met the "acceptable level of risk" requirements
Lessons learnt/Applicability to NSW • Strong learnings for establishing flow-ecology relationships in data-rich catchments • Scenario testing of Environmental Water Provisions provides an evidence-based approach to making trade-offs between environmental, social and economic needs • Managing extraction in unregulated catchments using storage rules embedded within water sharing plans

Legislative framework

Water management in South Australia is structured similarly, with similar objectives to its NSW counterpart. The overarching *Natural Resources Management Act 2004* (the SA Act) provides a framework for licensing and the power to make Water Allocation Plans that provide for the allocation and use of water so that—

(i) *an equitable balance is achieved between environmental, social and economic needs for the water; and*

(ii) *the rate of use of the water is sustainable*

The SA Act contains environmental objectives relating to the *achievement of ecologically sustainable development…that:*

(i) *recognises and protects the intrinsic values of natural resources*

(ii) *seeks to protect biological diversity and insofar as is reasonably practicable, to support and encourage the restoration or rehabilitation of ecological systems and processes that have been lost or degraded…*[1]

To achieve these outcomes the SA Act requires all water allocation plans to include:

- *an assessment of the quantity and quality of water needed by the ecosystems that depend on the water resource and the times at which, or the periods during which, those ecosystems will need that water…*[2]
- *an assessment as to whether the taking or use of water from the resource will have a detrimental effect on the quantity or quality of water that is available from any other water resource*

These assessments are conducted in three stages:

Stage 1: determines the environmental water requirements that must be met to sustain the ecological values of ecosystems that depend on the water resource at a **low level of risk**.

Stage 2: assesses the water sources ability to meet these environmental water requirements under current conditions.

Stage 3: sets environmental water provisions (rules) where environmental water requirements are not being met under current conditions. Environmental water provisions are set so that there is an **acceptable level of risk** to the environment while also recognizing existing users' rights and social and economic impacts. Such objectives and provisions will involve accepting a higher level of risk of environmental degradation but should have an acceptable probability of maintaining water-dependent ecosystems in a sustainable state in the long term.

Eastern Mount Lofty Ranges Water Allocation Plan

The Eastern Mount Lofty Ranges Water Allocation Plan covers an area of 2,800 km^2 that is located approximately 30 km southeast of Adelaide. The climate and hydrology are highly seasonal, with the great majority of runoff generated in winter and early spring and regular cease-to-flow periods in summer and autumn.

The plan divides the area into 16 catchments and 195 water management zones. A large number of small water management zones (WMZs) have been described to adequately address the large variation in rainfall and water availability across the plan area. The WMZs also correspond with geomorphic and ecological stream categories such as upland wetlands, basement-controlled streams and gorges, lowland rivers etc. WMZs are either Headwater Zones that generate runoff or Receiving Zones that also receive runoff from other zones. Waterways within Receiving Zones are classified as "Main Watercourses", and specific passing flow rules are in place for these waterways (Figure 1).

[1] *Natural Resources Management Act 2004 S.7(1)*
[2] *Natural Resources Management Act 2004 S.76(4)(a)(i)*

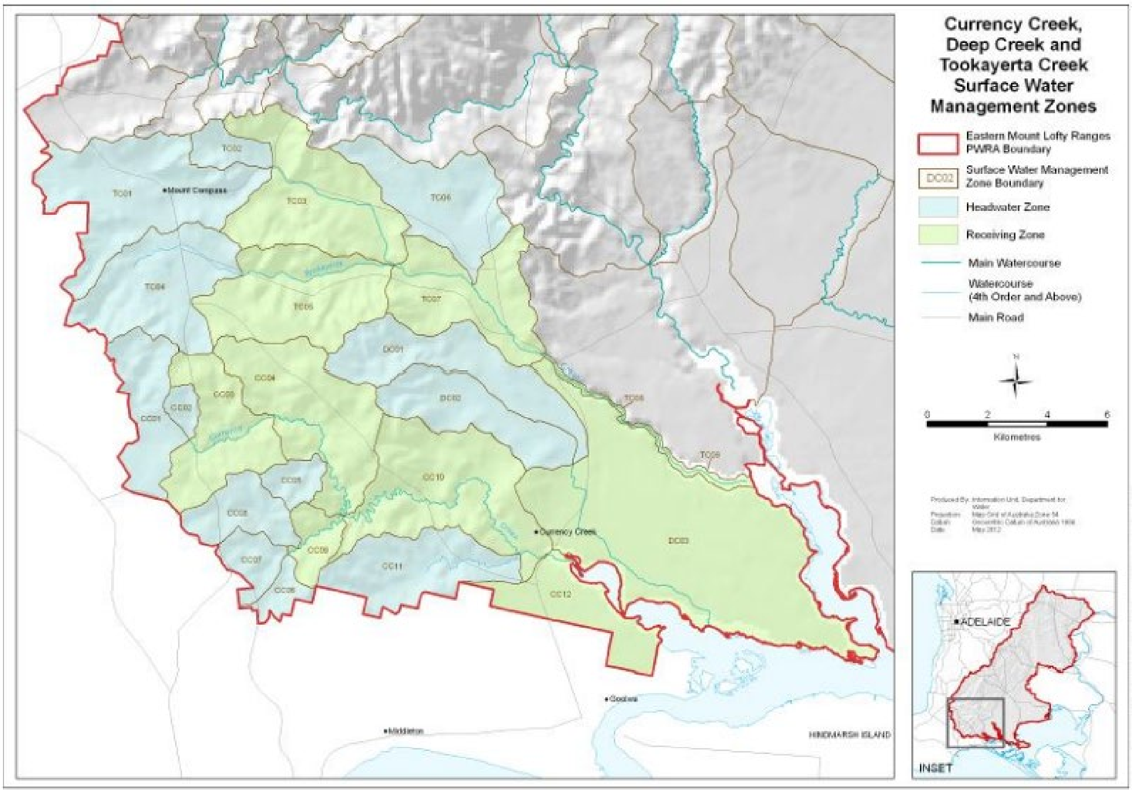


Figure 1 Water management zones in the Currency, Deep, and Tookayerta Creek catchments of the Eastern Mount Lofty Ranges Water Allocation Plan.

In addition to delivering on the objectives of the SA Act, the Eastern Mount Lofty Ranges Water Allocation Plan has specific objectives relating to water-dependent ecosystems and environmental water requirements including:

- *Maintain and, where possible, restore water-dependent ecosystems, by providing their water needs and addressing detrimental impacts from water affecting activities*
- *Maintain and/or restore self-sustaining populations of aquatic and riparian flora and fauna which are resilient in times of drought*

The objectives are delivered through the three-stage assessment of ecosystem water quantity needs.

Stage 1: Determine EWR's
An expert panel, existing literature and further studies were used to determine the environmental water requirements for surface water in the Eastern Mount Lofty Ranges. An environmental objective was set to describe the desired state to be achieved by providing environmental water requirements. This objective is to maintain and/or restore self-sustaining populations which are resilient in times of drought. The Eastern Mount Lofty Ranges Water Allocation Plan was clear that it is not the intention of the objective to restore the habitat and ecosystems to pre-European conditions.

Functional groups were assigned with similar life cycles, habitat requirements and environmental water requirements. This approach focused on well-studied groups such as fish, macroinvertebrates, and water-dependent plants. It was assumed that if EWRs for these functional groups could be met than other EWRs for other water-dependent functional groups would also be met.

Environmental water requirements were described for each biotic functional group by identifying the flow-dependent ecological processes required to meet the environmental objective for the group, and then identifying the water regime components required to support each of those processes. Water regime components were translated into measurable hydrological metrics.

Limits were set for each metric in terms of how far the metric can deviate from its value under natural conditions while still maintaining the ecological process supported by that flow component at low risk. Natural flows were defined as the “flow with the impacts of the 2005 level of dam development removed”. This definition accepts that some irreversible hydrological change has occurred from pre-European times and that it is highly unlikely that the river system will return to pre-development conditions. This work was conducted using a distributed hydrological model in the WaterCRESS platform.

The percentage of how far a metric can deviate from natural was developed by an expert panel and seen as a ‘first cut’ to be refined with on-ground monitoring.

Table 2 Priority groups for metrics and percentage deviation from the natural value associated with low ecological risk

Priority	Functions	Low risk deviation from natural (decrease)	Low risk deviation from natural (increase)
1	Maintenance of core refuge habitat or critical life-cycle processes	20%	25%
2	Promote resilience in the long term (e.g. large breeding events)	30%	50%
3	General information or metrics that represent resilient water requirements	50%	100%

A metric that remains within these limits is considered to ‘pass’, while a metric that exceeds these limits is considered to ‘fail’ to provide an adequate environmental water requirement. For example, a Priority 1 EWR such as the ‘average number of freshes per year’ cannot decrease by +20% or increase by +25% from what was seen under natural conditions and ‘pass’. This EWR is linked back to ecological outcomes such as maintenance of core aquatic habitat, flushing of mountain galaxias spawning sites and allowing localised fish movement”.

Passing all the metrics represents the quantity and timing of water requirements to sustain water-dependent ecosystems in the Eastern Mount Lofty Ranges at a low level of risk

Example - Setting environmental water requirements for fish (functional group)

Mountain galaxias and southern pygmy perch are relatively short-lived species (approximately 3 years). Suitable breeding conditions need to occur with enough frequency to build population numbers and promote resilience to withstand poorer flow years and ensure the survival of these species.

Better-than-marginal recruitment was related to the number of hydrological metrics such as “Average number of fresh events in the High Flow Season” as a Priority 1 function this was allowed to deviate up to 20% below or 25% above what would occur naturally and still ‘pass’.

Stage 2: Meeting EWR’s under current conditions

Sixty-nine sites across the water allocation plan area were modelled to test how EWRs are being met under current conditions. Daily flow data was modelled under current and ‘natural’ conditions from 1974-2006 using the WaterCress system. Natural conditions were calculated as the flow with the impacts of the 2005 level of dam development removed. This approach accepts that some irreversible changes from pre-European flows have occurred due to land clearance and other landscape changes.

The comparison between these two model runs will assess whether EWRs are currently being met to a low risk in the Eastern Mount Lofty Ranges.

Only 1 of the 69 sites passed all EWRs and can be said to represent the quantity and timing of water requirements to sustain water dependent ecosystems at a low level of risk. On average less than 70% of EWRs were met. This suggests that water dependent ecosystems are at an elevated risk of degradation at almost all test sites.

The number of EWRs met varied between flow 'seasons' and sites with higher water use generally passed fewer metrics.

Table 3 Average percentage of metrics passed in each flow season

Season	Average % metrics passed
Low flow season	45%
Transitional flow season 1 (low to high)	63%
High flow season	86%
Transitional flow season 2 (high to low)	62%

EWR pass metrics were then compared with on-ground ecological monitoring data. Adequate data was only available for fish and macroinvertebrate but showed a correlation between poor ecological condition and a lower number of passed EWR metrics at a site.

Stage 3: Setting Environmental Water Provisions (EWPs) (rules) to better meet Environmental Water Requirements

In the Mount Lofty Ranges EWRs are not being met by current conditions. In this circumstance the water allocation plan is required to develop, test and implement EWPs that better meet EWRs and achieve an equitable balance between social, economic and environmental needs for water. Ecosystems must be protected however having no water available for consumptive use will not meet the social and economic needs for water.

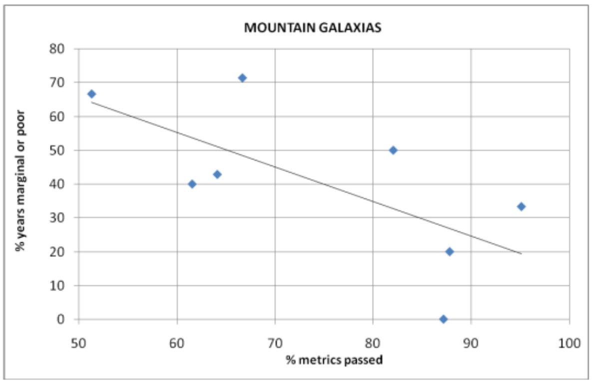
EWPs are set to achieve an **acceptable level of risk** to the environment. This is defined as the 'minimum acceptable ecological condition that is expected to allow populations to be self-sustaining' which meets the overall objective of maintaining and/or restoring self-sustaining populations of aquatic and riparian flora and fauna which are resilient in times of drought. The move to acceptable risk is a shift from the previous EWR assessment requirement to sustain water dependent ecosystems at a low level of risk.

Expert opinion was used to determine the acceptable level of risk to each functional group.

Acceptable risk to fish breeding, for example, was determined to be better-than-marginal recruitment events occurring at least seven years out of every ten. Periods of poor to marginal breeding events occur under natural conditions and native fish species have developed strategies to persist through these periods. While marginal, enough recruitment is expected to occur in these years to maintain sufficient population numbers for these species to recover

The percentage metrics passed was related to ecological condition to determine that an 85% metric pass rate equates to the requirement for better-than-marginal recruitment events occurring at least seven years out of every ten (Figure 2). A similar process was conducted to determine 'moderate to good macroinvertebrate community condition' with 85% metric pass rate also correlated to acceptable risk.

To shift from **a low to acceptable risk the EWP objective is to pass 85% of the EWR metrics.**



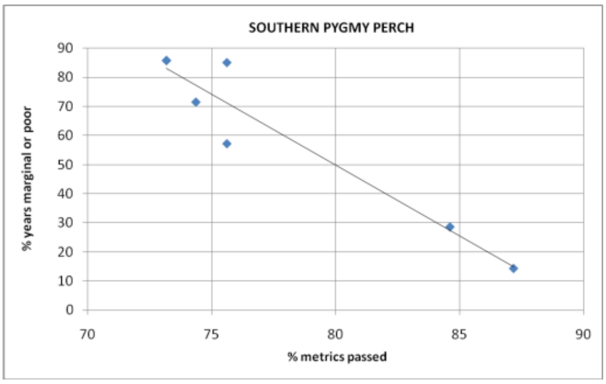


Figure 2 Relationship between fish recruitment and compliance with environmental flow metrics in the Mount Lofty Ranges (VanLaarhoven & van der Wielen 2009)

Scenario testing of EWPs

The surface water models were used to test the EWR metrics success rate (i.e. % metrics passed) under a range of water management scenarios. As part of the process of balancing social, economic and environmental water needs, it was considered that the environmental water provision objective should be met at the majority (at least 50%) of test cases within a management scenario.

> 85% of EWR = EWP Pass at site to acceptable risk.
>
> +50% of site passes = acceptable management scenario.

Scenario 1 – Managing extraction volumes only

Scenario testing indicated that the EWPs could be passed at 85% at more than 50% of sites if overall extraction is limited to 5% of resource availability. This assumes there are no other restrictions on the location, size and operation of farm dams apart from volumetric extraction (Alcorn 2011). The plan defines resource capacity as the mean annual runoff (Alcorn 2006, Alcorn et al. 2008) at a range of scales. Evaporation is a large component of the water balance in the plan area, and all plan provisions regarding storages include modelling its effects, as well as those of direct use. This scenario assumed full use of run-of-river entitlement and 50% use of licenced dam capacity.

However, extraction was less than the required 5% of runoff at only 10% of reporting sites. To achieve the reduction in take at the other site, a large number or volume of licences would need to be reduced or surrendered. This was determined to compromise the economic and social objectives of the water allocation plan.

Scenario 2 – Managing extraction volumes with Cease-to-Pump (CtP) thresholds

The current conditions analysis showed that the EWRs related to the smaller flow components (freshes and low flows) are particularly affected. If these lower flows were not diverted by farm dams and returned to the system, it may be possible to allocate larger volumes for consumptive use while maintaining an acceptable level of risk to the environment.

A scenario was developed that included a diversion rule that returns flows at or below a threshold flow rate from farm dams back to the system (CtP). Threshold flow rates equivalent to the 80th percentile were set based on the size of freshes in the two transitional flow seasons, as these are the largest of the flow components that have been strongly affected by surface water resource development.

1. 80th percentile CtP for licenced dams and varying of extraction volumes

In this scenario, an 80th percentile CtP was applied to licenced dams in the plan area before varying the extraction volume and assessing EWP compliance. Extraction volumes were increased from zero until the point where most sites still met the 85% EWP compliance rate. This was achieved at 5% of runoff.

The 5% of runoff extraction volume is similar to Scenario 1 and does not meet the economic and social considerations of the plan. Interrogation of this scenario showed the predominant issue was licenced dams passing below CtP flows that are then captured by downstream unlicenced dams that are not subject to the CtP requirements.

2. **80th percentile CtP for licenced and unlicenced dams > 5 ML dams and varying of extraction volumes**

In this scenario, an 80th percentile CtP was applied to both licenced dams and unlicenced dams greater than 5 ML in the plan area before varying the extraction volume and assessing EWP compliance. Extraction volumes could be varied to 20% of runoff and the majority of sites would still meet the 85% EWP compliance rate.

The result is 78% of sites in the plan area use 20% runoff or less. Setting a limit at this level meets the requirements of the environment whilst balancing the social and economic circumstances.

In order to balance social, economic and environmental water needs, it is recommended that both:

- an ongoing evaporation and consumptive use limit of 20% of upstream mean annual adjusted runoff is set; and
- provisions be made for existing licensed dams and diversion structures, and existing dams used for non-licensed purposes with a capacity of 5 ML or greater, to return or not capture flows at or below the threshold flow rate.

It is also recommended that all new and enlarged dams and watercourse diversions should return or not capture flows at or below the threshold flow rate to allow environmental water provision objectives to continue to be met as future development occurs.

Future development is catered for so long as the EWP objectives are maintained. This means that new dams are allowed but with appropriate CtP thresholds that may be higher than the standard 80thpercentile.

Extraction Limit = 20% RAINFALL RUNOFF IF 80TH PERCENTILE CtP APPLIED.

Additional management actions

Water is managed at a range of scales smaller than the plan area (see Figure 1) to prevent localised impacts and limit overall water diversions. In the 22% of water management zones (WMZs) where current allocation is greater than 20% of runoff, no further development is permitted. In the remaining 78% of WMZs where allocation is less than 20% of runoff, new licences can be granted, but only if overall diversion for the catchment and plan area is less than 20% and storage is less than 30%. In effect, this will mean that some WMZs remain permanently ‘under allocated’ to offset the overallocated catchments.

As well as the catchment and WMZ scale rules, any individual dam may only intercept 30% of its catchment’s runoff and use is limited to 20%. The dam and property scale rules are intended to share water amongst consumptive users and are not expected to meet environmental objectives.

3.2 Environmental Water Provisions in Water Plans – Queensland

Summary

- A six-step ecohydrological risk assessment focusses on the environmental water requirements of ecological assets, evaluates the effectiveness of an existing plan and makes recommendations for replacement plans. The steps are described below
- Identify ecological assets which have critical links to flows
- Define the critical flow requirements for chosen assets
- Determine thresholds of concern for the assets (EWRs)
- Assess risk based on model scenarios – which look at the frequency and distribution of when thresholds are met on a temporal and spatial scale (for example breeding opportunities)
- Minimum environmental flow objectives (modelled metrics) for various nodes are included in attachments to water management protocol
- Amendments to access rules during the life of a plan must be modelled and shown to meet the specified environmental flow objectives
- The Border Rivers and Moonie Water Plan is presented as a case study for how environmental objectives and measures were developed using the risk-based, three-stage process.

Lessons learnt/Applicability to NSW

- Risk assessment recognises and allows for localised extinction and recolonisation over the historical model period due to connected water sources
- Methods that can be applied to catchments with irregular hydrology
- Limit method is based on specifying minimum environmental water requirements as opposed to maximum average consumptive limits
- Modelling of entitlement and proposed access arrangements and the meeting of flow objectives over the historical model period is considered sustainable for the life of the plan (no annual modelling or AWD checks required)

Legislative framework

The Queensland *Water Act 2000* provides the legislative framework for the sustainable planning, allocation and management of water resources in Queensland. It defines sustainable management as management that

- *incorporates the principles of ecologically sustainable development;*
- *allows for the allocation and use of water resources and quarry material for the economic, physical and social wellbeing of the people of Queensland, within limits that can be sustained indefinitely; and*
- *sustains the health of ecosystems, water quality, water-dependent ecological processes and biological diversity associated with watercourses, lakes, springs, aquifers and other natural water systems, including, where practicable, reversing degradation that has occurred*[3]

Water plans provide the principal mechanism for achieving the Act's requirements. Although the Act does not explicitly identify the need to determine environmental water requirements or set a volumetric extraction limit, it does require water plans to

- *state the desired environmental outcomes of the management and allocation of water to which the plan applies*[4]
- *state arrangements for providing water for the environment*[5].

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[3] *Water Act 2000 S.2(2)*
[4] *Water Act 2000 S.43 (1)(b)*
[5] *Water Act 2000 S.43 (1)(d)*

A water plan for a particular catchment area specifies the *measures* for achieving a variety of economic, social, cultural and environmental *outcomes*, as well as *objectives* and *performance indicators* that will be used in periodic ministerial performance reports.

For the purposes of evaluating the effectiveness of water plans in achieving their ecological outcomes, the Queensland Government uses an ecohydrological risk assessment focussed on the environmental water requirements of ecological assets (McGregor et al. 2017). The risk assessments evaluate the effectiveness of the existing plan and make recommendations for replacement plans.

The environmental assessment uses a risk-based approach that identifies ecosystem values (ecological assets) that are linked to desired ecological outcomes, sensitive to flow alteration and representative as indicators of broader ecosystem requirements.

Summary of the risk assessment and plan-development process:

Stage 1 – Identify ecological assets

- Identify surface water and groundwater dependent ecological assets in the water plan area that are potentially vulnerable to water resource development
- Summarise results of monitoring relevant to the water plan
- Assess the effectiveness of the existing water plans

Stage 2 – Quantify environmental risks and recommend mitigation options

- Summarise the potential risks to the ecological assets as identified in Stage 1.
- Present the risk to the assets under a full entitlement scenario that assumes all entitlement is used when available. This full entitlement scenario represents the 'worst case' and is not representative of how water users actually take water.
- Define 'thresholds of concern' - frequency of hydrological events such as freshes required to protect the asset over the long term. Thresholds of concern represent failure points for the ecological asset and are synonymous with minimum ecological water requirements.
- Make conclusions on the relative overall risks to ecological assets from extraction in the water plan area.
- Provide recommendations and mitigation options to be considered in the draft water plans

Stage 3 – Develop environmental outcomes, objectives and performance indicators, and draft water plan measures

- Develop the draft water plans with consideration for the recommendations of the environmental risk assessment. The draft water plan also includes performance indications, objectives and other provisions to mitigate risks
- The draft water plan also considers the results of a parallel assessment of current risks to:
    - consumptive water users
    - Aboriginal values and uses
    - water quality

  and an assessment of risks that may be encountered over the ten-year life of the plan.

Risk-based environmental assessment

Two different government departments are currently responsible for developing environmental objectives and measures to achieve them through the water planning framework. Broadly speaking the responsibilities are as such:

- the Department of Environment and Science (DES) conducts the environmental risk assessment (Qld Govt 2018a) and recommends measures for inclusion in the Water Plan
- the Department of Regional Development, Manufacturing and Water (DRDMW, formerly Department of Natural Resources, Mines and Energy DNRME) develops the Water Plan, having regard to

recommendations from the environmental assessment, as well as its own parallel assessment of other risks.

A detailed discussion of each stage, including an example water plan, is included here:

Stage 1 - Identify ecological assets

During this stage, the DES reviews all available scientific information and relevant monitoring data with the overall objective of establishing a relationship between ecological values and elements of the flow regime.

1. *Ecological asset identification*

Ecological assets may be a species, a group of species, an ecosystem function, an ecosystem, or a place of natural value. They occur in the plan area, have (an) aspect(s) of their life history or process requirement critically linked to water, and are sensitive to hydrological alteration. Individual ecological assets are chosen as indicators to represent each component of the hydrograph. Mitigating the risk to these indicator assets is assumed to mitigate risks to all related assets with critical flow requirements in that component of the hydrograph. Indicator species are chosen using a cross-asset comparison of critical flow requirements and assessment of sensitivity to hydrological alteration. The availability of monitoring data is also considered.

2. *Defining critical flow requirements*

Flow facets (e.g. magnitude, duration, timing, frequency, rate of change) are developed for each ecological asset from the best available science and expressed as an ecological requirement that relates to a specific hydrological condition.

For example: *spawning trigger flow = X magnitude for Y period between T1–T2 time of the year*

These hydrological requirements are used in a modelling framework and applied to a daily flow time series representing a water resource development scenario to generate a time series of opportunities for an ecological response.

This likelihood data represents the probability of an ecological asset/indicator experiencing the critical hydrological conditions when and where they are needed over the assessment period.

3. *Defining assessment endpoints*

For most of the species-based ecological assets considered in this assessment, the measurement endpoints relate to spawning and recruitment opportunities linked to aspects of the flow regime. Measurement endpoints for ecological process- and service-related ecological assets vary; however, they typically relate to the provision of critical habitat, or the conditions which support ecosystem structure and/or function.

Example - Border Rivers and Moonie water plan

In the Border Rivers and Moonie Water Plan the indicator ecological assets and the hydrograph components they represent are:

- stable flow spawning fish (Border Rivers and Moonie)—low flows
- Macintyre River Billabongs (Border Rivers)—medium flows
- fluvial geomorphology and river forming processes (Border Rivers and Moonie)—bankfull flows
- floodplain wetlands (Border Rivers and Moonie)—overbank flows
- eastern snake-necked turtle (Border Rivers and Moonie)—overbank flows
- refuge waterholes (Moonie)—no flow and low flow.

By implementing mitigation strategies that address risks to stable flow spawning fish it is assumed that other environmental values that are dependent on low flows will also be protected. Similar assumptions are made for other elements of the flow regime (DES 2018).

Stage 2 - Quantify risks and recommend mitigation options

During this stage, the DES uses modelling approaches to estimate the level of risk to environmental values under different hydrological regimes

4. *Thresholds of concern (ToC)*

Thresholds of concern (ToC) are defined to represent the frequency of these flow events required to protect an environmental assets long-term viability. ToCs represent 'failure points' beyond which the ecological asset is not expected to survive over the long term. As such, ToCs can be considered as minimum environmental water requirements.

The process outlined above requires both a sound conceptual understanding of the flow-dependent ecological assets and detailed biological and/or process knowledge relating to their critical flow dependencies.

The probability of achieving a desired ecological outcome is directly related to meeting a ToC over time. Together, critical flow requirements and ToCs are an expression of the environmental watering requirements of ecological assets.

5. *Defining likelihood–ecological and hydrological modelling*

Information on the critical flow requirements of ecological assets is used to develop a time series of flow-related opportunities from modelled daily river flow simulations.

Simulated daily flow time series (as ML/day) were modelled for both scenarios at 18 assessment nodes representing stream flow gauging stations in the plan area (Figure 1), using the eWater Source model.

6. *Assessing risk to surface water ecological assets from water resource development scenarios*

The risk to ecological assets is assessed at all nodes of the hydrological model within the asset's known distribution. This basin-scale assessment of environmental risk accounts for natural variability and the mobility of flora and fauna. This ensures that risk is evaluated at the spatial and temporal scale over which assets function and recognises that local extinction and recolonisation can occur naturally.

Risk, as it relates to the measurement endpoint, is a product of the time series of flow-related opportunities (likelihood) and the frequency of ToC exceedance (consequence). Risk was assessed at a range of spatial scales relevant to the asset (assessment node, floodplain assessment reach, and assessment area).

Ecological assets with a low risk are likely to receive their environmental watering requirements at a frequency required to support their long-term viability, whereas assets at medium and high risk are less likely to do so, such that long-term viability may be compromised at various spatio-temporal scales.

Example – Border Rivers and Moonie water plan
Hydrological scenarios for the risk assessment

The risk to ecological assets within the plan area was assessed at all locations where hydrological simulations were available within its known distribution (DES 2018). Three surface water development scenarios were assessed:

1. pre-development: assumes no water resource development across the plan area, but with existing infrastructure in place.
2. full entitlement: full use of existing entitlements with current Resource Operation Plan (ROP) operating rules and existing infrastructure–this scenario does not reflect current utilisation of water entitlements.
3. Intergovernmental Agreement (IGA): represents the level of development in the border rivers at the time of the moratorium. Includes water licences, installed pumps, storages, and planting practices/areas.

Risk assessment outcomes

The environmental assessment of the Border Rivers Plan area identified low to medium risks to ecological assets (**Error! Reference source not found.**). Definitions of risk levels were not specified, other than that they were consistent with Chapter 10, Section 9 of the Murray Darling Basin Plan.

Table 4 Ecological risk in the Border Rivers plan area. Source: DES (2018)

Ecological asset	Element of flow regime	Level of risk	Description
Stable flow spawning fish	Low flows	Medium	Three of four species experienced notable reductions in recruitment opportunities under both development scenarios
Macintyre River billabongs	Medium and high flows	Low	Little change in the number of filling events under full development
River forming processes	High flows	Medium	Reduced sediment mobilisation in some parts of the plan area
Floodplain wetlands	High and overbank flows	Low	Frequency of fish breeding events and energy input to riverine food webs largely unchanged, despite a reduction in return intervals of overbank flow events
Eastern snake-necked turtle	No and overbank flows	Medium	Five of eight assessment nodes experience an increase in the average duration of stress periods under full development.

Recommended measures

The environmental risk assessment made several recommendations to improve the likelihood of meeting flow requirements for ecological assets in the Border Rivers and Moonie Water Plan area. In the border rivers, plan measures that were recommended include:

- rules governing extraction from waterholes within water supply schemes.
- rates of releases from storages to avoid fish kills
- flow passing conditions on water entitlements traded on to waterholes.

Other recommendations included improvements to monitoring and reporting of water releases in water supply schemes.

In the Moonie, improvements to monitoring and reporting of extraction from waterholes were recommended, given the relatively low persistence time of these waterholes.

Stage 3: Development of draft water plans and environmental flow objectives

Development of a draft water plan considers the findings and recommendations of the risk assessment

Draft water plans will include the proposed performance indicators and objectives for both water allocation security and environmental flows. A performance indicator is a hydrologic metric used to assess whether a target level (the objective) set in the water plan is being achieved.

Performance indicators for environmental flows have been developed using the information provided in the environmental assessments. Ideally, performance indicators are linked to specific environmental assets identified in the risk assessment and will protect those parts of the flow critical to their survival.

During the life of a plan, trades and changes to management rules will only be permitted if (when modelled) they meet the environmental flow objectives.

By specifying performance indicators and objectives in the plan, minimum limits are established for environmental water at given locations using various statistics. This contrasts with the NSW approach where the limit is placed on consumptive take.

Measures to achieve environmental objectives

Measures to achieve the environmental objectives are specified as conditions attached to water allocation licences, rather than specifically in the Water Plan. Conditions include limits on instantaneous take and storage, and minimum flow thresholds below which water cannot be taken. The minimum flow thresholds for different zones within the plan area are specified in the attachments to the Water Management Protocol (DNRME 2019b).

Example – Border Rivers and Moonie water plan

New performance indicators for environmental flows have been developed using the information provided in the environmental assessments. For surface water allocations, these new performance indicators are more closely linked to specific environmental assets and will be better able to protect those parts of the flow critical to their survival.

The environmental performance objectives in the Border Rivers and Moonie Water Plan are[6]:

- mean annual flow at 3 of the 11 nodes remains at the same percentage of the pre-development scenario as when the plan commenced.
- the no-flow period for all nodes remains at the same percentage of the pre-development scenario as when the plan commenced.
- The interval between fish migration events at all nodes is no less than that modelled at full development period. The flow rate that corresponds to a fish migration event is specified for each node.
- The interval between channel-forming events at all nodes is no less than that modelled at full development period. The flow rate that corresponds to a channel-forming event is specified for each node.
- The interval between floodplain inundation events at all nodes is no less than that modelled at full development period. The flow rate that corresponds to a floodplain inundation event is specified for each node.

[6] Water Plan (Border Rivers and Moonie) 2019, Schedule 7

3.3 Environmental Water Provisions in Western Australian Water Allocation Plans

Summary

- Two methods can be used for determining allocation limits and the environmental watering provision:
    - determining the 'Ecologically Sustainable Yield', and then considering social and economic values, or
    - determining the 'Sustainable Diversion Limit' that considers reliability of supply for consumptive users and environmental impacts.
- The ESY method is used where consumptive water use is high but is resource and data intensive and has not been applied widely.
- The ESY method identifies ecological assets and functions, flow depths / rates that support critical functions (EWRs)
- The ESY method then compares the frequency and duration of the EWRs between a base and development scenario
- Iterative development scenarios are run that change the proportion of flow that is extracted in a given flow range
- The final development case is the one where an expert panel decides that the deviation of all EWRs from the base case is an acceptable risk
- The SDL method determines cease to pump, maximum daily extraction and winterfill period parameters that would limit changes in hydrograph (compared to current development) to an acceptable level of ecological risk
- The above SDL parameters were assessed and developed for applicability across catchments at a regional scale, for use where the resources to determine ESY are not warranted or are unavailable
- The modelled volumes that can be extracted while being limited by the determined parameters forms the basis of the SDL figure
- Both the ESY and SDL method use a baseline / reference flow sequence that includes development at the time
- The SDL method is more widely applied and, in theory, enables an allocation limit to be set for dam storage rather than extraction.
- The highly seasonal hydrology and ubiquity of farm dams as the primary harvesting method presents a challenge when translating the allocation limit to licence conditions.

Lessons learnt/Applicability to NSW

- The Ecologically Sustainable Yield method can be used in data-rich catchments where consumptive use is high, and where licensing officers have detailed assessment tools.
- The Sustainable Diversion Limit method is more widely applicable.
- The assessment methods assume that the parameters used in the final development scenarios are able to be implemented in some form as management arrangements
- Less water can be allocated if the only management mechanism is storage volume than if extraction conditions can be actively enforced to avoid exceeding the SDL.

Legislative objectives

Management of water in Western Australia is governed in accordance with the *Rights in Water and Irrigation Act 1914*, and in instances where water is provided for the environment, the *Environmental Protection Act 1986*. Statewide Policy Number 5 (WRC 2000) describes the approach to providing water for the environment under both acts. The policy aims to be consistent with the national principles for the provision of water for ecosystems (ARMCANZ/ANZECC 1996). Statewide Policy Number 5 defines the environmental water requirement (EWR) as:

- *the water regime needed to maintain ecological values of water dependent ecosystems at a low level of risk* (WRC 2000).

Under the policy, Environmental Water Provisions (EWPs) are set in a process set out in the *Environmental Protection Act 1986* if the environmental impacts are deemed to be significant. EWPs are defined in the policy:

- *Environmental Water Provisions (EWPs) are the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic impacts. They may meet in part or in full the ecological water requirements.* (WRC 2000)

Management Plans for water resources are enabled under Division 3D, subdivision 1 of the *RIWI Act 1914* and can be regional, sub-regional or local. Regional plans cover a larger area and are broader in nature. They define water resource values but do not set out how water will be allocated. Sub-regional and local plans set out how water will be allocated, including to the environment, and the matters that will be considered when assessing licence applications. They are usually published as 'Water Allocation Plans'.

Whicher Allocation Plan

The Whicher Area Surface Water Allocation Plan (DoW 2009b) is a sub-regional plan that covers the far south-west corner of the state. The climate and surface hydrology of the region is highly seasonal, with more than half of annual rainfall recorded in the three winter months and most of the major waterways of the region regularly experience a cease-to-flow period each dry season. Consequently, on-stream dams are the only reliable source of surface water for irrigation.

Consistent with the Act, the Whicher plan sets out

- *how rights in respect of water are to be allocated to meet various needs, including the needs of the environment and*[7]
- *the Minister's assessment of –*
  - *(i) the capacity of water sources to provide water at sustainable levels of use; and*
  - *(ii) the environmental impact of developing those sources*[8]

The plan specifies allocation limits for 52 sub areas, with unallocated water available to be granted under new licenses in 37 sub areas (Figure 3). Seven sub areas have no limit specified and no provision for water licences to be granted, in order to protect existing forestry and/or conservation values. A further eight sub areas are deemed to be fully allocated, with the limit set at existing use to protect consumptive water-use values. The methods used to determine allocation limits are specified by DoW (2009a) and the decision-making process is illustrated in Figure 4.

The supporting methods report (DoW 2009b) references two methods for determining allocation limits and the EWP:

1. Explicitly defining the EWR through a process to determine the "Ecologically Sustainable Yield", and then considering social and economic values
2. Defining the EWP directly through a process to determine the "Sustainable Diversion Limit" that considers reliability of supply for consumptive users and environmental impacts

The Ecologically Sustainable Yield (ESY) method is used in sub areas where consumptive water use is considered to be high. However, it is resource and data intensive and has not been applied widely. At the time that the plan was introduced, it had been employed in only one sub area, the Cowaramup Brook catchment. The method has since been applied in two other sub areas, the Wilyabrup Brook and Margaret River catchments.

The Sustainable Diversion Limit (SDL) method requires less environmental and ecological data and has been applied in the vast majority of catchments. The method requires gauged or modelled flow, and regional-scale estimations of flow-ecology relationships.

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[7] *RIWI Act 1914 S.26GX(2)(b)*
[8] *RIWI Act 1914 S.26GX(2)(d)*

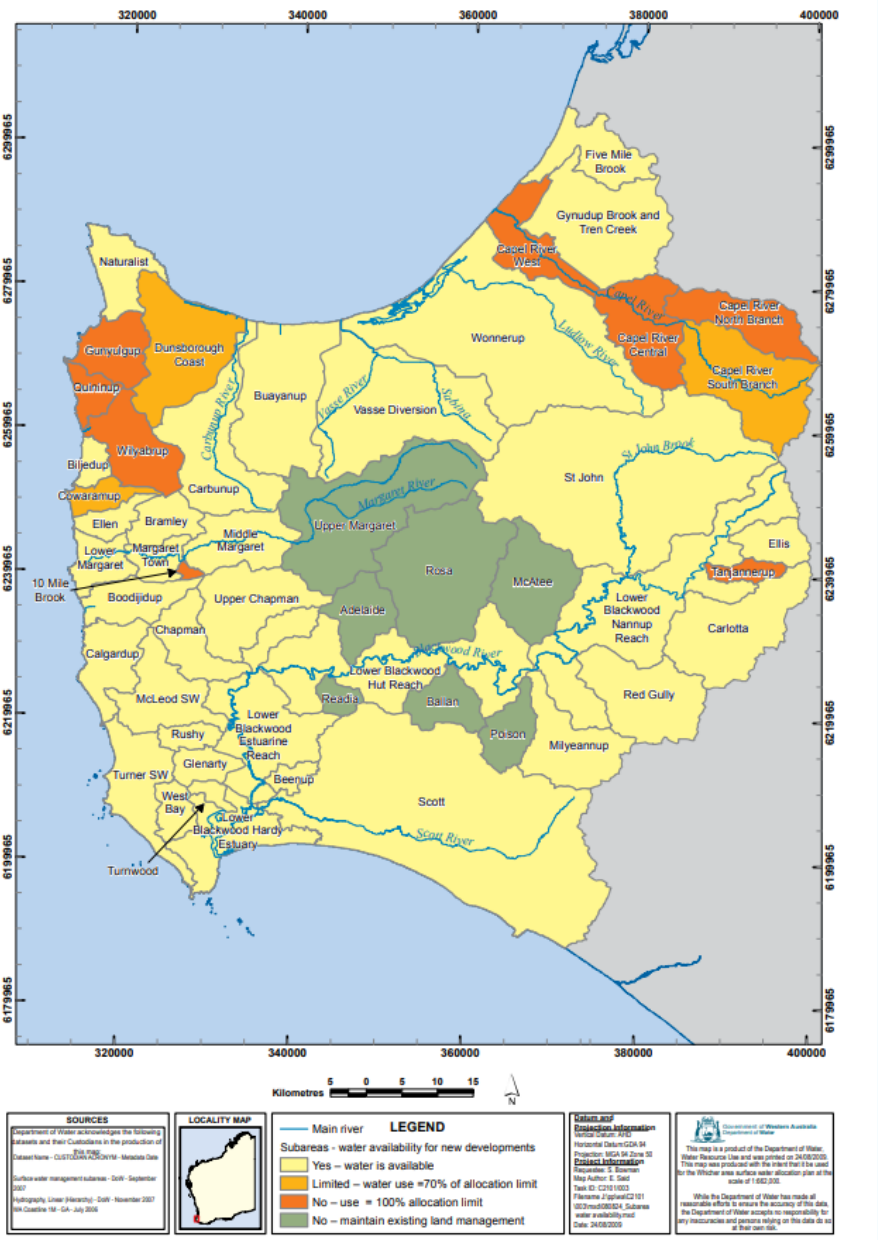

Figure 3 Surface water availability in the Whicher Area

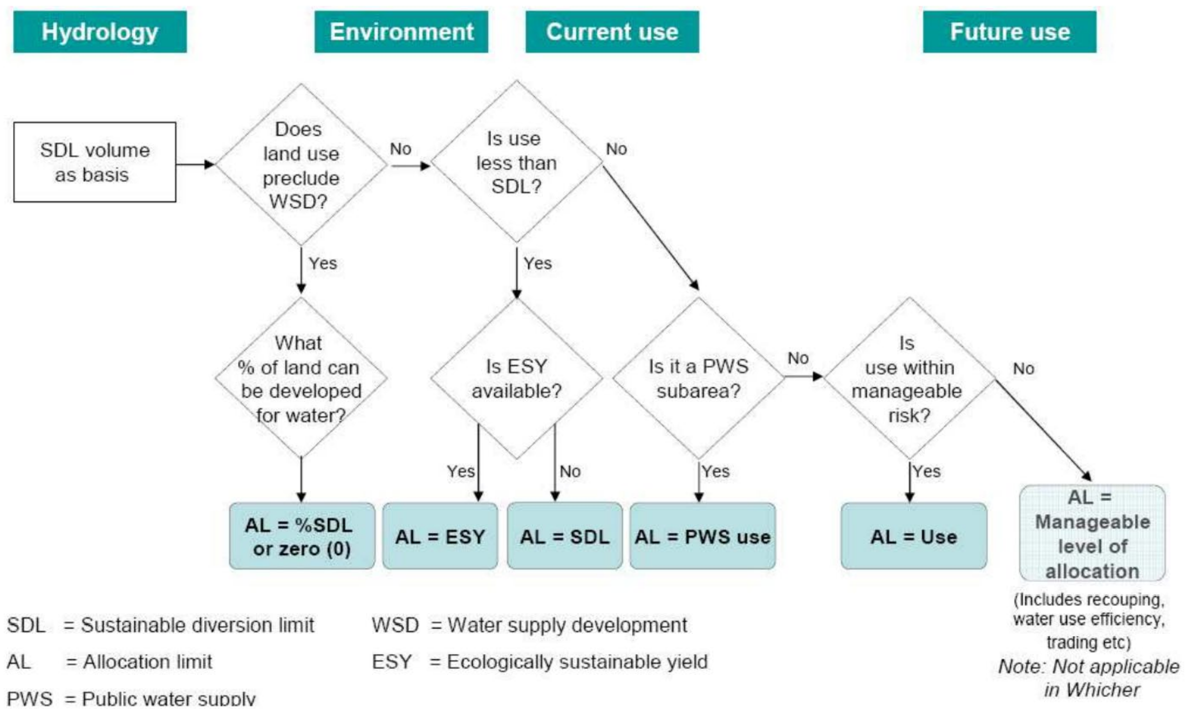

Figure 4 Allocation decision-making process in the Whicher Area Surface Water Allocation Plan (Source: DoW (2009a, section 5)

The level of environmental risk in eight sub areas where the allocation limit was set at current entitlement was deemed to be manageable (Figure 4). However, no justification for this assessment is provided and the risk assessment process is not described.

Sustainable Diversion Limits methodology

While in any given river it is possible to define threshold flows of ecological importance (EWRs), defining such flows for the entire south-west of Western Australia, with its variety of stream sizes and types, would be a prohibitively costly and time-consuming task. The SDL method was commissioned to address the challenge of developing a regional method for rapidly estimating the sustainable winterfill diversion potential for unregulated (and generally ungauged) streams in the south-west.

Estimates of SDL are based on a regionalised set of inputs, SDLs are conservative, and are used for broad regional planning or preliminary design purposes only. That is, rather than being viewed as a fixed cap, the SDL should be regarded as a limit that cannot be exceeded unless more detailed investigations indicate that additional extractions from the unregulated system would not represent an unacceptable risk to the environment.

The SDL method uses a model to estimate the annual volume of water that can be extracted from the catchment each year. The following model parameters were chosen, developed and tested to be applied to catchments on a regional scale which would keep risks to ecological assets to an acceptable level:

- The Winter-fill Period is the season in which harvesting is permitted, from 15 June to 15 October in the Whicher area. In theory, dams must pass flow outside of this season or be located on waterways that do not flow outside this season. The primary consideration in defining the winterfill period was to protect ecologically important higher flows that occur during the transition between wet and dry and dry to wet seasons
- The Minimum Flow Threshold. This is the flow rate in the waterway below which extraction must cease. In the Whicher area this is the maximum of 0.3 times the mean annual daily flow and the 95th exceedance percentile of the median winterfill period daily flow. The primary consideration in setting MFT (or cease to pump) is to ensure zero and low flows remain within the bounds experienced under

the base case scenario (the flow regime for a chosen historical period, reflecting in-river dam development and extractions for that period)

- The Maximum Extraction Rate (MER). This is the maximum amount of water that can be extracted from the waterway in one day. (Typically 25% of the flow above the cease to pump threshold). The primary consideration in setting MER is to minimise the percent of time that extractions cause the flow duration curve to flatline at the MFT level.

The final SDL metrics were developed via assessing various options across catchments to ensure they would be fit for purpose/use at a regional scale. A daily timestep model extracts water using the above parameters to determine the maximum sustainable yields for each year for a given catchment - the simulated annual yields vary depending on climate conditions and pumping opportunity

A final sustainable yield figure is then determined based of the percentage of years (80%) it could be fully extracted in the simulation

It should be noted that "current" development was reflected in the base case. However, the estimated current use was subsequently subtracted from the final sustainable yield figure to provide an indication of what volume of additional, unallocated water may be available for a given catchment.

This method does not involve an ecological condition assessment and assumes that base case (current) development is either underdeveloped or sustainable

The method assumes that no extraction from the waterway (either free-flowing or impounded in a dam) occurs during the low and cease-to-flow season. While this assumption may not be valid in catchments where consumptive demand is supplied by on-stream farm dams, it is possible that the panel concluded that the potential ecological impacts of an increase in the *duration* of the cease-to-flow period was manageable given the highly seasonal rainfall in the region and the regular seasonal cease-to-flow conditions that the aquatic ecosystems are adapted to. There is also anecdotal evidence that the proliferation of farm dams in the highly permeable sandy surface catchments of the region has decreased the duration of the cease-to-flow period due to seepage from dams (Donohue et al. 2009).

The DoW considers the SDL method to be a conservative estimate of water availability (i.e. reserves more water for the environment, DoW 2009), and relative to the ESY method, it is. Comparative EWPs for the three catchments where both methods have been implemented are provided in Table 5. It is clear that the SDL method reserves a greater proportion of flow for the environment than the ESY method. Note that the results for the SDL method, which relies primarily on statistical analysis of streamflow data and does not identify specific ecological components of the flow regime, produces more consistent results as a percentage of mean annual flow.

Table 5 Comparative Environmental Water Provisions in the Whicher Area

Catchment	Environmental Water Provision* (percentage of flow reserved for the environment) SDL method		Environmental Water Provision* (percentage of flow reserved for the environment) ESY method	
	Volume (ML)	% of total flow	Volume (ML)	% of total flow
Wilyabrup Brook	20 212	89%	15 600	69%
Margaret River	74 753	89%	62 968	75%
Cowaramup Brook	3 131	88%	2902	82%

* The Environmental Water Provision is the volume of water available for the environment. It is the inverse of the Sustainable Diversion Limit (SDL) or Ecologically Sustainable Yield (ESY).

A weakness of the SDL method is that it assumes that all entitlements are exercised through direct pumping, with no pumping occurring during the low flow season. Although this may be the case for free-flowing waterways, which will be dry in summer, it is not the case for waterways impounded by on-stream farm dams, which will experience most extraction in the driest months. The flow will then be significantly impacted during early winter when waterways begin to flow again and dams harvest a proportionally larger percentage of flow.

In reality, implementation of the SDL flow regime therefore requires a large investment in real-time monitoring and compliance of licence holders, and significant investment in on-farm infrastructure such as bypass structures and variable valves.

Ecologically Sustainable Yields method

In high-use catchments, the Ecologically Sustainable Yield (ESY) method may be used to determine the Environmental Water Requirement. The ESY method is a calculation of the theoretical maximum amount of water that could be extracted from the catchment while maintaining existing values at a low level of risk. The approach evolved out of experience with using other methods, such as the 'flow events method' to determine EWRs for rivers

Cowaramup Brook was the first waterway in the Whicher area to have its EWR defined through the ESY method (Donohue et al. 2009). The Cowaramup Brook catchment has been highly modified, with well over half of the land cleared and farm dam storage equivalent to nearly 9% of mean annual flow. The overarching objective of the EWR study was to determine the volume of water that could be extracted while maintaining the current post-development ecological values.

The ESY method uses a baseline flow sequence that reflects the development and extractions that occurred during that period. The method does not appear to consider the condition of ecological assets under the baseline development scenario. This issue was highlighted in a 2011 review of the ESY method (Stewardson et al. 2010)

The key steps in the ESY method can be summarised as follows

- a baseline flow series was generated for a 30 year period (this reflects in river dam development and extractions)
- critical depth requirements for various ecological processes are determined - these are determined in consideration of a comprehensive longitudinal channel profile
- The corresponding (ML/d) flow rates to achieve those critical depths thresholds are determined using a one-dimensional hydraulic model.
- 4 flow range parameters were used in a simple hydrological model for which a percentage of the daily flow within that range would be extracted (ie 30% of flow between 1.7ML/d and 26.6ML/d)
- iterative development scenarios are run that change the daily extraction percentages for a given flow range
- an expert panel compares frequency and duration statistics from the base case to a given development scenario
- if the panel considered there was a significant difference it was concluded that the development scenario was not consistent with a "low level of risk" to that EWR
- The model parameters that resulted in acceptable alteration to the frequency and duration for all ecological thresholds constitutes a final EWR compliant development case (Figure 5)
- the final development scenario involved both a lower and upper cease to pump
- the EWR is the inverse of the percentage of water that was extracted from a given daily flow range (ie 70% of water in the 1.7ML/d and 26.6ML/d range that was left in the system – See Table 6)
- The ecologically sustainable yield is the average annual volume of water that was extracted in the final accepted EWR model scenario

It should be noted that "current" development was reflected in the base case. However, the estimated current use was subsequently subtracted from the final ecologically sustainable yield figure to provide an indication of what volume of additional, unallocated water may be available for a given catchment.

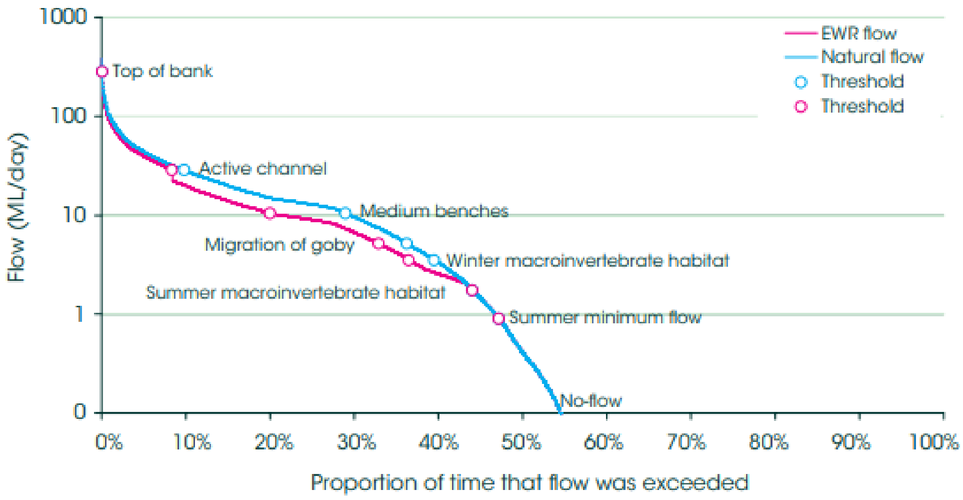

Figure 5 Flow duration curve and assumed extraction pattern used to determine the ecologically sustainable yield for Cowaramup Brook. Source: Donohue (2009)

Table 6 Daily Environmental Water Requirements as a percentage of total flow

Daily flow (ML)	Environmental threshold	EWR as a percentage of daily flow
< 1.7	Summer macroinvertebrate habitat	100%
1.7 < 26.6	Fish migration	70%
26.6 < 337.3	Active channel morphology	90%
> 337.3	Floodplain inundation	100%

It should be noted that the EWR time series represents a hypothetical extraction pattern designed to maximise the volume of water that can potentially be sustainably extracted. It does not represent how farm dams and/or direct extraction are expected to impact the flow regime, including via seasonal effects. In theory, the low flow requirement to pass all flow less than 1.7 ML/d can be achieved through bypass or valve structures and/or locating dams off the mainstem. Passing of all or almost all high flows (> 26.6 ML/d or 10th percentile exceedance) may be a realistic representation of farm dam impact in a general sense, but the volumetric impact on the EWR of small differences in the flow rate or extraction pattern in this part of the flow duration curve may be very large.

Implementation of EWPs in southwest Western Australia

The documentation detailing both the SDL and ESY methods mention that the effectiveness of the methods are dependent on management arrangements being implemented as required on dams or extractions that reflect the various parameters used in the model scenarios that supported a sustainable yield figure. This includes cease to pumps referencing a gauged flow, or daily extraction limits that change depending on current flow.

The SDL methodology assumes that all extractions occur through direct pumping, however in many catchments, a high proportion of both existing and future development is likely to be exercised through diversion from farm dams, including many that will be onstream dams or catchment dams on first order tributaries. Bypass structures and foot valves are expensive to install and maintain, and compliance is difficult to monitor or enforce. In reality, the only things that can be practically managed are:

- the volume of storage, which governs the maximum volume of water that can be harvested in any one year
- the licence volume, which governs how much of the harvested water is extracted and how empty the dam will be at the beginning of the winter-fill period

In this region, the impact on the flow regime will be proportionally greatest during the low flow season, and volumetrically greatest during the beginning of the high flow season as dams fill.

SKM (2009) modelled the relative impact on the flow regime of entitlements being exercised through direct pumping or farm dam harvesting across the whole southwest region[9]. They developed a relationship between the volume of farm dam storage relative to the SDL diversion volume that ensures that:

- the volume of water harvested over the winterfill period does not exceed the SDL
- the average volume extracted over the first half of the winterfill period (between 15 June and 15 August) does not exceed the volume available for pumped diversions.

A hypothetical relationship between the volume of 'storage licences' and 'extraction licences' is illustrated in Figure 6. In this example, 840 ML of extraction from farm dams operating without conditions has an equivalent impact on the high flow regime as 1000 ML of direct pumping extraction operating with cease-to-pump rules and maximum daily rates of take. Less water can be allocated if the only management mechanism is storage volume than if extraction conditions can be actively enforced. Across the region, the actual relationship between dam storage and pumped allocation varied between 0.63 and 1.00.

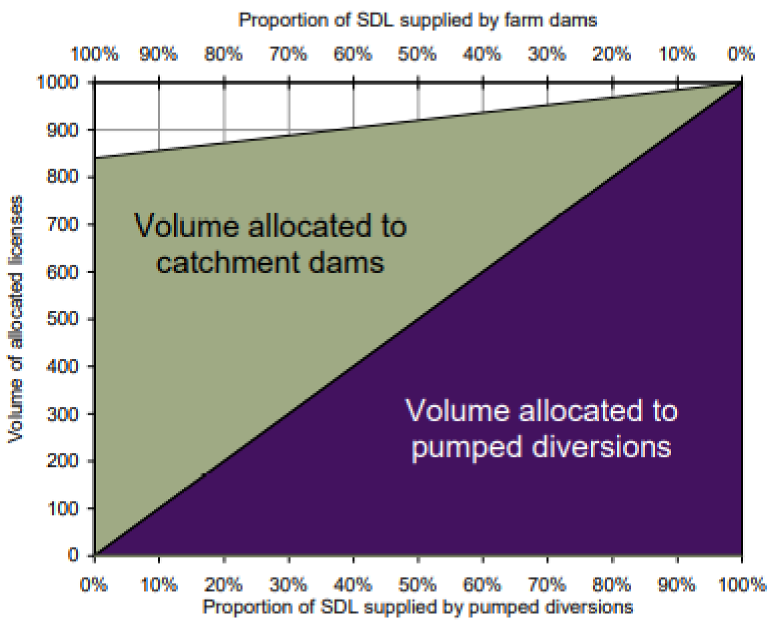

Figure 6 Hypothetical relationship between storage allocation and directly pumped (with conditions) allocation. Source: SKM (2009)

[9] SKM (2009) section 9

The modelled impact of farm dams that this method provides is based on an aggregate level of storage within each sub-catchment and depends on the location of the dams and the spatial resolution of the model.

In theory at least, the SDL method enables an allocation limit to be set for dam storage, rather than an extraction limit. The plan allows for licencing officers to require licence applications to include the volume of the dam[10], so it is technically possible, at least in catchments where use is still relatively low, to manage diversions via dam volume without needing to attach licence conditions that may be difficult to monitor.

The plan also enables licencing officers to assess the impact of an application on downstream users and the environment[11]. They can refer the application to the Environmental Protection Authority if they deem the impacts to be significant[12] and require certain flows to be bypassed[13].

[10] DoW (2009) policy 3.1.2
[11] DoW(2009) policy 6.1.3
[12] DoW(2009) policy 6.1.1
[13] DoW(2009) policies 3.3, 6.1.4

3.4 Long-term water resource assessments

Summary
- Long Term Water Resource Assessments cover very large areas, with diverse patterns of water resource development and environmental values.   - They determine whether there has been a reduction in the availability of water over a 15 year time period, whether there has been a disproportionate reduction in availability of water for the environment, and whether there has been a deterioration in waterway heath as a result.   - Their purpose is to determine if sustainable water strategies and water sharing plans are meeting their environmental objectives and while they do not set allocation limits, they provide a post hoc assessment of allocation limits with strong legislative foundations
Lessons learnt/Applicability to NSW   - Environmental objectives need to be measurable for plans to be properly adaptive.   - Resourcing for environmental monitoring must be proportional to water resource pressure and management intensity.   - Statistical methods should be standardised, formalised, and strike a balance between rigour and simplicity.

The long-term water resources assessment (LTWRA) is a process described in the Victorian *Water Act 1989*. Its purpose is to inform the development of Sustainable Water Strategies, which describe water resource allocation at the basin scale. A recent LTWRA for Southern Victoria highlighted that biological monitoring and statistical methods must be aligned with legislative requirements over the long term if environmental objectives are to be achieved.

Legislative requirements

In Victoria, Sustainable Water Strategies (SWS) have been prepared for the four major regions of the state:

- Northern Victoria, north of the Great Dividing Range
- Western Victoria, south of the divide
- Central Victoria, south of the divide
- Gippsland, eastern portion of the state south of the divide[14]

A Sustainable Water Strategy provides for the strategic planning of water resources[15] and must take into account the results of a Long-Term Water Resources Assessment (LTWRA)[16]. A LTWRA should be completed every 15 years[17] and must identify whether:

a) *there has been any decline in the long-term availability of surface water or groundwater and whether the decline has fallen disproportionately on the environmental water reserve or on the allocation of water for consumptive purposes*
b) *there has been any deterioration in waterway health for reasons related to flow*[18].

The Environmental Water Reserve is water that is set aside for the environment and is comprised of environmental entitlements (held environmental water) and water delivered through conditions on

[14] Central and Gippsland SWSs are being combined into a single strategy that will be finalised in 2022
[15] *Water Act 1989 S. 22C (1)*
[16] *Water Act 1989 S. 22C (2) (a)*
[17] *Water Act 1989 S. 22K*
[18] *Water Act 1989 S. 22L*

consumptive entitlements (planned environmental water)[19]. Planned environmental water may be further subdivided into:

- Passing flows: a requirement to maintain a specified flow rate at certain locations downstream of dams, weirs or diversions.
- Above cap water: limitations, either regulatory or physical, on the volume of water that can be harvested by dams.

The objective of the Environmental Water Reserve is to *preserve the environmental values and health of water ecosystems, including their biodiversity, ecological functioning and quality of water…*[20]

If the LTWRA identifies that there has been a *disproportionate* impact on the availability of water in the Environmental Water Reserve *or* there has been a deterioration in waterway health for reasons related to flow, the SWS *must set out the action required to*[21]*:*

c) restore the balance between the environmental water reserve and the allocation of water for consumptive purposes; or
d) restore the health of waterways[22]

while having regard to economic and environmental matters, Aboriginal cultural values and uses, and social and recreational matters[23].

The draft LTWRA must be referred to the Environmental Protection Authority for it to review

a) the methodology adopted to carry out the draft assessment
b) whether or not the data used is the best available
c) whether or not the conclusions reached are supported by the data and methodology[24]

LTWRA for Southern Victoria 2020
A Long-Term Water Resources Assessment (DELWP 2020) was completed for southern Victoria in 2020. It found that surface water availability had declined by up to 21% overall, with the decline falling disproportionately on the environmental water reserve in 5 of 18 catchments. Depending on the catchment, water availability for the Environmental Water Reserve declined by between 4 and 28%, compare with a decline of between 1 and 13% for consumptive uses. Water availability was assessed using hydrological models (usually REALM) of each of the 18 basins that simulated flow over the period of record (~100 years) under the allocation limits and access rules specified in Sustainable Water Strategies and their supporting water sharing plans.

The impact on the Environmental Water Reserve was mostly due to a reduction in above-cap water. This occurred because dams rarely full during the Millennium drought and so did not spill as frequently as in the past In some catchments, the reduction in the volume of spilled water more than offset the increase in availability due to the establishment of environmental entitlements (Figure 7).

[19] *Water Act 1989 S. 4A (1)*
[20] *Water Act 1989 S. 4B (1)*
[21] *Water Act 1989 S. 22C (4)*
[22] *Water Act 1989 S. 22P (1)*
[23] *Water Act 1989 S. 22P (2)*
[24] *Water Act 1989 S. 22N (2)*

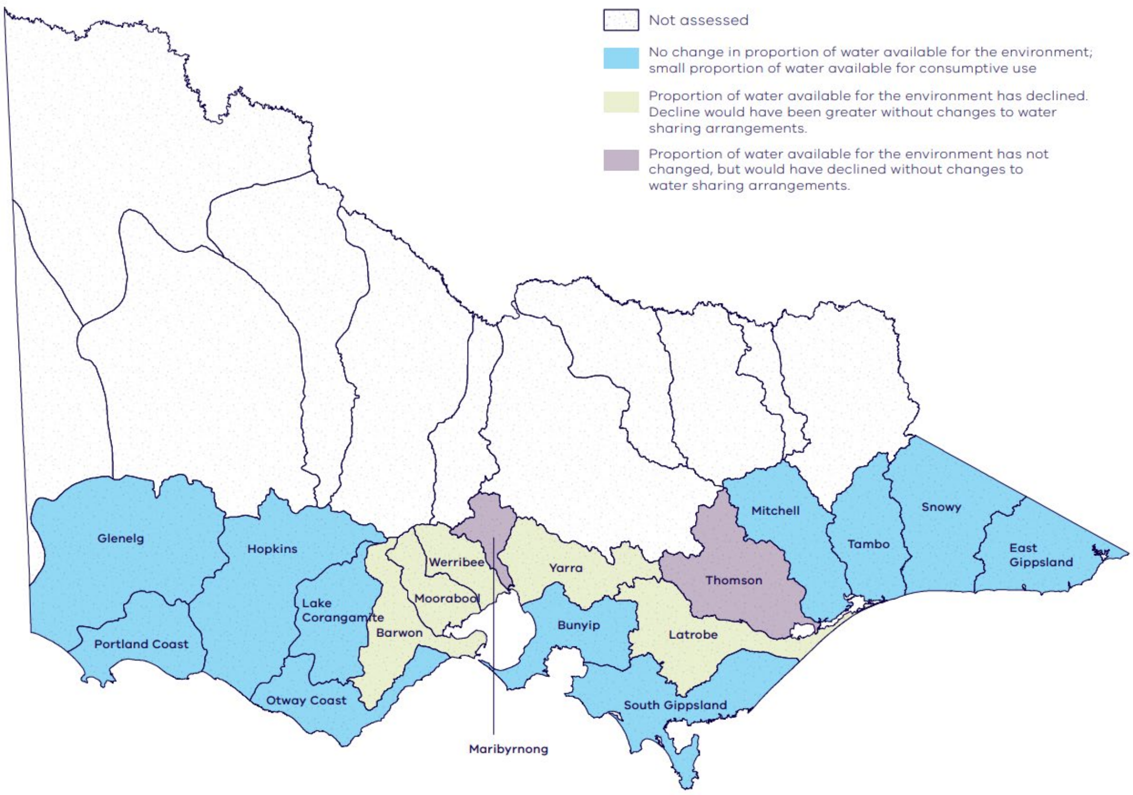

Figure 7 Changes in water availability in southern Victoria, 2005-2020 Source: DELWP (2020)

The executive summary of the overview report for the LTWRA stated that it could not clearly identify an overall deterioration in waterway health for reasons related to flow during the period from 1990 to 2018[25]. This was due to a lack of suitable baseline data and inconsistent data during the period of assessment.

Critically, no systematic monitoring plan was put in place to specifically *measure potential declines in waterway health due to reasons related to flow* upon the commencement of any of the SWSs. The Victorian Environmental Flows Monitoring and Assessment Plan (VEFMAP) was established in 2005 and by 2016 had delivered some meaningful results. However, it only monitored 8 regulated rivers across the state, and in the southern rivers focused primarily on the effect of held environmental water. The program found a link between the delivery of environmental flow events and migration of diadromous fish in one southern river[26].

The LTWRA chose to adopt a Before-After Quasi Control-Impact approach and excluded VEFMAP datasets because “they didn’t start until after the SWS water-sharing actions were implemented, so they cannot show if the SWS actions are improving waterway health for the current LTWRA”[27]. The only data on waterway health indicators that were numerous enough to illustrate a trend in condition were water quality parameters, with fish and macroinvertebrate data either insufficient or displaying no statistically significant trend.

Despite the lack of a dedicated monitoring program from which to draw data, the 2020 LTWRA attempted to do several things:

- directly measure a deterioration in *overall* waterway health
- attribute the deterioration to flow and separate this effect from other causes

[25] DELWP (2020) p.22, p.122
[26] https://www.ari.vic.gov.au/research/rivers-and-estuaries/assessing-benefits-of-water-for-the-environment
[27] DEELPW (2020) p. 129

- separate the effects of the millennium drought from the effects of the SWSs
- provide information on how current management arrangements are affecting waterway health

It adopted a phenomenological or statistical approach to addressing these questions at a regional scale. It did not use ecological models to draw inferences or derive flow-ecology relationships from well-studied systems that could be applied generally in mechanistic ecological models. Attempting to separate the effects of the millennium drought from the effects of the SWSs was the primary reason for using a 'segmented regression' method (Figure 8). The time periods that were used were:

- 1990-2005 – beginning of the millennium drought and prior to the Central SWS
- 2006-2010 – during Millennium drought and post commencement of the Central SWS
- 2011-2018 – post Millennium drought and Western and Gippsland SWSs

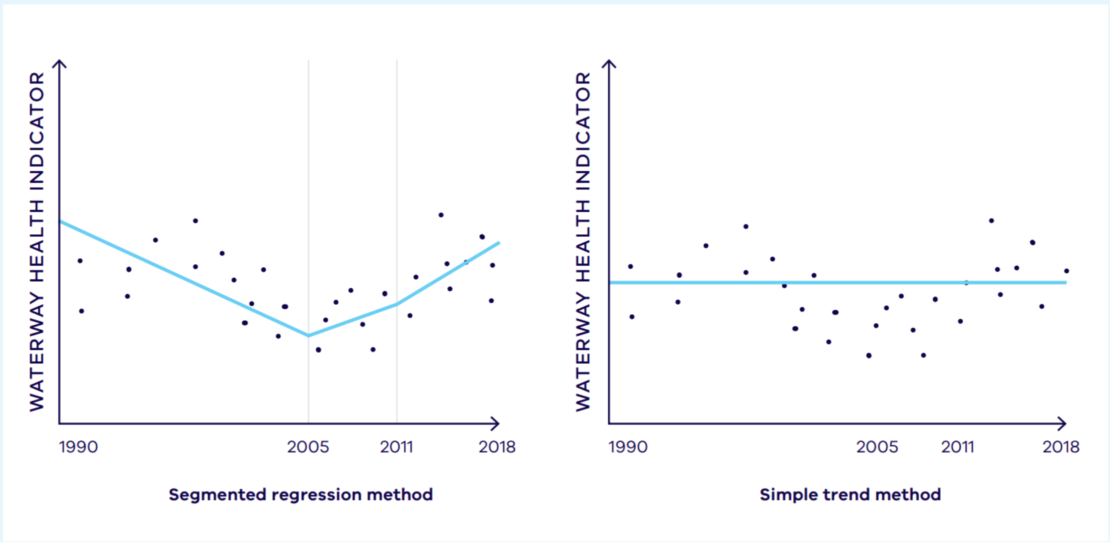

Figure 8 Methods used in the 2020 LTWRA for detecting changes in waterway health.

Review by EPA

The EPA review of the LTWRA (EPA 2019) made the following conclusions:

a) *The methods adopted to assess surface and groundwater availability as well as water sharing availability are appropriate.*
b) *The data used for the purpose of this assessment was appropriate. EPA notes and supports the view outlined in the LTWRA, that the primary constraint in assessing waterway health was the limited data available.*
c) *The conclusions reached in the assessment are supported by the methodology and data. EPA notes that data constraints have impacted the ability to make conclusive findings about waterway health, and that, given these constraints, the inconclusive finding is appropriate.*

However, it also noted several limitations in the method. Regarding the use of data, the review noted that

- pH and total nitrogen data were not used
- water quality data between 1975 and 1990 was available but not used.
- A large macroinvertebrate data set from metropolitan Melbourne was not used

The review Panel expressed concerns regarding the use of the segmented regression method and the time periods it adopted, considering that it overly complicated the interpretation of results. The time periods were applied to analysis of data across the whole region, despite the fact that the SWSs were in force in different regions during different time periods. The time periods adopted for the waterway health assessment were also different to the time periods adopted for the hydrological assessment. The panel also noted that it may not have been necessary to specifically structure the statistical model to isolate the effects of the Millennium Drought from other flow-related factors. For example, Thomson et al. (2012) demonstrated a flow-related decline in macroinvertebrate condition between 1989 and 2009 using a simple trend regression model that included a flow term.

In the panel's view, an assessment using a single time period would have made interpretation more straightforward. It also noted that the biological or ecological importance of trends in indicators was not assessed, with an assessment against objectives in the State Environmental Protection Policy (SEPP) for Inland Waters being one way that this could have been achieved.

The review recommended that biologically and ecologically significant indicators of waterway health should be regularly monitored to create a more fit-for-purpose evaluation framework, and that a broader review of statistical methods should be undertaken to help inform future LTWRAs.

Other relevant flow-ecology studies

Several contemporary studies that demonstrated statistically significant links between flow and biological indicators of environmental health were not used as part of the LTWRA. These studies can be used to either directly measure changes in waterway health and relate it to changes in flow or indirectly design better monitoring programs and more sensitive statistical models.

Macroinvertebrates

The study cited by the EPA review panel (Thomson et al. 2012) used the EPA's Rapid Biodiversity Assessment (RBA) 1990-2009 macroinvertebrate dataset for Victoria, containing 7372 records sampled from 2165 sites. Three different measures of condition were derived:

- Total number of families (total richness)
- Number of mayfly, stonefly, and caddisfly families (EPT richness)
- SIGNAL (Stream Invertebrate Grade Number- Average Level) score[28]

The authors used a hierarchical Bayesian linear regression model, relating the macroinvertebrate indicators to climatic variables and measures of riparian and catchment vegetation cover. During the period, streamflow declined by around 50%, with all catchments experiencing significant declines in streamflow. SIGNAL scores declined in all 29 basins across the state and EPT richness in all but one. Trends in total richness were variable at the basin scale, but negative overall for the state. Similar trends were also observed in NSW during the period 1994-2007 by Chessman (2009) who demonstrated correlation using a multiple logistic regression model.

Macroinvertebrate indices were positively correlated with vegetation cover, and the interaction with climate and flow was significant. Better vegetated catchments were generally more resilient and experienced less severe temporal declines in condition as the drought progressed.

Fish

Bond et al. (2011) found a significant relationship between measures of climate and vegetation and the distribution of freshwater fish in Victoria. They used data from 4477 sites across Victoria sampled between 1980 and 2006 and used boosted regression trees to relate the presence of fish species to measures of climate, hydrology and catchment vegetation. Relationship with hydrology were species-specific, with 90th percentile flows, zero-flow days, and flow variability being commonly related to species distribution. The results suggest

[28] A SIGNAL score gives an indication of water quality in the river from which the sample was collected.

that well-designed long-term datasets of fish presence may be useful for measuring waterway health and potentially detect a response to changes in flow.

Vegetation

Webb et al. (2015) analysed vegetation data from the VEFMAP and used a combination of methods to develop testable relationships between terrestrial vegetation encroachment and measures of seasonal inundation. They used expert elicitation and small-scale studies of vegetation response to flow to develop a process-based heuristic model of vegetation encroachment into river channels. They used VEFMAP vegetation data from 9465 quadrats at 27 sites across Victoria to parametrise a Bayesian hierarchical model that has the ability to predict vegetation response to flow and inform future environmental flow assessments such as the LTWRA.

3.5 Methods and governance in Spain

Summary

- Basin hydrological plans were required to achieve 'good' status by 2015, as mandated by Spanish legislation and Ministerial Orders compliant with the European Directive on water policy, with limited exceptions.
- In compliance with European law, the Ebro River Hydrological Plan (2010-2015) describes Environmental Objectives and the Measures planned to achieve them, including control over the abstraction of fresh surface water.
- A three-step process for establishing the ecological flow regime must sustainably maintain the functionality and structure of aquatic ecosystems and associated terrestrial ecosystems.
- The ecological flow regime must specify daily rates for minimum flows which must be exceeded and maximum flows with must not be exceeded from each month of the year.
- Ecological flows are determined as follows:
    - habitat preferences for various fish species are determined
    - minimum ecological flows are determined based on a flow height/depth at which between 50-80% of useful habitat is available
    - final height is determined in consideration of depth/available habitat inflection points
    - maximum ecological flows are determined in consideration of 50% of useful habitat being available at a flow velocity that will protect fingerlings and juveniles

Lessons learnt/Applicability to NSW

- The ability to pay for measures required to achieve environmental objectives must consider all private and alternative public funding sources, including user fees, Spanish government, and EU funding sources.

Management framework

The Ebro River Basin Authority was formed in 1926 to manage the waters of the Ebro Basin in Spain. The Basin is one of the largest in Spain and spans several autonomous regions. The role of the authority was formalised in modern law in the 1985 *Water Act*, which was based on the definitions of public and private property in the 1978 constitution. Administratively, it is a unit of the ministry of Agriculture, Food and Environment and 70% funded through fees from water users and polluters. It is responsible for managing:

- Water quality
- The ecological status and restoration of rivers
- Wastewater discharges
- Water extraction licences
- Water supply infrastructure
- Flood and drought mitigation

Public participation is formalised through the Water Council, a 93-member body, with around a third of members each representing autonomous regions, water users, and other public and government interests.

The first hydrological plan was developed in 1998 and was reviewed and updated in 2014. The 2014 plan covered the timeframe from 2010 to 2015 and was the first plan to be consistent with the European Framework Directive. Spanish water law was progressively amended during the early 2000s to be consistent with the European Framework Directive. Some of the Framework's articles were given effect to through legislation and others through Ministerial Orders, which are the equivalent of Regulations (Plaza & Margeli 2014, Embid 2002).

Legislative objectives

The purpose of the European Framework Directive on water policy (EC 2000) is to:

establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which:

> *(a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;*
>
> *(b) promotes sustainable water use based on a long-term protection of available water resources*[29]

The Spanish Water Act has been amended to be consistent with the Directive. Article 40 states that:

> *The general objectives of hydrological planning will be to achieve the good*[30] *status and adequate protection of the hydraulic public domain and the waters subject to this Law, the satisfaction of water demands, the balance and harmonization of regional and sectoral development, increasing availability of the resource, protecting its quality, saving its use and rationalizing its uses in harmony with the environment and other natural resources.*

Article 42 of the Act stipulates that the basin hydrological plans must include:

- *A general description of the uses, pressures, and significant anthropogenic impacts on the waters, including:*
- *The allocation and reservation of resources for current and future uses, as well as the conservation and recovery of the natural environment (for this purpose, ecological flows that maintain fish life that does or could inhabit the river, riparian vegetation, and the stretches of river with little or no human intervention will be determined).*

(ERBA 2013)

More specifically, all surface water bodies should achieve good status, except for heavily modified or artificial water bodies, that should achieve good ecological potential[31] and good chemical status by 2015. An extension in the timeframe to achieve good status, or less stringent environmental objectives may be adopted in waterways modified by human activity if achieving good status is infeasible or disproportionately expensive and:

- the socioeconomic benefits of the human activity cannot be achieved in a more environmentally beneficial way that isn't disproportionately expensive
- the highest possible status for this type of modified waterway is achieved
- environmental values do not deteriorate further
- the reasons for adopting the less stringent objectives are clearly mentioned in the River Basin Management Plan[32].

Plan objectives

The Ebro River Hydrological Plan 2010-2015 was the first version of the plan to be consistent with European law. Among other things the plan describes Environmental Objectives and the Measures that will be taken to achieve

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[29] EC(2000) Article 1

[30] 'Good' is defined as *showing levels of distortion resulting from human activity but deviating only slightly from those normally associated with the surface water body type under undisturbed conditions.* The biological elements considered are the abundance and composition of phytoplankton, aquatic plants, benthic macroinvertebrates, and fish. The hydro morphological elements considered are hydrological regime, river continuity, and channel morphology, which should be in a condition consistent with maintaining the biological elements. (EC 2000 Annex 5 S.1.2)

[31] Good Ecological Potential is a relative term meaning that values of biological elements are only slightly less than what is possible under the modified conditions. (EC 2000 Annex 5 S.1.2)

[32] EC(2000) Article 4 S.4, S.5

them, including *controls over the abstraction of fresh surface water*[33]. Possibly due to this fact, more supporting material was produced and/or included in the plan[34], so this version of the plan will be reviewed here.

The objectives of the Ebro hydrological plan (2010-2015) were to achieve good ecological status of water bodies in the basin, preserve and restore the river environments that were significantly damaged in the 1960s and 70s whilst retaining water's capacity to generate wealth (particularly as a basis for preserving the basin as one of the most important food producing areas in Europe) (Plaza & Margeli 2014).

Of the 644 surface water bodies in the plan area, measures were identified to achieve good status in 549 by 2015, an increase of 71 over conditions in 2010. The objectives for the remaining water bodies are described in Table 7[35].

Table 7 Environmental objectives for water bodies in the Ebro Hydrological Plan 2010-2015

Environmental objective	Number of water bodies
Achieves good status by 2015	549
Will achieve good status by 2027	76
Less stringent objectives adopted	10
Highly modified water body	7
Artificial water body	2
Total	644

Of the 10 water bodies where less stringent objectives were adopted, the reasons given were natural causes, mostly salinity and thermal characteristics.

Twenty-seven water body ecotypes were identified within the basin for the purposes of determining reference conditions. Types are determined by a combination of physical characteristics and ecoregions. Reference conditions may be determined through spatially explicit data, modelling, expert opinion or a combination of these methods[36].

Economic analysis to support the determination of objectives must include consideration of the costs to deliver water services, consistent with the objective of cost recovery, and the cost of measures required to achieve the plan objectives[37].

The Ebro Basin Authority has interpreted that the ability of users to pay for the measures required to achieve environmental objectives should not be the sole determinant of what constitutes 'disproportionate cost' and should not reduce the ambition of environmental objectives. The ability to pay must consider all private and alternative public funding sources, including user fees, Spanish government and EU funding sources. To be deemed disproportionate, these total costs must exceed the benefits 'appreciably' - it is not enough for the cost benefit ratio to be negative[38].

[33] EC(2000) Article 11 S.3(e)
[34] Hydrological Plan First cycle 2010-2015 - Portal CHEbro
[35] ERBA (2013) S. 7
[36] EC(2000) Annex 2 S.1
[37] EC (2000) Annex 3
[38] ERBA (2013) Annex 8 S.3.3.3

Environmental flow methods

Ministerial Order 2656/2008 details a three-step process for establishing the ecological flow regime.

1. Step 1 – Technical studies. The studies must identify water bodies with a high degree of hydrological alteration where there may be significant conflicts with consumptive water uses. The ecological flow regime may be less stringent during times of drought in these waterbodies and a temporary deterioration in ecological status may be accepted, consistent with the requirements of the European Council (2000)[39].
2. Step 2 – Public consultation on the proposed ecological flow regimes through which the actual provisions are determined.
3. Step 3 – Implementation and monitoring.

The ecological flow regime must be established in such a way as to sustainably maintain the functionality and structure of aquatic ecosystems and associated terrestrial ecosystems, helping to achieve good ecological status or potential in rivers and estuaries. Specifically, it must do the following:

- Provide adequate habitat conditions to meet the needs of the different biological communities of aquatic ecosystems and associated terrestrial ecosystems by maintaining the ecological and geomorphological processes necessary to complete their biological cycles.
- Offer a temporal pattern of flows that allows the existence, at most, of slight changes in the structure and composition of aquatic ecosystems and associated habitats and allows for maintaining the biological integrity of the ecosystem.

In the Plan, the ecological flow regime must specify daily rates for minimum flows which must be exceeded and maximum flows which must not be exceeded for each month of the year. Flow rates for floods and the maximum rate of change must also be specified[40].

The first step in determining ecological flow regimes is to identify reaches to which they will apply. Reaches are chosen to represent a broad range of ecohydrological characteristics:

- Reaches with gauging stations are preferred, although reaches with modelled flows may be used.
- Reaches where the flow regime will affect resource allocation
- Reaches with high environmental values, especially those within the European conservation network
- Reaches that are in good condition and can act as reference streams
- Reaches that are key for drought management (It is unclear whether this refers to drought refuges for fish or water supply for consumptive use)

At least 10% of all waterbodies and at least one of each ecotype should have a defined ecological flow regime.

Determining minimum flow rates

The reference hydrological regime for minimum flows is determined through analysis of gauged data in unregulated reaches and modelled natural flow in regulated reaches. Four reference statistics are generated to represent minimum flows

- 5th percentile flow
- 15th percentile flow
- Median and Mean of Q_{bm} for the period of record. Q_{bm} is the minimum flow in the first period of a two-period sequence when the difference in minimum flows is greatest. It appears to be a method for identifying minimum flows just before the 'break of season' flows that start the regular high flow season.

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[39] EC (2000) Article 4 S.6
[40] ERBA (2013) Annex 5 S.3.3

Habitat is modelled with a two-dimensional hydraulic model that simulates the spatial distribution of velocity in a reach across several surveyed cross sections (See Section 3.7 for further details). In each reach, the area of suitable habitat is modelled at each flow rate using habitat preference curves for 4 native fish species at different life stages (fingerling, juvenile and adult). The preference curves for each species are combined to create a combined curve. During the dry season, the curves for fingerlings and adults are combined, and in the wet season, the curves for juveniles and adults are combined.

The minimum ecological flow is defined as the flow rate at which 50-80% of the potentially useful habitat is available. Inflection points in the habitat/flow rating curve, if they are apparent, will be chosen as the ecological flow.

During prolonged droughts, when a temporary deterioration in ecological status may be accepted, 25% of useful habitat may be provided except in nature conservation areas, where the full 50-80% will be retained.

Determining maximum flows
Maximum ecological flows are determined for regulated reaches downstream of major storages. Different values are calculated for the wet season and the dry season.

The maximum flows correspond to the 90th percentile of flows to be provided to the reach so that large natural flows are not considered to have failed to meet the ecological flow regime.

Hydraulic habitat suitability models are used to determine the maximum flow rate at which 50% of the wetted area of a reach provides a refuge for fish. Habitat is considered to be refuge for fingerlings when the velocity is less than 1m/s and for juveniles when the velocity is less than 2 m/s. During the dry season, maximum ecological flow rates are set to protect fingerlings, and during the wet season, juveniles.

Determining rates of change
The methods section of the Plan[41] refers to a deviation from the rates of change in the natural flow regime, although it is not clear exactly how it was calculated.

Determining flood flows
For reaches downstream of major storages, the flood flow is expressed as the flow rate, duration and maximum rates of change in the 1.5- and 2-year ARI flow of the modelled natural time series. The flood flow may be modified to account for potentially detrimental impacts to the environment or infrastructure.

[41] [41] ERBA (2013) Annex 5 S.3.3

3.6 Methods in USA

Summary

• Massachusetts, Colorado, and Ohio use the ELOHA framework to develop volumetric limits
• These jurisdictions appear to make widespread use of:
    ○ Large datasets and multiple regression models to determine ecologically significant hydrological variables
    ○ Stream categorisations based on hydrological alteration and ecological value to set different objectives

Lessons learnt/Applicability to NSW
• Good information and some robust methodologies for determining ecological indicators • Little information on how critical thresholds in the flow-ecology relationship are identified and environmental objectives are determined.

Several states in the USA use the Ecological Limits of Hydrological Alteration (ELOHA) framework to develop a volumetric limit (Kendy et al. 2012). The key assumption underpinning the ELOHA framework is that as flow becomes more altered from a reference condition, impacts on ecosystems increase (Poff et al. 2010).

The ELOHA framework follows four general steps:

(1) Setting a hydrological reference condition from which alteration can be assessed.
(2) classifying streams to generalize results and plan monitoring strategies.
(3) quantifying hydrological alteration
(4) developing flow-function curves that relate hydrological alteration to ecological impacts.

In addition to this scientific process, the following principles support a social aspect of developing flow criteria:

• The development of environmental flow criteria and the policies for their implementation are closely linked. Defining a clear path to policy implementation from the onset ensures that the ensuing science answers the right management questions.

• Flow criteria are developed through a transparent, inclusive social process informed by sound science. A structured social process for identifying, understanding, and negotiating trade-offs is critical.

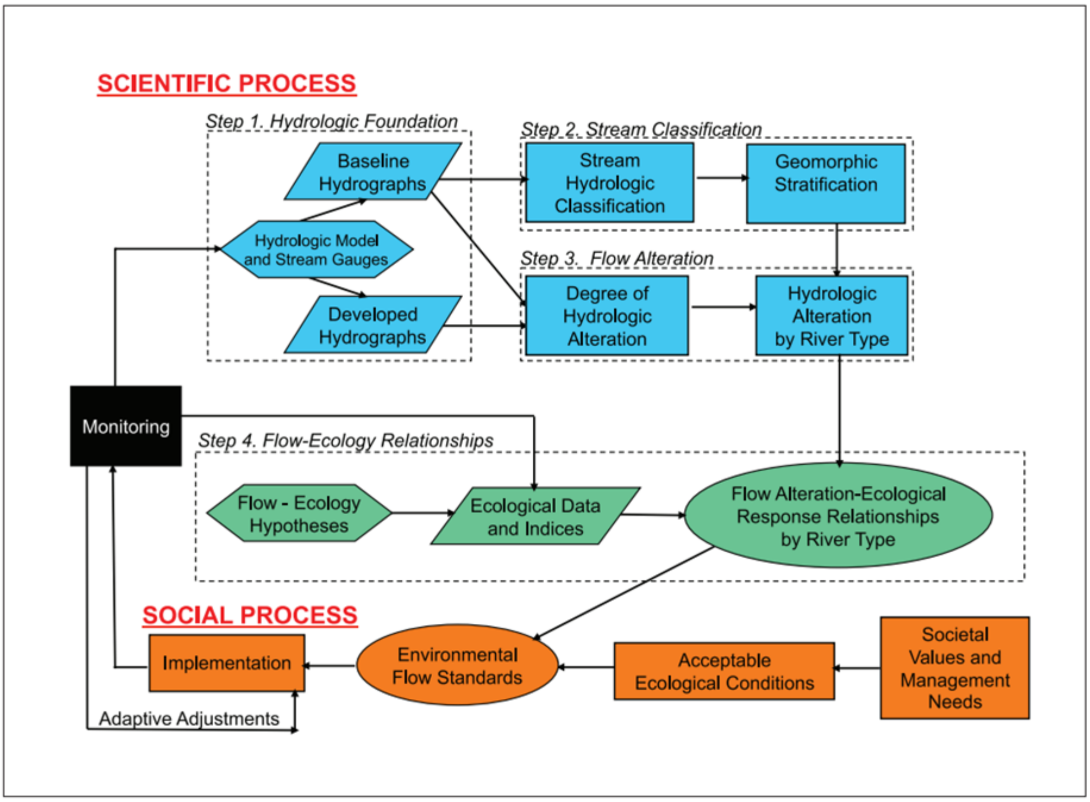

Figure 1.1. Steps of the ELOHA framework (Poff et al. 2010).

Massachusetts Sustainable Water Management Initiative

The *Massachusetts Water Management Act* (WMA) is a water withdrawal permitting system that was established in 1987 in response to concerns about the quantity and quality of water in the state's waterways. Twenty years later, implementation of the Act was falling short of its objectives, as evidenced by persistent impacts from stream depletion. Consequently, environmental groups appealed permit decisions for not adequately protecting rivers and streams from excessive water withdrawals and filed legislation requiring the development of environmental flow protection standards. In 2009, responding to continuing controversy, the state launched the Massachusetts Sustainable Water Management Initiative (SWMI). Both the social and scientific processes of SWMI closely follow the ELOHA framework.

The SWMI demonstrates the use of:

(1) a duration-curve regression approach to establish reference flow conditions across the state
(2) Seasonal bio periods as a foundation of streamflow criteria
(3) quantitative flow-ecology response curves to inform decision-making, and
(4) A set of criteria for assessing the impact of new extraction licences

Reference flow conditions
The MA SYE tool estimates an adjusted daily mean time series of streamflow at un-gauged sites from reported withdrawal and discharge volumes at locations within the basin (Archfield et al. 2010). The tool uses regression analysis to determine catchment variables that are correlated with flow duration curves from gauges across the state and then uses the regression models to derive flow in ungauged catchments.

Withdrawal and discharge volumes used in the MA SYE tool are obtained from a spatially referenced state-wide database of groundwater and surface-water withdrawals, groundwater discharges, and National Pollutant Discharge Elimination System (NPDES) surface-water discharges. For a user-selected basin, groundwater and surface-water withdrawal and dis-charge volumes are subtracted and added, respectively, from the unregulated, daily streamflow.

Seasonal streamflow criteria

The Technical Committee of stakeholders, guided by state resource agencies, identified four seasonal bio periods necessary to support life histories and biological needs of resident fish communities and fluvial-dependent diadromous species: overwintering and salmonid egg development, spring flooding, rearing and growth, and fall salmonid spawning (Armstrong et al., 2008). The Technical Committee confirmed that January, April, August, and October adequately represent the four bio periods to allow for simplified criteria development. For each of these months, the reference and current-conditions median flow was used as the hydrological criteria for determining the existing level of hydrological alteration. Flow alteration was found to be most significant in August, during the height of summer, when evaporation and groundwater extraction is likely to be greatest and streamflow lowest.

Quantitative flow-ecology relationships

Flow-ecology relationships were derived using fish abundance as the ecological indicator (Armstrong et al. 2011). Regression models were used to find catchment variables such as vegetation, land use, dam density and hydrology that were related to fish abundance. Flow alteration in August (reference daily median – current daily median) was found to be correlated with fish abundance and was independent of other catchment variables, so it was chosen as the ecologically critical measure of flow to managed.

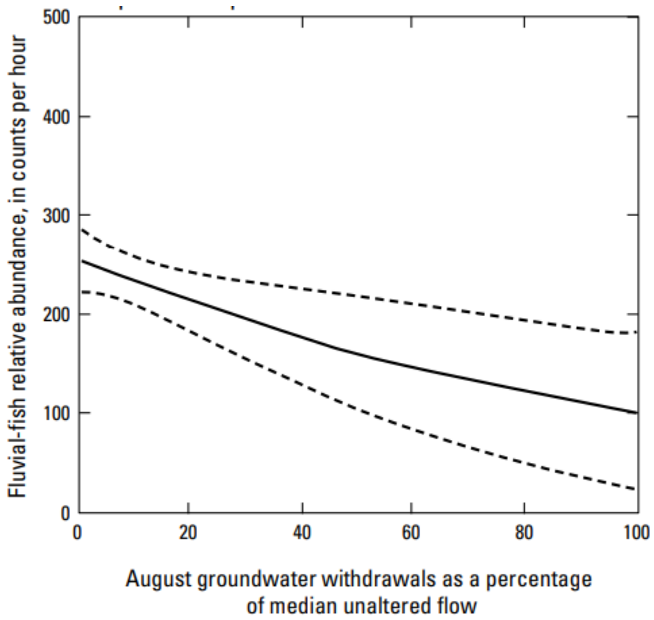

Figure 9 Relationship between fish abundance and flow alteration in August for Massachusetts

Hydrological impact criteria

The technical panel developed categories of flow alteration that correspond to a certain level of ecological impact, relying on statistical analysis, stakeholder input and best professional judgement, and supported by concepts in the scientific literature (Davies and Jackson, 2006). The categories chosen were:

- 3% alteration of August median flow leads to a shift from Biological Category 1 to 2;
- 10% alteration leads to a shift from Category 2 to 3;
- 25% alteration leads to a shift from Category 3 to 4; and
- 55% alteration leads to a shift from Category 4 to 5.

The purpose of regulation is to ensure that streamflow alteration remains within the existing categories, so that good fish populations in relatively unaltered streams are protected and highly altered streams can support further extraction of water.

Application of the Sustainable Water Management Initiative

A product of the SWMI is the SWMI interactive map, which displays biological categories, groundwater withdrawal categories, and net groundwater depletion data layers

The Water Management Act requires that new groundwater sources and/or increases in groundwater withdrawals from existing sources be evaluated for impact to streamflow. The WMA Permitting Tool, in conjunction with the SWMI interactive map, is for use by Public Water Suppliers, consultants, watershed groups, government agencies and others to evaluate the impact of groundwater withdrawals.

When a WMA permit application is received, a determination will be made of the Seasonal Streamflow Criteria at each of the applicant's withdrawal points (well fields may be considered as a single location). For example, each location will have Seasonal Streamflow Criteria associated with that location's Groundwater Withdrawal Level and Biological Category, (as developed in 2011 using 2000 to 2004 withdrawal data). Existing sources in sub-basins that are classified as Groundwater Withdrawal Level 4 or 5 will evaluate the potential to minimize existing impacts and develop a plan for feasible improvement.

Agency staff will assess the potential impact of the applicant's requested withdrawal increase on the Seasonal Streamflow Criteria. For example, if the entire withdrawal volume were to be pumped from a single well, the impact of that withdrawal will be assessed in terms of how that would affect the achievement of Seasonal Streamflow Criteria in each of the seasonal periods. This analysis will be used to determine if "backsliding" would occur because of the proposed increased withdrawal. Backsliding refers to conditions that would put a stream into the next lower level of either the Groundwater Withdrawal Level (in any season) or Biological Category (for example, from Biological Category 3 to 4). New or increased withdrawals with seasonal flow alterations above those listed for Groundwater Withdrawal Level 3 or with proposed backsliding will only be permitted with a demonstration that no feasible alternative source is available that is less environmentally harmful.

A permittee has the option of doing a site-specific study to demonstrate that local conditions are significantly different from those that are reflected in the state-wide Groundwater Withdrawal Level and Biological Category as shown on the SWMI maps.

Colorado Watershed Evaluation Tool

Baseline
The State of Colorado's water supply model, StateMod, is a monthly water accounting program that begins with gauged streamflow data under current conditions. Reservoir storage changes, water diversions, and return flows are incorporated to obtain baseline flows. Simple water accounting, weighted by drainage area and precipitation, is then used to calculate baseline flows at ungauged sites. Groundwater withdrawals and return flows are simulated with aquifer-dependent time delay (Kendy et al 2012).

Streamflow characteristics
Indicators of Hydrologic Alteration (IHA) software (The Nature Conservancy 2009) used outputs from StateMod to calculate changes in five ecologically relevant flow statistics—mean annual flow, mean August flow, mean September flow, mean January flow, and mean annual peak daily flow—for water-use scenarios. Relationships were developed between streamflow and fish, riparian vegetation, invertebrates, and recreation, based on a literature review. Quantitative approaches varied, depending on the form and abundance of relevant

information, and ranged from statistical analysis using quantile regression (Cade and Noon 2003) to categorical relationships and expert consultation (Camp Dresser & McKee Inc. et al. 2009).

The technical team then identified 3-5 risk classes for each ecological attribute. Using the flow-ecology relationships, they determined the range of flow values associated with each ecological risk class.

Three major stream types in Colorado were determined: Rocky Mountains, Western Interior and Great Plains. Because the number of combinations of stream type, community and flow parameter would be unwieldy, specific combinations that represent an important component of ecosystem function, and for which data exists, were focussed on to provide a basis for flow-ecology relationships. Except for invertebrates, stream communities were identified by roundtable groups. Invertebrates were included because fish and birds depend on them for food, directly or indirectly. It was acknowledged that an acceptable level of change, or risk of change, is a social process that can be informed by (not necessarily resolved by) the scientific information gathered.

Some general guidelines were followed in determining what should represent an individual response (i.e. data points for flow-response plots). For example, sites were used as individual data points for diverse invertebrate communities, with community information summarised using abundance and diversity metrics. The response of less diverse communities was sometimes represented using individual species as data points (e.g. biomass of Colorado pikeminnow). Ecological responses were limited to species that are indigenous to the area of study, although brown, rainbow and brook trout were exceptions due to their recreational value.

Investigations focussed on the effects of peak flow and low flows. Because flow parameters used by researchers were not consistent, peak flows were standardised to 24-hour average annual peak flow and low flows were standardised to 24-hour average annual low flow.

By comparing measured ecosystem parameters across a range of flow conditions (varying levels of modification), emerging patterns provided a basis for quantifying ecosystem response. Analysis methods were tailored to suit the available data. Because variables exist that affect response to flow, quantile regression was used to define the upper bound because it was expected to express complex relationships in an easily digestible form for end-user application compared to multi-dimensional models (Cade and Noon 2003).

These are incorporated into a Watershed Flow Evaluation Tool (WFET) (Sanderson et al 2011), which Basin Roundtable groups use to map the levels of flow-related ecological risk for all river segments in their watersheds under different future water use scenarios.

Application of the watershed evaluation tool

The WFET provided useful insight into the flow-related ecological risk. The primary output from a pilot of the tool on the Roaring Fork basin was a series of maps that clearly and quickly convey risk for several ecosystem components. The pilot identifies that this new knowledge of flow-related risk can be useful for both research and water-use planning. For water-use planning, WFET results can be used to screen for high-risk areas that need site-specific investigation of flow requirements or, conversely, to identify areas where flows are intact. In Colorado, the WFET will be used to assess impacts to rivers that can be expected under future climate change and water development scenarios (e.g. for energy development or municipal water supply).

Given the regional nature of the WFET, it can support large-scale assessments of impacts from a suite of projects spread over an extensive area. For both existing and future water-supply projects, the WFET has the potential to support strategic decision-making about project placement and design, as well as system-wide operations to optimize ecological outcomes. This can aid developers interested in finding the path of least resistance before committing to the expense of a full impact assessment.

Ohio Thresholds for Ecological Flow Protection

This case study demonstrates:

(1) the integration of flow-ecology relationships and proposed streamflow protection standards with existing water quality standards using a tiered Aquatic Life Use (ALU) approach and

(2) the development of flow-ecology response curves using extensive habitat and biological databases.

The process was carried out independently by a non-profit research institute, the Midwest Biodiversity Institute (MBI), with funding from The Nature Conservancy (TNC). A coalition of environmental groups is using the results to secure ecologically based low-flow protection in the ongoing Ohio Great Lakes Compact Implementation process.

Ohio's development of ecological flow protection standards stems from Ohio's commitment to comply with the Great Lakes Compact. The Ohio Legislature's ratifying language and allotted time of one year to develop implementation language, constrained the initial focus to low flows, which represent the most ecologically stressful period of the year. Given the time limit, water users' resistance to new regulatory programs, and the highly altered condition of many of Ohio's streams, the approach was designed to mesh with the Ohio Environmental Protection Agency's existing ecological monitoring and tiered ALU framework. Because the Compact drove the process, it was initially developed only for the Ohio streams that are tributary to the Great Lakes.

The hydrologic foundation is a database of mean daily flow for the month of lowest flow (historically September) over a 20-year period. Flow regression modelling (Koltun and Whitehead 2002) was used to estimate this flow statistic for ungauged sites using current conditions as the baseline.

The Ohio ALU classification stratifies on the basis of ecological condition, existing flow alteration, and thermal regime. Ohio's flow-ecology curves relate the number of sensitive fish species to mean daily flow in September for each river type. The habitat portion of this relationship was developed from Ohio's Quantitative Habitat Evaluation Index which includes a measure of niche availability.

To comply with the Great Lakes Compact, withdrawals will need to be managed actively to prevent "adverse resource impact." Pollution-sensitive fish species were proposed as an indicator of adverse resource impact due to their sensitivity to flow alteration and a correlation with the responses of other sensitive aquatic species.

The Midwest Biodiversity Institute and The Nature Conservancy proposed to representatives of regulated industries and the Ohio Chamber of Commerce that adverse impact be defined in terms of percent loss of sensitive fish species. Allowable losses of sensitive fish species for each river type were specified. For streams of highest ecological quality that contain the largest number of sensitive fish species, an allowable loss of 2% was proposed. For stream types that generally have fewer sensitive species with less sensitivity to flow alteration, an allowable loss of 10 percent was proposed. For altered streams with few sensitive and no rare fish, a 50 percent species loss threshold was proposed. A proposed withdrawal rate that would approach the level at which adverse species loss occurs would trigger agency review of a water withdrawal application.

The flow-ecology curves would allow the Ohio Department of Natural Resources (ODNR) to determine the cumulative amount of low-flow depletion that would cause predetermined unacceptable losses. Only withdrawals that maintain cumulative flows above threshold levels would be permitted automatically. Proposed withdrawals that trigger the permit process would be reviewed individually.

The proposed Ohio thresholds would provide the benefit of protecting ecologically sensitive freshwater ecosystems, while allowing future development in more resilient ecosystems. Because the process developed for Ohio uses existing river condition to classify river types and uses current conditions as the baseline, it "grandfathers in" existing water uses and sets no restoration goals at present. Even so, regulated interests rejected the proposal and sought alternative legislation to exempt most withdrawals from regulation.

3.7 Water resource consents in Canterbury

Summary

- The Canterbury Land and Water Regional Plan rules allow a proportion of the flow above the river's minimum flow to be abstracted, in most cases, a 50:50 sharing ratio.
- In smaller rivers with no limit on total abstraction, restrictions are placed when the flow falls below particular thresholds. There may be an additional threshold above the minimum flow when takes are restricted to 50%.
- Rules are informed by the Environmental Flows Strategic Allocation Platform (EFSAP), but it is unclear how the rules in the Resource Plan were developed.
- Overallocated catchments are not meeting environmental objectives, so policies require allocation to be reduced.
- For less developed systems, general guidelines recommend minimum flows and allocation limits based on percentages of the "Mean Annual Low Flow" (MALF) For example the cease to pump might be 90% of the MALF
- For more developed systems iterative model scenarios are run changing cease to pump and extraction limits and then assessing residual flows against pre determined objectives
- Objectives include setting limits to loss of available habitat (similar to Spain)
- Available literature is unclear on the specifics of how objectives were developed

Lessons learnt/Applicability to NSW

- Environmental methodologies and objectives should be specified before water sources are placed under extraction pressure
- Good metering data can support intensive water resource management that protects environmental values and facilitates economic development.
- Sophisticated hydraulic modelling of environmental water requirements for fish is feasible if there is sufficient ecological data.

Legislative framework

Water is managed in New Zealand under the *Resource Management Act 1991*, which regulates the use of non-mineral natural resources to promote sustainable management. Sustainable management is defined as providing for the social, cultural and economic well-being of current and future generations while

> *Safeguarding the life-supporting capacity of air, water, soil, and ecosystems*[42]

Under the Act, a Regional Council may prepare a Regional Plan to support its functions of:

> *the control of the taking, use, damming, and diversion of water, and the control of the quantity, level, and flow of water in any water body, including—*
>
> *(i) the setting of any maximum or minimum levels or flows of water:*
>
> *(ii) the control of the range, or rate of change, of levels or flows of water*[43]

[42] *Resource Management Act 1991 S.5(2)(b)*
[43] *Resource Management Act S.30(1)(e)*

The Regional Plan must state the objectives, policies and rules for the region and how water has been allocated. It may state the environmental results that are expected from the implementation of rules and policies[44].

Water Permits, a form of Resource Consent[45], are granted in line with the policies and rules within the Regional Plan.

Plan objectives

The Canterbury Land and Water Regional Plan has been developed by Environment Canterbury and provides the framework for managing water in all the waterways in Canterbury (ECan 2017). Its stated objectives, as they relate to environmental outcomes, include:

Water management applies the ethic of ki uta ki tai – from the mountains to the sea – and land and water are managed as integrated natural resources recognising the connectivity between surface water and groundwater, and between fresh water, land and the coast[46].

The quality and quantity of water in freshwater bodies and their catchments is managed to safeguard the life-supporting capacity of ecosystems and ecosystem processes, including ensuring sufficient flow and quality of water to support the habitat and feeding, breeding, migratory and other behavioural requirements of indigenous species, nesting birds and, where appropriate, trout and salmon.[47]

Plan policies

The plan has 23 policies relating to the damming, diversion and abstraction of water[48] that support the environmental objectives. Policy 4.44 mandates that damming and/or diversion of water must

not have more than a minimal adverse effect on:

(a) values of significance to Ngāi Tahu associated with the mainstem;

(b) the passage of floods and freshes needed to maintain river processes, ecosystem health and the removal of vegetation encroaching onto the bed of the mainstem;

(c) sediment transport within the river and to the coast;

(d) fish passage;

(e) downstream water quality;

(f) the ecological values of the river and its margins;

(g) threatened native riverbed populations and significant indigenous biodiversity;

Plan rules

Rules controlling the diversion and abstraction of water are specified for each of the 10 sub-regions by ECan, which is the licencing authority. The rules for 'unregulated' rivers where diversions are mostly run-of-river or groundwater extraction are illustrated in Figure 10 and specify:

- Environmental flows - minimum flow rates in the river below which water cannot be extracted

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[44] *Resource Management Act 1991 S.67*
[45] *Resource Management Act 199 S.87*
[46] ECan(2017) S.3.2
[47] ECan (2017) S.3.8
[48] ECan(2017) policies 4.42 – S.4.64

- Allocation limits - the maximum total *rate* at which water can be diverted from the river reach (Franklin et al. 2012)

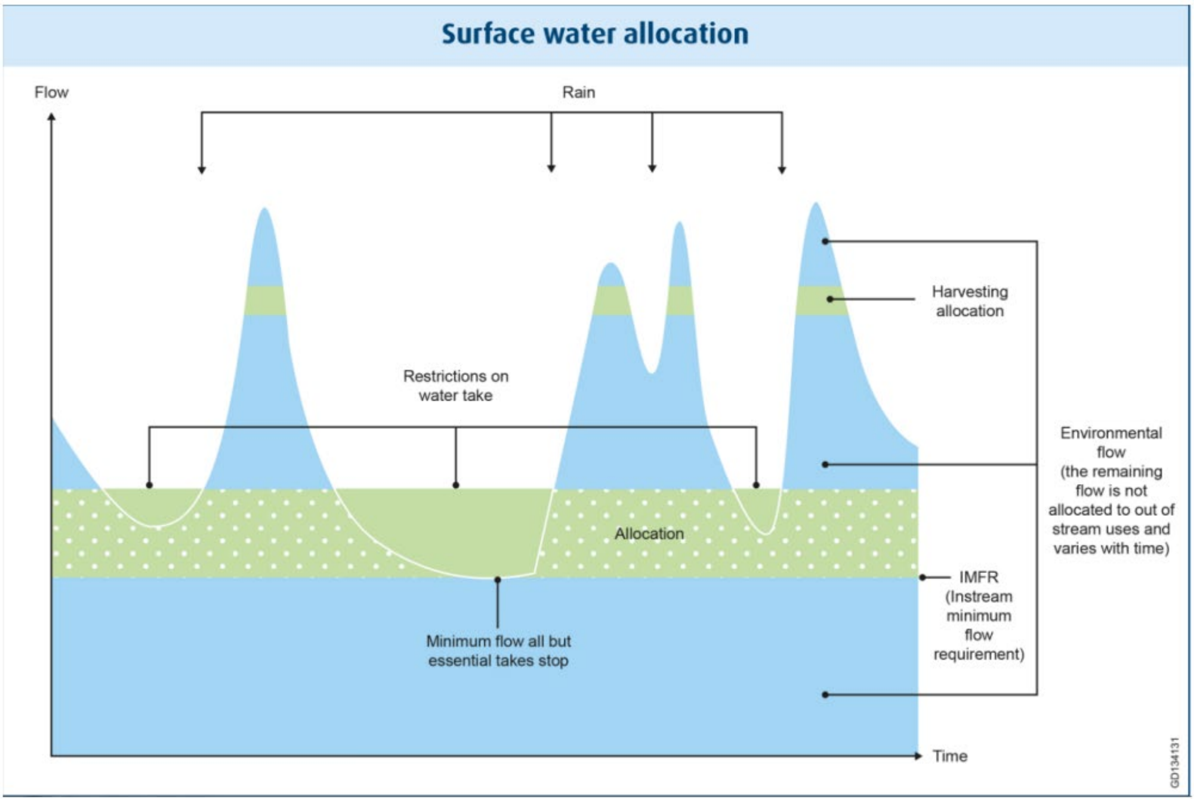

Figure 10 Surface water allocation in New Zealand Rivers. Source: 2018-03-15-wma-env-flow-setting_info-sheet-for-all-wma-engagement.pdf (boprc.govt.nz)

At flow rates between the instream minimum flow requirement and the management flow, some proportion of the total flow, often 50% or 100%, can be licenced for harvesting. Above the management flow, no further flow can be taken, in order to protect high flow events that maintain the unique braided channel form that characterises many of the region's rivers. Individual consent applications will be granted until the allocation limit has been met. The proportion of time that the management flow is exceeded is the reliability, which is the primary metric for quantifying consumptive use values.

In some catchments, an additional "B block" of take and store consents is allocated to be taken from high flow events, under the condition that they do not materially impact the reliability of A block consents.

Some of the different rule regimes are illustrated in Figure 11 (Morgan et al. 2002) and described below.

Rules for flow sharing

This type of allocation regime is illustrated in row 1 of Figure 11. Rules allow a proportion of the flow above the river's minimum flow to be abstracted, in most cases, a 50:50 sharing ratio. These rules protect the river's flow variability. Sharing rules require a high level of awareness and compliance from water users and telemetered monitoring of take, which is mandated within the Resource Plan[49]. ECan has implemented a comprehensive telemetry program, with 83% of consents providing daily data as of 2017 (ECan 2017b).

[49] ECan (2017) policy 4.54

Rules for bulk allocation

This type of allocation regime is illustrated in row 2 of Figure 11 and allows all flow above the minimum flow up to the management flow. Sometimes no upper limit is set, so all flows greater than the minimum flow can be abstracted. If no upper limit is set on the abstractable flow range, this type of regime has the potential to reduce river flows to a constant flow, although this is unlikely in unregulated systems.

Rules for cutbacks

This allocation regime occurs on many of the region’s smaller rivers and is illustrated in row 3 of Figure 11. There is no limit on total abstraction. However, restrictions are placed on abstractive users when the flow falls below particular thresholds. Generally, all takes must cease when the flow falls below the minimum flow, and there may also be an additional threshold above the minimum flow when takes are restricted to 50%. It has a similar intent to flow sharing rules but has been considered to be easier to manage. With the advent of improved information technology and awareness, the apparent simplicity of cutback rules is reduced.

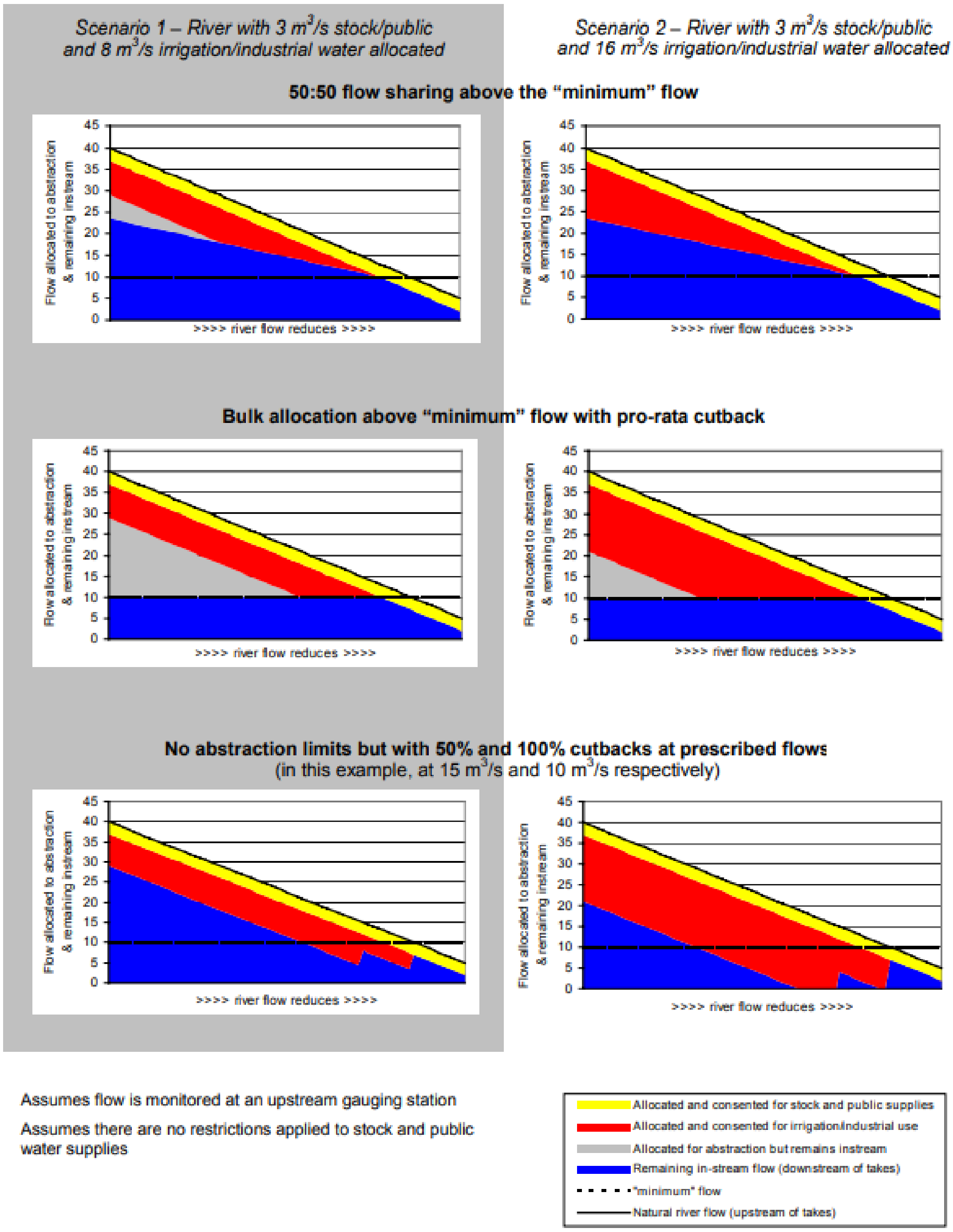

Figure 11 Graphical representation of the three main allocation regimes (top to bottom) in Canterbury rivers under two different levels (left and right) of allocation

Methods for determining rules

Currently, rules are informed by the Environmental Flows Strategic Allocation Platform (EFSAP)[50]. The EFSAP was developed in response to the 2011 National Policy Statement for Freshwater Management (New Zealand Government 2011), which required water quantity limits to be set for all New Zealand rivers. The platform assists in the quantification of physical habitat for fish and reliability of supply for consumptive users under a range of different flow and allocation limits. A range of environmental flow tools and methods are available for use within the EFSAP[51], with guidance provided for which method to be used in different circumstances[52].

It is unclear how the rules in the Resource Plan (ECan 2017) were developed. Some of the rules were developed prior to the plan and are included in other planning instruments, which are referred to in the Resource Plan. It is also unclear what environmental information or objectives was considered prior to the 2011 National Policy Statement. Many of the larger rivers with significant water abstraction pressure had rules in place, which differed markedly from catchment to catchment.

For rivers with a low degree of hydrological alteration and low to medium significant instream values, rules of thumb can be employed to determine environmental water requirements[53]. The proposed national environmental standard (Ministry for the Environment 2008) proposes rules of thumb for rivers as set out in Table 8 (Franklin et al. 2012). Rules are expressed as a percentage of Mean Annual Low Flow (MALF), which is the flow rate over the lowest 7-day period of the year, averaged over all years in the period of record. MALF has been calculated or estimated for all streams in New Zealand and data is available online[54].

Table 8 Rules of thumb for determining environmental water requirements for less altered or significant streams in Regional Plans

River size	Minimum flow	Allocation limit
Mean flow less than $5 m^3 s^{-1}$ (2.5 ML/d)	90% of MALF	80% of MALF
Mean flow greater than $5 m^3 s^{-1}$ (2.5 ML/d)	30% of MALF	50% of MALF

In streams with a greater degree of hydrological alteration, or more significant instream values, more complex hydraulic habitat modelling methods that consider the water requirements of fish are recommended to be used. A two-dimensional hydraulic model of the reach is constructed using several representative cross sections along a reach and simulating depth and velocity at different points across each cross section (Figure 12). Two dimensional representations of the reach can then be made that illustrate the area experiencing certain conditions of depth and velocity. The approach is used in many parts of the world (see Franklin et al. 2012 p.17 for examples) and is similar to methods used to set limits in Spain and investigate water requirements in the USA. In New Zealand, PHABSIM is a standard tool that is employed. Elsewhere, the simpler RHYHABSIM tool, that requires less variable inputs, has been employed (e.g. Thorn and Conallin, 2006).

[50] Decision Support Systems Directory « Environmental Flows Strategic Allocation Platform (envirolink.govt.nz)
[51] Environmental flow tools | NIWA
[52] https://niwa.co.nz/freshwater-and-estuaries/management-tools/environmental-flow-tools/overview
[53] ibid
[54] NZ River Maps (niwa.co.nz)

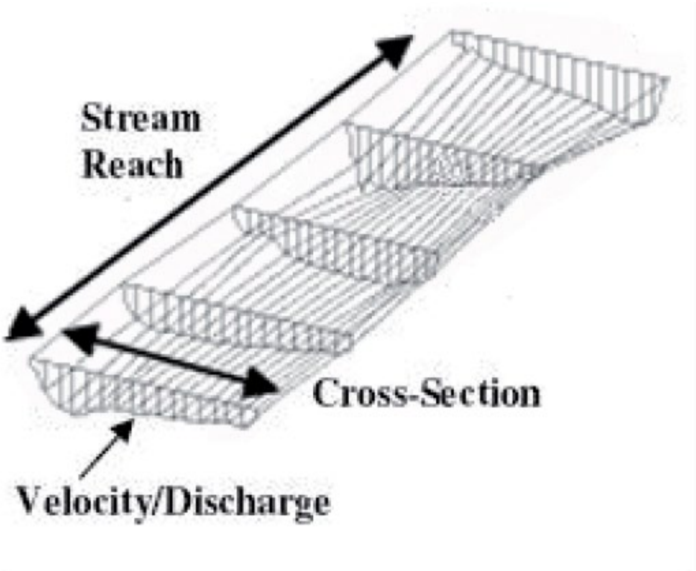

Figure 12 Conceptual representation of a 2D hydraulic model (Thorn and Conallin 2006). Depth and velocity are simulated at several points across each channel cross section, in contrast to a 1D model, that only simulates the average velocity at each cross section and a 3D model that simulates velocity across each cross section and at different depths.

The modelling approach requires:

- Hydrological data that includes MALF, mean flow, and the shape of the annual and monthly flow duration curves
- Rating curves that describe the relationship between flow and wetted area
- Species-specific habitat-preference coefficients that describe the relationship between flow and habitat suitability, or “Weighted Usable Area” (WUA).

An example output of the hydraulic habitat modelling for Brown Trout is shown in Figure 13.

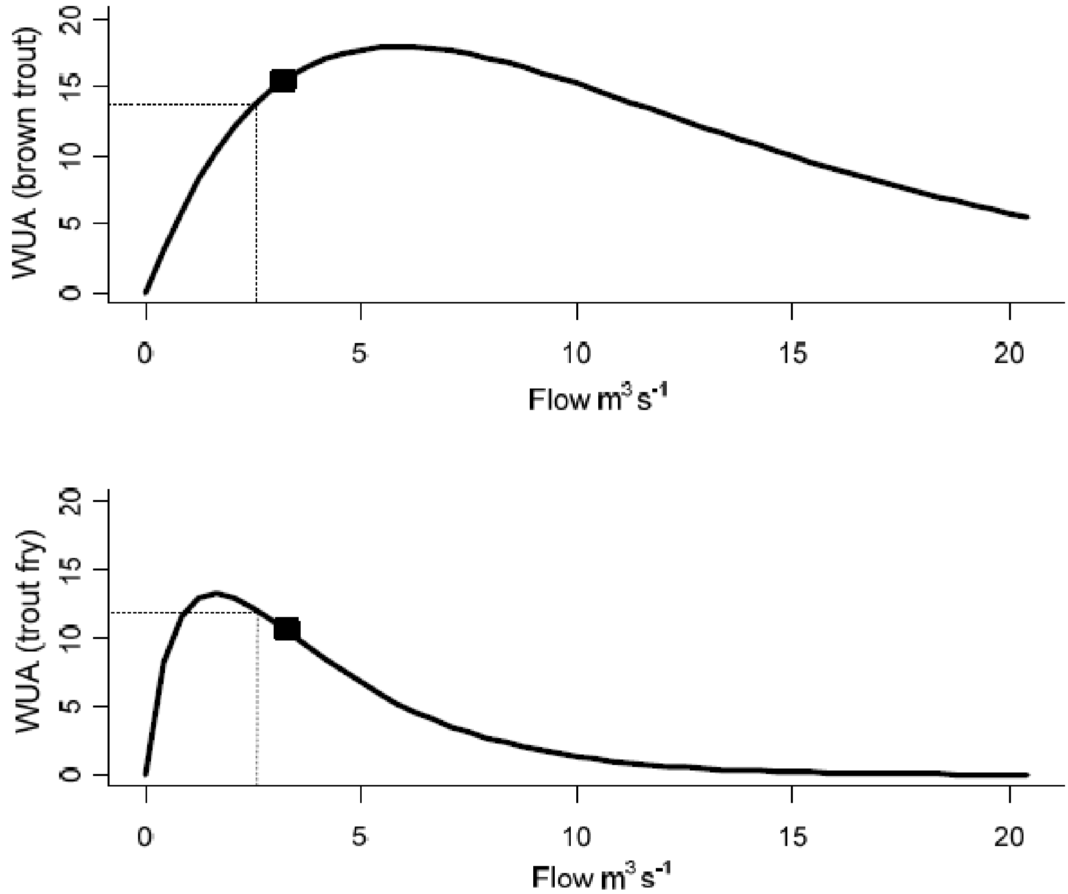

Figure 13 Weighted Useable Area (WUA) for Brown Trout at different life stages in a stream in Canterbury. The MALF is illustrated by the black square, and the habitat availability at the default minimum environmental flow of 80% MALF by the dashed line. Note that fry have access to habitat in a narrower band of flow than adults and prefer lower flow rates. WUA is an aggregate measure of physical habitat quality and quantity, expressed as an area per length of stream, that considers wetted area, depth, and velocity.

Within Canterbury, default objectives for water allocation rules in streams with a low degree of hydrological alteration is:

- Annual median reliability across the catchment of >95% at the management flow
- Median reliability across the catchment of at least 95% at the minimum flow
- Median loss of habitat across the catchment of less than 25%

As mentioned previously, it is unclear how these objectives were set. Scenarios were run minimum flows ranging from 10-100% of the MALF and extraction limits ranging from 10% to 150% of MALF – each in 10% increments..

Scenarios were then checked for compliance with all three statistical objectives

Where various scenarios meet all objectives, resource managers must set limits considering locally relevant details and the trade-off of balancing protection and maximising extraction.

In most streams in Canterbury, these objectives can rarely be achieved using the default environmental water requirements, so trade-offs must be made using the EFSAP. Different combinations of rules are tested as scenarios by the National Institute of Water and Atmospheric Research and may be presented to relevant regional council in a consequences report (Franklin et al. 2012). The regional Council will then develop flow rules based on the scenarios.

Reducing allocation in overallocated catchments.

The Resource Plan (ECan 2017) states that 3 of the 10 catchments are overallocated. Catchments are considered overallocated if environmental objectives are not being met[55]. In any overallocated catchment, policies require allocation to be reduced by reducing individual consent allocation by 10% upon:

- replacement[56] every 15 years[57]
- trade[58].

In addition to these regional scale policies, catchment-scale policies to reduce overallocation include:

- allocation of equivalent take from deep groundwater in return for surrender of surface or stream-depleting groundwater take in the Ashburton/Hakatare catchment[59]
- prioritising the use of inter-catchment transfers from the Rangitata supply scheme in the Orari catchment[60]
- a domestic supply system improving its efficiency and surrendering allocation in the Orari catchment [61]
- prohibition on consent transfers except to new owners of the same property in the Orari catchment [62]
- a requirement that applications to replace a consent must demonstrate need and efficiency in the Orari catchment [63].

The Rangitata River is one of the three rivers that make up the Central Canterbury Alpine Rivers catchment in the Regional Plan. While the catchment is not considered to be overallocated, the Rangitata supports New Zealand's largest irrigation scheme and proportionate allocation from it is more than double the other two rivers (Morgan et al. 2002). Concerted efforts have been made by Maori traditional owners and freshwater anglers to reduce allocation in the river.

The 2020 National Policy Statement for Freshwater Management has the force of legislation and adopts the fundamental concept of Te Mana o te Wai as its overarching objective (New Zealand Government 2020).

Te Mana o te Wai is a concept that refers to the fundamental importance of water and recognises that protecting the health of freshwater protects the health and well-being of the wider environment. It protects the mauri of the wai. Te Mana o te Wai is about restoring and preserving the balance between the water, the wider environment, and the community[64].

The statement articulates a central role for tangata whenua (Maori traditional owners) in delivering this objective in traditional lore[65] and contemporary legislative terms[66] and represents a strong commitment.

The statement has been cited as the reason for the surrender of an 864 ML/day B block consent to take and store from the Rangitata River in Southern Canterbury. The relevant water authority stated that it "would like to have a stronger relationship with Te Rūnanga o Arowhenua", who had been pursuing a legal challenge to ECan's granting of the consent in 2018[67].

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[55] ECan (2017) S.2.6
[56] ECan (2017) policy 4.50 (replacement is the equivalent of licence renewal)
[57] ECan (2017) policy 4.74
[58] ECan (2017) policy 4.71
[59] ECan (2017) policy 13.4.5
[60] ECan (2017) policies 14.4.1, 14.4.2
[61] ECan (2017) policy 14.4.3
[62] ECan (2017) policy 14.4.4
[63] ECan (2017) policy 14.4.6
[64] *National policy statement for freshwater management 2020 S1.3(1)*
[65] *National policy statement for freshwater management 2020 S1.3*
[66] *National policy statement for freshwater management 2020 S3.4*
[67] Timaru Herald, March 08 2021 Freshwater changes led to relinquishing of Rangitata River irrigation consent | Stuff.co.nz

4 Long listed examples

This section contains descriptions of all examples that were part of the long list referred to in section 2 of this report. The descriptions were reviewed by the Water Group's advisory group when formulating the short list of examples described in detail. In Section 3. Some elements of the long-listed examples were highlighted for further review in the short list, so the descriptions in this section may differ substantially from the corresponding description in Section 3.

4.1 Storage management and harvestable rights

This example was modified to focus more on the derivation of the extraction limit and is described in detail in section 3.1

Description of the limit

Rules on the size and location of storages can be used to limit take in unregulated catchments where water diversion is facilitated by dams located on waterways.

In South Australia, the Eastern Mount Lofty Water Allocation Plan specifies the volume of storage for 195 individual sub catchments with an average area of only 14.6 km^2. Harvesting storages must either be located off-stream or have a bypass mechanism that passes all flow less than a certain flow rate specified in the plan.

In Queensland, the Baffle Creek Water Management Protocol places a limit on the amount of overland flow that can be taken as entitlement by specifying an "entitlement factor" for storages of certain sizes. Storages that are large compared to their catchments will have a lower entitlement factor, whereas smaller storages will have higher entitlement factor.

In the Yarra Valley in Victoria, new storages on waterways are prohibited. However, storages with catchments less than 60 Ha can support seasonal winter-fill licences because runoff in small catchments in this seasonal climate is usually limited to the winter months.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes share water between extractive users etc.

The South Australian plan aims to protect environmental values at local and catchment scales and prevent water users from impacting each other at a local scale. The aim of Victorian regulations is to limit the take of water during the low flow season. The intent of Queensland regulations is not explicit within the water plan, but is one instrument used to limit the overall volume of water taken.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The limits are generally not referred to in legislation but are attached as conditions on licences to meet the catchment-scale objectives of the plan. Storage conditions may be formally documented in policies of government or regulatory authorities.

What types of information/data are used as the basis for establishing the limit? Is a model required?

The South Australian limits require a distributed Source model that represents all 195 sub catchments to allow storage volumes and passing flow rates to be calculated. In the Queensland example, a rainfall-runoff model calibrated to the local climate would probably be needed to calculate the entitlement factors, with the model calibrated to different slopes, vegetation and soil types to create a more robust calculation. The catchment size in the Victorian example is based on am administrative definition of "waterway", but could be derived from a rainfall runoff, or distributed hydrological model.

How applicable is this method to the NSW context?

A certain proportion of the runoff from a property can be harvested in NSW without a licence, so regulations regarding the size and location of storages would need to account for this right.

Does the example describe a volumetric limit?

No, but the regulations may be linked to a volumetric limit via a hydrological model

Does the example attempt to achieve specific environmental objectives?

The South Australian limits on dams were developed specifically to achieve an environmental objective in the water plan. The environmental objectives of the Queensland and Victorian limits are not explicit.

The impact of storage rules on environmental objectives has been explicitly modelled in South Australia, but not in Queensland or Victoria. Storage rules can be used to limit extraction in data-poor regions if rainfall-runoff relationships are reasonably well understood, but linking them to specific environmental objectives is a complex undertaking. Rainfall-runoff relationships are also likely to be complex in coastal NSW catchments where rainfall is relatively uniform compared to states to the north and south, and topography is highly variable.

Is the legislative and governance context in the example relevant to NSW?

All Australian states operate under the Westminster system of government and their relevant water and natural resource acts share many similarities. However, the Victorian and South Australian catchments are intensively managed, with significant resources employed to manage licence approvals and compliance.

Newly established rights to harvest runoff in coastal catchment without the need for a licence may make it difficult to implement storage rules.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

South Australian and Victorian catchments have relatively reliable, seasonal patterns of runoff and streamflow and the storage rules reflect this. The Baffle Creek catchment in southeast Queensland probably has hydrology that is more similar to the NSW coast.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

None of the three states highlighted in this example have a guaranteed right to harvest overland flow. The South Australian and Victorian examples identified have significant resources devoted to managing licences and enforcing compliance with conditions and/or plan prescriptions.

Is the example suitable for application to data-poor catchments?

The Queensland and Victorian examples can be implemented using a regional-scale calculation of runoff.

Is the example suitable for application to data-rich catchments?

The South Australian example would require a significant amount of hydrological data to be employed elsewhere.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

The South Australian water plan contains a detailed description of how the storage limits are linked to specific ecological objectives through testing scenarios within a hydrological model.

References – see section 3.1

4.2 Environmental risk management

This example was modified to focus on the Queensland methodology for determining environmental risk and is described in detail in section 3.2

Description of the limit

Western Australia is unique in having a state-wide policy describing its management of environmental risk when determining Environmental Water Provisions. The *Rights in Water and Irrigation Act (1914)* is over one hundred years old and is in many ways inadequate for dealing with water resources that are nearly fully allocated, or overallocated.

The Queensland *Water Act (2000)* requires Water Plans to specify the environmental objectives and the scenario-based risk assessment methodology developed by government is effective at transparently determining and communicating levels of environmental risk within Water Plans. The Queensland legislation offers more support in determining environmental objectives than the Western Australian legislation, but the supporting policy is not as explicit.

The Eastern Mount Lofty Ranges Water Allocation Plan contains a detailed description of environmental risk within the plan that while not as prescriptive as the Queensland and WA examples, may provide useful perspective.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes share water between extractive users etc.

The approaches to risk management do not specify a limit, but a process or method for determining the level of environmental risk associated with a water plan and the mechanisms it uses to achieve its objectives. Each approach specifically focuses on the risks to environmental objectives (not economic or social) and is designed around the nature and uncertainty of scientific environmental information.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The Western Australian Statewide Policy number 5 fills a gap in the legislation (over one hundred years old), making the connection between a very high-level legislative objective of sustainable resource management and specific levels of environmental risk. Being a policy, and not legislation, a good amount of context for decision making is presented, and a relatively detailed process for engaging with community and the environmental regulator is described.

The risk-based approach to determining environmental objectives of Water Plans is documented independently of the legislation and plans themselves. It is focused more on the technical treatment of hydrological and ecological information and less on the involvement of stakeholders and decision makers than the Western Australian example. The South Australian approach is similar to the Queensland approach and is described in detail within the plan.

What types of information/data are used as the basis for establishing the limit? Is a model required?

The Western Australian example is not specific to any particular method for determining extraction limits, whereas the Queensland and South Australian examples specify the use of a hydrological model and scenario-testing to determine environmental risks.

How applicable is this method to the NSW context?

Developing a clear policy around environmental risk and how it should be treated throughout the water management framework would offer great benefits for water resource planning in coastal NSW. Clear policy enhances the social licence of Water Sharing Plans, provides avenues for engaged stakeholders to contribute, and guidance for water planners. The examples presented span the full hierarchy of the framework from overarching policy to technical methods.

Does the example describe a volumetric limit?

The risk assessment approaches can be used to develop and assess volumetric limits and can potentially be applied to any other water management mechanism.

Does the example attempt to achieve specific environmental objectives?

Yes. This example is the strongest of those reviewed in its development, assessment, and articulation of environmental objectives.

Is the legislative and governance context in the example relevant to NSW?

Yes. Coastal WSPs in NSW are all scheduled for review in the near future and historical application of the 'macro' planning approach and absence of federal jurisdiction means that new policy can be developed and implemented. The legislative contexts for developing environmental objectives are similar, and the approaches to risk management, especially in Queensland and WA, could be applied to coastal NSW catchments.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

The approaches described are independent of hydrology and climate and can be applied to NSW catchments relatively easily. The Western Australian approach has been applied to groundwater plans.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Yes. The approaches can be applied to any type of management instrument.

Is the example suitable for application to data-poor catchments?

Risk assessment approaches can also be developed for data-rich or data-poor situations and can be used to assess the efficacy of any number of water management mechanisms, including extraction limits.

Is the example suitable for application to data-rich catchments?

The South Australian and Queensland examples both relate to relatively data-rich catchments.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

The Queensland and South Australian examples relate to an iterative method for determining environmental water requirements and associated levels of risk.

References

See section 3.2

4.3 Water plans in under allocated unregulated systems

This example was modified to focus on the Whicher area surface water allocation plan from Western Australia and is described in detail in section 3.3

Description of the limit

Two water plans from under allocated catchments were reviewed, the Baffle Creek Water Plan and Protocol in Qld and the Whicher Surface Water Allocation Plan in WA. A scenario-based risk assessment has been used in the Baffle Creek plan and a combination of environmental flows studies and statistical hydrology in the Whicher plan.

Both plans describe a methodology for releasing new entitlement and granting new licences. New entitlement may be released on a first come first served basis or reserved for specific uses such as the Aboriginal Water Reserve in Queensland.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes share water between extractive users etc.

The allocation limit may have been developed using a high level assessment of sustainable yield that meets legislative environmental objectives without defining specific outcomes (Whicher) or that delivers generic hydrological outcomes that are assumed to meet environmental objectives (Baffle).

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

In these plans, the environmental objectives are usually high level, and relate directly to legislative obligations without defining them specifically. Other objectives, such as promoting water trade or use, or enabling access for Aboriginal people and communities, may be more prominent.

What types of information/data are used as the basis for establishing the limit? Is a model required?

Limits may be developed using hydrological data only and may not require a model.

How applicable is this method to the NSW context?

A high-level assessment of licenced allocation as a proportion of mean annual flow could identify potentially low risk catchments in coastal NSW that these plans could be relevant to.

Does the example describe a volumetric limit?

Yes, and the limit is often the only management mechanism identified within the plan.

Does the example attempt to achieve specific environmental objectives?

Usually not.

Is the legislative and governance context in the example relevant to NSW?

Yes. The legislative context is similar to NSW and resources required for plan implementation are limited.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

The hydrology of the Baffle Creek catchment is similar to that of coastal NSW, perhaps with a greater frequency of cease-to-flow periods. The hydrology in the Whicher plan area is strongly seasonal, with a regular high flow period in late winter and cease to-to-flow period in Summer and Autumn.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Yes, with the major, and often only mechanism being the Allocation Limit.

Is the example suitable for application to data-poor catchments?

Under allocated catchments are usually data-poor areas, with little historical incentive to collect long-term streamflow data. However, there may be considerable ecological data available as the near-reference ecosystems may support significant ecological values worthy of study.

Is the example suitable for application to data-rich catchments?

No. More robust methods for determining EWRs in data-rich catchments are available and well documented.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

Methods for determining EWRs are better covered in other examples.

References

See section 3.3

4.4 Long-term water resource assessments

This example is described in detail in section 3.4

Description of the limit

The Victorian *Water Act (1989)* contains unique provisions to carry out Long-Term Water Resource Assessments (LTWRA) to support regional scale Sustainable Water Strategies. The Minister must carry out LTWRAs in 30 basins across the state every decade to determine the balance of water availability between environmental and consumptive users.

The LTWRA must determine whether the balance in water availability has shifted since the previous LTWRA and whether the environment has been impacted by reduced water availability. The LTWRA must be reviewed by the environmental regulator. If the balance has changed, and it can be shown that the environment has been impacted by the change in water availability, the Minister is required to identify actions to either restore the balance or improve the environment through other mechanisms.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes share water between extractive users etc.

The LTWRA refers to the 'availability' of water resources for environmental and consumptive uses and the balance between the two. The average annual volume available to each pool is not specified as the measure of availability in legislation but has been adopted in the past. In theory, the reliability and seasonality of available water are very important and can relate directly to the environmental objectives or values being targeted. There is a requirement to specifically link water resources to environmental values, although the scale and methods used to establish the link are not specified.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The LTWRA is a specific requirement of the Victorian *Water Act (1989)* and links directly to the environmental objects of the Act.

What types of information/data are used as the basis for establishing the limit? Is a model required?

Hydrological models are used to determine the balance between consumptive and environmental water, although 'availability' should be defined in more detail and in terms that are more relevant to environmental values.

The method for determining whether there has been a change in environmental condition or values and the scale at which the assessment is made has a large bearing on whether a change can be demonstrated and attributed to a change in water availability. The interpretation applied historically is that environmental changes must be demonstrated at a basin scale, over the same time frame as the sustainable water strategy (~10 years). This approach requires large amounts of data collected over more than a decade. Such data sets are rare and very unlikely to have been initiated with this purpose in mind, making it very difficult to meet the environmental objects of the act

Ecological modelling should be considered as an alternative approach for determining relationships between water availability and environmental condition, especially in light of new modelling techniques and environmental investigations designed specifically to find flow-ecology linkages.

How applicable is this method to the NSW context?

The fundamental question of how to review water sharing arrangements between consumptive and non-consumptive water resources is important and lessons could be drawn from recent experience in Victoria.

Although the legislative framework surrounding the LTRWA is strong, little detail is provided around the methodology for determining changes in environmental health and their causes, or the process for considering trade-offs between environmental and other objectives. Developing a hypothetical policy to fill these gaps would be a useful initiative for supporting the review of coastal water sharing plans.

Does the example describe a volumetric limit?

Yes. The assessment is summarised as the average proportions of mean annual flow that is 'available' to consumptive and environmental uses. The assessment could be improved by better defining the seasonality and reliability of water available to each pool.

Does the example attempt to achieve specific environmental objectives?

In practice, the method has only been used to find links between flow and water quality or macroinvertebrates as these are the only environmental values with sufficient data. New ecological modelling methods that establish links between more flow-dependent values such as fish and vegetation should be considered in the future.

Is the legislative and governance context in the example relevant to NSW?

The LTWRA is not required under NSW legislation and is a time consuming and resource intensive process, so should probably not be considered for implementation. However, newer ecological techniques that require less data could be considered.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

In contrast to coastal NSW, Victorian hydrology is more seasonal with a regular period of high baseflow in winter and spring. However, the example is not specific to a particular ecosystem and lessons learnt may be applicable to the NSW context.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

No, the LTWRA is unique.

Is the example suitable for application to data-poor catchments?

No. Even using newer techniques, significant amounts of ecological data are required.

Is the example suitable for application to data-rich catchments?

Yes. The intent of the LTWRA can be met in catchments where there is significant amounts of ecological data. Anticipating the questions that will be posed by a LTWRA or its equivalent non-statutory process in NSW can help to design better ecological monitoring or investigation programs.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

The example highlights an example of a strong legislative remit being weakened by inappropriate methodology.

References

See section 3.4

4.5 Methods and governance in Spain

This example is described in detail in section 3.5

Description of the limit

In Spain, water resources should be managed so that waterways "deviate only slightly from reference". However it is unclear from our high-level investigation how reference levels are identified. The Hydrological Planning Instruction sits below the legislation and regulations in the management framework and describes how specific environmental and hydrological objectives are set.

A prioritisation process is used to gather the information and complete investigations required to understand water requirements and develop environmental objectives. Rivers with highly modified hydrology (regulated rivers) are targeted for environmental flow studies, and rivers that are known to support significant ecological values must have a hydrological study completed for them.

Several environmental flows methods have been employed and documented, including methods that use hydraulic and habitat models to develop flow-ecology relationships. Methods include analyses of hydrological alteration that rely on generic ecohydrological relationships to develop environmental objectives. some environmental flow assessment methods include recommendations related to infrequent interannual events such as floods and severe droughts.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes share water between extractive users etc.

The environmental objective is described in relation to a reference condition rather than specific ecological values. The hydrological objectives are interannual, with specific flow objectives for drought years identified as the main measure of success in water planning documents.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The water plans are established under the Spanish Water Act and the EU Water Framework Directive. Policy regarding planning processes and objective setting that sits underneath legislation in the management framework is mentioned in material reviewed so far but availability of the references has not yet been confirmed.

What types of information/data are used as the basis for establishing the limit? Is a model required?

A wide range of data have been used in the published examples. Ecological and physical habitat models are employed to highlight flow-ecology linkages and test the environmental outcomes of different water resource scenarios.

How applicable is this method to the NSW context?

The prioritisation process for investigating waterways has the potential to be applied in NSW, especially in identifying catchments or water sources that are at higher risk and require further ecological and/or hydrological data to be gathered.

Does the example describe a volumetric limit?

Annual limits not identified in the literature reviewed so far. Restrictions on 'irrigation quotas' can be used to limit water use on daily timescales.

Does the example attempt to achieve specific environmental objectives?

Yes. Objectives related to ecological conditions in estuaries and deltas appear to be especially well developed.

Is the legislative and governance context in the example relevant to NSW?

Like NSW, Spain has a Water Act, and regulations that govern water planning. Like Australia, water is also publicly owned. The Act and regulations are consistent with the European Union Water Framework Directive, which requires waterways to deviate only slightly from reference.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

Spain experiences a Mediterranean climate, in contrast to the humid subtropical climate of NSW. However, the planning framework and prioritisation approaches for data-rich and data-poor situations suggests that further investigation may yield valuable lessons.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

The well-documented catchments are likely to be regulated systems with large storages, as this is where the most serious environmental impacts are encountered.

Is the example suitable for application to data-poor catchments?

Probably not, although the framework for prioritising investigations may offer some useful lessons.

Is the example suitable for application to data-rich catchments?

Yes. Being an international example from a non-English speaking country, it is likely that the published and accessible information is concentrated in high-risk, catchments with large amounts of available data. Habitat Suitability models in particular require a lot of field work to develop

Does the example provide lessons regarding methodologies for determining environmental water requirements?

Yes. Several different models have been documented, including hydrological, habitat-area and hydro-economic models. Work on interannual water requirements and drought refuges is of particular interest.

References

See section 3.5

4.6 ELOHA based approach to maintain ecological integrity (USA)

This example is described in detail in section 3.6

Description of the limit

Application of the Ecological Limits of Hydrological Alteration (ELOHA) framework to develop a volumetric limit in nine areas of the United States including Ohio, Massachusetts and Colorado. The ELOHA framework compares the current or hypothetical future flow regime to a modelled reference regime. The framework is uses to determine how much water can be extracted from different parts of the flow regime while maintaining ecological integrity. The methodology could be used to develop generic flow-ecology relationships. These generic relationships could be used to modify the statistical method for determining sustainable diversion limits (example 2 in this project) and make it more ecologically defensible in data-poor situations.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes share water between extractive users etc.

ELOHA framework seeks to achieve a hydrological outcome with that outcome linked back to the maintenance of ecological integrity. Ecological integrity is maintained when the hydrology remains within X% of the reference condition across all flow classes.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

Governance in the USA is quite different to Australia, with water resources not vested in the Crown and much a greater recognition of private rights. However, in states where water resources are not as well developed and extraction as a percentage of total flow is lower, government's ability to regulate resource extraction may be greater and the overall governance framework more similar to the NSW context.

For example, In the State of Massachusetts the limit is imposed under the Water *Management Act (1986)*. This legislation limits take to a 'safe yield' that is defined in regulations as 'the maximum dependable withdrawals that can be made…including…during a period of years in which the period of greatest water deficiency id likely to occur."

What types of information/data are used as the basis for establishing the limit? Is a model required?

ELOHA framework is based purely off hydrological data. Two model scenarios are used. A natural model run scenario that shows the 'desirable' state of the catchment and an impact scenario that includes extraction. To develop these model scenarios X, Y and Z are required.

Need gauge data representing the catchment. Need understanding of extraction behaviour.

How applicable is this method to the NSW context?

The nine case studies presented are well-documented, with supporting context and scientific knowledge that is accessible. The hydrology of the catchments studied is varied, with examples from humid temperate and Mediterranean-type climates. Although the hydrology may not be exactly similar, enough examples are presented to be able to make generalisations that are applicable to coastal NSW

Does the example describe a volumetric limit?

Several limits are described, including daily and monthly flow limits, and dam release rules.

Does the example attempt to achieve specific environmental objectives?

Examples are overwhelmingly centred around objectives for freshwater fish, with some objectives cited for invertebrates, vegetation, and recreational uses.

Is the legislative and governance context in the example relevant to NSW?

Rights to water and the ability of regulatory agencies to manage water resources are determined by a combination of legislation and case law. Ownership of water is not invested in the Crown and a stronger culture of individual property rights prevails.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

Most catchments experience high flow sin spring, when snow melts, and precipitation exceeds evapotration by the greatest amount. The climate of the catchments varies widely from Humid Continental in the northeast and Semi-arid and Mediterranean in the Southwest. The Humid Subtropical catchments of the Southeast have a climate most similar to coastal NSW.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Management instruments may be similar for regulated catchments. Instruments in unregulated catchments may differ substantially due to primacy of property rights for small-scale water diverters.

Is the example suitable for application to data-poor catchments?

Most examples rely on substantial local data to determine flow-ecology relationships that are used in the assessments. Some generic relationships may be used.

Is the example suitable for application to data-rich catchments?

Most examples rely on substantial local data to determine flow-ecology relationships that are used in the assessments. Some assessments make use of extensive hydrogical data.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

Yes. Nine different examples are presented.

References

See section 3.6

4.7 Water Resource Consents in Canterbury

This example is described in detail in section 3.7.

Description of the limit

The majority of New Zealand's consumptive water is used for irrigation in the Canterbury district on the south island. The land most suitable for irrigation is confined to the highly permeable coastal plain, where interactions between groundwater and surface water are strong. Most of the water is taken under water Resource Consents (the equivalent of licences) for run-of-river or groundwater extraction that are managed by local government.

The Canterbury Land and Water Regional Plan describes the environmental objectives for managing water extraction, the allocation limits and environmental flow provisions. Some catchments do not have an allocation cap, with resource consents limited at the margin by assessments of their potential impact on environmental flows and other users.

Within the plan area, some river catchments are subject to Water Conservation Orders, which are pieces of legislation that confer stronger restrictions on activities, including the take and use of water and activities that interfere with a watercourse.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes, share water between extractive users etc.

The plan aims to integrate the management of land and water to a greater degree than NSW water sharing plans. Hydrological and ecological outcomes are both listed alongside water quality indicators as plan objectives, reflecting the strong linkages between land use and quality of surface and groundwater.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The plan and orders are implemented under the *Resource Management Act 1991*, which manages natural and physical resources other than minerals. The purpose of the act is to promote the sustainable management of resources, with more specific objectives described in regional plans or subordinate instruments.

What types of information/data are used as the basis for establishing the limit? Is a model required?

Extensive ecological and hydrological information is required to develop the environmental water requirements and flow limits and a hydrogeological model will be required to assess applications for resource consents. The information and/or models used by local council to assess applications has not been identified yet.

How applicable is this method to the NSW context?

Management of licences and overall extraction is similar in that the catchments are largely 'unregulated', with most take coming from resource consents to extract direct form watercourses or groundwater.

Does the example describe a volumetric limit?

In some of the catchments within the plan area, a 'cap' has been put on water allocations. In less developed catchments, no cap has been established.

Does the example attempt to achieve specific environmental objectives?

Yes. specific environmental objectives are described in the plan, and the mechanisms to achieve the objectives are not limited to managing water extraction

Is the legislative and governance context in the example relevant to NSW?

The structure of New Zealand legislation is more similar to NSW than the American or Spanish examples but does integrate the management of other natural resources in a more complex way than most Australian legislation. It is not clear from the documents reviewed so far how well resourced local government is to manage the plan and implement its provisions.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

The hydrology and geomorphology of rivers differs significantly form the coast NSW situation. Flow is likely to be strongly seasonal with a spring high resulting from snowmelt and summer baseflow sustained by groundwater discharge in the relatively dry climate of the Canterbury Plain. The rivers are high-energy braided systems containing very coarse sediments.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Similar to flow class licences in NSW, Resource Consents allow extraction of baseflow down to a certain level described in the plan and for 'harvesting' of high flows. Groundwater Resource Consents are probably used more than in coastal NSW.

Is the example suitable for application to data-poor catchments?

No. The highly specific hydrological objectives require an extensive network of streamflow gauges and observation bores. The devolution of decision-making regarding allocations to licencing officers requires robust hydrogeological models and decision support tools.

Is the example suitable for application to data-rich catchments?

Yes. see above.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

Yes. Several online resources are available from the National Institute of Water and Atmospheric Research.

References

See section 3.7

4.8 Statistical streamflow analysis – Victoria and Western Australia

- **Statistical analysis of gauged data that aims to quantify the volume that can be diverted without impacting existing licence holders**
- **Uses a cease to pump and maximum extraction rate to calculate volume of water that can be diverted in 80% of years**
- **Limited utility for environmental protection**
- **Potential application in low risk, data poor NSW catchments**

Description of the limit

Victoria and Western Australia both employ similar statistical streamflow analysis methods for determining the volume of water that can be diverted 'sustainably' from a catchment. The method was first developed in Victoria and later applied in Western Australia and is to be used in data poor regions. It has been applied across all catchments in Victoria and all catchments within the Whicher area in Southwest Western Australia (see section 4.3).

The method uses gauged streamflow data and calculates three variables:

- The Minimum Flow Rate, below which water cannot be diverted (equivalent to NSW cease to pump threshold)
- The Maximum Daily Extraction Rate at which water can be diverted
- The Sustainable Diversion Limit, which is the volume of water that can be diverted in 80% of years, within the limits imposed by the first two variables.

This method can be extrapolated to ungauged catchments if a representative sample of catchments within a region have available gauged data.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes, share water between extractive users etc.

The method is used to estimate the amount of water that can be diverted from a catchment without licence holders impacting each other at the catchment scale. Reliability is secured for existing licence holders whilst also determining if there is any potential for growth.

There is the potential to base the Minimum Flow Rate on ecological information and provide better protection for the environment. An example of this would be to link the Minimum Flow Rate to outcomes such as riffle habitat for macroinvertebrates or connectivity for fish movement.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The Victorian *Water Act 1989* and Western Australian *Rights in Water and Irrigation Act 1914* and *Environmental Protection Act 1986* have overarching objectives to sustainably manage water use and water resources. The calculated limits are used in data-poor or under allocated/low-risk catchments to define 'sustainable' water use and to protect the resource.

More advanced methodologies are used to determine limits in data-rich catchments within these jurisdictions (see Section 4.3).

What types of information/data are used as the basis for establishing the limit? Is a model required?

The method can be employed using hydrological data only and complex hydrological models are not required. The data should preferably be gauged but can be extrapolated into ungauged catchments if there is enough data at a regional scale from within the same climatic zone.

How applicable is this method to the NSW context?

The method would be useful in low-risk or data-poor catchments, especially if the annual volumetric limit is regarded as the main management tool. Although the method has relatively weak links to environmental objectives, it provides security to existing users and may be a more robust method of determining the annual volumetric limit than the sum of licenced entitlement current used in coastal LTAAELs.

Does the example describe a volumetric limit?

Yes, as well as corresponding minimum flow rates below which water cannot be taken and maximum rates of water diversion.

Does the example attempt to achieve specific environmental objectives?

Not explicitly. The intent is to quantify how much water can be reliably diverted within a catchment for the purposes of harmonising licence reliability and supporting trade.

Is the legislative and governance context in the example relevant to NSW?

Yes. The objectives of the Victorian and Western Australian legislation to sustainably manage water use and resources is similar to the NSW legislation and all jurisdictions recognise a similar definition of ecologically sustainable development.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

Somewhat. The seasonally regular hydrology of the southern Australian states is possibly more amenable to this type of analysis, with relatively regular baseflows being generated in the cooler months of the year. Although rainfall and runoff in NSW is less seasonal than the southern states, the relatively wet climate probably generates enough baseflow to make this method applicable.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Possibly. The method has been employed in data-poor catchments with limited licencing and enforcement resources in Victoria and Western Australia. This may reflect the resourcing situation in coastal NSW catchments.

Is the example suitable for application to data-poor catchments?

Yes. The method can be employed using hydrological data only, and findings can be extrapolated to ungauged catchments. Ecological data could be incorporated into the method and would only need to relate to low-flow or base flow requirements.

Is the example suitable for application to data-rich catchments?

No. More robust methods that are linked to specific and measurable environmental objectives are available and have been widely employed throughout Australia.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

No. See previous point.

References

SKM (2008, 2009), DoW (2009a), DEPI (2014b)

4.9 Tribal and other rights in California

- **Case law used to develop hierarchy of water rights that protect the rights of Native American tribes to achieve economic self-sufficiency**
- **Californian legislative framework not relatable to NSW context**
- **Limited utility or potential for application in NSW**

Description of the limit

This example relates to efforts by Native American tribes to establish and exercise rights to water for instream and consumptive uses. It does not establish a volumetric limit on extraction.

The Winters decision in 1908 established the right of Native American tribes to achieve self-sufficiency by using the waters that flow through their reservations for economic purposes. The California Water Board has the authority to manage the water resources held in its storages for 'public welfare' and tribes have taken court action to support the board in meeting these obligations through instream use.

The legislative context of water rights in California and the United States is very different from Australia, with water rights generally established through case law rather than legislation. Water rights are often exercised by demonstrating prior use or rights through court action, which establishes a hierarchy of rights. In this system the entitlements of 'senior rights' holders take precedence over 'junior rights' holders. Public agencies must operate within this rights framework, and do not 'own' water resources as is the case for the Crown in Australia.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes, share water between extractive users etc.

The example does not relate to an allocation limit but to establishing links between consumptive water use, instream hydrology, and environmental outcomes in a court of law.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The method for establishing water rights in unregulated catchments in the USA probably has more in common with Australian common law than the statutory law under which water is mostly managed. The California Water Board, which manages large, regulated catchments, is governed by the *Water Code (1943)*.

What types of information/data are used as the basis for establishing the limit? Is a model required?

A wide range of information is required to establish the hierarchy of rights, including legal precedent, economic information, and data on water use, hydrology, and ecology.

How applicable is this method to the NSW context?

Despite the differing legal frameworks, some principles are common. In Australia, the water rights of established users are often given precedence over 'sleeper' licences, sometimes explicitly as in the case of non-interference assessments of groundwater licences, and sometimes through administrative precedents as is the case with Bulk Entitlements in Victoria. Although most of the higher profile cases in California will be from regulated catchments with large storages, an exploration of how an explicit hierarchy of rights is developed could provide useful guidance for policy development in coastal NSW.

Does the example describe a volumetric limit?

No. The example is about establishing a hierarchy of water rights.

Does the example attempt to achieve specific environmental objectives?

Environmental objectives usually relate to fish, especially estuarine residents in the Sacramento – San Joaquin Delta and migratory Salmon.

Is the legislative and governance context in the example relevant to NSW?

Not directly. The NSW government has made significant commitments in the State Water Strategy to increase Aboriginal ownership and control over water, for both consumptive, and non-consumptive uses. Similarities between the Winters decision and the intent of the *Aboriginal Land Rights Act (1983)* may highlight alternative interpretations of water law and avenues for achieving outcomes for Aboriginal communities in NSW.

The recognition of Native Title rights as a form of basic landholder rights that enjoy primacy under the *Water Management Act* is analogous to the American situation.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

The hydrology of California is very different from coastal NSW. The rivers are large and highly regulated, with a highly seasonal pattern of streamflow that peaks in spring.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

The management instruments are very different to NSW, with tribal, economic, and environmental interests represented by independent lawyers, and public agencies recognised by courts as only one of many competing stakeholders.

Is the example suitable for application to data-poor catchments?

Potentially. A hierarchy of rights can be established and exercised in the absence of data or management objectives.

Is the example suitable for application to data-rich catchments?

Yes. The Californian situation is supported by a large amount of published information.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

There is a large amount of published literature relating to environmental flows in California, but this would only be reviewed in relation to how it is used to support tribal rights within the hierarchy. Environmental flow methodologies from the USA are presented as a standalone example in section 3.6.

References

CEFWG (2021), SCC (2015), WWT (2022), State Water Resources Control Board: https://www.waterboards.ca.gov/waterrights/water_issues/programs/public_trust_resources/#dedication

4.10 Catchment management strategies - South Africa

- **Environmental Water Provisions are expressed as a monthly flow volume, but operational plans to deliver these flows have not always been met.**
- **The legal framework is similar to the NSW context, but state capacity in South Africa is more limited.**
- **Policy and implementation part of the hierarchy more applicable to NSW than the development of objectives.**
- **Major lessons in leadership, resource requirements and stakeholder engagement and collaboration, particularly establishing social licence in catchments with limited on-ground resources, can be applied in NSW.**

Description of the limit

The overarching *National Water Act 1998* (SAF Act) provides for the establishment of regional water management boards that develop catchment management strategies that provide for environmental objectives and manage trade-offs between consumptive and non-consumptive uses at a regional scale. This framework is based on that found in NSW and is very similar.

Some boards have been established and developed catchment management strategies, whereas in other areas of the country, boards are yet to be established.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes, share water between extractive users etc.

Limits are designed to protect the environment, although this objective under the Act is subservient to social objectives. International treaties make provision for shared management of water resources in the South African tributaries of the Limpopo River and provide for passing flows to be provided from dams to users in Mozambique.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The legislative framework for managing water in South Africa, including the SAF Act, has been based on NSW and is very similar. The SAF Act explicitly recognises social injustices and contains clear objectives for addressing them. Although environmental objectives are included, the purpose of the act appears to be more focused on equitable development and sharing of water resources.

Water is managed to meet the requirements of the SAF Act. Monthly flow requirements have been developed to protect environmental values, although in practice the operational plans to deliver these flows have not always been developed or effectively implemented.

What types of information/data are used as the basis for establishing the limit? Is a model required?

Hydrological models are required and can be employed with generic ecological models, although ecological data allows for more specific environmental objectives to be developed. However, the major lessons of this example probably lie more in the policy and implementation part of the hierarchy than the development of objectives.

How applicable is this method to the NSW context?

Useful information has been published regarding state capacity to implement the entire management framework, from establishing governance mechanisms to implementing environmental flow regimes. Lessons can be learned in the areas of leadership, resource requirements and stakeholder engagement and collaboration. Overall, positive lessons can be learned regarding the legislative and methodological levels of the management framework and lessons on what not to do can be learned regarding policy and unwritten precedent.

Does the example describe a volumetric limit?

Environmental Water Provisions are expressed as a monthly flow volume that is required to be met.

Does the example attempt to achieve specific environmental objectives?

There is currently not a strong link between water resource management and environmental objectives.

Is the legislative and governance context in the example relevant to NSW?

The legal framework is similar to the NSW context, with the legislation bearing many similarities to the NSW Act. State capacity in South Africa is limited compared to NSW, although lessons can be learned regarding establishing social licence in catchments with limited on-ground resources.

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

Water management in the easterly flowing rivers in the northeast of South Africa is relatively well documented, with water strategies developed, and the region has a similar climate to coastal NSW, if slightly hotter.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Yes, however, on-ground management instruments have only been developed in a limited number of catchments.

Is the example suitable for application to data-poor catchments?

Yes. Examples of desktop approaches for determining environmental flows have been documented that rely on hydrological data and hydraulic models only. Many of the documented governance challenges arise in catchments with limited data, state capacity, and human resources.

Is the example suitable for application to data-rich catchments?

Potentially yes if limited to methods for determining environmental flows. Documented methods include building block approaches and the Habitat Flow-Stressor Response method.

Does the example provide lessons regarding methodologies for determining environmental water requirements?

Potentially yes.

References

BGCMA (2017), DWAF(2006), DWS(2014), Pollard & du Toit (2011), Riddell et al. (2014), Schreiner (2013)

4.11 River Kennett in England

- **Linked groundwater – surface water model used to derive impacts of groundwater extraction on low flow recommendations related to fish habitat outcomes**
- **Used to attach drought-related conditions to town water supply extraction**
- **Highly localized and focused on achieving outcomes for single ecological functional group**
- **Some potential learnings for establishing flow-ecology relationships but limited utility for application in NSW catchments**

Description of the limit

The River Kennet in the North Wessex Downs Area of Outstanding Natural Beauty is a significant spring-fed chalk stream that supports significant environmental and social values. Groundwater supports baseflow that maintains submerged aquatic vegetation that provides habitat for trout, which support a significant and influential recreational fishery. Groundwater extraction by distributed small-scale users, as well as town water supply, reduces baseflow in dry seasons and during periods of extended drought.

An environmental flows study was carried out with the main environmental objective of protecting trout populations. Flow recommendations for low flows were developed to maintain minimum water depths and to maintain physical habitat by maximising wetted area to support submerged aquatic macrophytes. A hydrogeological model was also developed to relate groundwater extractions to water depth in the river. The results of the study were used to attach conditions to the licence of the town water supplier that limited the daily volume of water that can be extracted from groundwater during periods of low flow and support the business case for an alternative supply during drought.

What is the limit trying to achieve? Is it there to achieve environmental outcomes, hydrological outcomes, share water between extractive users etc.

Limits on groundwater extraction in times of drought are linked explicitly to the achievement of social and environmental objectives in the river. The flow study was used to support a business case for an alternative town water supply.

What legislation is the limit imposed under? How does the limit achieve or contribute to achieving the jurisdictions legislative requirements?

The limits were developed under the *Environment Act (2021)* and implemented under the *Water Act (2014)*.

What types of information/data are used as the basis for establishing the limit? Is a model required?

A coupled groundwater-surface water model is required to determine the link between groundwater extraction, water table levels and dry-season baseflow in the river. Ecological and hydraulic models that relate streamflow to water depth and wetted area are required to quantify the quantity and quality of habitat for fish.

How applicable is this method to the NSW context?

This example may be applicable to situations where perennial groundwater-fed streams on the coastal plain support recreational freshwater fisheries or other ecosystems with high social values.

Does the example describe a volumetric limit?

Not on an annual timescale. The limits put in place relate to daily extraction rates of groundwater during dry seasons.

Does the example attempt to achieve specific environmental objectives?

Yes. The objectives are to maximise the area of submerged aquatic vegetation and the population of trout.

Is the legislative and governance context in the example relevant to NSW?

Yes, the legislative framework for delivering environmental flows in the Kennett River is similar to NSW. The *Environment Act (2021)* the *Water Act (2014)* enable the Environment Agency to determine environmental flow requirements and for water agencies to implement them

Is the hydrology that the mechanism applies to similar to NSW coastal catchments?

The spring-fed hydrology is probably unique but may be applicable to areas on the coastal plain of NSW, and/or where groundwater interacts strongly with streams. The type of environmental flow methodology applied would be relevant to ecosystems in coastal NSW rivers that are highly dependent on baseflow, such as riffle-inhabiting macroinvertebrates.

Are the management instruments that are employed in this example similar to those in unregulated NSW catchments?

Yes. It is similar for water sources along the coast where groundwater is used as a substitute for surface water and extraction is considered to pose significant environmental risks in dry years.

Is the example suitable for application to data-poor catchments?

No.

Is the example suitable for application to data-rich catchments?

Yes. Sufficient data on groundwater, surface water, and ecological condition is required to be able to demonstrate a quantitative relationship between groundwater extraction and environmental objectives

Does the example provide lessons regarding methodologies for determining environmental water requirements?

Yes, in perennial groundwater-fed systems.

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