

FLOWS

– a method for determining environmental
water requirements in Victoria

Edition 2



Published by the Victorian Government
Department of Environment and Primary Industries Melbourne
June 2013

© The State of Victoria Department of Environment and Primary Industries 2013
This publication is copyright. No part may be reproduced by any process except in accordance with the provisions of the *Copyright Act 1968*.

Authorised by the Victorian Government, 8 Nicholson Street, East Melbourne.
Print managed by Finsbury Green. Printed on recycled paper.

ISBN 978-1-74287-746-4 (print)
ISBN 978-1-74287-747-1 (online)

For more information contact the DEPI Customer Service Centre 136 186

Disclaimer

This publication may be of assistance to you but the State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

Accessibility

If you would like to receive this publication in an accessible format, such as large print or audio, please telephone 136 186, or email customer.service@dse.vic.gov.au

Deaf, hearing impaired or speech impaired? Call us via the National Relay Service on 133 677 or visit www.relayservice.com.au

This document is also available in PDF format on the internet at www.depi.vic.gov.au

This document may be cited as follows:

Department of Environment and Primary Industries 2013. FLOWS – a method for determining environmental water requirements in Victoria Edition 2. Report prepared by Sinclair Knight Merz, Peter Cottingham and Associates, DoDo Environmental and Griffith University for the Department of Environment and Primary Industries, Melbourne

Cover images:

Left: Wimmera River. Photo by Greg Fletcher Wimmera CMA.

Middle: Toorong River. Photo by Alison Pouliot.

Right: Goulburn River. Photo by Alison Pouliot.

Contents

Acknowledgements	iii
Definitions	iv
Executive Summary	v
Preface (Preamble to the updated method)	vi
1. Introduction	1
1.1 Overview of the FLOWS method	1
1.2 Roles and responsibilities	4
2. Preliminary tasks	7
2.1 Needs assessment and data availability	7
2.2 Groundwater and groundwater-dependent ecosystems	9
2.3 Hydrological considerations	9
2.3.1 Surface flow	9
2.3.2 Surface water and groundwater interaction	11
3. FLOWS method description: Stage 1 – Project inception, system condition and issues	13
3.1 Project inception	13
3.2 Data collation	13
3.2.1 Environmental assets	14
3.2.2 Geomorphological data	15
3.2.3 Hydrology	15
3.2.4 Hydrogeology	15
3.2.5 Plans and strategies	15
3.2.6 System operation	15
3.2.7 Condition assessment	16
3.3 Reach and site selection	16
3.3.1 Site Paper	17
3.4 Environmental Flow Technical Panel – field assessment	17
3.4.1 Reach assessment	19
3.4.2 Site description	19
3.4.3 Cross-sections	19
3.5 Development of environmental objectives	22
3.5.1 Regional policy objectives	22
3.5.2 Process for determining environmental and flow objectives	24
3.6 Issues Paper	28
4. FLOWS method description: Stage 2 – Development of flow recommendations	30
4.1 Surveying	30
4.2 Hydraulic modelling	31
4.2.1 Cross-sections	31
4.2.2 Low flow determination	32
4.2.3 Hydraulic roughness and boundary conditions	32
4.2.4 Model calibration	32

4.3 Analysis and environmental flow recommendations	34
4.3.1 Flow recommendations	36
4.3.2 Interactions between flow components and downstream reaches	37
4.3.3 Uncertainty	37
4.4 Performance against flow recommendations	37
4.4.1 Performance assessment	38
4.4.2 Risk framework	39
4.5 Supporting recommendations	39
4.5.1 Operational issues	39
4.5.2 Other environmental effects	40
4.5.3 Monitoring	40
4.6 Final reporting	40
4.6.1 Final Report document	41
References	42
Appendix A Flow components	44
A.1 Background to the flow component philosophy	44
A.2 Definition of the flow components	44
A.3 References	46
Appendix B Hydrological and hydraulic modelling	48
B.1 Hydrology	48
B.2 Hydraulics	50
B.3 Hydrological modelling tools	51
Appendix C Site description	53
Appendix D Field data sheets	55
Appendix E Water-dependant species	65
Appendix F Calculating performance	66
F.1 Preamble	66
F.2 Using daily data	66
F.3 Summer low and winter low	66
F.4 Summer fresh and high; winter fresh and high	66
F.5 Bankfull and overbank	67
F.6 Cease to flow	67
F.7 Assessing performance using monthly data	67

Acknowledgements

The update of the FLOWS manual acknowledges the support of the Water Group Department of Environment and Primary Industries and its Technical Audit Panel members: Barry Hart, Michael Stewardson, Tom McMahon, Terry Hillman, Gerry Quinn and Ian Rutherford.

The update is based on the work of a team of specialists with knowledge of stream and floodplain ecology, water quality, geomorphology, hydrology, wetlands, and catchment management. The project team was a consortium led by Sinclair Knight Merz in partnership with Peter Cottingham (Peter Cottingham and Associates), Paul Boon (Dodo Environmental) and Nick Bond (Griffith University).

During the course of the project a number of people generously contributed their time and ideas at a stakeholder workshop, including:

Simon Baker	Department of Environment and Primary Industries
David Crook	Arthur Rylah Institute
Barry Hart	Water Science Pty Ltd
Terry Hillman	Consultant
Michael Jensz	Victorian Environmental Water Holder
Lance Lloyd	Lloyd Environmental Pty Ltd
Anna Lucas	Melbourne Water
Tom McMahon	Melbourne University
Steve Nicol	Department of Environment and Primary Industries
Gerry Quinn	Deakin University
Ian Rutherford	Melbourne University and Department of Environment and Primary Industries
Fiona Spruzen	Department of Environment and Primary Industries
Michael Stewardson	Melbourne University

The original FLOWS method report was prepared in 2002 by a project team led by Sinclair Knight Merz in partnership with the Cooperative Research Centre for Freshwater Ecology, Freshwater Ecology (NRE) and Lloyd Environmental Consultants. The contribution of others to the development of the original FLOWS method is acknowledged in the 2002 FLOWS method report (NRE 2002a).

Definitions

The terms used in the report are explained below.

Ecosystem response curve is the relationship between an ecosystem response variable and an environmental driver variable, such as river flow. Response curves can be defined in a variety of ways depending on the specific variables and the data available to inform the relationship. For FLOWS studies, response curves are typically based on the level of risk to an asset in relation to how well a flow regime meets the specific flow requirements of that asset (see Figure A.1 for an example curve).

Environmental water requirement is the amount of water required to sustain aquatic ecosystems, with a minimum risk of degradation.

Environmental Water Reserve is 'the legal term used to describe the amount of water set aside to deliver environmental outcomes' (Victorian Environmental Water Holder 2011). It was established in 2005 to provide greater protection for environmental water in our rivers and aquifers (groundwater systems). Its objective is to preserve the environmental values and health of water ecosystems. Water in the Environmental Water Reserve is provided in three ways:

- **Environmental water entitlements** are set aside water held by the environment in perpetuity. In general, they are a share of the available resource (in flows) in storages.
- **Obligations on consumptive entitlements** include the passing flows that water corporations or licensed diverters are obliged to provide out of storage or past a diversion point to protect environmental values.
- **'Above cap water'** is the water left over after limits on consumptive use have been reached and unregulated flows cannot be captured in storage. In groundwater systems, the Environmental Water Reserve is provided

by limiting the volume of groundwater that can be extracted for consumptive use.

Regulated rivers are those with structures that regulate river discharge in order to provide storage of water for extractive uses (for example, potable use and irrigation) or for hydroelectric purposes. This usually results in a significant alteration of the downstream flow regime, through reductions in overall flow and changes in the seasonality and timing of flow. Most large rivers in Victoria fall into this category: the Campaspe, Glenelg, Goulburn, Latrobe/Thomson/Macalister, Loddon, Wimmera and Yarra Rivers.

Unregulated rivers do not have large structures that provide water for extractive uses or electricity generation. Only a few large rivers in Victoria are unregulated (such as the Ovens and Mitchell Rivers). Many smaller streams are also unregulated (for example Tarwin River and Painkalac Creek).

The **Environmental Flows Technical Panel (EFTP)** is the multidisciplinary panel, usually of four to six people, who provide the core team undertaking a FLOWS investigation. Members of the EFTP have specific expertise in hydrology, geomorphology and aquatic ecology. They undertake the field assessment and devise the environmental objective and flow recommendations. They are assisted by a team of hydrologists and modellers who undertake hydrological and hydraulic modelling.

The **unimpacted flow regime** is defined as the flows that would exist if no diversions or storage of water occurred (no large reservoirs, farm dams or water extraction), accepting that there have been changes in flow associated with land-use alterations. See Section 2.3.1 for a more detailed definition and clarification on the difference with the term **natural flow**, which has been used in previous FLOWS studies.

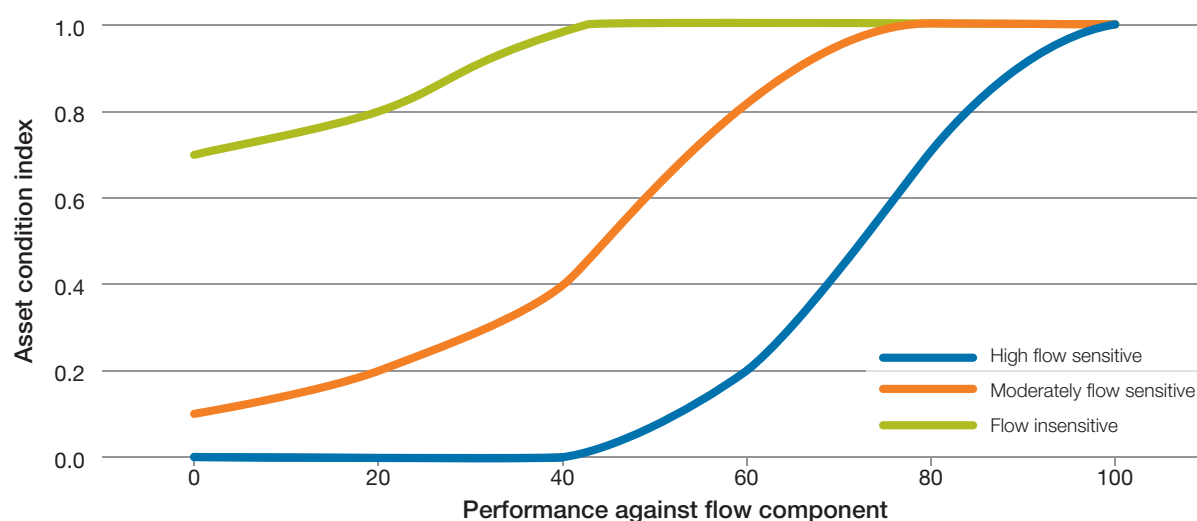


Figure A.1 Example of relationship between asset condition and performance against flow component recommendations for assets that are sensitive or insensitive to flow (a score of 1 indicates good condition or low risk, whereas a score of 0 indicates poor condition or high risk).

Executive Summary



This updated version of FLOWS incorporates recommendations made by reviews of the method and captures the improvements, new approaches and updates in science and modelling since the FLOWS method was first released in 2002. This includes refinements to the approach arising from the experience of managing waterways through the 1997-2009 drought.

The overall method and key steps remain the same as in the original FLOWS approach. However, this new edition updates the method to current best practice, and will facilitate greater consistency in application of the FLOWS process.

New features in FLOWS Edition 2 include:

- additional opportunities for engagement and consultation with local stakeholders to provide input and feedback to the process and allow for a level of community ownership of the outcomes;
- requirement for more justification for the link between flow recommendations and ecological response based on relevant science, monitoring and conceptual models and to highlight areas of uncertainty in the recommendations;
- recognition and consideration of the potential for groundwater to provide important contributions to stream flows;
- development of objectives for wet, average or dry conditions to allow more realistic consideration of the high variability of Australian stream flows, and to prioritise flow components;
- defined protocols for calibrating hydraulic models and sensitivity analysis, and for reporting to ensure there is a discussion of the implications of the results for flow recommendations;
- an appendix with detailed checklists for hydrological and hydraulic modelling that ensure protocols and standards have been followed, as well as revised lists throughout the text which describe the minimum requirements for successful completion of each step in the process; and

- assessment of flow scenario performance against flow recommendations.

The report is structured into the following sections:

- background information (Chapter 1);
- three chapters about the FLOWS method
 - Preliminary activities to understand the level of work needed for a particular stream, including hydrological modelling (Chapter 2)
 - Stage 1 – Project inception, system condition and issues (Chapter 3)
 - ~ Gathering information about the stream and its ecology and condition and how it may be affected by an altered flow regime; and developing the environmental flow objectives for the system
 - Stage 2 – Development of flow recommendations (Chapter 4)
 - ~ More detailed studies and modelling to identify the stream's flow needs
- references and appendices.

For each component of the method, there is

- a description of the method(s) to be followed to undertake an assessment; and
- discussion of the inputs and data sources for the assessment (clear boxes).

Summaries of the key outputs during the assessment are highlighted in blue-shaded boxes at the relevant points in the description of the method.

A range of appendices have been added with technical information to support the method and assist practitioners. This includes detailed checklists for hydrological and hydraulic modelling to highlight the major requirements in developing and using the models and to ensure any uncertainty and assumptions have been documented and considered.

Top: Yarriambiack Creek. Photo by Sinclair Knight Merz.

Preface (Preamble to the updated method)



The Victorian FLOWS method was developed by the Department of Natural Resources and Environment (now the Department of Environment and Primary Industries) in 2002 (NRE 2002a) and has since underpinned the development of environmental flow recommendations in Victoria. Before 2002, a number of different approaches were used to devise environmental flow recommendations and there was little consistency across studies or jurisdictions. The FLOWS method was developed to provide a consistent statewide approach for assessing the flow requirements of environmental assets associated with waterways.

The major steps in the implementation of the FLOWS method have remained largely unchanged over the last ten years. However, some minor modifications have been sporadically introduced over recent years in the light of new information on the hydrological requirements of the biota (especially fish, and to a lesser extent vegetation) and in some cases, an assessment of flow component

performance and prioritisation. A review of the FLOWS method (undertaken by Alluvium and GHD in 2008 (Turner et al. 2008) on behalf of Melbourne Water) identified a range of issues with the original FLOWS and water supply (hydrological and hydraulic) modelling methods and made a number of recommendations to address these issues.

The then Department of Sustainability and Environment's Technical Audit Panel also made a range of recommendations for improvements based on their reviews of numerous FLOWS studies.

This document updates the method based on these recommendations.

More background on the specific recommendations and a description of the broad approach to updating the method can be found in an accompanying background document, *Background to Victorian FLOWS Method Edition 2* (SKM 2012).

Top: Yarriambiack Creek. Photo by Sinclair Knight Merz.

Introduction



1.1 Overview of the FLOWS method

The FLOWS method is a scientific and transparent approach to assessing the flow requirements for the freshwater reaches of river systems (including broad requirements for overbank river flows for floodplain and river-fed wetlands) where sufficient information and expertise is available on hydrology, geomorphology and ecology, and for which specific environmental objectives have been, or can be, established. In particular, the FLOWS method provides a process for developing flow-dependant environmental objectives and the flow regime required to meet these objectives and maintain them at a low level of risk that are based on:

- an understanding of the current condition of flow-dependent environmental assets and their response to flow;
- relevant national, state and regional policies, strategies and plans; and
- stakeholder expectations, through consultation during the project with a Project Advisory Group comprised of agency and community representatives.

FLOWS studies are used for:

- identifying environmental water recovery targets in fully allocated or stressed systems, through sustainable water strategies and statutory water plans;
- assisting environmental water reserve management by informing development of seasonal water proposals and best use of available water; and
- informing small scale water supply augmentations. For example, through helping to develop an understanding of the risk and benefits of changed rules or storage capacity on the environment.

The broad FLOWS framework can also be used as an approach for identifying the water regime requirements of more complex wetland systems, although additional steps may be required. It is beyond the scope of the FLOWS method update to provide specific advice on approaches to wetland water regime determination.

A detailed review leading to the development of the FLOWS method can be found in the original manual (NRE 2002a). A summary of the main components of the flow regime that are likely to be important to protect or improve ecological values and for which recommendations are generally set is provided in Appendix A2. A summary of the key features of

these flow components is included in Table 1.1, and includes the indicative periods of timing, frequency and duration.

The FLOWS method incorporates a degree of flexibility that can be adapted to site-specific issues and data availability. Adoption of a standard approach across the State of Victoria aims to ensure consistency between assessments. This factor has become increasingly important since the method's introduction ten years ago as different teams are used to implement the method in different parts of the state on a competitive basis.

Some preliminary work by the environmental water manager is required to confirm a FLOWS assessment is required prior to commissioning a FLOWS study. This preparatory work includes:

- the collation or development of flow data for current (impacted) and unimpacted conditions;
- collation of data sets of relevant ecosystem attributes; and
- identification of any location specific issues that need to be highlighted in the project brief (e.g. groundwater issues).

Implementation of the FLOWS method occurs in two stages (Figure 1.1). Stage 1 largely revolves around a description of system condition and issues. It involves:

- identifying individual reaches and practicable sites within each reach;
- documenting the main flow related issues; and
- developing a set of environmental objectives for the management of water-dependant values within each reach.

The early components of Stage 1 are often of a desk-top nature, but in almost all cases a number of field inspections are also required, firstly to confirm the preliminary identification of reaches and suitability of sites, then for the EFTP to visit the various sites to inform their description and analysis of environmental issues. Two important outputs from Stage 1 are:

- the production of a Site Paper, which describes the reaches and sites selected for further assessment and the justification of that selection; and
- an Issues Paper, which outlines the expected flow-environmental responses.

Top: Wimmera River. Photo by Greg Fletcher, Wimmera CMA.

Table 1.1 Summary of key features of flow components.

Flow component	Channel flow characteristic	Timing	Frequency	Duration	Key functions
Cease to flow	No surface flow	Summer	Annual	Vary from days to months	Ecological disturbance Dries habitats and substrates Facilitates organic matter and carbon processing
Low flow	Minimum flow in channel Continuous flow in some part of channel	Summer	Annual	Weeks to months	Connect instream habitats System maintenance
Freshes	Flow greater than median flow for that period	Summer Spring	Can be several in each period	Generally days	Biological triggers Inputs to habitats Physico-chemical changes
High flow	Connect most in channel habitats Less than bankfull May include flow in minor floodplain channels	Autumn Winter Spring	May be several annually	Weeks to months	Inundation of instream habitats Channel connectivity Allows migration Inundation of organic matter Sediment movement
Bankfull	Highflow within channel capacity Flow in other channels (anabranches etc.)	Winter Spring	Generally at least annual	Days to weeks	Channel and habitat forming Sediment transport
Overbank	Flow extends to floodplain surface flows	Winter Spring	Can be annual or less frequent	Days	Floodplain and wetland inundation and connectivity Organic matter inputs

Generally, the field inspection by the EFTP takes place after the production of the Site Paper but before the finalisation of the Issues Paper.

Stage 2 involves the use of survey and hydraulic modelling (mostly using HEC-RAS¹) to derive flow recommendations aimed at meeting the flow requirements of the water-dependent assets and values identified in Stage 1. There is often a hold point at the end of Stage 1 to enable agreement (by the client, often after considering input from other stakeholders through the Project Advisory Group) on objectives related to the water-dependent assets and values.

In this revised FLOWS method a number of checklists have been developed that describe the minimum requirements for successful completion of each stage. These include demonstrating that relevant reviews of critical data inputs and models have been completed to verify that the inputs are fit-for-purpose.

The following sections describe in more detail the roles and responsibilities of stakeholder, client and project team members, preparatory tasks and the important factors to be considered during Stages 1 and 2 of the FLOWS method. The required outputs of a task are highlighted.

.....
1 HEC-RAS: Hydrologic Engineering Center – River Analysis System

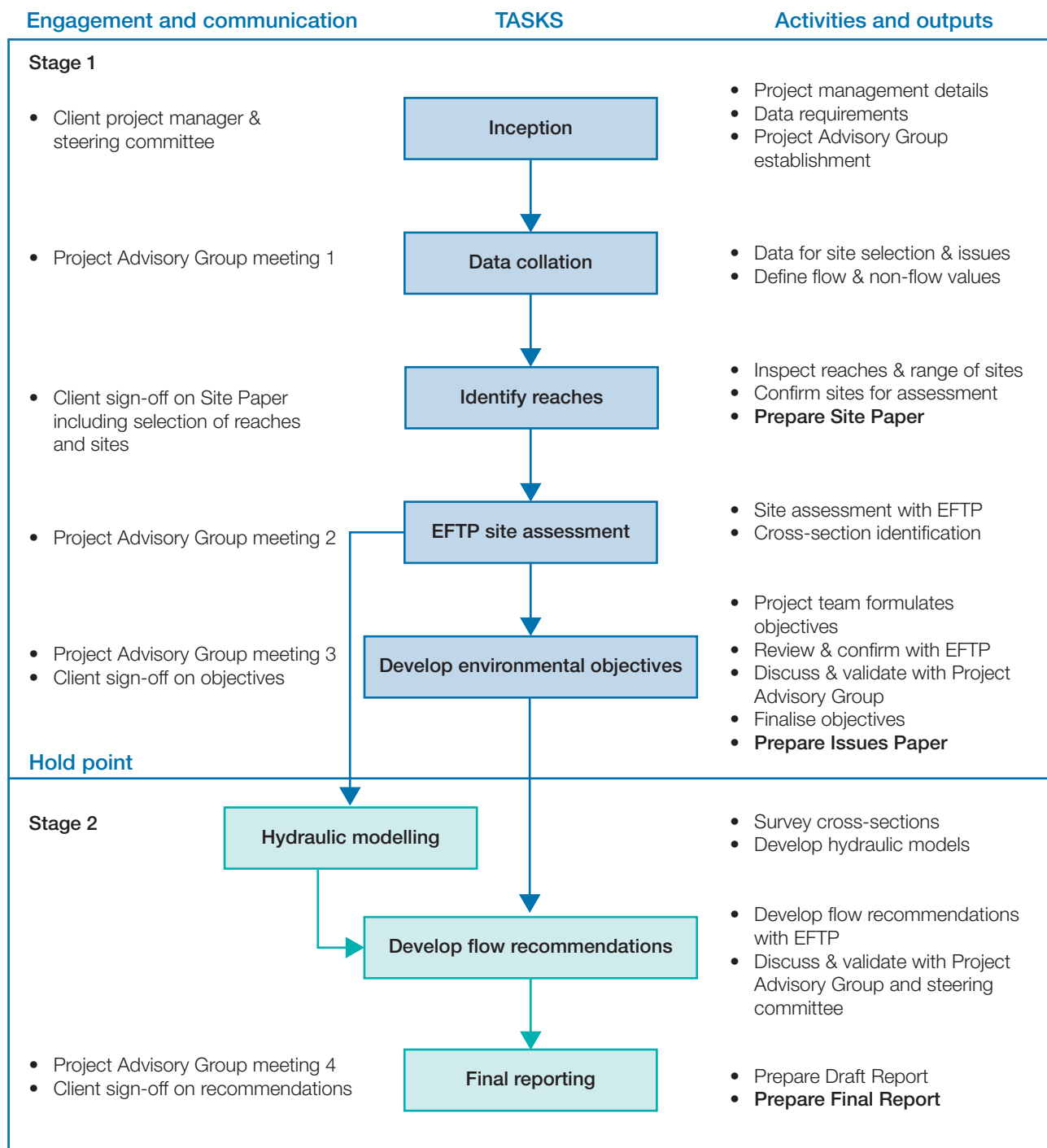


Figure 1.1 Outline of the environmental water requirements determination method.
Note: EFTP – Environmental Flows Technical Panel

1.2 Roles and responsibilities

As part of the project initiation a number of individual and group roles are established with defined responsibilities (Table 1.2). The client project manager will establish a project steering committee and a Project Advisory Group to provide advice on various aspects of the project. The project team includes the Environmental Flows Technical Panel (EFTP).

During a typical FLOWS study the consultant project manager would meet with the steering committee at project inception to confirm the project scope and method, timelines, data requirements and review processes. The steering committee would also meet to provide sign-off on agreed flow objectives, the selection of reaches and sites for cross-section survey and hydraulic modelling and flow recommendations.

The Project Advisory Group is different to the steering committee in that it includes a broader range of stakeholders, including local landholder, community and environmental group representation. Its role is to provide input and feedback to the process from a local viewpoint. The group is established by the client project manager and is expected to meet on three or four occasions:

- 1) The first Project Advisory Group meeting is held during the project inception and data gathering phase. The client project manager will brief the group on the project, explain the general approach and seek feedback on catchment and river health issues, community perceptions of environmental values and expectations for future environmental condition. The Project Advisory Group may advise on additional data to be considered and sites to be visited. Project Advisory Group members who are landholders can also provide access to parts of the system, or facilitate access. This meeting usually takes about two hours.
- 2) The second Project Advisory Group meeting (optional) is generally held during the EFTP field assessment. The

Project Advisory Group is invited to attend one of the sites, meet the EFTP and observe the site assessment process and ask any relevant questions. This meeting usually takes about one hour.

- 3) The third Project Advisory Group meeting is held once draft environmental objectives have been developed by the EFTP. The main issues and objectives are presented to the group and discussed to gain some consensus. Although objective setting should be informed by relevant river health strategies and the deliberations of the EFTP on what is achievable, it is important that the Project Advisory Group has an opportunity to comment on the objective with the aim of achieving a shared vision of future stream condition. If the group cannot agree on objectives the client and steering committee will need to take the discussion off-line and come to an agreement before the project continues. This meeting takes two to three hours.
- 4) The fourth Project Advisory Group meeting is held once draft flow recommendations are developed. The consultant project manager summarises the process followed to arrive at the flow recommendations, presents how well the current stream flow regime is meeting the recommendations and what opportunities there are for improvement. Any minor comments or observations from the Project Advisory Group may be incorporated into the flow recommendations report before finalisation. This meeting takes one to two hours.

The input received from the steering committee and Project Advisory Group should be documented throughout the project, along with comments on how this input has been considered by the project team. If the steering committee or Project Advisory Group has asked particular questions or has particular concerns then the reports should specifically address these concerns if relevant. Meeting attendees and minutes should be recorded by the project or client project manager or other agreed person and included in an appendix in each report.

Table 1.2 Roles and responsibilities.

Title	Definition and responsibilities
Client project manager	A project manager from the client organisation will be nominated as the day-to-day contact for the project. This person has the authority to sign-off on key project outputs and outcomes. Depending on the region, the project manager could be an employee of a water corporation, the State Government or a catchment management authority.
Steering committee	A project steering committee will also be formed, consisting of additional members of the client organisation and from other agencies and authorities relevant to the project area (e.g. the Department of Environment and Primary Industries, the Victorian Environmental Water Holder, the Environment Protection Authority, rural and urban water corporations.). This committee will be responsible for overseeing implementation of the project, providing direction on the scope of work, and assisting the client manager with sign-off on outputs.
Project Advisory Group	In addition to steering committee members the Project Advisory Group includes other stakeholders such as land holders, irrigators, environmental representatives, etc. The group provides a source of local knowledge and insight into community values and expectations for future river health. Engagement with the Project Advisory Group allows for a level of community ownership in the study outcomes.
Consultant project manager	The project manager from the consultant team responsible for the project team and outputs.
Project team	The project team assembled by the consultants specifically for this project. This includes the Environmental Flows Technical Panel (EFTP), project officers, hydraulic modellers, surveyors and specialist reviewers.
Environmental Flows Technical Panel (EFTP)	Members of the EFTP provide expertise throughout the project. All key decisions and recommendations are made by the EFTP jointly. This integration by the EFTP ensures that a range of disciplines are involved in the outcomes. The panel members should include specialists in the following fields: - Aquatic ecologist - Fluvial geomorphologist - Hydrologist - Hydraulic modeller Additional specialists depending on catchment specific issues (e.g. vegetation ecologist, fish ecologist, hydrogeologist).

Composition of the Environmental Flow Technical Panel (EFTP)

Members of the EFTP provide expertise throughout the project and all major decisions and recommendations are made jointly by the EFTP. This integration by the EFTP ensures that a range of disciplines are involved in the outcomes.

The panel members should include the following specialists:

- aquatic ecologist
- fluvial geomorphologist
- hydrologist
- hydraulic modeller
- additional specialists depending on catchment specific issues (for example, a vegetation ecologist, fish ecologist, hydrogeologist).

All members of the EFTP will also have specific expertise relating their core experience to assessment of environmental water requirements.

Specialist skills should be sought if there is an ecological issue within a catchment that is likely to significantly influence the environmental water requirements. The specialist ecologist will provide the ecological skills relevant to the system being studied. Commonly this EFTP member will be a fish ecologist, due to the strong link between fish ecology and flow-related processes. In other cases, however, different specialist skills may be called upon. The presence of acid sulphate soils, for example, would require specialist skills.

The hydrologist is likely to spend time on the assessment of flows at a number of points in the catchment as well as in the analysis of any additional data collected. If the hydrologist does not attend the field inspection, one of the other specialists selected should have a good understanding of the hydrological issues in order to be of assistance to the technical panel during the field visit.

Furthermore, a senior hydraulic modeller should also be available to the project team and it is recommended that the hydraulic modeller attend site inspections (either as part of the site identification, panel assessment or channel survey stages) to identify issues that may impact on hydraulic modelling, for example boundary conditions, roughness assumptions and calibration. The hydrologist and hydraulic modeller may be the same person.

If it has been identified or considered likely that groundwater plays an important role in stream and stream-based ecosystem function (refer to Section 2.2), a hydrogeologist must be included in the EFTP. The hydrogeologist will be able to assist in conceptualisation of the system, particularly with respect to the groundwater dynamics during wet and dry conditions, and the influence groundwater has on river hydrology, and provide recommendations on the structure of the hydraulic model and resulting environmental water requirements.

The consultant project manager should attend the field assessment, where their role is to coordinate and lead the EFTP through the project and key steps. The consultant project manager could be a member of the EFTP and fill one of the specialist technical roles.

The members of the EFTP and their specialist skill areas needs to be documented in all reports.

Preliminary tasks



2.1 Needs assessment and data availability

Most Victorian rivers with significant flow issues have already been subject to an environmental flow study using the FLOWS method. As the original FLOWS method is a decade old, many of the systems examined in its early applications are now being considered for reviews of the early objectives and recommendations (such as the Yarra River). In part these re-appraisals are a function of improved knowledge of the relationship between flow and ecological response and the need for more flexibility in flow recommendations to account for wet and dry conditions, rather than just the 'average'. Furthermore, some small, mostly unregulated, systems are now being considered for an assessment due to emerging flow-related issues such as over-extraction, declining groundwater levels and consequent impacts on surface flows, for example the Little River and Lang Lang River.

Environmental water managers now need to make decisions about whether a completely new FLOWS study is required, or whether only some aspects of existing recommendations need review. The revised FLOWS method documented here has not changed so fundamentally as to warrant repeating all previous studies. However, reviews or new studies should be considered where:

- there was a fundamental problem with the original hydrological or hydraulic modelling that means there is low confidence in current flow recommendations;
- the original FLOWS study did not provide sufficient information to enable recommendations to be implemented or the recommendations were overly complicated or difficult to interpret. For example, the Victorian Government has adopted a 'seasonally adaptive approach' to decision making and planning for environmental water delivery from year to year (Victorian Environmental Water Holder 2011). This approach aims to prioritise different flow components for delivery depending

on the prevailing climatic conditions (wet, average, dry), the year to year level of risk to water dependant values, and the critical thresholds which will have an irreversible impact on the ecology. Current flow recommendations may not provide sufficient detail to enable decisions to be made within this seasonally adaptive approach;

- new data is available that would help to better define and provide more confidence in flow recommendations. For example, the numerous papers in recent publications on ecosystem response modelling to flow, edited by Saintilan and Overton (2010), and the water regime requirements of floodplain and wetland biota in the Murray Darling Basin, edited by Rogers and Ralph (2011) provide a ready source of information on the current scientific knowledge of ecological response to flow. The often cited Roberts and Marston (2000) also has been extensively reviewed and updated (Roberts and Marston 2011);
- objectives may have changed. These may have altered in several ways. FLOWS studies may have become more closely linked with regional river health strategies. Newly emerged issues may have arisen over the past decade, for example, newly discovered species or the recognition of the incidence of acid sulphate soils in inland settings and the effect that altered wetting and drying regimes have on their activation (see Hall et al. 2006; Lamontagne et al. 2006). Monitoring outcomes and learnings from the recent drought may provide new insights into water-dependent values and their condition.

Furthermore, the additional requirements incorporated into the FLOWS method as part of this review, particularly around the issues of risk, ecosystem response modelling, uncertainty and performance assessment, are likely to significantly increase the cost of and time required to complete a FLOWS study. This needs to be considered when deciding whether to undertake a new FLOWS study or revise an old study.

The following box includes new data sources that can inform FLOWS studies.

Since the original FLOWS method was developed there has also been a significant increase in the amount of, and advancement in the quality of, data that can inform FLOWS studies. New data includes:

Light Detecting and Ranging (LiDAR)

LiDAR surveys have been completed for many waterways. This provides high-resolution elevation-mapping that can be used to analyse stream form to assist with site selection and to provide data that may allow additional stream cross-section to be sourced. LiDAR has typically not been able to penetrate water, so for channel surveys its utility is generally restricted to upper banks and floodplains, but it can be easily integrated with channel cross-section surveys to extend models to include broader floodplain extents. New LiDAR technology may provide water-penetrating radar in the future.

High definition aerial photography and low level aerial videography (for example, Gyrovision)

These data provide up-to-date images of river reaches that enable more rapid assessments to assist in reach identification and site selection. They can also be useful for assessing trends in condition if collected over time. Most river systems have recent aerial photography and many of Melbourne Water's waterways have aerial video.

New hydrological models

Over the past ten years there has been significant development in the quality of hydrological models. Existing models have been revised and new models have been developed that provide more accurate estimates of flow. The drought conditions experienced through most of the 2000s also means that many hydrological models have been updated to enable more accurate modelling over a wider range of flow conditions and now also include climate change modelling. In the next few years the eWater Source suite of models will be adopted to provide a new standardised modelling platform for the Murray Darling Basin. Source will enable modelling on a daily time step and will also incorporate groundwater-surface water interactions and the ability to model some water quality variables, although this is not a substitute for detailed groundwater investigation and selection of an appropriate methodology for considering groundwater surface water interactions in complex systems.

Improved ecological understanding of flow-ecology relationships

Over the past five years the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) has collected data on the physical and ecological responses to flow. The project has developed conceptual models for typical flow-response relationships and has collected data to help further refine these models (e.g. Chee et al. 2006). This data (available from the relevant catchment management authorities and the Department of Environment and Primary Industries) can be used to better define flow-response relationships. Other, ongoing monitoring data is also available and significant research into the water regime requirements of biota (particularly fish and plants) has been completed in the past ten years (see for example recent analyses and reviews compiled by Saintilans and Overton (2010), Roberts and Marston (2011) and Rogers and Ralph (2011)).

A number of new ecological modelling platforms and prioritisation tools are also now available. Examples include the eWater tools Concept, EcoModeller and eFlow predictor (see <www.ewater.com.au/products/ewater-toolkit/>), Bayesian approaches and various in-house decision support, prioritisation and optimisation tools.

Links with marine-influenced waters

The Estuary Environmental Flow Assessment Method (EEFAM) (Lloyd et al. 2012) has recently been developed. This method defines the approach to assessing the freshwater requirement for Victoria's estuaries. A particular consideration for future FLOWS studies and estuary flow studies is that the freshwater requirements for an estuary may be greater than the freshwater requirements for upstream (freshwater) river reaches. It is necessary to consider the flow requirements of both freshwater reaches and the estuary in an integrated way (ideally this should be done as part of an integrated project, although this may not always be possible) so that the outcomes of one study do not conflict with the requirements of another part of the system. If estuary studies are completed after a freshwater study and it becomes evident that more water is required to meet estuary requirements than has been recommended for freshwater reaches, further work may be required to: 1) secure additional entitlement for the estuary and 2) test that estuary recommendations do not compromise the ability to meet the requirements of freshwater reaches and vice-versa.

2.2 Groundwater and groundwater-dependent ecosystems

Many Victorian catchments are likely to support Groundwater-Dependant Ecosystems (GDEs) to a greater or lesser extent, and at some point (spatially and temporally) groundwater is likely to be a contributor to stream flows and of relevance to surface water (flow) dependant assets and values. Groundwater inputs may also represent a threat to values, for example, if it is saline and intrudes into pools during low flows.

Groundwater-Dependent Ecosystems have been mapped across northern Victoria by the then Department of Primary Industries (Dresel et al. 2010) and for some southern Victorian streams by Melbourne Water (SKM 2010). A national mapping project (the GDE Atlas) has been completed by the National Water Commission <<http://www.bom.gov.au/water/groundwater/gde>>, although local input will still be required for particular catchments. Furthermore, the Western Region Sustainable Water Strategy (Victorian Government 2011) acknowledges the importance of Groundwater-Dependent Ecosystems (which includes river baseflows) and outlines a new policy that uses a risk-based approach to the identification and protection of high value Groundwater-Dependent Ecosystems.

Groundwater was not recognised explicitly in the original FLOWS method. If groundwater is likely to be of importance to a particular system it needs to be identified prior to hydrological modelling and accounted for in that modelling if necessary. If possible, modelling should demonstrate the relative contribution that groundwater makes to stream flow and under what circumstances (for example, seasonally, only during drought). The process for determining this is discussed in more detail in Section 2.3 on hydrological modelling.

Where relevant, groundwater issues need to be highlighted in project briefs so that project teams are aware of specific groundwater issues and can include relevant expertise on technical panels.

The following checklist should be used so that environmental water managers can determine beforehand whether groundwater is an issue and include the requirement for groundwater assessment in the brief for both hydrological modelling and the FLOWS study (adapted from Eamus et al. 2006):

- Does the stream continue to flow all year, or does a floodplain waterhole remain wet all year in dry periods?
- Does the volume of flow in a stream increase downstream in the absence of tributary inflow?
- Is the level of water in a wetland or river pool maintained during cease to flow or extended dry periods?
- Is there evidence of groundwater discharge to surface (springs, salt scalds, and seeps in channel banks)?
- Do low flow conditions persist through extended dry periods?
- Do groundwater levels fluctuate under different climatic conditions or levels of extraction?
- For estuarine systems, does the salinity drop below that of seawater in the absence of surface water inputs (assuming groundwater is not itself saline)?

An affirmative answer to one or more of these questions is suggestive of groundwater inputs to the system.

Environmental water managers should seek advice from a hydrogeologist on the relevance of groundwater in particular catchments as part of the preliminary work leading up to the completion of a FLOWS study. However, project teams undertaking hydrological modelling and responding to a FLOWS brief should also make their own enquiries and assessment of the need to account for groundwater.

2.3 Hydrological considerations

2.3.1 Surface flow

An important aspect of the FLOWS method is the derivation of daily time-series of current and unimpacted² flows. There are two considerations here. First, it is necessary that the time-series be on a daily basis, not a monthly basis. This matter is discussed below. Second, the hydrological meaning of 'current', 'unimpacted' and 'natural' needs to be clearly defined. 'Current' refers to the flow regime under current levels of water resource development, whereas 'unimpacted' refers to the flow regime that would occur if all anthropogenic extractions, water harvesting

2 The previous manual and hence FLOWS studies to date have used the term 'natural' flow. The natural flow is often used when setting frequency and duration recommendations for environmental flow thresholds. In this manual, and future FLOWS studies, it is recommended that the term 'unimpacted' flow be used instead. It is important to clearly state which impacts have or have not been taken into account in deriving the unimpacted flow time-series. A checklist of impacts which the FLOWS studies should transparently indicate have or have not been taken into account in preparing the unimpacted flows are:

- extractions from rivers and streams
- flow regulation from upstream reservoirs
- extractions from small catchment (farm) dams
- changes in runoff from anthropogenic changes in vegetation cover or type
- changes in runoff from urbanisation
- changes in baseflow from changes in groundwater recharge (climate, land-use change, river regulation, irrigation accessions) and extraction
- changes in baseflow from anthropogenic changes in vegetation cover or type
- changes in baseflow from urbanisation.

The climate conditions over which the unimpacted flows have been derived should also be clearly stated.

and impoundments were removed (large reservoirs, farm dams, diversions for irrigation, urban, stock and domestic purposes). 'Unimpacted' however does not equate with 'pre-European' flows, as the modelling does not consider the effect that landscape-scale changes (such as vegetation clearing) have had on river discharge and river-groundwater interactions, as described in the footnote on the previous page.

Of the two flow series, the 'unimpacted' is the most important for the EFTP, who often analyse it to set

recommendations about the required frequency and duration of flows above or below environmentally important thresholds. The following section provides a discussion of the preferred method for modelling daily flows. A checklist is also provided in Appendix B, which should be completed and included with the hydrological modelling report. The checklist provides a reference point for reviewers of the hydrological modelling and also the FLOWS teams to ensure that issues associated with uncertainty and assumptions have been documented.

Hydrological modelling

Often a Resource Allocation Model (REALM) will be available for simulating time-series of current and unimpacted flows. REALM is a generalised computer program that can simulate flows through simple and complex river systems under different inflow and water resource development scenarios <<http://www.water.vic.gov.au/monitoring/surface-water-modelling/realms>>. Inputs required include time-series of unimpacted catchment inflows, current urban and rural demand characteristics, reservoir and river operating rules, and environmental flow requirements.

Daily models are preferred for the derivation of current and unimpacted flow time-series. REALM models are generally limited in their application for environmental flow studies because they typically operate on a monthly time-step (although weekly or daily models may be available for some systems). Currently, the eWater CRC (Cooperative Research Centre) is developing the Source IMS software, and it is envisaged that over time Source models operating on a daily time-step will replace existing REALM models <<http://www.ewater.com.au/products/ewater-source/for-rivers/>>.

If a monthly REALM model is the only available option for simulating current and unimpacted flow series, monthly flows can be disaggregated to a daily time-step using patterns from nearby streamflow gauges that are unaffected by river regulation. This was the approach used to derive daily flows for the Yarra River (SKM 2005; referenced in <http://www.water.vic.gov.au/__data/assets/pdf_file/0006/28347/Yarra-EWR-flow-recommendations-report_final-211105.pdf>). In the absence of appropriate streamflow gauge records, daily patterns can be simulated for longer periods using rainfall records, and rainfall-runoff models with either calibrated parameters or parameters estimated using regional prediction equations. For example, Chiew and Siriwardena (2005) provide advice on estimating parameter values for SIMHYD³ rainfall-runoff models applied to ungauged catchments. However, use of rainfall-runoff models that have not been calibrated to daily data should be avoided where possible.

Other options for deriving daily time-series of unimpacted flows include:

- For systems with a large reservoir in the headwaters of the river system, it is possible to model inflows to the storage(s) on a daily time-step, and then route these inflows and gauged tributary inflows downstream using hydraulic routing algorithms (as described for the Broken River environmental flow study by Cottingham et al. 2001) <http://www.water.vic.gov.au/__data/assets/pdf_file/0020/28271/Broken-River-and-Broken-Creek.pdf>.
- For small unregulated systems, where the main influences on the flow regime are private diversions and farm dam impacts, an alternative approach may be used: using time-series of gauged flows to represent the current level of development, and then applying rainfall-runoff, consumptive demand, farm dam impact and water balance modelling techniques as appropriate. An example is provided for the Broken Creek and Boosey Creek in SKM (2006).

3 SIMHYD is a conceptual rainfall runoff model that estimates daily stream flow from daily rainfall and areal potential evapotranspiration data.

The method used to derive the current and unimpacted daily flow series needs to be chosen with careful consideration of a number of factors, including:

- the nature of the river system (for example, large regulated rivers, where a complex water resource model may be required, versus small unregulated rivers where farm dam impacts and stock and domestic diversions may be the only impacts);
- time and budget available;
- trade-offs between length and quality of the derived time-series; and
- whether the work done has additional uses. For example, work done to update a REALM model, or extend the period of time it covers, may be used for the FLOWS project and subsequent projects which require a water resource model (examining how often environmental flows are provided under different inflow and consumptive use scenarios).

It is important to note that much of the work involved in estimating unimpacted flows is done outside water-resource models such as REALM. For example, modelling daily diversions for irrigation, farm dam impacts or groundwater-surface water interactions may all happen outside the model used to simulate flow through the river system. Appendix B includes a list of tools that may be applicable at different stages of modelling daily time-series of current and unimpacted flows.

Regardless of the methods used, the daily time-series of current and unimpacted flows (including wet, dry and average scenarios) should extend for a minimum of 30 years, including the 2006–07 drought and the 2010–11 floods. Thirty years of flow data is considered sufficient to ensure that climate variability, including major droughts and floods, is included in the modelling and is also the minimum length of record required to estimate the mean annual streamflow with a given standard error for a given coefficient of variation (Erlanger and Neal 2005). Once derived, the daily current and unimpacted flow time-series can be used to develop:

- flow duration curves to examine the percentage of time that a flow of a given size is exceeded; these may be done on a daily, monthly or seasonal basis depending on the system-specific issues;
- time-series graphs to examine the sequence of flow events, particularly during very dry or very wet conditions;
- baseflow separation to highlight the potential for significant groundwater-surface water interactions (see below for more detail);
- spells analysis to describe flow spells (flow events above or below a defined threshold, such as freshes); and
- flood frequency analyses to examine the frequency and magnitude of larger floods.

2.3.2 Surface water and groundwater interaction

We have noted above (Section 2.2) that groundwater was not explicitly recognised in the original FLOWS method. A critical issue of interest in relation to an environmental flow study is whether the baseflow contribution to streams is ecologically relevant, and if so:

- 1) Has the baseflow contribution to streams historically been influenced by anthropogenic impacts such that current baseflow differs from unimpacted baseflow?
- 2) Is the baseflow contribution likely to be susceptible to future changes?

There are a number of steps that an EFTP may take in considering the importance of surface water and groundwater interaction for environmental flow recommendations. These steps are designed to be progressive in terms of the level of effort and understanding required as the ecological importance of groundwater and surface water interaction increases.

- 1) Is groundwater maintaining baseflow, spring flow or permanent pools during cease-to-flow periods that are of critical importance to maintaining ecological values in the reach?

The Lyn and Holick digital recursive filter can be used to estimate baseflow contribution to streams in unregulated rivers (see reference below). If the baseflow contribution to streams is high, particularly at times of essential ecosystem function, further investigation into groundwater and surface water interaction may be required. If the baseflow contribution to streams is low or is not critical to ecosystem function, then further investigation into groundwater and surface water interaction may not be warranted. A copy of the Lyn and Holick filter is publically available in the Basejumper software: <http://www.skmconsulting.com/Markets/Australia/Water-Environment/Natural-Resource-Management/Natural-Resource-Management.aspx>.

- 2) If so, is there a significant volume of groundwater extraction (or potential for future groundwater extraction) within the catchment that is likely to cause stress to ecological assets by decreasing spring flow, base flow or lowering permanent pool levels?

This question also applies if there is significant land-use change, such as plantation forestry development or urbanisation, which can also influence baseflows.

Data on historical groundwater extractions can be sourced from the relevant water authority. If historical groundwater extractions are negligible compared with other types of water extractions, or compared with streamflows during low flow periods, or have no impact on groundwater level, there is no need to account for these when modelling daily time-series of unimpacted flows.

- 3) If the answer to questions one and two is yes, what is the influence of groundwater extractions on streamflow?

Answering this question requires the advice of a hydrogeologist. At first, they may be able to provide an estimate of the degree of connectivity between groundwater extraction bores and nearby streams. For example, for every one ML of groundwater extraction from bores within one km, five km and ten km of the river, the reduction in streamflow will vary, with time lags ranging from days to years. Changing the aquifer being used means pumping from different depths at the same location and will also result in different impacts on stream flow. Other variables, such as evapotranspiration, hydraulic gradient and climate will affect the consequence of pumping groundwater on streamflow. Analytical approaches may provide some means to estimate groundwater use impacts on streamflow that account for time varying changes to water levels. These impacts can then be taken in to account when the time-series of unimpacted flows are derived, similar to the way that private diverters from the river are analysed.

If the initial advice indicates that estimates of unimpacted flows are sensitive to assumptions of surface water and groundwater interaction, a more detailed model is needed to simulate the influence of groundwater extractions on streamflow. The Source model includes a module for modelling surface water and groundwater interaction, and these are a significant improvement on how such interactions are handled in existing river models (Jolly et al. 2010). However, these modules are not aimed at replacing detailed groundwater models. Therefore, in situations where the baseflow component of streamflow, groundwater extractions, and surface water – groundwater interactions are all significant, and estimates of unimpacted flows are sensitive to how these are modelled, using a more complex groundwater model such as MODFLOW⁴ is recommended. Modelled time-series of flux between groundwater stores and surface water can then be included in the river system models (i.e. REALM or Source) used to simulate current and unimpacted flows. This will also provide greater flexibility if sensitivity testing to future climate, vegetation cover or groundwater management rules is required.

Any modelling approach needs to consider the level of calibration required to link groundwater and surface water processes. An experienced hydrogeology modeller should be consulted to help identify the best approaches to considering groundwater surface water interactions, especially the applicability of various models.

The hydrological modelling and flow regimes for the river system being studied should be reviewed, using the checklist in Appendix B, prior to using the daily time-series of current and unimpacted flows to inform environmental flow recommendations.

⁴ MODFLOW is the United States Geological Survey Modular Three-Dimensional Groundwater Flow Model

FLOWS method description:

Stage 1 – Project inception, system condition and issues



As noted in Section 1.1, the first stage of the FLOWS method identifies the high value environmental assets of the system, their condition, and how they may be affected by an altered flow regime. This information is then used, in conjunction with national, state and regional strategies, policies and plans, to develop the environmental objectives upon which flow recommendations are based.

The information and data collected to meet these outcomes provides the basis of the Issues Paper, which documents the rationale for developing flow recommendations as part of Stage 2 (see Figure 1.1).

3.1 Project inception

The initial (inception) meeting between the consultant project manager and the steering committee is a crucial meeting for establishing the scope of the project and identifying additional sources of information that will be required during the project. Prior to the inception meeting, the project team should collate all the available relevant information on the project area, including reports listed as part of the brief, relevant strategies and plans, a map of the project area and a list of the likely knowledge gaps (see preliminary tasks in Section 2). Much of this information will be made available by the client, but an important role of the EFTP is to obtain supplementary information in the Site and Issues Papers. The outputs of the initial collation of the data (specifically database searches and previous studies) should also be assembled at this stage.

At the inception meeting itself the following items should be discussed and confirmed:

- outline and agreement on project scope;
- project timelines and project deliverables (Site Paper, Issues Paper and Final Report);
- summary of reports and data currently held by the project team;
- any outputs from data already collated;
- any outstanding data requirements;
- discussion of potential reaches for the study river; and
- communications plan.

Key output 1 – Documented outputs from inception meeting as specified

The outputs of the inception meeting will include:

- agreed project scope (outputs, timelines, project area);
- data to be included in the study, specifically including raw data and reports (refer to Section 2.1);
- tasks to be completed by project team, steering committee or client project manager (e.g. data provision, reports to be obtained etc.);
- confirmation of terms of reference for the Project Advisory Group; and
- agreement on project process, including timing of subsequent meetings and communications plan.

In addition to the steering committee inception meeting, a meeting will be held with the Project Advisory Group to provide input to reach selection, the characteristic features of the reach, important environmental assets, and potential sites within the study area.

It is important to remember that a FLOWS project is the determination of environmental water requirements for a river system or, in some studies, parts of that system. At this stage the Project Advisory Group will only provide input and information to the process; they do not provide direction on specific outputs, as the outcomes of the environmental water regime assessment should be based on the independent scientific evaluation.

3.2 Data collation

Data collation should commence prior to and within the project inception stage. The collation should include:

- existing regional waterway management strategies and other planning documents (to help inform environmental assets, values, conditions and objectives);
- information and monitoring data on environmental assets (most often flora and fauna assets) and ecosystem condition;

Top: Goulburn River. Photo by Alison Pouliot.

- information on system geomorphology (system features and processes);
- hydrological data (daily flow series for each site plus daily rainfall and appropriate evaporation estimates); and
- information on hydrogeology (groundwater level or hydrographs from bores located within close proximity to the river);
- previous environmental water requirement studies or other investigations or monitoring (if any); and
- information on water system operation (understanding of the water resource operation for the system).

Data sources

The sources of information may include, but are not limited to:

- Victorian Water Resources Data Warehouse, includes Victorian Water Quality and Quantity Monitoring Program Data and Index of Stream Condition (ISC) data <<http://www.vicwaterdata.net>>;
- Waterwatch Victoria, includes community water quality data and reports <<http://www.vic.waterwatch.org.au>>;
- Victorian Biodiversity Atlas: combines the former Victorian Freshwater Fish database, Atlas of Victorian Wildlife and Flora Information System. Contact: Department of Environment and Primary Industries ph. 136 186;
- Biodiversity Interactive Map: includes biotmaps, threatened flora and fauna and vegetation community data <<http://www.dse.vic.gov.au/about-dse/interactive-maps>>;
- Victorian Index of Wetland Condition (IWC) mapping tool <<http://www.dse.vic.gov.au/about-dse/interactive-maps>>;
- government agencies, water authorities and land managers:
 - Department of Environment and Primary Industries – regional and Melbourne offices <<http://www.depi.vic.gov.au/home>> and <<http://www.water.vic.gov.au/>>
 - relevant catchment management authorities and water authorities (see <<http://www.water.vic.gov.au/governance>> for links)
 - Museum of Victoria <<http://museumvictoria.com.au/>>
 - Environment Protection Authority <<http://www.epa.vic.gov.au/>>
 - Murray Darling Basin Authority <<http://www.mdba.gov.au/>>
 - National Water Commission publications and resources <<http://www.nwc.gov.au>>.
- regional river health strategies and bioregional plans (available from the relevant catchment management authorities, the Murray-Darling Basin Authority and the Department of Environment and Primary Industries;
- Project Advisory Group and steering committee members;
- local landholders and friends groups (see Victorian Environment Friends Network <<http://home.vicnet.net.au/~friends/index.html>> for links);
- historical photographs and maps (available from the Department of Environment and Primary Industries historical photograph library, State Library of Victoria and local historical societies);
- reports and expertise from research institutes such as the Arthur Rylah Institute; and
- scientific papers and book chapters.

The approach for accessing data depends on the data holder, although most are now available via the internet and can be obtained for little or no charge, provided appropriate permission is received and the data source acknowledged. Historical information on the catchment would also be useful and could include photos, maps or oral history. This can help present a picture of the original state of the system and any changes that have occurred.

The data sources listed above should not be considered as exhaustive. However, these are relevant to all regions within the state and should be regarded as a minimum level of data coverage.

3.2.1 Environmental assets

Environmental assets can include both the physical (for example, geomorphological) and ecological (for example, individual species, populations, communities and ecological

interactions or processes) components of the reach in question, noting that some values may be expressed at a spatial scale different from the reach scale. The environmental assets that are considered flow dependent will form the basis of the environmental objectives and flow recommendations for the system.

In assembling the data on the environmental assets of the river under study, it is important to include a suitable level of detail to characterise the asset and its condition and to justify its selection for inclusion in the study. For different groups of flora and fauna, a catalogue of water-dependent species or communities recorded in the study area can be compiled from the state managed databases and maps (such as the Department of Environment and Primary Industries Biodiversity Interactive Map). Minimum data requirements will vary for different environmental assets, but should include where possible:

- species (for example, for fish, birds, frogs and other fauna) or other appropriate taxonomic grouping (for example, Ecological Vegetation Class or family groupings). For large groups, like plants or macroinvertebrates, it may be sufficient to list only rare, threatened or endangered species or only those species or communities that are especially important to the study area in question;
- abundance or other similar measure (such as number, percentage cover, area, distribution);
- location of record; and
- date of record.

In addition, information such as the method of collection and size of individuals is often relevant, as it provides information on recruitment.

The absence of records of water-dependent species or communities in a study area does not necessarily mean there are none present. There may have been no surveys in the area, or surveys may have been conducted at the wrong time of year to detect some species. It should be noted if surveys have been conducted in an area but no relevant species or communities recorded.

3.2.2 Geomorphological data

Geomorphological data are used to provide an insight into the river of interest and its physiographic setting.

Data that may be available from the relevant catchment management authority or the Department of Environment and Primary Industries include:

- maps and plans
- existing river, floodplain and wetland cross-section surveys (for example from VEFMAP or flood studies)
- LiDAR
- aerial and oblique photos
- video (for example Gyrovision is available for many of Melbourne Water's waterways)
- catchment management authority, the Department of Environment and Primary Industries, and water corporation files
- physical descriptions of the streams.

It is often very beneficial to have discussions with catchment management authority staff and local residents with a good knowledge of the river system (members of Landcare, Waterwatch, Friends or historical groups) to gather anecdotal information and historical evidence.

3.2.3 Hydrology

Current and unimpacted flow time-series will be provided by the client project manager to the FLOWS team at the commencement of the study. The specifications outlined in Section 2.3 should be used by the consultants developing the current and unimpacted flow series.

3.2.4 Hydrogeology

Where groundwater is expected to play a significant role in the river system (see Section 2.2), groundwater level data from bores in close proximity to the river should be collated and analysed to quantify the influence of groundwater on stream flows. At a minimum this should include:

- identification of groundwater gain or loss sites;
- determination of gaining and losing reaches;
- time-series analysis of baseflow contributions at the site or reach scale (subject to time-series data availability) with focus on critical periods such as low flow and cease to flow; and
- identification of critical groundwater contributions in a spatial and temporal sense (i.e. when and where groundwater supplies critical low flow and/or sustains surface water levels during cease-to-flow periods).

Project teams will require the expertise of a hydrogeologist when groundwater is a factor that influences stream flow or the condition of water-dependant assets. It may also be necessary to develop a conceptual model of the relationship between groundwater, surface flow and water-dependant assets and values.

3.2.5 Plans and strategies

The FLOWS study should be undertaken within the context of the relevant national, state and regional strategies (see Table 3.2 in Section 3.5 for a list of relevant documents). These strategies and plans should also guide the identification of complementary actions (e.g. riparian revegetation) that would increase the likelihood of achieving the desired environmental objectives.

3.2.6 System operation

It is important to develop an understanding of the river system operation and how the water is managed in the catchment. This has an influence on reach and site selection and for helping to understand how system operation impacts on environmental values.

Information on system operation is most likely to be obtained from the relevant water managers. Discussions should be held with relevant diversions inspectors or storage operators to gain an understanding of potential operational issues.

The FLOWS method works for both regulated and unregulated rivers, where unregulated rivers are those without a substantial dam or diversion system. A summary of some of the issues to consider in terms of operational effects on the hydrology of regulated and unregulated systems are presented in Table 3.1.

System operation may affect the flow regime in both regulated and unregulated streams but the ability to manipulate the flows is much greater in regulated systems. The extent to which flows can be manipulated is likely to influence how environmental flow recommendations may be implemented.

Table 3.1 Summary of issues to be examined in regulated versus unregulated streams.

Regulated rivers	Unregulated rivers
Large dams may enable major diversion of water, change the volume and seasonality of downstream flow regime and change downstream water quality (e.g. temperature). There is a need to understand the implications of dams and weirs on all components of the flow regime and water quality. Need to understand the outlet capacity on structures and effects on downstream flows (this information may be available in some systems where studies have been completed on flow constraints).	In unregulated rivers, diversions are generally smaller than in regulated. However, flow can be impacted by private diversions, farm dams, groundwater extraction and land-use change. There is a need to understand the distribution (location) and type of diversion licences in the catchment, the current diversion rules and how these impact on various components of the flow regime and water quality.

3.2.7 Condition assessment

The final issue to consider integrates across all of the above components to provide an assessment of ecological condition and the processes that may be affecting ecological condition, especially where there is a clear hydrological relationship (e.g. river red gums and incidence of overbank flooding).

In some cases, such as with the Index of Stream Condition or for macroinvertebrate data, there are accepted processes for determining ecosystem condition (e.g. AUSRIVAS and Signal scores). For many other ecosystem assets and values (e.g. native fish, aquatic vegetation, amphibians and waterbirds), however, expert opinion will be required to assess condition. An assessment of ecosystem condition should seek to integrate all the values and issues described in previous sections. The description of a healthy river from the Victorian River Health Strategy (NRE 2002b) (currently being updated through the draft Victorian Waterway Management Strategy) provides a valuable starting point from which to consider ecosystem condition.

3.3 Reach and site selection

The study catchment is generally divided into a number of representative reaches, each exhibiting uniform geomorphology, hydrology (e.g. no major inflows or losses within the reach), hydrogeology, system operation and biological characteristics. However, most reaches are initially identified by the environmental water manager commissioning the FLOWS study, usually on the basis of operational features, gauge locations and major tributaries, or based on Index of Stream Condition (ISC) reaches. These reaches usually match the reaches adopted for the hydrological modelling of current and unimpacted flows. It is necessary for the EFTP to undertake a check of these assessments and adjust reach boundaries, to ensure they provide a representative basis for the determination of environmental water requirements for each reach. For example, reach boundaries may be adjusted to better account for variations in channel form, habitats, hydrology or presence of particular species or communities.

Typically, stream reaches are identified by considering:

- location of major tributaries;
- channel morphology and structure (e.g. fast flowing pool or riffle versus slow flowing pools);
- floodplain morphology and structure (e.g. confined versus floodplain sections);
- presence of high-value habitats;
- system operation (e.g. location of dams, major offtakes or outfall channels);
- flora and fauna structure and value (e.g. reaches with intact riparian vegetation versus cleared sections); and
- ability to deliver flows to various parts of the system (e.g. via outfall channels in regulated systems).

The ISC reaches may also be appropriate as a starting point for reach identification, although they may not be at a scale appropriate for a flows assessment.

One or more sites within each reach are chosen that represent the assumed characteristics of the reach. Site selection is an important step, as it will influence the hydrological and hydraulic modelling undertaken for the reach. If the site is not fully representative of the key features of the reach, then flow recommendations developed for that site may not be suitable for the broader reach. For example, the depth of water over the shallowest riffle at one site may not be representative of the shallowest riffle over the whole reach. Under such circumstances, more sites are required within the reach to capture the full range of reach characteristics and to give increased confidence in subsequent flow recommendations. Alternatively, more reaches may be required.

Minimum features that should be considered in site selection include:

- representativeness of the site in terms of the wider features of the reach (e.g. sequence of pool or riffles, presence of instream habitat features like benches and backwaters, connectivity with floodplains and wetlands);
- ability to develop a suitable hydraulic model that is representative of the reach (i.e. suitable control features are available downstream in order to establish downstream boundary conditions of the hydraulic model);

- proximity to stream gauges (useful for calibrating hydraulic models and for compliance);
- availability of data on environmental assets of the site; and
- ease of site access, noting that impacts from constructed features like bridges and weirs should be avoided.

It is recommended that a field inspection be undertaken at the reach and site selection stage. Ideally the entire EFTP should be involved in this step (especially for complex or high profile systems), but as a minimum, the geomorphologist and consultant project manager should attend. It is also preferable that the hydraulic modeller attend the site inspection to provide advice on aspects that may be relevant to the development of accurate hydraulic models (e.g. to identify areas of channel control, or locations where modelling may be difficult due to complex channel characteristics, such as braids or anabranches).

Several new sources of information are available that can help with reach selection and site characterisation. These include LiDAR (generally available across Victoria), low-level geo-referenced aerial video (e.g. gyrovision) available for some systems (e.g. Melbourne Water) and low-level aerial photography. This information should be used to look at gross channel form (e.g. proportion of pools, benches, cross-sections, longitudinal profiles) and to confirm the extent to which reaches are homogenous and to select representative sites that exhibit features typical of the reach. Videography and photography allow for large lengths of reach to be visually inspected without the expense of travel or difficulties related to access. Such analysis can help confirm if sites that are more easily accessible are indeed characteristic of the entire reach. LiDAR may also be used to generate additional cross-sections to extend hydraulic models, especially to include floodplains and wetlands, and to help with establishment of boundary conditions (see Section 4.2.3).

It is not possible to give a standard number of reaches within a system, or number of sites within a reach, as this will depend on waterway and reach characteristics, as well as the specific aims and budget of each FLOWS study. A low number of reaches may be appropriate in a uniform system, while more may be needed in a heterogeneous and large system.

3.3.1 Site Paper

The rationale for reach and site selection are detailed in the Site Paper. The Site Paper is prepared for client approval and sign-off prior to the EFTP assessment to ensure agreement is reached between the client project manager and the project team on the site selection and justification. In some cases a number of options may be presented (along with justification) for different sites within a reach. The sites may subsequently be altered on the basis of any specific issues or observations during the EFTP assessment.

Key output 2 – Site Paper

The Site Paper should include as a minimum:

- details of the reaches within the study area (presented descriptively and as a schematic plan of the main features);
- the rationale for reach selection, including critical features (e.g. flow management, geomorphology, hydrology or biology) that define each reach;
- site details for each reach, presented with sufficient information to allow location of a site at a later date, and the rationale for site selection; and
- a statement on any risks to the validity of the FLOWS assessment by using the chosen reaches/sites. Risks might relate to:
 - the ability to develop a representative, or calibrated hydraulic model;
 - whether water levels at the site are likely to be applicable across the broader reach (the effort required to resolve this uncertainty is typically beyond the resources of a FLOWS study, but it needs to be acknowledged in each study and a statement of uncertainty/confidence in outcomes provided);
 - problems with access that mean that the most appropriate site(s) are not accessible.

EFTP members should also consider the relevance of assessing some reaches where there is limited opportunity for managing flows, or where the reach characteristics or data availability mean there is likely to be significant uncertainty in flow data, model calibration or ecological values. It may be better to focus effort on reaches where management intervention is more achievable or where suitable data is available.

3.4 Environmental Flow Technical Panel – field assessment

The EFTP field assessment (note this is separate to and after the initial reach and site inspection described in Section 3.3) has three components:

- reach assessment – determination of general flow related issues in the reach;
- specific site description and assessment; and
- identification and description of cross-sections within the site for later surveying and use in hydraulic modelling.

A schematic representation in Figure 3.1 illustrates the relationship between the reaches, sites and cross-sections. It is suggested, where possible and practical, that the EFTP field assessment be conducted during a low flow period to allow the best identification of instream habitat features and representativeness. Moreover, it is often better to conduct the assessment at a time of year with long rather than short days,

as that maximises opportunities for safe and effective field work.

It is also strongly recommended that the hydraulic modeller attend the site visit in order to help identify additional cross-sections that may be required to enhance model accuracy and improve downstream boundary conditions. The hydraulic modeller can also make observations on channel roughness and other characteristics that may be important for model development. Furthermore, it may be useful for a

hydrologist or engineer from the operating authority, or other suitably knowledgeable people, to also attend the site visit to provide advice on river operations and help the EFTP to visualise how the site may look under various flows.

For most studies an opportunity should be provided at one of the sites for the Project Advisory Group to meet with the EFTP and discuss aspects of the project. One hour should be allowed for this meeting.

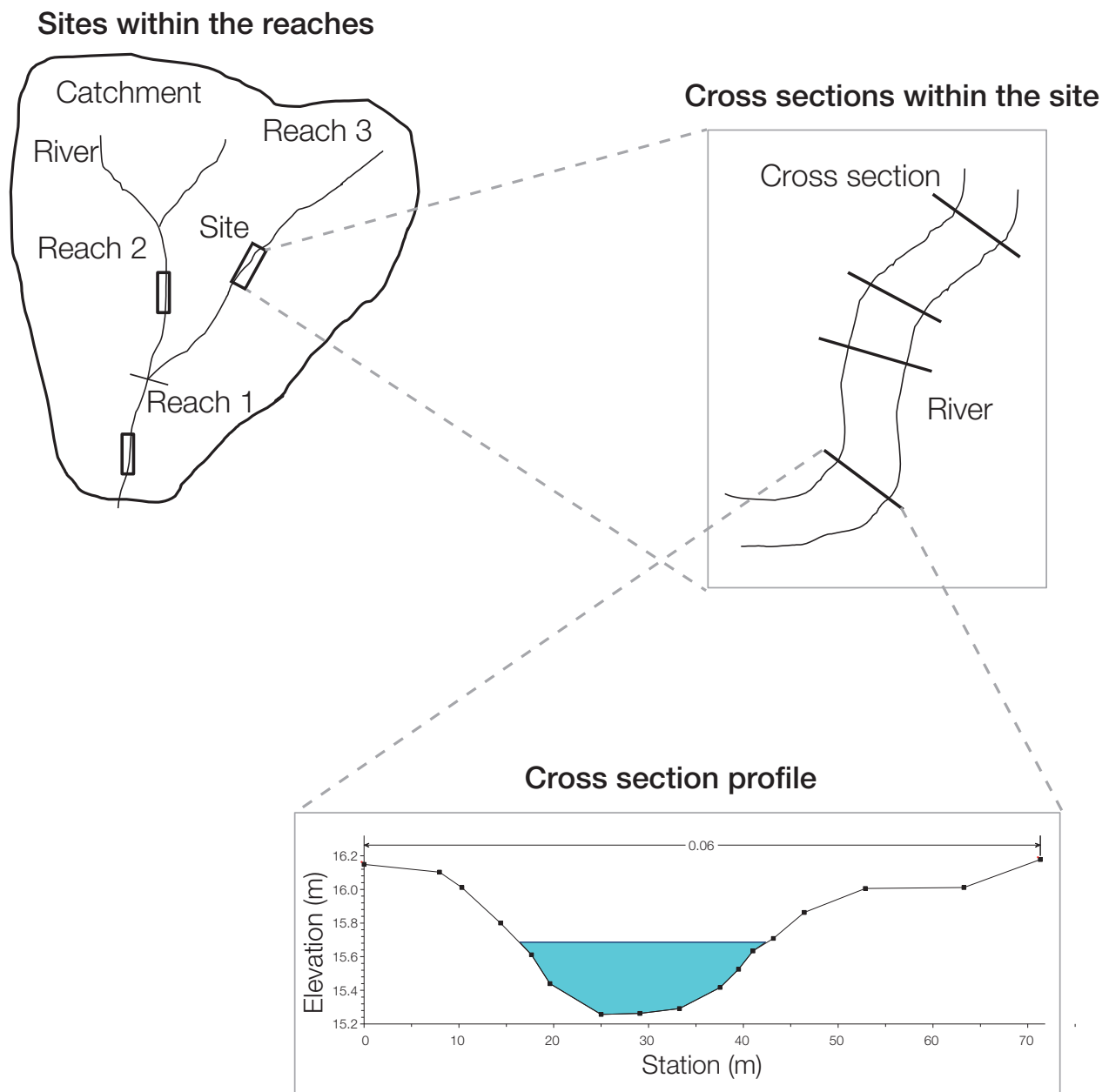


Figure 3.1 Links between the catchment, reaches, sites and cross-sections.

3.4.1 Reach assessment

Part of the reach assessment conducted by the EFTP will include an overview of key flow-related features of each reach. These features could include:

- major topographic and geomorphic features (e.g. gorges, floodplains, benches, pools);
- key water management features (e.g. dams, weirs, irrigation off-takes);
- nature of groundwater – surface water interactions and importance to river hydrology;
- biological values; and
- important sub-catchment areas or features of high ecological value (e.g. Ramsar wetlands, minimally disturbed sub-catchments).

The purpose of this assessment is to gain an understanding of the implications of flow management beyond the specific site selected for hydraulic modelling. The sites assessed in detail should be as representative of key reach features as possible; visiting as many areas of the reach as possible will put the sites assessed in the context of the whole reach. It will also allow the EFTP to consider the implications of flow recommendations on other features present in a reach but not present at the site modelled.

3.4.2 Site description

Data sheets are filled in during site visits to collect basic site and condition information using a standard set of descriptors. These provide a consistent format for the description of key features of the site, in relation to system ecology, hydrology and geomorphology. This preserves information on the key features that will be considered as part of the subsequent analysis and development of recommendations and serves as a reminder of the site features. Data sheets are consistent with other monitoring programs, like AUSRIVAS⁵ and VEFMAP⁶, so that results are comparable over time with different programs.

Important tasks for the completion of the site description are discussed in Appendix C. Data sheets for recording reach and site scale information are provided in Appendix D.

3.4.3 Cross-sections

A series of cross-sections should be established to characterise the channel dimensions at each site. This information is crucial to the subsequent development of the hydraulic model. Cross-sections need to capture the important flow related features of the site. They should be located to:

- describe the main habitat features;
- identify flow restrictions;

- indicate changes in flow direction or major changes in wetted area;
- include any features that are indicative of potential groundwater-surface water interactions at the site (e.g. bank seepage, riffles, springs or geological faults);
- characterise areas of minimum depth (e.g. bars isolating pools longitudinally);
- include important flow features (such as riffles, runs, pools, backwaters and bars); and
- facilitate later access by surveyors.

As cross-sections are required to define changes in stream channel morphology, the actual number of cross-sections required depends on the variability of the hydraulic characteristics and channel orientation along a reach. Experience has shown a minimum of six cross-sections are needed to provide a representative sample of the key features and flow control points within a site. However, additional cross-sections (up to a further 6–8 cross-sections) are preferable, especially for more complex sites and to adequately establish downstream boundary conditions for the hydraulic model (see Section 4.2 for more details on hydraulic model requirements with regards to numbers of cross-sections and calibration requirements).

EFTP members need to consider the relative benefits of additional cross-sections at a single site to enable the development of a more accurate hydraulic model, versus survey at a second site to enable some assessment of within reach variability. Moreover, the development of a more accurate hydraulic model may not provide significant additional value given the uncertainty in the ecological response to flows. It may be better to provide a range of flow recommendations to account for model uncertainty, rather than try to build the most accurate model.

EFTP members should mark the desired location of cross-sections at each site for subsequent surveying. This can be done using a single peg located on one bank. The peg should be numbered, a Global Positioning System location recorded, and the direction or bearing of the cross-section indicated on the peg.

Once pegged, each cross-section should be drawn by a member of the EFTP and flow components identified on the sketch. The cross-sections are to be drawn to identify key features of ecological or structural relevance within the section (Figure 3.2). These are then correlated to the surveyed cross-sections to allow accurate determination of the ecological flow components.

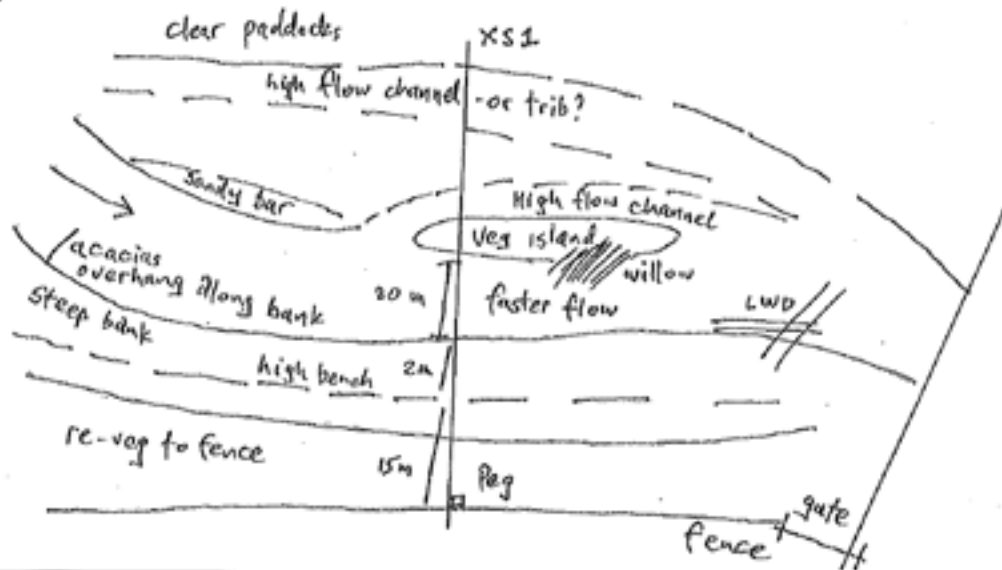
⁵ AUSRIVAS (Australian River Assessment System) is a rapid prediction system used to assess the biological health of Australian rivers.

⁶ VEFMAP (Victorian Environmental Flows Monitoring and Assessment Program) is a statewide program for assessing ecosystem responses to environmental flows in eight high-priority regulated rivers.

Cross-section Profile

Site Name Tarrawarra River Yarra Recorder Simon T Sheet 9
 Site Number 4
 Cross-section Number 1 Cross-section Location _____

Planform



Cross-Section Profile

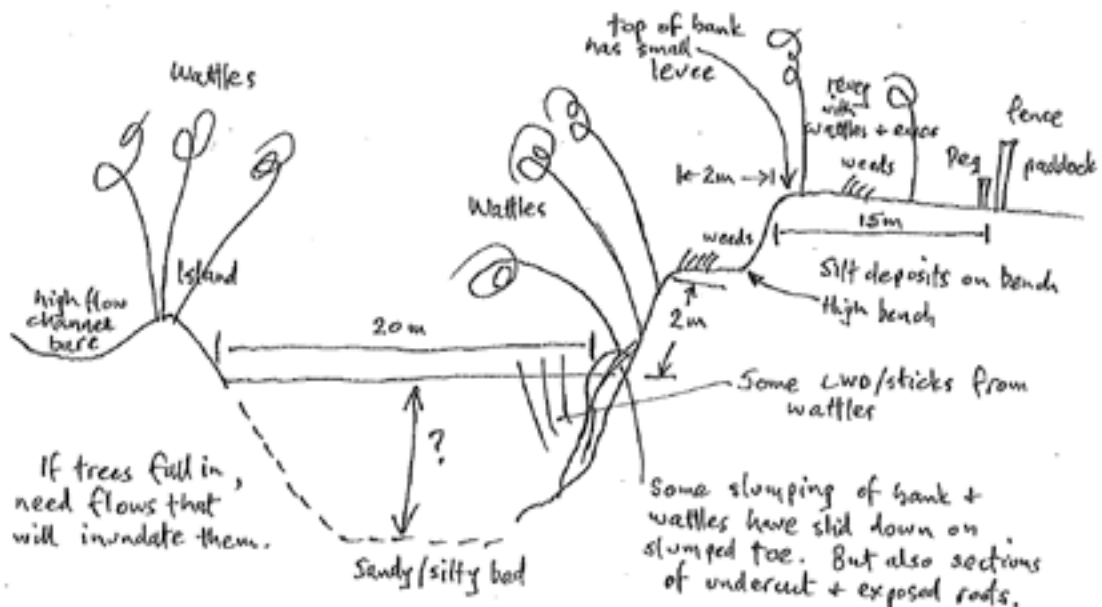


Figure 3.2 Example drawing of cross-section showing the key features of the cross-section in both planform and cross-section. Including bed and bank structure, vegetation, springs, distances and other characteristics of note.

A series of photos of general site features at each cross-section should be taken as a record at each site. Examples of key photos are provided in Figure 3.3. As a minimum, photos should be:

- at each cross-section:
 - along the cross-section, perpendicular to the channel (a)
 - upstream in the stream channel perpendicular to the cross-section (b)
 - downstream in the stream channel perpendicular to the cross-section (c);
- of general site features (d);
- of instream features present (a,b,c);
- to record the water level at habitats within the stream (c); and
- to assist in the assessment of hydraulic roughness parameters for the hydraulic modelling (a,c).

The drawings, photographs and completed reach and site data sheets provide a record of the key observations made during the site inspection and are referred to during the flow recommendation workshop and also during the development of the hydraulic models.

During the site inspections a temporary water level gauge should be installed at each site and the water level noted. The water level will then be recorded on later occasions (e.g. during channel surveys) and linked to the cross-section elevations. These recordings will help to more accurately calibrate hydraulic models (see Section 4.2 for more details on water level gauging to improve accuracy of hydraulic model calibration).



a. Cross-section



b. Upstream through cross-section



c. Downstream through cross-section



d. General site photo

Figure 3.3 Examples of site and cross-section photos (Cross-section 3, Yarriambiack Creek). These photos are an indication of the photos that could be used to satisfy the site description photos.

3.5 Development of environmental objectives

The environmental objectives set the direction and target for the flow recommendations and are developed as part of the Issues Paper. The Issues Paper then forms the basis of Stage 2, providing the key issues and the objectives that the recommendations are developed to meet. A shortcoming in some FLOWS studies to date is that the environmental objectives raised in the studies often had little direct and explicit relationship with objectives that had been established in other strategies and plans for the catchment broadly or the river specifically, such as regional river health strategies, or at least provided little justification why objectives may differ from existing strategies.

The overriding philosophy is that the objectives should focus on flow-dependent assets and outcomes and, within Stage 2 of a FLOWS study, need not consider objectives related to wider catchment management issues that are not flow related.

The Victorian River Health Strategy (NRE 2002b) (currently being updated through the draft Victorian Waterway Management Strategy) defined the concept of an ecologically healthy river as:

‘A river which retains the major ecological features and functioning of a river prior to European settlement and which would be able to sustain these characteristics into the future’.

This does not mean that the river is pristine. It recognises that there has been some change from a pre-European natural state but not to the point that there is a major loss of natural features, biodiversity or ecological functions. An ecologically healthy river will have flow regimes, water quality and channel characteristics such that (NRE 2002b):

- in the river and riparian zone, the majority of plant and animal species are native and no exotic species dominates the system;
- natural ecosystem processes are maintained;
- major natural habitat features are represented and are maintained over time;
- native riparian vegetation communities existing sustainably for the majority of its length;
- native fish and other fauna can move and migrate up and down the river;
- linkages between river and floodplain and associated wetlands are able to maintain ecological processes;
- natural linkages with the sea or terminal lakes are maintained; and
- associated estuaries and terminal lake systems are productive ecosystems.

This definition of a healthy river and its characteristics gives direction on the key components that should be considered in the development of objectives for a FLOWS study.

3.5.1 Regional policy objectives

Regional policy objectives can be found in plans, strategies and acts that govern national, state or regional natural resource management context. There are a series of documents that could provide a minimum list of those to be considered (Table 3.2). The development of environmental objectives is not meant to restate the objectives of these documents, rather refer to them and aim to have the environmental water requirements implemented in that context. Specific objectives or recommendations may be explicitly listed in the supporting recommendations section.

Table 3.2 Examples of relevant plans, strategies and acts at the national, state and regional level that should be considered.

National	National Principles for the Provision of Water for Ecosystems (1996)
	National Water Quality Management Strategy – Australian and New Zealand guidelines for fresh and marine water quality (ANZECC guidelines) (2000)
	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
State	Victorian River Health Strategy (NRE 2002) (currently being updated by the draft Victorian Waterway Management Strategy)
	Index of Stream Condition
	Waters of Victoria: State Environmental Protection Policy (EPA 2003)
	State Environment Protection Policy (Groundwaters of Victoria) (1997)
	<i>Flora and Fauna Guarantee Act 1988</i>
	Management of Victoria's Ramsar Wetlands (2002)
	Estuary Entrance Management Support System (2009)
	Sustainable Diversion Limits Project. Recommendations for Sustainable Diversion Limits over Winterfill Periods in Unregulated Victorian Catchments. (SKM and CRCFE 2002).
	Indigenous Partnership Framework (2007)
	Catchment Condition reports
Regional/local	Regional catchment strategies
	Regional river health strategies (to be replaced by regional waterway strategies)
	Regional sustainable water strategies
	Environmental watering plans
	Fisheries management plans
	Estuary management plans
	Ramsar site management plans and ecological character descriptions
	Murray-Darling Basin Authority Sustainable Rivers Audit
	Murray-Darling Basin Authority Native Fish Strategy (2003)

3.5.2 Process for determining environmental and flow objectives

The process of setting objectives involves first identifying the environmental assets, setting environmental objectives to support them, identifying those that are flow dependent and then identifying the components of the flow regime that are important to achieving the environmental objective.

Environmental flow objectives should be developed only for those assets that have a clear dependence on some aspect of the flow regime. Environmental flow objectives could be developed for:

- particular species and communities;
- habitats; and
- ecological processes.

Objectives should be measurable and include target statements describing the expected ecological response and the flows (magnitude, timing, frequency and duration) needed to produce that response. Conceptual models of ecological-flow response should be developed to clearly show and justify the relationship between flow components and ecological response (see discussion below).

The objectives need to be those which would, if met, mean that the recommended environmental flow could sustain an ecologically healthy river at a low level of risk. Therefore the objectives need to protect current conditions or environmental assets of special concern, such as threatened species, as well as sustain the natural communities and processes that are essential for river health. This means that during the process of developing objectives, consideration must be given to identifying and rehabilitating, where necessary, the environmental assets that would support a healthy river rather than maintenance of current condition.

The steps involved in the development of the environmental and flow objectives are summarised in Figure 3.4 and described in detail below. It will be up to individual project teams to determine how they approach the objective setting process. Options include using team workshops, or having each member of the EFTP develop objectives relevant to their specialist area before then discussing these with the rest of the panel.



Toorong River. Photo by Alison Pouliot.

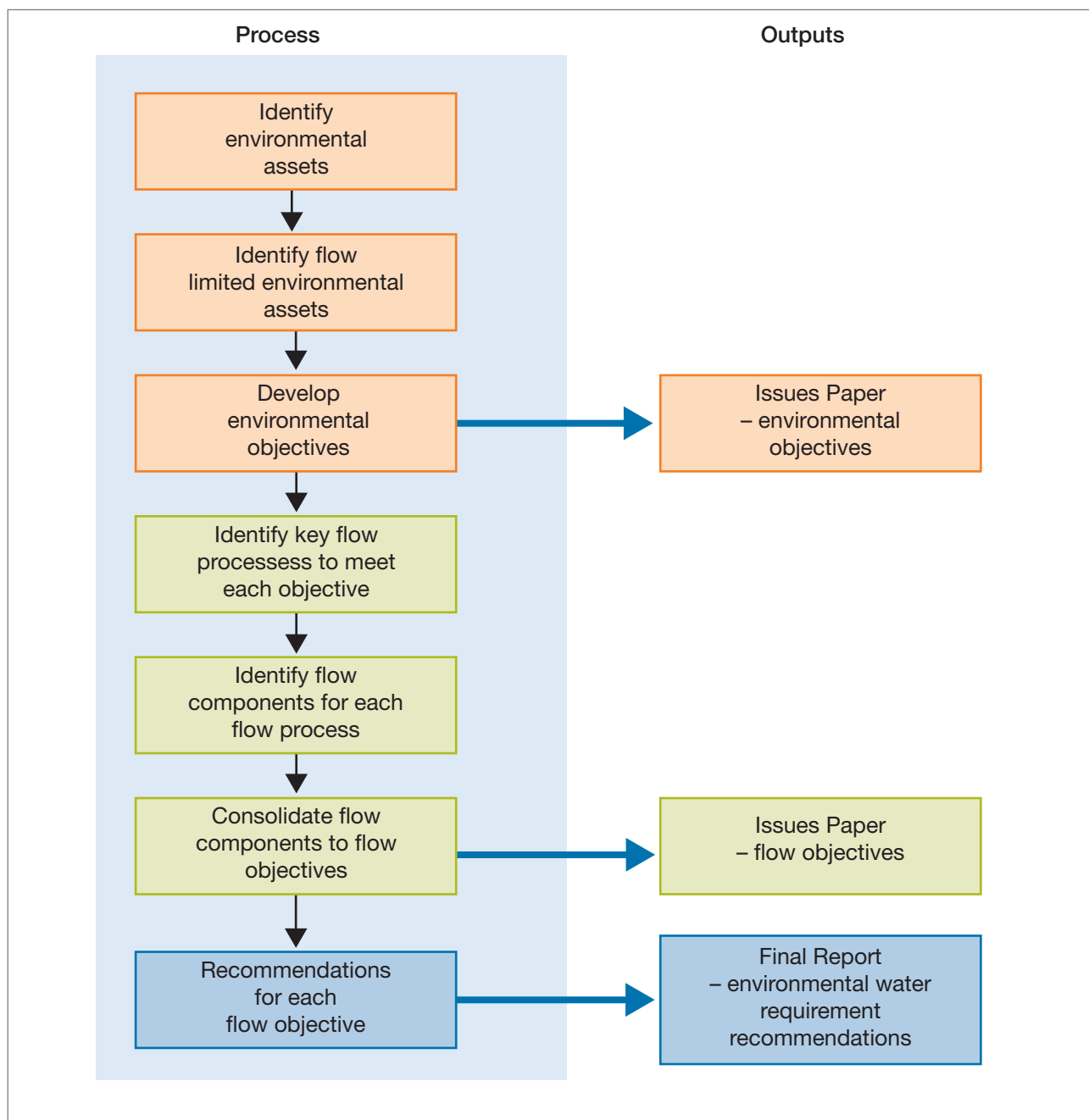


Figure 3.4 Outline of process for the determination of environmental and flow objectives.

1. Identify the current environmental assets

A list of the current environmental assets of the river will be compiled during the data collation phase. Although this initial list may be extensive it will be refined later to include only those assets that are dependent on aspects of the flow regime. The list of ecological assets should be based on the checklist below. Note this checklist may be amended by the Department of Environment and Primary Industries over time.

When collating lists of species and communities, it is important that this is not restricted to threatened biota, although flow recommendations should describe conditions required for the protection of threatened species or communities. It is recommended that where threatened species or communities do exist, they should be included in the final selection of assets against which environmental objectives are set. (A link to lists of the water-dependant threatened biota is provided in Appendix E.)

Checklist for environmental assets:

- Species and communities

Species

- threatened aquatic invertebrates
- all fish
- all frogs
- all aquatic reptiles
- all aquatic mammals
- colonial-breeding water birds
- threatened species of water birds
- threatened species of aquatic and riparian plants

Communities

- Riparian Ecological Vegetation Classes (for this information refer to the catchment management authority vegetation planners. For the small areas where the information is not yet available, the catchment management authorities can refer to the relevant land system databases)
- wetlands of significance (e.g. Ramsar-listed sites)
- AUSRIVAS score for the aquatic invertebrate community.
- Flagship species, locally significant species and communities
- Processes
 - longitudinal and lateral linkages/connectivity
 - geomorphic processes
 - nutrient cycling
 - water quality.
- Habitats
 - channel morphology (pools, benches, riffles, backwaters etc.)
 - instream habitat
 - large woody debris
 - aquatic vegetation
 - wetlands and floodplains.

2. Identify assets expected to be associated with a healthy waterway

An assessment is required to determine if the river is in an ecologically healthy state. This can be based on the identified environmental assets in their current condition and compared with a conceptual model or vision for a healthy river. To guide this process, the EFTP should consider the characteristics of a healthy river as noted above, and draw on the current environmental assets, the historical condition of the river as well as knowledge of similar but healthy rivers. Based on the conceptual model of a healthy river, the environmental assets that need to be maintained, improved or reinstated in order to achieve the desired condition can be identified.

3. Develop environmental objectives

From the list of environmental assets developed in steps one and two, a group of high priority assets should be selected that are flow dependant and for which there is a good understanding of their flow requirements. Environmental objectives must then be developed for each of these environmental assets, consistent with the maintenance of a healthy river.

Objectives need to be measurable, so that in future it is possible to determine whether provision of the environmental water achieves the desired environmental outcome. An example of an environmental objective could be 'to maintain a self-sustaining population of Murray cod within a particular river reach'. The measure of success of this objective may be to do with maintenance of particular size classes within the population.

Some objectives may appear on first reading to be appropriate but, upon further inspection, are seen not to be valid or useful. For example, an objective to 'improve water quality' is not a useful statement of intent; the aspect of water quality that needs to be improved should be stated (e.g. dissolved oxygen concentrations) and the link between the objective and flow made explicit (e.g. sufficient flow to turn-over and mix deep, stratified pools). Similarly, an objective to 'protect and rehabilitate aquatic habitats' is not a useful objective; it becomes more meaningful when the species of interest is signified (e.g. Murray cod, river red gum) and the specific aspect of the habitat stated both spatially and temporally (e.g. wetting of shallow levees along river banks in spring).

4. Identify critical flow-related events and flow components to meet each environmental objective

For each flow limited environmental asset identify the flow-related events or processes that are critical in order to meet the environmental objective. There may be a number of these for each asset. The flow-related events may be to meet a biological need, such as a trigger for spawning, or to provide physical habitat, such as inundation of snags or maintenance of suitable water quality in pools.

Table 3.3 Examples of flow processes and components for golden perch.

Ecological asset	Objective	Flow-related events	Flow component
Golden perch	Self-sustaining populations of golden perch	Movement	High flow (winter)
		Recruitment	Freshes (winter/spring)
		Habitat availability in summer	Low flow (summer)
		Habitat quality in summer	Freshes (summer)

For example, environmental flows may be provided to maintain golden perch populations by:

- maintaining habitat availability;
- initiating pre-spawning movement; and
- initiating spawning.

Once the desired ecosystem responses have been identified, the flow components must be specified for each of them. An example of the flow components suggested for golden perch are described in Table 3.3.

The causal link between the desired ecosystem response and flow component needs to be clearly justified and documented. Recent scientific literature (e.g. Saintilan and Overton 2010, Roberts and Marston, 2011, Rogers and Ralph 2011) provides new evidence describing the response of various biota and ecosystem processes to flow. Conceptual models of response to flow (or flow-ecology relationships) are also described for several Victorian rivers as part of VEFMAP by Chee et al. (2006). The VEFMAP monitoring data is also available from catchment management authorities and the Department of Environment and Primary Industries and this, along with other suitable monitoring data (e.g. water quality data), should be used to test the validity of conceptual models.

Conceptual models should be developed that describe the ecology-flow response and where possible, quantify any relationships. A thorough description of these relationships is required (e.g. through the development of a conceptual model), along with justification and full referencing so that it is clear where the information has come from to support the relationship. A list of assumptions and a clear statement of confidence or uncertainty in any relationship is also required. Information on which flow components are most critical to the asset is needed, as is advice on the interrelationship between, and sequencing of, flow components. Again, this information can be provided in a conceptual model or description of the life history requirements of particular species.

The use of conceptual models is a way to formalise an understanding of the major components of a given river system, interactions between the biotic and abiotic components, and how external changes can modify the system. Ultimately a conceptual model should reflect the information known about the study area and should help form a shared understanding of the ecosystem (ANZECC

and ARMCANZ 2000). Conceptual modelling uses the available documented information, in addition to any knowledge gained in targeted data collation (such as site visits) or data analysis (such as hydrograph analysis) activities, to formulate a series of statements as to how the system functions. These statements can be expressed as written narratives, tables, mathematic formulations and schematic diagrams such as box-and-arrow models, but most commonly pictorially as system cross-sections or oblique aerial views of the landscape.

There are two types of conceptual models that could be used to assist this process. The first type are generic models that identify broad flow components important for typical FLOWS objectives. Such models have already been developed through VEFMAP (see Chee et al. 2006) and future studies should make use of these models and the data collected to help determine which components of the flow regime are most important for particular objectives. VEFMAP data is available from the relevant catchment management authorities and the Department of Environment and Primary Industries.

The second type of model is more specific and relates to the individual ecosystem response-flow relationship (including response to flow magnitude or velocity, frequency of or interval between events, timing and duration of events). These relationships are likely to be site specific, although some general criteria may apply, for example the duration of inundation required to 'drown' terrestrial vegetation or the flow velocity required to scour algal biofilms or move certain sediment size classes. Site specificity is then based on hydraulic modelling that determines a site specific flow magnitude that achieves the velocity (or other) criteria.

Whenever possible, conceptual models should be developed collaboratively amongst EFTP members, with specialist advice sought where necessary. In the case of environmental flow assessments, this should include the hydrologist, ecologist and if required, hydrogeologist at a minimum.

The process of conceptualisation should identify the following:

- important linkages between the water regime (and characteristics thereof) and ecosystem response, with reference to both surface water and (where required) groundwater flow components;

- any critical ‘knowns’ and the ‘unknowns’, and thus the serious gaps in knowledge and where research investment needs to be focussed; and
- predictions relating to the likely impacts of different management interventions.

When constructed with these points in mind, the conceptualisation process will prove useful in informing construction of the hydraulic model and prioritisation of resultant flow recommendations. It will also indicate requirements for future monitoring though providing the basis for the development of ‘management hypotheses’ that link the execution of flow recommendations to the predicted ecological outcomes – thus providing the foundation for an adaptive management cycle and the framework for compliance and intervention monitoring.

Over time it is envisaged that the Department of Environment and Primary Industries will establish and maintain a library of conceptual models that will be made available for each FLOWS study. It will then be a requirement that models developed or modified during a FLOWS study be submitted to the department to ensure continual update of the conceptual model library.

5. Develop flow objectives

Each flow component must be described (as far as possible) in terms of timing, magnitude, frequency or duration required to meet the environmental objectives for each reach; the flow will be quantified in Stage 2 of the FLOWS method (see Section 4.3).

It is essential that flow objectives are matched to the specific needs of environmental assets and objectives as demonstrated through the conceptual models. All required components of the flow regime need to be clearly identified and justified and advice on the levels of confidence in each recommendation provided. Furthermore, advice on which components are most important (i.e. the minimum critical requirements) is also required. For example, is it the number of events, the magnitude or the duration? It also needs to be clear how these conclusions were reached (e.g. based on known biological or physical requirements or by using the natural hydrology of the site as a template) and appropriate referencing provided to support the conclusions.

A significant addition to this revised FLOWS method is the inclusion of the development of objectives for long-term wet, average and dry conditions. Current studies typically set objectives for average conditions. However, the high variability in Australian stream flows and the way in which regulated rivers are operated, means that average conditions do not always occur. It is thus necessary for objectives and recommendations to incorporate a degree of variability to enable them to be adapted to different climatic and management conditions, both within and from year-to-year (adapted for very dry, dry and wet years in addition to average years). For example, during dry years it may not be necessary for some high flow events to be delivered and during wet years it may be more appropriate to have fewer but longer duration high flows.

This has been termed the ‘seasonally adaptive approach’ by the Department of Environment and Primary Industries. The seasonally adaptive approach involves adapting environmental watering decisions to prevailing climate conditions in any year. It provides the greatest protection to the most important parts of the environment through drought and dry years, and builds ecological resilience in wetter years (see Table 3.4).

This will be most effective in regulated river systems, where water can be stored and released when needed. Nonetheless, the guiding principles are the same for any management decisions for unregulated rivers.

In any given year, the approach identifies priorities for environmental watering, works and complementary measures, depending on the amount of water available. It is a flexible way to deal with short-term climatic variability. In dry years, the focus is to avoid catastrophic events, such as major fish kills, and to protect drought refuges. In wet years, the focus is to provide high flows and floods to build resilience and enable recruitment and dispersal of key aquatic animals and plants.

The definition of drought, dry, average and wet to very wet years could be determined in several ways (for example, based on antecedent or climate forecasts). An appropriate definition is likely to be catchment specific and may be different for regulated versus unregulated systems. It is recommended that EFTPs explore and agree on relevant criteria for what represents dry, average and wet years for the specific system in question in consultation with the relevant environmental water manager prior to the development of objectives and recommendations.

Where there is uncertainty in particular relationships, FLOWS studies should provide a comment on what would be needed to increase confidence in recommendations or understanding of ecological response. It should also be noted that objectives for dry conditions are not a ‘fall back’ or minimum set of objectives that can be applied to all other seasons and still provide a low level of risk.

6. Develop recommendations to meet each flow objective

The environmental water recommendations will be developed to provide the described flow objectives in Stage 2 of the environmental flow study. This is described in Section 4.

3.6 Issues Paper

The Issues Paper documents the objective-setting process for environmental assets and environmental flows. It contains background information on the ecosystem assets, issues, values and threats as determined by the initial data collation and assessment phase. Some of this material may have been covered in the Site Paper, but the Issues Paper is more exhaustive and specifically addresses the most important environmental assets and the flows required to maintain or rehabilitate them. The Issues Paper therefore aims to provide an overview of the flow-based assets and flow threats to those assets in the river system.

Table 3.4 Seasonally adaptive approach to guide objective development.

Objectives	Drought	Dry	Average	Wet to very wet
Short-term ecological	• Priority sites avoid irreversible losses and have capacity for recovery	• Priority river reaches and wetlands maintain their basic functions	• Maintain or improve the ecological health of priority river reaches and wetlands	• Improve the health and resilience of priority river reaches and wetlands
Annual management	• Avoid critical loss • Maintain key refuges • Avoid catastrophic events	• Maintain river functioning with reduced reproductive capacity • Maintain key functions of high priority wetlands • Manage within dry-spell tolerances	• Improve ecological health and resilience	• Maximise recruitment opportunities for key river and wetland species • Minimise impacts of flooding on people • Restore key floodplain linkages

Key output 3 – Issues Paper

As a minimum the Issues Paper will have the following components:

- Identification of values and condition of the river system (current state versus natural or desired state), specifically for the following ecosystem components:
 - flora
 - fauna
 - water quality
 - geomorphology
 - role of groundwater
 - habitats (wetlands, floodplains etc.).
- Discussion of the system hydrology and hydrogeology – including comparison of unimpacted and current flow regimes and potential future water demands.
- Identification of degrading factors, flow-related and non-flow issues that can affect asset condition (e.g. surface water extraction, groundwater extraction, clearing of riparian zone, livestock access and de-snagging).
- Description and discussion of the implications of the current system operation.
- Confirmation of environmental flow objectives for the system.

The Issues Paper will include the description of important features identified as part of the field assessment, and a discussion of the implications of the flow-related issues at specific sites within each reach. Ultimately, it provides the context for the FLOWS assessment and its flow recommendations.

Although it is usually beyond the scope of a FLOWS study, consideration should also be given to assessing extant issues, such as the freshwater requirement of estuaries, the implications of land-use change and the effects of dry land salinisation.

The draft Issues Paper will be sent to the client project manager for review. For most studies the client will also require a meeting with the Project Advisory Group and steering committee to present and discuss the objectives. Feedback, either in writing or from a meeting shall be provided through the client project manager. Any conflict with recommended objectives needs to be resolved at this stage and a final set of flow-related objectives agreed to prior to commencing Stage 2.

FLOWS method description:

Stage 2 – Development of flow recommendations



In Stage 2 of FLOWS, the cross-sections that were identified in Stage 1 are surveyed and used to develop hydraulic models for each site. These models assist in the development of relationships between stream flow, water level and inundation of channel features, and are used to derive flow recommendations aimed at meeting the environmental flow objectives developed in Stage 1.

4.1 Surveying

Cross-section surveys are required to provide the necessary data on channel dimensions (including an appropriate distance into the floodplain, if any) that will be used in the development of an hydraulic model for each study reach. The surveys will identify any significant variation in channel shape, longitudinal profile and physical habitat structure. See Section 4.2 for more specific detail on the cross-section selection to support the development of hydraulic models.

All cross-sections (those capturing ecological features and any additional cross-sections deemed necessary by the hydraulic modeller) will have been identified and marked by the EFTP during the panel assessment. The consultant project manager will provide the surveyors with a detailed brief of cross-section locations and instructions for survey. It is recommended that the EFTP members such as an ecologist, a geomorphologist or the hydraulic modeller, participate in the surveying to ensure that habitat and hydraulic features of interest to the EFTP are surveyed in appropriate detail.

The following field survey records are necessary for hydraulic model development:

- Sufficient cross-sections and a long-section to characterise the ecological and hydraulic features of the site.
- Locations of hydraulic control sections, and other representative sections for use in the modelling.
- Flow depths at major hydraulic control sections.

Surveying equipment that enables recording of position and relative height of survey points is required. A Total Station (an electronic theodolite integrated with an electronic distance meter) is recommended. Modern differential GPS based systems are also appropriate because they allow positioning

within a standard datum to be achieved (e.g. Australian Height Datum – AHD), a requirement of some clients.

All cross-sections within a site need to be linked together (either at the time of survey or using post-processing procedures) to enable the slope (long section) and planform shape (meander-pattern) of the channel to be documented. As indicated above, some clients also require surveys to be linked to AHD. Permanent positions need to be provided so that cross-sections can be re-located and re-surveyed at later stages (e.g. as part of a monitoring program).

Substrate type should be recorded for each point measurement taken on a cross-section (Table 4.1). If there are significant accumulations of sediment present on the cross-section then the depth of sediment should also be recorded. Point measurements should be taken at intervals to show changes in slope, structure and substrate type, rather than at regularly spaced intervals.

Table 4.1 Habitat classes to be used for surveying (from Summerfield 1993).

Substrate class	Size
Bedrock	–
Boulder	>256 mm
Cobble	32–256 mm
Pebble	4–32 mm
Gravel	2–32 mm
Coarse sand	0.5–2 mm
Fine sand	0.06–0.5 mm
Silt	0.004–0.06 mm
Clay	<0.004 mm
Small woody debris	<100 mm diameter
Large woody debris	>100 mm diameter
Undercut bank	
Riparian vegetation	
Submerged vegetation	

TOP: Yarriambiack Creek. Photo by Sinclair Knight Merz.

A sufficient number of cross-sections should be surveyed downstream of the specified site, to assist in setting the downstream boundary conditions for the hydraulic model. The distance surveyed downstream of the site should be a minimum of the distance of the greatest separation between cross-sections within the site (see Section 4.2 for more details in this requirement in respect to the hydraulic model development). The hydraulic modeller must:

- identify the location of these additional cross-sections;
- identify the location of any other cross-sections that may be required throughout the reach to assist with model development (e.g. to infill between ecological cross-sections that are spaced far apart, provide for the development of a long profile and provide information on channel blockages or other hydraulic control features with the site); and
- include this information in the instructions to surveyors.

Surveyors are also required to record water surface level in each cross section and any level gauges that may have been installed at the site (see Section 4.2 for more details on water level gauging and hydraulic modelling). When water levels are being surveyed, it is important that it is done in a consistent manner. For example, for a site with:

- **Muddy banks:** surveyors could consider putting a flat rock or block of wood on the bank so that an accurate water level can be measured. If the survey staff sinks 20 mm into the mud, it can make calibration of the model very difficult. Placement of a flat object such as a rock can allow a more accurate water level to be obtained.
- **Significant wave action:** surveyors could consider using a bucket with a small hole or similar to provide an accurate static water level, without the effect of waves.
- **A substrate layer of very soft mud:** surveyors should be instructed whether it is better to obtain the cross-section representing the top of the mud, or the bottom of the mud, or both.
- **A rock or cobbled substrate:** consideration should be given as to whether to survey the cross-section representing the top of the cobbles, or the levels between cobbles. This can have a significant effect on estimates of low flows for objectives such as fish passage.

The consultant project manager and hydraulic modeller must provide explicit instructions to the surveyor on how to record water levels and whether gauges need surveying (in addition to the cross-sections described above).

A typical site that is wade-able and containing 8–10 cross-sections will take around one day to survey. Additional time may be required if access is difficult, riparian vegetation is thick, a boat is required or access to AHD benchmarks is difficult.

4.2 Hydraulic modelling

A hydraulic model must be used to assist in the development of relationships between stream flow and water level for each site. The hydraulic modelling can be undertaken using the HEC-RAS software, which is designed to perform one-dimensional steady state calculations for a full network of natural and constructed channels or a single river reach. Other one-dimensional hydraulic models (e.g. Mike11) may also be suitable. For sites where interactions with a broader floodplain, high-flow channels and wetlands are of critical importance to the outcomes of the FLOWS study it may be necessary to use a two-dimensional model. However, the data and modelling requirements for two-dimension modelling are significant and generally beyond the scope or budget of a typical study that focuses on in-channel objectives.

The modelling needs to be undertaken by an experienced hydraulic modeller, as considerable judgement is necessary to establish appropriate cross-section locations, downstream boundary conditions, and hydraulic roughnesses. Whilst modelling is considered the best available method for this application, modelling results should be viewed with caution, particularly for low flows and in the absence of calibration data. Furthermore, observations taken during site inspections should be used in conjunction with the hydraulic modelling, to assist, particularly, in definition of low flow conditions.

Sensitivity analyses are recommended to assess impacts on results of a range of possible model parameters, particularly boundary conditions and hydraulic roughness.

4.2.1 Cross-sections

Separate hydraulic models should be constructed for each representative site, using the surveyed cross-sections (see Sections 3.4 and 4.1 above for details on cross-section selection). The surveyed cross-sections may be supplemented by LiDAR data (see Section 2.1) where this is available and if the latter has sufficient accuracy. LiDAR data may be particularly useful for increasing the amount of data available for characterising banks and floodplains.

It is critical that cross-sections that coincide with major hydraulic controls that govern flow behaviour over the required range of flow magnitudes are included in the model development (see Section 4.1). Hydraulic control features can include:

- bridges, culverts, and weirs (although note that these structures should be avoided as being unrepresentative of the natural condition of a reach);
- deep pools;
- tops and toes of riffles;
- sudden changes in bed roughness; and
- sudden changes in cross-sectional area.

Often these geomorphological features are the same as the features of ecological interest, but care should be taken to ensure that sufficient cross-sectional information is captured to allow them to be correctly represented in the hydraulic model. For example, it may be of ecological interest to capture a cross-section across a riffle. However, to allow accurate calibration of the hydraulic model, it is also important to understand the water levels and cross-sectional properties immediately upstream and downstream of the riffle.

The EFTP needs to consider the relative benefits of an additional survey at a single site to enable the development of a more accurate hydraulic model, versus survey at a second site to enable some assessment of within reach variability.

4.2.2 Low flow determination

Field reconnaissance will often be undertaken during low flow conditions, and, as noted above, flow depth should then be measured at major hydraulic control points. The hydraulic model can then be used to calculate flow in an ungauged stream based on critical depth considerations, or to check model validity where gauged flows are available. The accuracy of the model is poorest at low flows, and the data collected at low flows will assist in increasing the accuracy of the outputs at low flows.

Model results at locations other than hydraulic controls will generally become more reliable as flow and depth increase, and controls then become drowned.

4.2.3 Hydraulic roughness and boundary conditions

The two hydraulic model parameter inputs, the hydraulic roughness (Manning's n^7) and the water level at the most downstream cross-section in a reach, require values to be estimated by the hydraulic modeller. If calibration data is available, viz streamflow and water level(s), this information can be used to assist in determining roughnesses and boundary conditions. In some cases, however, no streamflow data will be available for model validation, and a sensitivity analysis for both parameters should be used to assess potential error bounds.

Manning's n values can be estimated by examining site photographs with comparison to values suggested by hydraulic engineering references. Suitable references include:

- Chow, V.T. (1959). *Open Channel Hydraulics* McGraw-Hill, New York
- Henderson, F.M. (1966). *Open Channel Flow* Macmillan Co., New York
- French, R.H. (1985). *Open Channel Hydraulics* McGraw-Hill, New York.

Many of the values listed in these references relate more specifically to major rivers, and some caution should be used in applying them to smaller streams, particularly under low flow conditions. Note that Lang et al. (2004) provide a summary of empirical equations that may be more applicable to estimating Manning's n values for Victorian streams.

The best way to reduce the uncertainty associated with estimates of roughness is for an experienced hydraulic modeller to inspect the site. As part of the inspection, the modeller can prepare a roughness 'map' indicating different Manning's n values for different areas of substrate and vegetation throughout the site. This is also an ideal time to note waterway features between cross-sections that may affect hydraulic performance, but which have not been captured in cross-section survey (Figure 4.1).

Assuming flow is subcritical, the downstream boundary condition is the starting water level used in the computation of upstream water levels. The influence of the downstream water level on computed water levels diminishes with distance upstream. Hence it is desirable to ensure that surveyed cross-sections are obtained a sufficient distance downstream from the site of interest to minimise the impact of the downstream boundary condition on results within the reach of interest. For sites where the extent of downstream cross-sections is limited, a range of downstream water levels should be trialled to establish the sensitivity of the computed water levels. The required distance from the downstream boundary to the downstream extent of the reach of interest will depend on the slope of the stream. For steeper streams, a lesser distance is required. The number of cross-sections required downstream of the reach of interest depends on the variability of the stream geometry. More cross-sections are required for more variable streams.

Other ways of improving the downstream boundary condition for a model include:

- **Using existing cross-section data**

It may be possible to extend a hydraulic model using cross-sections from an existing model or from existing surveys undertaken, from earlier FLOWS studies, flood estimations or bank-erosion investigations. For example, there are many existing cross-sections available for the Yarra River between Upper Yarra Reservoir and Melbourne CBD.

- **Using LiDAR data**

High quality LiDAR elevation data can be used to provide additional downstream cross-sections (above the water level) without the need for survey. Also, LiDAR can provide details about possible downstream controls such as culverts and bridges that may not be immediately obvious at the site itself.

- **Using existing gauge rating data**

The flow-depth rating curve for a nearby streamflow gauge can be transposed to the model site. This should only be done if the hydraulic properties of the two sites are likely to be very similar. It is also important to document the uncertainties associated with this technique.

4.2.4 Model calibration

A critical area of uncertainty in hydraulic models is calibration. Calibration success, and hence model accuracy across a range of flows, can be significantly improved by capturing water surface elevation at a number of flow

7 Manning's n is an estimate of channel roughness, used in the calculation of flow velocity and discharge.

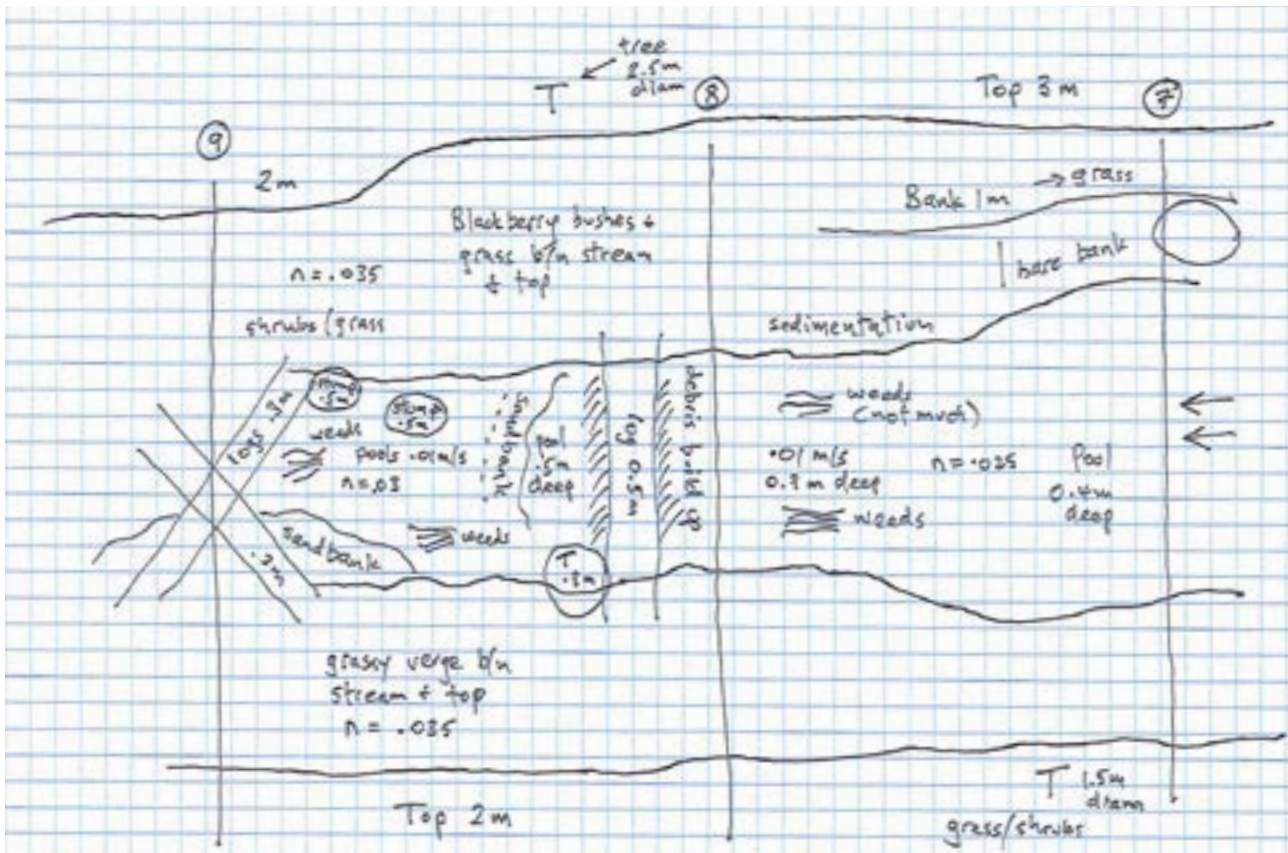


Figure 4.1 Example of roughness map detailing features between cross-sections to assist with hydraulic model calibration.

magnitudes within the assessment reach. The following is a list of the types of data that could be used to calibrate the hydraulic model of each site, in descending order of usefulness:

- depth loggers placed at each cross-section to capture daily or hourly water depths. Data could be recorded for however long is required to get water depths for a good range of flows. The datum of any depth loggers would need to be tied to the existing survey of cross-sections;
- depth loggers placed at the upstream and downstream ends of the model and data collected for a range of flows. This is a good solution providing a high level of confidence if the depth logger is in place for flows ranging from low to bankfull flows;
- a single depth logger placed at the most downstream cross-section and data collected for a range of flows; and
- water levels could be recorded for several different flows, preferably including a low flow, a high flow (at least ~70 per cent of bank full), and a median flow. Water levels would be captured for key points in the model, such as changes in grade or at key control features.

The preferred option is for the installation of data loggers. They are relatively cheap and easy to install, and are useful provided they can be protected from vandalism. Hiding them in camouflaged pipes amongst rocks on the stream bed or

attaching them inconspicuously to pylons can often minimize the risk of vandalism. Having duplicate sets of data loggers in different locations (possible because they are relatively cheap) also lowers the risk of losing information. The second option is to install temporary staff gauges (which can be as simple as a metal picket with a ruler or tape measure attached).

However, these above approaches do require more than one site visit. This is achievable for most FLOWS studies, as sites are usually visited during the reach and site assessment stage, during the EFTP assessment at the issues development stage, and by surveyors during cross section surveys. It is thus feasible for data loggers or a temporary staff gauge to be installed during one of the initial visits. These fixtures would then be captured in the cross-section survey and water levels could be recorded on several occasions and used for model calibration. It may also be feasible for the client project manager or water operations staff to visit sites from time-to-time and record water levels.

Less preferred options for model calibration are:

- surveyors record water levels for a single flow. Ideally, this flow would be near the median but as surveyors often prefer to work when water levels are low, it tends to occur mostly during low-flow periods. This approach currently occurs when cross sections are surveyed;

- the hydraulic modeller can use the rating curve of a nearby gauging station as the downstream boundary. This approach is only appropriate when there are no water levels to survey (e.g. during cease-to-flow conditions); and
- the hydraulic modeller can look at a topographic map to determine the approximate slope of the waterway. This slope can then be adopted as the downstream boundary condition for the HEC-RAS model.

The last two approaches do not include any measured water levels at the site. In this case, 'calibration' as such is not possible, and the uncertainty associated with the model increases significantly.

To calibrate the hydraulic model, estimates of flow are required that correspond with the water levels surveyed. In many cases, there is no operational flow gauge near the site to provide an accurate assessment of flow rate. This presents two problems:

- with no nearby gauge, flow measurements from more distant gauges must be transposed to the site. A strategy for this transposition needs to be determined prior to the survey being undertaken; and
- most gauge sites in Victoria have no regular telemetry, so recorded flow data will not be available until it has been downloaded and processed. This may be possible in as little as two to three weeks, but it is more likely that the data will not be available until one or two months after collection. Given this time delay, it is essential that a strategy for obtaining recorded flow data is in place well in advance of the survey to ensure that the overall project is not significantly delayed. Occasional water level data from some gauges may be available via the Bureau of Meteorology flood warning website or from the relevant catchment management authority or rural water authority however, it should be noted that this data is unchecked and may contain errors.

However, stream flow can be relatively easily estimated in the field (Gordon et al. 1992). Of these simple measures, the most accurate is to use a velocity meter to measure water velocity at regular intervals across the channel at a level equivalent to 4/10 the depth of water from the stream bed. This provides an average flow velocity across the channel, which can be multiplied by the cross sectional area of flow to provide an estimate of flow volume linked to water level. If flow and water level are measured on several occasions a simple rating curve can be developed that will help with hydraulic model calibration.

Once calibrated, the hydraulic model should be run for each site over a range of flows to establish relationships between flow and water level.

A report is then prepared that documents the development and testing of the hydraulic model. This report should be incorporated into or included as an appendix to the Final Report. A checklist is provided in Appendix B.2 that highlights the major requirements of hydraulic model development. This checklist should be completed and provided as a record of model development to assist with

the technical review of the hydraulic model and to inform the EFTP of any specific areas of uncertainty that need to be considered when using the outputs of the hydraulic model for the quantification of flow recommendations.

For most hydraulic models, technical and quality reviews should be provided by a relevant member of the project team and checked against the checklist. However, for complex or high-profile systems where even greater scrutiny of results is likely, the client may choose to undertake an independent review of the hydraulic model prior to approving its use for the development of flow recommendations.

4.3 Analysis and environmental flow recommendations

The EFTP integrates all of the outputs generated in the previous tasks to develop flow recommendations. The work is primarily completed collaboratively in an EFTP workshop, supported by hydrological and hydraulic data generated and interpreted for the EFTP prior to the workshop (Table 4.2). The workshop duration will depend largely on the number and complexity of reaches included in the study area. Experience has shown that the development of recommendations for three to four reaches can be achieved in one day. However, more time may be required for complex systems.

The workshop should be an interactive and iterative process where the EFTP use the data and models to arrive at flow recommendations that will meet the stated flow-related ecosystem objectives. The hydrology and hydraulic information should be available at the workshop so that the EFTP can interrogate the data; this requires the presence of someone capable of undertaking the required hydraulic and hydrological analyses.

Recommendations are developed for each reach within the system and should be summarised in a table format. The minimum details to be provided in the flow recommendation table are:

- river name;
- reach description and site location;
- a compliance point against which the delivery of the flows can be assessed. This must be an operating gauge within the waterway and the flow recommendations should be relevant at that compliance point. If there is no operating gauge in the system, it will be necessary to recommend the commissioning of an appropriate gauge; and
- specific recommendations for each relevant flow component, including season, magnitude, frequency, duration, rates of rise and fall, minimum or maximum interval between events and acceptable variation around each element. Separate recommendations should be provided for drought, dry, average, wet and very wet years. The objectives relevant to each component should also be specified, as should a comment on the expected response of value to the flow component.

Table 4.2 Information requirements for the EFTP workshop.

Data	Description	Task output
Daily flow series	Daily flow series for minimum 30 years of current and unimpacted flows at each site Summary statistics for hydrology at each site	Hydrological data
Objectives	Draft environmental flow objectives	Issues Paper
Flow components	Identified flow components	Field visit
Photos	Site and cross-section photos	Field visit
Field summary	Field data sheets	Field visit
Hydraulic model	Hydraulic model for each site	Hydraulic models and output
Issues summary	Key issues for each reach	Issues Paper

Notes should be kept to document the outcomes and rationale at each step of the flow recommendation process. These notes should include a summary of the relevant data used to make the decision and an outline explaining the rationale. These could include (in order of confidence from high to low):

- empirical data from studies of ecology-flow response at the reach being investigated;
- empirical data from specific studies in other similar locations;
- reference to the unimpacted hydrology at the site; and
- the opinion of the EFTP.

These notes are used to write the explanation for the Final Report, but specifically should be documented and provided to the catchment management authority and the Department of Environment and Primary Industries or rural water authority for their records.

Recommendations should be developed for each flow objective using the following process:

- 1) Examine flow objectives for the reach developed in the Issues Paper.
- 2) Examine the deviation of the current system from the unimpacted conditions for each relevant flow component within a reach.
- 3) Identify the trajectory of change for the site (e.g. trends in conditions for identified ecosystem components).
- 4) Determine the implications, and potential risk, of the current changes in the flow regime on the identified objectives.
- 5) Iteratively determine appropriate flow conditions for that flow objective that removes the risk factors identified (e.g. provision of flow cues, habitat restoration or wetting).

- 6) Run hydraulic and hydrological model scenarios using the flow components to extract information on the magnitude, timing, frequency and duration of these flows (this can be used to determine trigger flows or extraction rates under various flow conditions, or could be used to examine potential management implications for the recommendations that should also be documented).

- 7) Repeat point 6 for each identified flow component.

A number of key inputs must be considered and documented for each recommendation when following the process listed above:

- 1) Hydrology – the daily time-series is a key data source and input for developing flow recommendations.
- 2) Hydraulic model – the hydraulic model should be used to examine flow levels and wetted area for different flow magnitudes. In the recommendations, the precision of flow magnitudes should be relevant to the sensitivity and accuracy of the model and typically be limited to two decimal places.
- 3) Flow components – the flow components (including gains from and losses to groundwater where applicable) relevant to the stated flow objectives will drive the determination of the environmental flow recommendations.
- 4) Conceptual models, ecology-flow response curves and cross-section drawings developed in Section 3.5. This information should be used to relate the features seen in the field to the outputs of the hydraulic model.
- 5) Environmental objectives – flow recommendations will be developed to meet each of the environmental objectives.
- 6) Site description – the site description notes and photos should be used to confirm issues, features and stressors observed at sites.

- 7) Catchment stressors – catchment stressors may include other risks in the catchment to the health of the waterway (e.g. water quality, salinity, fish barriers, thermal pollution, riparian vegetation). The potential for these stressors to influence the achievement of ecosystem objectives should be considered when developing recommendations. If further actions are required to address the issues, this should be detailed in the complementary recommendations.
- 8) Impact of system operation – the system operation effects and constraints should be considered on a recommendation-specific basis. Recommendations that are affected by specific system operation constraints may need to be addressed in the supporting recommendations.

Documenting the rationale behind each of the above steps provides the initial basis for the justification of the recommendations in the Final Report. This documentation will be provided as supporting information to the client project manager. The documentation should include:

- the scientific basis behind decisions or any assumptions made (e.g. refereed journals, unpublished data, or expert opinion);
- the rationale for the decision and the data summary used (e.g. ecology-flow response relationships, conceptual models, direct channel or habitat features, unimpacted regime as a template);
- the risk of the recommendations not having the desired effect or other constraints impacting on its efficacy;
- any uncertainty in the recommendations and the source of that uncertainty. For example, lack of understanding of ecological-flow response; and
- the relative priority of different recommendations and sequencing and the rationale for these priorities.

4.3.1 Flow recommendations

Flow recommendations for individual reaches should be summarised and tabulated as described above, showing the link between the flow recommendations and flow components to the ecosystem objectives. This summary also provides the basis for identifying future monitoring needs. The rationale for each recommended component is then discussed including the basis for the recommendation and the risks to the environmental assets should the recommendation not be met. Furthermore, a statement of confidence in each recommendation should also be provided; this can be as an additional summary column in the recommendations table, with further discussion in the accompanying text.

Flow recommendations are also required for individual climate scenarios when objectives have been developed for drought, dry, average and wet conditions (or sequence of conditions). These recommendations describe the components that are considered to be of highest priority under each climate scenario and may differ depending on the climate conditions. For example, a low flow during a dry

period may be of lower magnitude than would be the case during a wet period. Or, fewer but longer duration events might be acceptable in wet years, whereas more frequent short duration events might be required in dry years to prevent deterioration in water quality.

Furthermore, consideration should be given to providing variability in flow components and rates of rise and fall when satisfying the requirements of a particular objective. For example:

- a low flow recommendation could be presented as 100 ± 10 ML/day with a weekly average of >100 ML/day. This would allow for some variation around 100 ML/day provided the average flow over a period of time was at least 100 ML/day; or
- the duration of freshes could be presented as an acceptable range, e.g. '4 events per season lasting three to five days provided the total number of days above the threshold exceeds 16'.

Where flow recommendations are made for wet, average and dry years, the EFTP members should also provide specific advice on the minimum (independency) and maximum interval between critical events to ensure that dry year recommendations do not become the default flow recommendations. For example, during a sequence of dry years, advice on the maximum interval between bankfull and overbank flow events to minimise risks to riparian, wetland and floodplain vegetation objectives needs to be provided. Similarly, the maximum interval between events that cue migration and spawning for fish or other biota that have short life spans needs stating. Explicit advice is also needed on the timing and season of recommendations. For some rivers it may be necessary to recommend an upper bound or a maximum flow at certain times of the years. This applies to rivers downstream of major impoundments that might be subject to alteration in the timing of flows due to unseasonal or untimely releases for irrigation or power generation.

The recommendations need to be specified sufficiently well so that the intent is clear and understood by stakeholders. In particular, acceptable levels of variability, the relative priority or importance of each component (i.e. low flow, freshes) and the importance of elements within each component (i.e. timing, magnitude, number of events, the duration or the interval between events) needs to be specified and justified. Levels of acceptable variability and statements on priority will allow river operators some flexibility in delivering flow recommendations, such as to incrementally implement recommendations as water is made available for the environment. For example, a recommendation for a summer low flow may be considered a priority over bankfull and overbank flows. This also informs the risk assessment processes (see later sections) because it helps define which flow components are most important and hence which, if failed to be delivered, contribute most to risk.

Often the 'or natural' proviso is included in flow recommendations. Recommendations need to clarify how the 'or natural' proviso should be interpreted. For example, it needs to be clear as to whether it applies to all elements of

a specific component (magnitude, frequency and duration) or to just one or two elements. It also needs to be clear how the 'or natural' regime should be determined, for example, based on inflows to storages. Recommendations also need to specify an interval of independence between events and, for regulated rivers, rates of rise and fall in discharge.

4.3.2 Interactions between flow components and downstream reaches

Whilst the above discussion has focused on within reach recommendations, it is important to consider the likely interactions between flow components and whether there will be any downstream relationships, especially in the case of estuarine reaches further down the river.

The 'within reach' interactions have two elements:

- 1) where an ecological objective requires several flow components to be delivered in order to maximise success; and
- 2) where an individual flow component may be important for more than one objective.

EFTPs need to provide advice on the critical components and the specific flow recommendations required to achieve multiple objectives and which objectives will suffer if these flow recommendations are not achieved. They should also provide advice (and appropriate justification and confidence) on the sequencing of events and risks to objectives (unintended outcomes). A number of examples exist to illustrate this point:

- if no winter high flows are achieved, then risks of blackwater events (deoxygenation and resultant fish kills) in the following summer might be increased due to the accumulation of excessive organic material that is not flushed through the system. Under this circumstance, an investigation into the amount of accumulated organic material and consequent risk of a blackwater event being initiated should be undertaken prior to any decisions being made regarding the release of summer freshes;
- if an autumn spawning flow is delivered for Australian grayling, then a follow-up spring migration flow event should be a high priority to take best advantage of the earlier successful spawning;
- the drying of wetlands that activate acid sulphate soils may represent an unintended risk, so wetland inundation may be a priority for these types of wetland in every year, regardless of climate conditions.

Advice may also be needed on the reach-to-reach interactions. An example is where a flow recommendation (e.g. for a summer fresh) needs to progress downstream from one reach to the next, in order to ensure that opportunities for fish passage between reaches is provided, or to transport organic material, eggs, larvae, plant propagules etc. to downstream reaches.

Where freshes and higher magnitude flow events are recommended in the same season, it should be made clear as to whether these events are treated independently or whether a higher magnitude event also means a lesser event is complied with. For example, whether a bankfull flow also counts as a fresh.

Flows studies in coastal systems may also need to consider estuary requirements. It is essential that estuary and freshwater reaches are not considered in isolation. In some instances the estuary flow requirements may exceed the freshwater reach requirements. Environmental water managers need to take into consideration the integration of freshwater and estuary requirements.

4.3.3 Uncertainty

Throughout the FLOWS process it is necessary to document sources of uncertainty and implications for the recommendations. Sources of uncertainty in FLOWS studies, approaches to estimating uncertainty and implications for the project are provided in Table 4.3.

4.4 Performance against flow recommendations

In the most recent FLOWS studies, there has been a trend towards assessing how well the current flow regime and alternative flow regimes (e.g. incorporating alternative demand patterns, climate change and land-use change) meet (perform against or comply with) flow recommendations, how large any shortfall is in meeting flow recommendations, and what this means in terms of risk to achieving environmental objectives. An alternative demand pattern that is commonly assessed is one assuming full development of water resources.

A new FLOWS study will be required to calculate performance against recommendations and shortfalls, as well as to provide advice on the relationship between performance and risk. For a typical FLOWS study, performance and risk assessments would be completed for the current flow regime. However, the process also needs to be applicable for assessing performance and risks associated with alternative flow scenarios.

Table 4.3 Components of the FLOWS process where uncertainty needs to be considered, and implications for the project if uncertainty is intolerable (adapted from Estuary Environmental Flows Assessment Methodology for Victoria, Lloyd et al. 2012).

Component of the FLOWS process	Approach to estimation of uncertainty	Implications for project
Flow-ecology, flow water quality and flow-geomorphology relationships	Qualitative statement of uncertainty regarding the need for the flow objective to be satisfied in order to achieve good health. Qualitative statement of uncertainty regarding the hydraulic/hydrologic criteria used to specify the objective (e.g. preferred depth and velocity ranges for particular species, or shear stress for sediment mobilisation).	If highly uncertain, the project needs to collect or further analyse basic ecological data before proceeding (e.g. through more rigorous literature review or analysis of VEFMAP or other monitoring data).
Hydrological time-series (flow data)	Qualitative statement of uncertainty regarding the daily predicted flows for each scenario. Kennard et al. (2010) suggest flow records >15 years have acceptable uncertainty. Erlanger and Neal (2005) recommend 30 years, which is the minimum period of record recommended for FLOWS studies.	If predicted daily flows are unavailable, then REALM modelling (or similar) should be undertaken before proceeding. Modelling uncertainty should be described and justified as fit for purpose. If model is uncertain or only monthly, then model should be upgraded. If record length is <15 years then model should be upgraded.
Hydraulic modelling	Qualitative statement of uncertainty in model. Undertake sensitivity analysis on magnitude of flows required to inundate certain parts of the channel. Undertake sensitivity analysis of effects of roughness estimates on water levels.	Modelling uncertainty should be described and justified as fit for purpose.

4.4.1 Performance assessment

Performance against flow recommendations can be calculated in a number of ways and there may be no single method that suits all systems. The type of flow data also influences the ability to determine performance and any shortfalls. For example, it is difficult to calculate a measure of performance with fresh events for flow scenarios with a monthly time step. For these scenarios performance can only be assessed based on the volume needed to deliver the total duration of freshes above the recommended magnitude but not whether the recommended number of freshes or interval between freshes is likely to be met. The most appropriate method depends on the intent of the recommendations for a specific system and the type of scenario data being assessed. In addition to calculating performance, the process enables shortfall volumes to be calculated. The shortfall volume is the additional volume of water needed to fully meet the flow recommendations. A process for calculating performance and shortfall volumes on daily and monthly timesteps is provided in Appendix F.

In order for performance to be assessed, EFTPs need to clearly describe the intent of their flow recommendations (see Section 4.3). Panels should also provide advice on how performance should be assessed. It needs to be clear which component of the flow regime a particular value or objective is most sensitive to (e.g. magnitude, frequency, duration, timing, interval between events) and whether there are critical combinations of components that must be achieved in order for the objective to be met (e.g. if spawning flows are provided in autumn for Australian grayling then upstream migration flows for juveniles are needed in the following spring). Once the specific component(s) of the regime that are most critical to achieving the objective is identified then the method for performance calculation becomes more obvious, as does the intent of the flow recommendations.

The performance assessment process is also to be used for comparing the relative impacts and benefits of alternative flow regime scenarios that may be developed from time-to-time. For example, different climate change scenarios or resource development scenarios.

4.4.2 Risk framework

The risk framework aims to assign a level of risk to ecological objectives based on how well flow recommendations have been met. Flow recommendations set the flow regime required to deliver a low level of risk to ecological values (or to provide a high degree of confidence that values will be maintained or improved if the flow recommendations are delivered). Barring some other unidentified critical non-flow related requirement, anything less than full compliance with the flow recommendations results in an increased risk to objectives.

In regulated systems with environmental entitlements, the entitlement available is usually less than the volume of water needed to deliver the full suite of flow recommendations. In these cases, it is useful for EFTP panels to provide advice on how best to deliver available environmental water in order to maximise environmental outcomes (i.e. least risk to objectives). Indeed, it is probable that objectives for some values may still be achievable even if the full recommendations are not delivered (i.e. performance is less than 100 per cent). For example, a low flow of 50 ML/day may be recommended to maintain fish habitat; if 48 ML/day is delivered every day instead of 50 ML/day then, under strict interpretation, the compliance would be zero per cent. Yet from an ecological perspective the difference between 50 and 48 ML/day may not constitute a substantial increase in risk. In other situations (e.g. a flow magnitude required to inundate wetlands or create a velocity sufficient to mobilise sediment), anything less than the recommended threshold might constitute a significant increase in risk to those objectives. This situation can be addressed by EFTPs specifying an acceptable range of flow magnitude, duration or frequency. For example, a flow magnitude could be specified as 100 ± 5 ML/day or the duration of an event as four to six days.

The relationship between performance and risk (risk profile) needs to be defined and documented by the EFTP for each objective, along with appropriate justification. The risk profile should be derived from the conceptual models and ecosystem response curves (curves that describe the relationship between ecological response and flow) generated in earlier stages of the study. The EFTP needs to provide advice on which recommendations have a degree of acceptable variability (i.e. by how much and under what circumstances – time of year, wet versus dry years) and which do not. Better understanding of the ecological response to flow, and specific flow components, will make a major contribution to understanding acceptable variability and hence contribute to an understanding of risk.

There are a number of tools that could be used for the risk assessment, including Bayesian networks, eWater CRC Ecomodeller and various assessment tools used by the Environment Protection Authority, the Department of Environment and Primary Industries, catchment management authorities and consultants. The most important requirement is that whatever tool is used, the approach must be clearly documented in terms of:

- level of performance and shortfall volumes for each flow component;
- the relationship between performance and risk; and

- which components are contributing to risk to objectives and how much additional water is needed to achieve compliance and hence achieve a low risk.

Ideally, the risk assessment process should incorporate antecedent conditions (i.e. risk increases the longer a recommendation is not complied with) and clearly outline the consequences to ecosystem values of recommendations not being met.

4.5 Supporting recommendations

In many cases, the causes of degradation in aquatic ecosystems are not always related to flow: some are often related to grazing or other forms of land use. Accordingly, a chapter should be included in the draft Final Report that provides advice on complementary actions that would help to increase the effectiveness of flow recommendations and enhance river health in general. These recommendations cover a range of issues, such as:

- on-ground works (e.g. removal of barriers to fish passage, fencing, protection of refuge habitats, restrictions on groundwater extractions);
- further work to fill knowledge gaps such as biological surveys; and
- regional monitoring programs to assess impacts from regional management actions, not just flow changes.

Some of the issues to be considered in developing supporting recommendations are discussed below.

4.5.1 Operational issues

These may include issues related to the delivery of water through the system and the efficient assessment of water resources, such as the location of appropriate flow gauges or recommended changes to water supply infrastructure. In some cases flow gauges may not be located in reaches of the river that were subject to the FLOWS investigation, limiting the ability to monitor the delivery of the environmental flows. Recommendations may need to address this by suggesting reinstatement of discontinued gauges or building of new gauges.

In some systems the lack of flexibility or release capacity in the water supply infrastructure may limit the potential to deliver the environmental flow recommendations appropriately. For example:

- dams may not have the outlet capacity to deliver flows large enough to satisfy an 'overbank flow' requirement;
- some structures may have no flexibility to alter release volumes (e.g. fixed crest weirs or v-notch weirs);
- there may be constraints related to the capacity share of channel volume; and
- there may be risks to third parties or other infrastructure if large volumes of water are released, e.g. lower Melbourne floodplain.

It may be necessary to recommend changes to infrastructure to increase flexibility in the system.

4.5.2 Other environmental effects

There are a number of confounding environmental effects that may potentially limit the benefits of providing environmental flows. These can include, but are not limited to:

- barriers to fish movement;
- catchment activities that may adversely affect in-stream habitat or water quality (e.g. catchment clearing, land-use change, treated sewage discharge);
- cold water pollution below large dams that can directly affect biota and ecological processes such as rates of primary production or fish breeding;
- the presence of noxious species;
- the presence and management of threatened species;
- the need for instream habitat rehabilitation;
- the need for riparian vegetation management and restoration; and
- the need for weed management.

The supporting recommendations should identify and prioritise when further investigations are required, or where on-ground works are needed to maximise the benefits expected from the delivery of environmental flows. For example, environmental values in river reaches downstream of large dams may be adversely affected if environmental water is in the form of cold water sourced from the bottom of the storage. In this circumstance, an investigation will be required to examine the implications or risks associated with cold-water releases. Another example is when habitat condition along a waterway is degraded and extensive instream or riparian habitat rehabilitation may be required before the benefits of environmental flows may be expected. There may be little benefit to restoring a flow regime if the effects of poor catchment condition outweigh potential flow benefits.

4.5.3 Monitoring

Monitoring of the implementation and benefits of environmental flows is critical to demonstrating that the desired responses have occurred. Monitoring is also critical as part of an adaptive management approach whereby recommendations can be continually revised on the basis of monitoring outcomes. The Victorian Environmental Flows Monitoring and Analysis Program (VEFMAP) is addressing this issue to some extent, although site specific and other targeted programs are also required.

In the past, monitoring has not been recommended or has been implemented in a piecemeal or ad hoc fashion. This means it is not possible to determine if the flow recommendations implemented have been effective at delivering environmental objectives. Lack of effective monitoring also limits the ability to modify objectives and recommendations through adaptive management, learn

from the implementation of environmental flows and add to our knowledge on the flow-based relationships. For example, Streamflow Management Plans are required to be reviewed, and revised as necessary, on a five-year timeframe and without monitoring, decisions about future improvements may be baseless.

It is beyond the scope of a FLOWS study to design a monitoring program. However FLOWS studies should provide advice on broad monitoring needs and note which objectives and flow components should be considered priorities for monitoring. These priorities could be chosen because there is well established relationship between flow and response that can be tested with an appropriate monitoring program, or where the ecological response is uncertain and monitoring could help to improve the understanding of the flow-response relationship in order to improve the basis for the flow recommendations.

Key output 4 – Draft Final Report with preliminary environmental flow and supporting recommendations

It should be noted that FLOWS sets out the method for developing environmental flow recommendations, but the changes to environmental flows that may be implemented following a FLOWS study result from management decisions. The outcomes of that decision process will influence the scope of monitoring on a case by case basis. In addition, development of a monitoring program will need to consider the scale of change to environmental flows, as well as the influence of other catchment factors.

4.6 Final reporting

The Final Report stage involves a steering committee and Project Advisory Group meeting to achieve support and ownership of the recommendations. The meeting will provide any additional direction on the documentation of the recommendations, compliance and risk assessment, complementary or supporting actions, and monitoring requirements prior to finalising the report.

The draft recommendations and their rationale should be presented to the Project Advisory Group by the consultant project manager. The aim of the meeting is to achieve sign-off on the recommendations and objectives. The Project Advisory Group input is fundamental to the FLOWS process. The Final Report should document the outcomes of the Project Advisory Group consultation, including comments made and how they have been addressed in the process. If consensus on recommendations cannot be achieved through this process the client project manager and steering committee will make the final decision and inform the consultant project manager and the Project Advisory Group.

4.6.1 Final Report document

The Final Report is the culmination of the project and should be readable as a stand-alone document with reference to the Site and Issue Papers for further details. The report will draw elements from each project stage to provide a rigorous rationale for the final environmental water requirement recommendations.

Key output 5 – Final Report

The Final Report must include:

- a summary of the key issues in the catchment (based on the Issues Paper)
- environmental objectives
- environmental flow objectives
- flow recommendations (including the hydraulic modelling report as an appendix)
- performance against the flow recommendations
- supporting recommendations
- completed checklists demonstrating all required elements of the FLOWS method have been completed.

The Final Report should include a detailed explanation of the development of the recommendations to explain the context and process undertaken, justification and rationale. Recommendations should be ranked in terms of relative priority and importance so that they can be implemented incrementally as part of the risk management process. Appropriate referencing must be provided, including the source of information and decisions (e.g. expert opinion, scientific literature). The Final Report should also detail the names and areas of expertise of panel members.

References



ANZECC & ARMCANZ (2000), *Australian guidelines for water quality monitoring and reporting. Summary*. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Chee, Y.E., Webb, A., Cottingham, P. & Stewardson, M. (2006). *Victorian environmental flows monitoring and assessment program. Monitoring and evaluation of environmental flow release in the Campaspe River*. eWater CRC, Canberra

Chiew, F.H.S. & Siriwardena, L., (2005), *Estimation of SIMHYD Parameter Values for Application in Ungauged Catchments*. In: MODSIM 2005 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Melbourne, December 2005, pp. 2883–2889, CDROM (ISBN 0-9758400-2-9).

Cottingham, P., Stewardson, M., Roberts, J., Metzeling, L., Humphries, P., Hillman, T. and Hannan, G., (2001), *Report of the Broken River Scientific Panel on the environmental condition and flow in the Broken River and Broken Creek*. Report to the Department of Natural Resources and Environment. Cooperative Research Centre for Freshwater Ecology, University of Canberra, ACT.

Dresel, P.E., Clark, R., Cheng, X., Reid, M., Fawcett, J. and Cochraine, D. (2010) *Mapping Terrestrial Groundwater Dependent Ecosystems: Method Development and Example Output*, Victoria Department of Primary Industries, Melbourne VIC.

Eamus, D., Froend, R., Loomes, R., Hose, G. and Murray, B. (2006), A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation. *Australian Journal of Botany* **54**(2): 97–114

Erlanger, P. and Neal, B. (2005). *Framework for Urban Water Resource Planning*. Water Services Association of Australia Occasional Paper No. 14, June 2005.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L. (1992), *Stream hydrology: an introduction for ecologists*. (John Wiley and Sons Ltd, Chichester).

Hall, K.C., Baldwin, D.S., Rees, G.N., and Richardson, A.J. (2006), Distribution of inland wetlands with sulfidic sediments in the Murray-Darling Basin, Australia. *Science of the Total Environment* **370**: 235–244.

Jolly, I., Rassam, D., Pickett, T., Gilfedder, M. and Stenson, M. (2010),. Modelling groundwater-surface water interactions in the new generation of river systems models for Australia. *Proceedings of Groundwater 2010*. 31st October – 4th November 2010, Canberra, Australia. Available from <http://www.ewater.com.au/uploads/files/Jollylan_000.pdf> [accessed 14 October 2011]

Kennard, M.J., Pusey, B.J., Mackay, S.J., Olden, J.D. and Marsh, N. (2010), Quantifying uncertainty in estimation of hydrologic metrics for ecohydrological studies. *River Research and Applications* **26**: 137–156

Lamontagne, S., Hicks, W.S., Fitzpatrick, R.W. and Rogers, S. (2006), Sulfidic materials in dryland river sediments. *Marine and Freshwater Research* **57**: 775–788.

Lang, S., Ladson, A.R. and Anderson, B. (2004), A review of empirical equations for estimating stream roughness and the application to four streams in Victoria. *Australian Journal of Water Resources*. **8**: 69 – 82.

Lloyd, L.N., Anderson, B.G., Cooling, M., Gippel, C.J., Pope, A.J. and Sherwood, J.E. (2012). *Estuary Environmental Flows Assessment Methodology for Victoria*, Report prepared by Lloyd Environmental Pty Ltd Report for the Department of Sustainability and Environment, Melbourne Water and Corangamite CMA, Colac, Victoria, Australia.

Neal, B., Sheedy, T., Godoy, W. and Hansen, W. (2005), *Modelling of Complex Daily Environmental Flow Recommendations with a Monthly Resource Allocation Model*. 29th Hydrology and Water Resources Symposium, 21–23 February 2005, Canberra, Australia.

Neal, B.P., Lang, S. And Treadwell, S. (2011), *Interpreting the Ability to Meet Daily Environmental Flow Recommendations from Monthly Water Resource Models*. 33rd Hydrology and Water Resources Symposium, Brisbane, June 2011.

NRE (2002a), *FLOWS – a method determining environmental water requirements in Victoria*. Report by Sinclair Knight Merz, Cooperative Research Centre for Freshwater Ecology, Freshwater Ecology (NRE) and Lloyd Environmental Consultants for the Department of Natural Resources and Environment.

NRE (2002b). *Victorian River Health Strategy*. Victorian Department of Natural Resources and Environment.

TOP: Yarriambiack Creek. Photo by Sinclair Knight Merz.

Roberts, J. and Marston, F. (2000), *Water regime of wetland and floodplain plants in the Murray-Darling Basin*. CSIRO Land & Water Technical Report 30-00, Canberra.

Roberts, J. and Marston, F. (2011), *Water regime for wetland and floodplain plants: a source book for the Murray-Darling Basin*. National Water Commission, Canberra.

Rogers, K. and Ralph, T.J. Eds. (2011), *Floodplain wetland biota in the Murray-Darling Basin*. CSIRO Publishing, Collingwood.

Saintilan, N. and Overton, I. Eds. (2010), *Ecosystem response modelling in the Murray-Darling Basin*. CSIRO Publishing, Collingwood.

SKM (2005), *Determination of the minimum environmental water requirements for the Yarra River: Minimum environmental water requirements and complementary works recommendations*. Report prepared by Sinclair Knight Merz for Melbourne Water.

SKM (2006), *Broken and Boosey Creeks environmental flow determination – current and natural flows*. Report prepared by Sinclair Knight Merz for the Goulburn Broken Catchment Management Authority.

SKM (2010), *Identification of Groundwater Dependent Ecosystems within Melbourne Water Catchments*. Report prepared by Sinclair Knight Merz for Melbourne Water.

SKM (2012), *Background to Victorian FLOWS method Edition 2*. Report prepared by Sinclair Knight Merz for the Department of Sustainability and Environment

Stewardson, M. and Howes, E. (2002), *The number of channel cross-sections required for representing longitudinal hydraulic variability of stream reaches*. *Proceedings of the 27th Hydrology and Water Resources Symposium*, 20th – 23rd May 2002, Melbourne, Australia.

Summerfield, M.A. (1993), *Global Geomorphology*. Longman Scientific and Technical, Essex.

Turner, M., Wealands, A., van Rensburg, J., Roach, S. and Arnott, C. (2008), *Value adding to the FLOWS methodology used to determine environmental flow requirements in Victorian rivers – Final Report*. Report P108021_R01 prepared by Alluvium and GHD for Melbourne Water.

Victorian Environmental Water Holder (2011), *Seasonal Watering Plan 2011–12*. Victorian Environmental Water Holder.

Victorian Government (2011), *Western Region Sustainable Water Strategy*. Department of Sustainability and Environment.

Appendix A Flow components⁸



A.1 Background to the flow component philosophy

The philosophy of flow components is fundamental to the FLOWS method developed in this project for the determination of environmental water requirements. In this case the FLOWS method described is based on the natural flow paradigm (Poff et al., 1997; Richter et al., 1996) and then uses identified flow components as the conceptual tool in the development of the recommendations. Richter et al. (1996) emphasise the importance of the components of the natural flow regime, including the range and variability of flows. Flow components are the conceptual link between hydrology and the ecological processes, and a description of different parts of a flow regime relevant to the ecosystem.

The magnitude, duration, frequency and timing of flows are key aspects of a natural flow regime required to maintain channel form and viable populations of freshwater biota (Baldwin and Mitchell, 2000; Nielsen et al., 2000; Poff et al., 1997; Puckridge et al., 1998; Richter et al., 1997; Sheldon and Walker, 1997). The recommended flow regime, produced using this FLOWS method, incorporates the key components of the natural flow regime that are necessary for the biological, geomorphological and physicochemical processes. The flow components are used to describe the magnitude of the differentiated parts of a natural flow regime. All of the flow components are considered in regard to the temporal variability and the frequency, timing and duration may vary between and for each flow component.

Habitat is defined throughout this section as the place or environment in which organisms live. It is used throughout this section indicative to a range of organisms, without specific reference. Flow components may provide water in structural areas, for example riffles or benches, which make them appropriate 'habitat' for a range of organisms. So a consideration for each flow component is to understand the implications, benefits or otherwise, for habitat for a range of biota.

Discharge in many Australian river systems is naturally highly variable and this variation is apparent on a variety of temporal

scales including, inter-annual and seasonal variation, and also variation between months, weeks and days. Maintaining natural variability in stream discharge is important for both ecological and geomorphological processes. Under natural conditions variations in water surface level and associated wetting and drying regimes of stream banks are important for the creation of channel forms (for example, pools, riffles, bars, benches) and habitat attributes (such as large woody debris transport and placement). However, constant flows and water surface levels tend to accelerate the rate of scour at the bank toe which, in turn, may lead to bank slumping. Furthermore, constant discharge may be detrimental to life history strategies and subsequent recruitment of native fish, macrophyte and macroinvertebrate species. As a result all flow components should be examined and specified to incorporate the overriding philosophy of variability, where possible. Appropriate use of the suite of flow components in recommendations will incorporate the variability.

A.2 Definition of the flow components

The following list describes the flow components applicable to a range of systems and these are illustrated as examples in Figure 5.1. The flow components aim to provide a simplified summary of the inherently complex flow regime that allows recommendations to be developed to represent this complexity in some form. All flow components should be explicitly described with regard to timing, frequency and duration.

In developing recommendations for different systems a series of key assumptions can be made based on previous studies. These assumptions need to be understood for appropriate development of recommendations, as they helped shape the underlying concepts of the FLOWS method.

The flow components discussed below can be described in terms of their timing, frequency, duration and seasonality and also in terms of their key functions.

Each flow component is defined hydrologically and has associated with it specific ecological functions.

⁸ This review is taken from the original FLOWS manual. There have been significant advancements in the science of environmental flows and ecological response over the past ten years. However, it is beyond the scope of the current project to update this review.

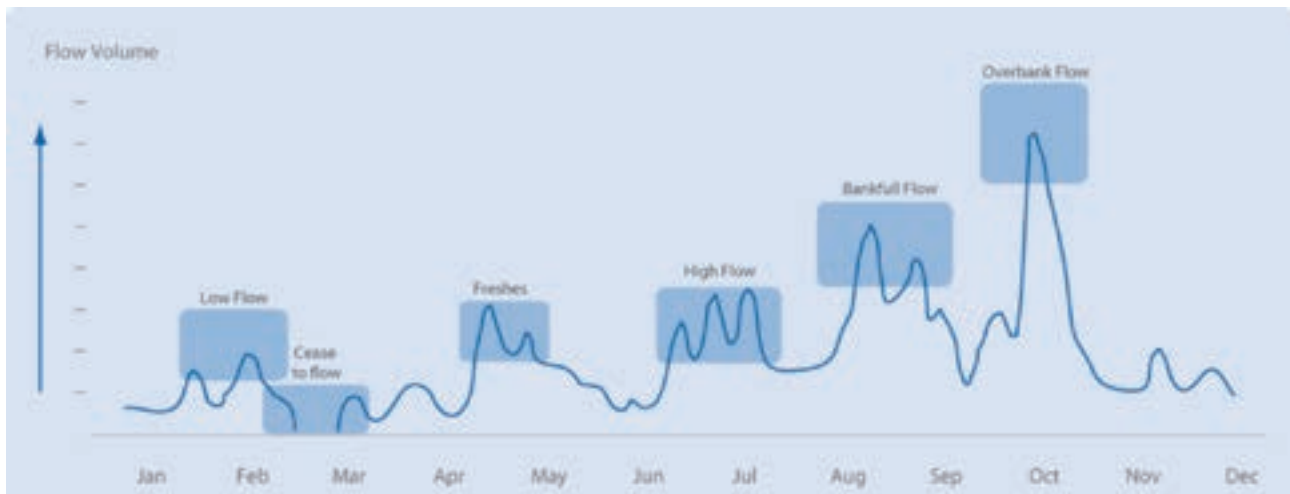


Figure 5.1 Examples of freshwater flow components (from NRSWS Discussion Paper, Victorian Government 2008)

Cease to flow

The cease to flow is the period of no discernible flow in a river, or in practice when there is no measurable flow at a stream gauge, representative of the relevant reach. This may lead to either total or partial drying of the river channel, depending on the specifics of the system.

Cessation of flow is a common natural occurrence in Australian rivers and there are a range of ecological functions provided by this flow component (Boulton et al., 2000; Burns and Walker, 2000; Poff and Ward, 1989). During these periods the river may contract to a series of isolated pools. The biota in these pools are likely to be subject to intensified predation and physicochemical stresses (for example low dissolved oxygen concentrations). Periods of cease to flow often result in short-term localised extinction of certain species (Puckridge et al., 2000) with long-term changes in diversity and biomass (Humphries and Lake, 2000; Puckridge et al., 2000). Stream communities are relatively mobile (Allan, 1975; Boulton and Lloyd, 1991; Townsend and Hildrew, 1976) and will most likely have the ability to recolonise these habitats following the restoration of flow, as long as there are effective refuges (Cooper et al., 1990; Jowett and Duncan, 1990). Drying of habitats and organic matter facilitates the decomposition and processing of organic matter and following rewetting this then provides a fresh pool of nutrient and carbon inputs for the system (Baldwin and Mitchell, 2000; Nielsen and Chick, 1997).

Overall there is a significant ecological benefit from this component. The risks are in the removal or extension of the duration of the flow or addition of the component in a system in which it did not naturally occur. The cease-to-flow period is a period of stress for the ecosystem and extension of the duration of this period can have deleterious effects on the ecosystem.

Low flow

The low flows may be described as the low flow that generally provides a continuous flow through the channel within the representative reach. The flow may be limited to a narrow area of the channel in the high points of the stream, but will provide flow connectivity between habitats within the

channel. In some systems a low flow may inundate a range of habitats and be more than a sustaining level of flow. There are two key benefits of a low flow; either in the maintenance of a flow above a cease to flow, or in the provision of habitat as a change from high flows.

During summer periods the low flow may be a critical flow, sustaining the habitats in stress through an overall lack of flow. Low flows are critical to sustain flow stressed streams and link habitats in rivers in times of limited flow. Restoration of low flows have been used to ameliorate poor water quality and sustain suitable aquatic habitat (Mitchell et al., 1996). Low flows also provide important water for soils and banks for the maintenance of aquatic and riparian vegetation (Arthington et al., 2000).

Low flows may act as a refuge from high flows, biota need periods of slow flowing water for a range of functions. Low flows have been suggested as important for recruitment of some native fish in lowland rivers (Humphries et al., 1999), and high flows also often drown out riffle or other shallow habitats and low flows are critical in the maintenance of these habitats and resulting diversity for biota (Arthington et al., 2000).

Freshes

A fresh is the term that is used to denote small and short duration peak flow events. These are flows that exceed the baseflow and last for at least several days, often as a result of intensive, and sometimes localised, rainfall. They are distinct from persistent long term changes in the seasonal baseflow or large high flow and flood events.

Freshes are generally characteristic of either summer or spring. Summer freshes are usually a result of short peak summer rain events and often are brief flows in periods of very low or no flow over summer. Summer freshes are particularly important in rivers for the maintenance or improvement of water quality, as the short periods of high flow mixes pools and allows an input of fresh water.

Freshes are a key component of the variability of flow regimes providing short pulses in flow and the short temporal scale variability that is identified as a key

component of natural flow regimes for a range of ecosystem factors (Hughes and James, 1989; Jowett and Duncan, 1990; Poff and Allan, 1995; Poff and Ward, 1989; Puckridge et al., 1998).

The expert panel of the Sustainable Diversions Limits Project for the Department of Natural Resources and Environment stated that flow above the median for a period of five days or more was a surrogate for events of ecological importance over winter (NRE 2002). The freshes have been described in a way that has consistency with the indices used in the Sustainable Diversions Limits Project. The duration of a fresh will be dependent on the ecological process that is linked to that fresh; there is no consistent duration that can be applied for all seasons.

High flows (in channel)

This flow component encompasses a broad range of flows. The key characters that distinguish this flow component from freshes or other large flows are the persistent increases in the seasonal baseflow that remain within the channel. These flows are those which cover the bed of the stream and some of the lowest in-channel benches may be flooded, creating further habitat. High flows do not fill the channel to bankfull and are unlikely to provide substantial channel forming forces. High flows effectively wet and connect most habitats within the main channel. Specific discharges have been linked as a requirement for breeding by some fish species (Koehn and O'Connor, 1990; O'Connor and Koehn, 1998) and can act as triggers for breeding for other species (Harris and Gehrke, 1997; Humphries, 1995; Koehn and O'Connor, 1990). High flows are important to provide connectivity for fish migration through a system.

Bankfull flows

These flows are of sufficient magnitude to reach bankfull condition with little flow spilling onto the floodplain. All benches are inundated creating further habitat for macroinvertebrates, plants and fish. Bankfull flows are an important trigger flow for fish breeding and while it may only last for several hours and up to a maximum of a day or so, high flows may last for considerable periods afterwards which enables enable fish recruitment.

Bankfull flows are also important geomorphologically in shaping and maintaining river and tributary channels and also in preserving the condition and availability of instream habitats (Leopold and Maddock, 1953). For example, bank-full flows will assist in the resuspension and distribution of sediments (Chorley, 1962) that would otherwise smother important benthic habitats (large woody debris and leaf-packs).

Overbank flows

These flows are greater than bankfull and result in inundation of the adjacent floodplain habitats. Inundation of the floodplain is ecologically important and provides significant carbon returns to the river after a period of significant production (Baldwin and Mitchell, 2000; Gehrke, 1991; Robertson et al., 2001). Overbank flows are critical for a range of ecological factors including floodplain productivity (Boulton and Lloyd, 1992), invertebrate colonisation (Nielsen et al., 1999; Quinn et al., 2000), fish community diversity (Geddes

and Puckridge, 1989) vegetation community maintenance (Nielsen and Chick, 1997), waterbirds (Kingsford et al., 1999) and linkages with the stream channel.

A.3 References

- Allan, J.D., 1975, The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. *Ecology*, 55: 1040–53.
- Arthington, A.H., S.O. Brizga, S.C. Choy, M.J. Kennard, S.J. Mackay, R.O. McCosker and J.L. Ruffini, 2000, *Environmental flow requirements of the Brisbane River downstream from Wivenhoe Dam*. South East Queensland Water Corporation Ltd and Centre for Catchment and Instream Research, Brisbane.
- Baldwin, D.S. and A.M. Mitchell, 2000, The effects of drying and re-flooding on the sediment or soil nutrient dynamics of lowland river floodplain systems: a synthesis. *Regulated Rivers: Research & Management*, 16(5): 457–67.
- Boulton, A.J. and L.N. Lloyd, 1991, Macroinvertebrate assemblages in floodplain habitats of the lower River Murray, South Australia. *Regulated Rivers: Research and Management*, 6: 183–201.
- Boulton, A.J. and L.N. Lloyd, 1992, Flooding frequency and invertebrate emergence from dry floodplain sediments of the River Murray, Australia. *Regulated Rivers: Research & Management*, 7: 137–51.
- Boulton, A.J., F. Sheldon, M.C. Thoms and E.H. Stanley, 2000, Problems and constraints in managing rivers with variable flow regimes. In P.J. Boon, B.R. Davies and G.E. Petts (eds.), *Global perspectives on river conservation, policy and practice*. Wiley, Chichester.
- Burns, A. and K.F. Walker, 2000, Effects of water level regulation on algal biofilms in the River Murray, South Australia. *Regulated Rivers: Research & Management*, 16(5): 445–56.
- Chorley, R.J., 1962, *Geomorphology and general systems theory*. United States Geological Survey Professional Paper, 500-B.
- Cooper, S.D., S.J. Walde and B.L. Peckarsky, 1990, Prey exchange rates and the impact of predators on prey populations in streams. *Ecology*, 71(4): 1503–14.
- Geddes, M.C. and J.T. Puckridge, 1989, Survival and growth of larval and juvenile native fish: the importance of the floodplain. In *Proceeding of the Native Fish Management Workshop*, Canberra. Murray-Darling Basin Commission.
- Gehrke, P.C., 1991, Avoidance of Inundated Floodplain Habitat by Larvae of Golden Perch (*Macquaria ambigua* Richardson): Influence of Water Quality of Food Distribution? *Australian Journal of Marine and Freshwater Research*, 42: 707–19.
- Harris, J.H. and P.C. Gehrke, 1997, *Fish and Rivers. The NSW Rivers Survey*. NSW Fisheries Research Institute Cooperative Research Centre for Freshwater Ecology, Sydney.

- Hughes, J.M.R. and B. James, 1989, A hydrological regionalization of streams in Victoria, Australia, with implications for stream ecology. *Australian Journal of Marine and Freshwater Research*, 40: 303–26.
- Humphries, P., 1995, Life history, food and habitat of Southern Pygmy Perch, *Nannoperca australis*, in the Macquarie River, Tasmania. *Marine and Freshwater Research*, 46: 1159–69.
- Humphries, P., A.J. King and J.D. Koehn, 1999, Fishes, flows and floodplains: links between Murray-Darling freshwater fish and their environment. *Environmental Biology of Fishes*, 56: 129–51.
- Humphries, P. and P.S. Lake, 2000, Fish larvae and the management of regulated rivers. *Regulated Rivers: Research & Management*, 16(5): 421–32.
- Jowett, I.G. and M.J. Duncan, 1990, Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. *New Zealand Journal of Marine and Freshwater Research*, 24: 305–17.
- Kingsford, R.T., A.L. Curtin and J. Porter, 1999, Water flows on Cooper Creek in arid Australia determine ‘boom’ and ‘bust’ periods for waterbirds. *Biological Conservation*, 88(2): 231–48.
- Koehn, J.D. and W.G. O’Connor, 1990, *Biological Information for the Management of Freshwater Fish in Victoria*. Arthur Rylah Institute for Environmental Research, Melbourne.
- Leopold, L.B. and T. Maddock, 1953, *The hydraulic geometry of stream channels and some physiographic implications*. United States Geological Survey Professional Paper.
- Mitchell, B., I. Rutherford, A. Constable, F. Stagnitti and C. Merrick, 1996. *An Ecological and Environmental Flow Study of the Glenelg River from Casterton to Rocklands Reservoir*. Aquatic Resource Utilisation and Management Research Group, Deakin University, Warrnambool.
- Nielsen, D.L. and A.J. Chick, 1997, Flood-mediated changes in aquatic macrophyte community structure. *Marine and Freshwater Research*, 48(2): 153–7.
- Nielsen, D.L., T.J. Hillman and F.J. Smith, 1999, Effects of hydrological variation and planktivorous competition on macroinvertebrate community structure in experimental billabongs. *Freshwater Biology*, 42(3): 427–44.
- Nielsen, D.L., F.J. Smith and T.J. Hillman, 2000, Impact of water regime and fish predation on zooplankton resting egg production and emergence. *Journal of Plankton Research*, 22(3): 433–46.
- NRE, 2002. *Sustainable Diversions Limit Project, Recommendations for sustainable diversions limits over winterfill periods in unregulated Victorian Catchments*. A report prepared by Sinclair Knight Merz and the Cooperative Research Centre for Freshwater Ecology.
- O’Connor, W.G. and J.D. Koehn, 1998, Spawning of the broad-finned Galaxias, *Galaxias brevipinnis* Gunther (Pisces: Galaxiidae) in coastal streams of south-eastern Australia. *Ecology of Freshwater Fish*, 7: 95–100.
- Poff, L.N. and J.D. Allan, 1995, Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology*, 76(2): 606–27.
- Poff, L.N., J.D. Allan, M.D. Bain, J.R. Karr, K.L. Prestegard and B.D. Richter, 1997, The natural flow regime, a paradigm for river conservation and restoration. *Bioscience*, 47(11): 769–84.
- Poff, L.N. and J.V. Ward, 1989, Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Science*, 46: 1805–18.
- Puckridge, J.T., F. Sheldon, K.F. Walker and A.J. Boulton, 1998, Flow variability and the ecology of large rivers. *Marine and Freshwater Research*, 49: 55–72.
- Puckridge, J.T., K.F. Walker and J.F. Costelloe, 2000, Hydrological persistence and the ecology of dryland rivers. *Regulated Rivers: Research & Management*, 16(5): 385–402.
- Quinn, G.P., T.J. Hillman and R. Cook, 2000, The response of macroinvertebrates to inundation in floodplain wetlands: a possible effect of river regulation. *Regulated Rivers: Research & Management*, 16: 469–77.
- Richter, B.D., J.V. Baumgartner, J. Powell and D.P. Braun, 1996, A method for assessing hydrologic alteration within ecosystems. *Conservation Biology*, 10(4): 1163–74.
- Richter, B.D., J.V. Baumgartner, R. Wigington and D.P. Braun, 1997, How much water does a river need? *Freshwater Biology*, 37: 231–49.
- Robertson, A.I., P. Bacon and G. Heagney, 2001, The responses of floodplain primary production to flood frequency and timing. *Journal of Applied Ecology*, 38(1): 126–36.
- Sheldon, F. and K.F. Walker, 1997, Changes in biofilms induced by flow regulation could explain extinctions of aquatic snails in the lower River Murray, Australia. *Hydrobiologia*, 347: 97–108.
- Townsend, C.R. and A.G. Hildrew, 1976, Field experiments on the drifting, colonization and continuous redistribution of stream benthos. *Journal of Animal Ecology*, 45: 759–72.
- Victorian Government, 2008, *Northern Region Sustainable Water Strategy Discussion Paper*, Department of Sustainability and Environment.

Appendix B Hydrological and hydraulic modelling

B

B.1 Hydrology

Before the EFTP workshop where flow recommendations are determined

- 1) Have the assumptions regarding 'current' and 'unimpacted' levels of development been defined?

For example:

Have land-use changes and farm dam impacts been modelled when deriving the time-series of 'unimpacted' flows?

What other water resource impacts have been considered?

Has groundwater-surface water interaction been considered and modelled?

- 2) Have you stated the period of recorded and modelled streamflow data used to develop the current and unimpacted time-series of daily flow? Do the time-series cover a minimum of 30 years, including the 2006–07 drought and 2010–11 floods?

For example:

Flows recorded at gauge 404204 were used in the derivation of current and unimpacted flows for Boosey Creek. The record for gauge 404204 extends from November 1966 to present.

If there are limited periods of recorded data, has anecdotal evidence been sought to inform estimates of the frequency and duration of important threshold flows (e.g. cease to flow and overbank flows)?

- 3) Have major historical events affecting the time-series of current and unimpacted flows been identified?

For example:

Was there a major bushfire in the catchment in 1983, after which streamflows increased because of reduced vegetation cover?

- 4) Has the quality of the recorded streamflow data and the accuracy of the modelled streamflow data been documented?

For example:

What percentage of the gauge record is missing?

What percentage of the record is based on extrapolation of the gauge's rating curve beyond the minimum and maximum flow gauging measurement?

Or another example:

Time-series of current and pre-development flows for Nine Mile Creek were taken from the 40-year, daily time-step water resource model of the catchment. The calibration of the water resource model to recorded streamflows between 1998 and 2010 is considered moderate for high flows and excellent for all other flows. That is, below 500 ML/day the water resource model is within $\pm 10\%$ of the recorded flow, while above 500 ML/day it is within $\pm 30\%$.

- 5) Has the consistency of current and unimpacted flows been examined?

For example:

Downstream of a major dam used to release water for irrigation, are current flows higher than unimpacted flows in summer and autumn, and lower in winter and spring?

- 6) Has the consistency of flows at upstream and downstream sites been examined?

For example:

Does flow increase or decrease as expected downstream of major tributaries and demand extraction points?

- 7) Have illustrative examples been provided of any inconsistencies identified in step five or step six?

- 8) Have flow duration curves and selected time-series plots been presented for current and unimpacted levels of development at each site?

- 9) Has the relative level of confidence or uncertainty in the derived flows been qualitatively or quantitatively specified for each level of development, each site and each flow component? Have the main sources of uncertainty been identified and qualitatively ranked in terms of their importance?

For example:

Daily time-series of current and unimpacted flows for the Example River downstream of the Big Reservoir were based on monthly outputs from a water resources model, disaggregated to a daily time-step using the patterns recorded at nearby gauges. Therefore, there is low to moderate confidence in the day to day magnitude of modelled flows.

Further information on quantifying the uncertainty associated with time-series of daily flows is provided in Kennard et al. (2010).

- 10) What events should trigger a review of the current and unimpacted flow series?

For example:

If there are bushfires, extended droughts or large scale land-use changes in the catchment, or if a new streamflow gauge is installed, the current and unimpacted flow series may need to be re-derived.

- 11) Has a plain English summary on the derivation of current and unimpacted flows been provided to the EFTP that is developing the environmental flow recommendations? Does the plain English summary include the major assumptions and issues involved? Does it include recommendations for model improvement in future studies?
- 12) Has the daily time-series of current and unimpacted flows been audited by the Technical Audit Panel or another independent reviewer if directed by the client?

During the EFTP workshop where flow recommendations are determined

- 1) Has everyone understood the plain English summary on the derivation of current and unimpacted flow series? Are there any issues that need to be explained further?

- 2) Are the assumptions involved in any spells analysis of flows above or below selected thresholds explicit to everyone?

For example:

What is the period of independence for events?

Does the count of spell duration reset each time flows drop below the threshold, or only once the period of independence is exceeded?

Is the calculation of spell frequency independent or dependent on duration? For example, is frequency calculated using all spells above the threshold, or only those spells that lasted at least 3 days?

Does the calculation of spell frequency and duration consider all events above the threshold (e.g. > 200 ML/day) or only events between thresholds (e.g. 200–500 ML/day)?

- 3) Have results from the spells analyses been presented in a way that everyone understands?

For example:

- *Distributions of spell frequency and duration above given magnitudes under current and unimpacted conditions over the whole record.*
- *Bar charts of spell frequency per year above or below given flow magnitudes under current and unimpacted conditions (with consideration given to whether the frequency count includes all spells, or only spells which meet the recommended duration).*
- *Gantt charts of spells above or below a given magnitude under current and unimpacted conditions.*

- 4) For regulated systems, has a recommended rate of rise and fall been calculated for each relevant flow recommendation, as a percentage of the previous day's flow?

- 5) Has the percentage of time or years that the flow recommendations would have been provided been calculated for current and unimpacted levels of development? Does this calculation reflect the intent of the Panel's recommendations? Do the estimates make sense?

Further information on estimating the proportion of time that environmental flow recommendations are met is provided in Appendix F.

After the EFTP workshop, when the delivery of environmental water is being modelled under possible future climate and demand scenarios

- 1) Is the intent of the flow recommendations clear?

For example:

Are the flow recommendations required every year, or are the recommended frequencies and durations 'averages' around which there can be some variation?

Do the recommendations change depending on whether it is a 'wet', 'average' or 'dry' year?

Are there 'or natural' clauses on the flow recommendations? If so, is it clear what the EFTP means by 'or natural' in relation to the unimpacted regime?

Are the environmental flow recommendations independent of each other, or can a single flow event be 'counted' as meeting a fresh and high recommendation (for example)?

Is there an order or priority in which environmental flow recommendations are provided?

- 2) Is the purpose of the scenario modelling clear?

For example (for a given climate scenario):

Is it to estimate the change in supply to other consumptive users if all environmental flow recommendations are met?

Is it to estimate the volumetric shortfall or performance in meeting environmental flow recommendations given current consumptive use and system operation?

- 3) Has it been agreed which scenarios will be modelled?

For example:

Full development of current consumptive use entitlements.

A continuation of climate and inflows observed post 1997.

- 4) Has it been agreed how rainfall, evaporation and inflows under different climate scenarios will be modelled?

For example:

Factor historic time-series by a single number, based on predicted percentage changes.

Use flow duration curves for the period post 1997 to factor different parts of the historic time-series (i.e. high, medium, low flows) by different amounts.

- 5) Has it been agreed how scenario modelling results will be presented?

B.2 Hydraulics

When developing the hydraulic models

- 1) Has it been determined which type of hydraulic model will be developed for each site?

Typically HEC-RAS is appropriate for developing the site-specific hydraulic models. However, if it is important to model flow characteristics in two dimensions (e.g. the passage of water through floodplains), then software such as MIKE-Flood should be used instead.

- 2) Have all the sources of existing data been identified and collected?

For example:

- previously developed hydraulic models for the same reach or river
- data from previous cross-section surveys
- historic flood extents or heights
- GIS data sets, especially LiDAR data, but including aerial photography and topographic maps.

- 3) Has the number and location of cross-sections to be surveyed been confirmed by the hydraulic modeller?

For example:

The first FLOWS method manual recommended a minimum of six cross-sections per site; whereas Stewardson and Howes (2002) recommend 15 cross-sections as an adequate sample for representing hydraulic conditions along a reach. A minimum of six cross-sections are required but the hydraulic modeller should consider the need for more cross-sections in order to ensure a suitable hydraulic model can be developed.

What trade-off has been considered between surveying a large number of cross-sections at one site, versus fewer cross-sections at a number of sites within the same reach?

Have cross-sections surveyed downstream of the site been considered by the EFTP? This is very important for reducing the influence of assumptions about downstream boundary conditions on the water levels modelled at cross-sections of interest to the EFTP.

- 4) Has it been determined how a range of water levels and the corresponding flow will be measured or estimated for each site (to which the hydraulic model can be calibrated)?

For example:

Will a depth logger be used to record flow depths at the site over a range of flows?

Will a range of water levels be surveyed at each site?

For the recorded water levels, is there a nearby gauge that can be used to estimate the corresponding flow? If so, how readily available is the data? If not, how will flow at the site be estimated?

- 5) Has it been determined how the roughness coefficients for each hydraulic model will be estimated?

For example:

Has the hydraulic modeller visited the site to make notes and take photos of the channel substrate, in-stream vegetation and riparian vegetation?

Have the estimates of roughness coefficients been checked against published values or empirical equations?

- 6) Has the boundary condition for the hydraulic model been developed using the best available information?

The boundary conditions are one of the biggest sources of uncertainty in a hydraulic model, so they require careful attention. The best available information should be used to develop the boundary condition, including calibrated gauge rating curves at the site, nearby rating curves, additional cross-sections, or LiDAR. The method used to develop the boundary condition should be clear, and the data used well defined.

Before the EFTP workshop where flow recommendations are determined

- 1) Has a summary of the hydraulic model for each site been provided to the EFTP, highlighting cross-section numbering, downstream reach lengths, key ecological features represented, and whether each cross-section was surveyed or interpolated?

A brief summary of cross-sections can provide guidance regarding the nature of each section. The downstream reach length is particularly important, as this can easily become confused in the modelling process. Also, it is important to highlight what ecological features are represented in each section, and whether that feature was actually surveyed, or whether its properties have been interpolated from other data.

- 2) Where cross-sections have been interpolated, has justification for the interpolation been provided?

For example, cross-sections could be interpolated using an automated routine, or alternatively by manually building a new cross-section based on features shown in other sections and from site inspection notes. Some indication of the method of interpolation should be provided and some justification as to why the additional section was required.

- 3) Has a summary of critical parameters been provided, including roughness coefficients?

- 4) Has the basis of the hydraulic model boundary conditions been described?

- 5) Has a summary of the model calibration been provided, including an indication of how closely the surveyed water levels are predicted?

- 6) Were any changes required to the model during calibration? If so, what were those changes, and what is the justification for them?

For example, it may have been necessary to modify cross-sections to add ineffective areas or blocked obstructions. Also, it may have been necessary to increase or decrease roughness coefficients, or manually adjust cross-section details. Each of these changes should be outlined clearly.

- 7) Has a sensitivity analysis been undertaken to show the effect of model uncertainty on the high and low flow recommendations?

The sensitivity analysis should take into account model uncertainty resulting from the following sources. This is not an exhaustive list, and other sources of uncertainty should be included if appropriate:

- roughness
- estimated flows on the day of survey
- downstream boundary condition assumptions
- surveyed water levels and feature elevations (including errors in substrate elevation such as cobbles or soft mud, or errors in water level measurement).

- 8) Have the hydraulic modelling results been audited by the Technical Audit Panel or confirmed through some other agreed process?

B.3 Hydrological modelling tools

Tool	Description	Website reference
<i>If modelling current and unimpacted flows in REALM</i>		
REALM (Resource Allocation Model)	REALM is a <i>Windows</i> based computer program that can simulate the operation of both urban and rural river systems during droughts as well as during periods of normal and high streamflows. There are REALM models of all the major river systems in Victoria. REALM is often used to model the current and unimpacted flows in rivers, which in turn are used to inform FLOWS studies.	< www.water.vic.gov.au/monitoring/surface-water-modelling/realm >
PRIDE (Program for the Regional Irrigation Demand Estimation)	PRIDE estimates irrigation demand by using a combination of climate data, crop culture and knowledge of traditional farming practices. PRIDE is available as a 'node' in REALM.	< www.water.vic.gov.au/monitoring/surface-water-modelling/realm/download_realm_manuals >
STEDI (Spatial Tool for Estimating Dam Impacts)	STEDI is a <i>Windows</i> based computer program that can simulate the impact of farm dams on streamflow. STEDI outputs generally form an input to the REALM model of a river system.	< www.water.vic.gov.au/monitoring/surface-water-modelling/stedi >
RRL (Rainfall Runoff Library)	The RRL is designed to simulate catchment runoff by using daily rainfall and evapotranspiration data. The models may be applied to catchments from 10 km ² to 10,000 km ² on a daily time step. The models are typically used to fill gaps and extend streamflow records. The RRL includes the AWBM, Sacramento, SimHyd, SMAR and Tank rainfall-runoff models.	< www.toolkit.net.au/tools/RRL >

Tool	Description	Website reference
<i>If modelling current and unimpacted flows in eWater Source IMS</i>		
Source Catchments	Source Catchments (formerly WaterCAST and e2) is a spatially distributed water quality and quantity model developed by the eWater Cooperative Research Centre (CRC). It simulates the effect of climate and catchment properties (such as land use and farm dams) on water quantity (runoff) and quality (contaminant loads) through unregulated catchments and onto receiving water bodies. Source Catchments includes a simplified version of STEDl, and a library of rainfall-runoff models.	< www.ewater.com.au/products/ewater-source/for-catchments/ <
Source Rivers	Source Rivers is a river system modelling software package developed by the eWater Cooperative CRC. Source Rivers can be used to simulate the physical (storages, rivers, channels) and management or policy (allocations, demands) components of any river system. Source Rivers models will eventually replace REALM models in Victoria. The main advantage of Source Rivers over REALM for FLOWS studies is that it has more capability to model the lag and attenuation of flows on a daily time-step.	< www.ewater.com.au/products/ewater-source/for-rivers/ >
<i>If modelling the impact of land-use change on flows, when either developing REALM model inflows, or as a plug-in for Source IMS</i>		
FCFC (Forest Cover Flow Change)	FCFC is designed to adjust a time-series of observed or simulated daily flow to account for significant changes in forest cover. The model may be applied to catchments from 100 ha to 1,000 km ² . The model is typically used to adjust inputs to larger scale catchment models (e.g. REALM or Source models)	< www.toolkit.net.au/tools/FCFC/ >
<i>Relevant references to consider if routing daily streamflow</i>		
Tewolde, M.H. & Smithers, J.C. (2006). Flood routing in ungauged catchments using Muskingum methods. <i>Water SA</i> , 32 (3), pp. 379 – 388. Available from: < www.ajol.info/index.php/wsa/article/viewFile/5263/1371 > [accessed 11 October 2011]		
Boyd, M.J., Pilgram, D.H., Knee, R.M., & Budiawan, D. (1989), Reverse Routing to Obtain Upstream Hydrographs. <i>Proceedings of the Hydrology and Water Resources Symposium</i> . I.E. Aust, Christchurch, New Zealand, November 1989: 372–376		
Fenton, J.D. (1992), Reservoir routing, <i>Hydrol. Sci. J.</i> , 37, pp. 233–246.		
Zoppou, C. (1999), Reverse routing of flood hydrographs using level pool routing. <i>J. Hydrologic Engineering</i> , 4, pp. 184–188.		

Appendix C Site description



Flow characteristics

Flow characteristics should be described prior to a field inspection using the hydrological inputs. In the field a descriptive statement is suggested on the relationship between flow conditions and habitat factors at that site. This statement should be based on the observations made at the site relative to the data provided.

Substrate type

An on-site assessment of the occurrence of different categories of sediment and substrate type is important in understanding the habitat type, to make links with the flow regime and to identify potential issues (such as fine sediments clogging interstitial spaces in the streambed) or indications of groundwater – surface water interactions (such as seeps in channel banks and springs).

Channel form

A description of channel form and process provides information about the links between habitat elements (pools, riffles, benches, bars) and the response of the site to flows of various magnitudes. An assessment of both channel form and processes assists in discriminating habitat threatening adjustment processes. These may be occurring now or in the future. All assessments are related to the selected cross-sections as drawn.

Vegetation type characteristics

A brief description of the vegetation types, dominant species and environmental condition is made for the floodplain, riparian and instream aspects of the vegetation communities. Knowledge on the species of vegetation in a zone provides information on habitat available in the stream or its floodplain, as well as allowing water requirements to be determined for key species.

In the riparian zone, additional information on the height of the species present and the proportions of native and exotic species will provide important information on the role of the riparian zone along this reach. For example, a tall native riparian zone will result in very different instream conditions from a riparian zone dominated by very short species. Tall vegetation in the riparian zone would shade the stream and may mean that the stream is reliant on energy sources from upstream; conversely an open canopy would mean algal and macrophyte growth is likely to be important at the site.

Instream habitat

A standard habitat assessment technique used in many assessments is the presence or absence of key habitat types, including various structural and biotic elements, such as:

- overhanging vegetation
- aquatic vegetation
- overhanging bank
- boulder/bedrock habitat
- logs and log jams
- branch piles
- leaves and organic debris
- other
- no cover.

This can be rapidly assessed and provides information on habitat and environmental conditions. It can also be used as a guide to developing relationships between water depth and habitat availability. If a site has extensive instream habitat throughout the whole stream profile, then habitat complexity is likely to increase with water depth.

Instream disturbances

The presence of roads, bridges, instream works, structures and other instream disturbances are likely to degrade the current environmental condition as well as limit the degree of response to flow improvements. A brief description of these potential instream disturbances will allow other management actions to be identified to minimise any potential impacts.

Land use impacts

A description of the potential impacts from adjacent land use, particularly from stock grazing, erosion, channelisation and sedimentation will assist in identifying potential impacts on the instream environment and indicate the management actions necessary to minimise any effects.

Features of the reach (including habitat condition and description)

A description of the habitat features within a zone is important to understand the likely benefits, which could be derived from environmental flow provisions. The features are a summary of the key types of habitats that may be available within the reach. These features could include:

- rock, riffle or pool zone
- range of habitat

- permanent pools
- springs and soaks
- diversity of species
- macrohabitat types
- vegetation diversity (structural and floristic)
- fauna present or potentially supported at this site
- water quality (salinity, turbidity, flow).

For example, the key features of a lowland reach of the Glenelg River may include: sand substrate, high electrical conductivity, lack of wood debris, long runs with little habitat diversity.

This also allows an inventory of the features of a zone and allows an overall condition assessment of the zone.

Linkages

A description of the linkages between upstream and downstream zones as well as connections with the floodplain and wetlands is another guide to possible benefits of providing environmental flows.

Additional information

While the EFTP is on site there is additional information that can be easily be identified and recorded. This includes:

- knowledge gaps
- monitoring required
- management actions required
- landholder information
- other notes.

Flow components

The EFTP field trip allows the panel to identify the key flow components specific to that particular reach of the river, based on the features and assets present. The generic flow components that should be considered at each site are described in Appendix A. These components are described hydrologically and by their specific ecosystem functionality. At each site it is necessary for the EFTP to examine the flow components they believe are specifically relevant or important for that site, based on the ecosystem present and key flow indicators. This may be confirming the flow components that are apparent through the examination of the hydrology for the site, or be based on the field observations and knowledge of the biota or habitats present.

Important components of the flow regime would be confirmed by linking visible flow markers, habitats and features to key geomorphological and ecological requirements understood for the site. For example, the presence of vegetation at certain levels in the channel or areas of undercutting or erosion may indicate levels at which flow commonly reaches. Points such as these should be specifically noted on the cross-section drawings, discussed below. Each flow component should be described specifically for that site, including the role of that flow component at the site.

Appendix D Field data sheets



A series of field sheets are included in this section. They include:

- general site description sheets;
- the United States Environmental Protection Agency field description sheets as used by the Victorian Environment Protection Authority;
- a sheet for description of the cross-sections and their location; and
- a photo record sheet.

The sheets are included as a guide to the forms of recording the site data.

Site details

Sheet 1

River _____

Date _____

Site name _____

Site number _____

Recorder _____

Panel 1 _____

2 _____

3 _____

4 _____

Site description

Site location – Schematic

Key landholder contact details

Comments

Cross-section location**Sheet 2**

Site name _____ River _____ Site number _____

Cross-section	1	Northing/Easting	Start		Description
			L	R	
	2	_____	L	R	_____
	3	_____	L	R	_____
	4	_____	L	R	_____
	5	_____	L	R	_____
	6	_____	L	R	_____
	7	_____	L	R	_____

Distance between

1 – 2	_____
2 – 3	_____
3 – 4	_____
4 – 5	_____
5 – 6	_____
6 – 7	_____

Cross-section location

Planform

River _____ Date _____ Location code _____

Low gradient streams

Habitat parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal substrate/available cover	Greater than 50% of substrate favourable for epifaunal colonisation and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonisation potential (logs/snags are not newly fallen and not transient).	30–50% mix of stable habitat; well-suited for full colonisation potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newly fallen logs but not yet 'seasoned' (may rate at high end of scale).	10–30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat obvious; substrate unstable or lacking.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Pool substrate characterisation	Mixture of substrate materials with gravel and firms prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud or clay; mud may be dominant, some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Pool variability	Even mix of large/shallow, large/deep, small/shallow and small/deep pools present.	Majority of pools large/deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small/shallow or pools absent.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Channel alteration	Channelisation or dredging absent or minimal; stream with normal pattern.	Some channelisation present, usually in areas of bridge abutments; evidence of past channelisation, i.e., dredging (greater than past 20 yrs) may be present, but recent channelisation is not present.	Channelisation may be extensive; embankments or shoring structures present on both banks; and 40–80% of stream reach channelised and disrupted.	Banks shored with gabion or cement, over 80% of stream reach channelised and disrupted. Instream habitat greatly altered or removed entirely.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Sediment deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravels and/or fine sediment; 5–30% (20–50% for low gradient streams) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30–50% (50–80% for low gradient streams) of the bottom affected; sediment deposits at obstructions, constrictions and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low gradient streams) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

River _____ Date _____ Location code _____

Low gradient streams

Habitat parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
6. Channel sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was a straight line. (Note: channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.)	The bends in the stream increase the stream length 2 to 3 times longer than if it was a straight line.	The bends in the stream increase the stream length 1 to 2 times longer than if it was a straight line.	Channel straight; waterway has been channelised for a long distance.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7 Channel flow status	Water reaches base of both lower banks, and minimal amount of channel substrate exposed.	Water fills >75% of available channel or <25% of channel substrate exposed	Water fills 25–75% of available channel and/or riffle substrates are mostly exposed	Very little water in channel and mostly present as standing pools.
Score	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank vegetative protection (score each bank)	More than 90% of the streambank surfaces covered by native vegetation, including trees, understorey shrubs or non-woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally	70–90% of the streambank surfaces covered by native vegetation, but one class of plants is not well represented; disruption evident but not affecting full plant growth potential to any great extent	50–70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank is very high; vegetation has been removed to 5 cm or less.
Score	Left bank 10 9	8 7 6	5 4 3	2 1 0
Score	Right bank 10 9	8 7 6	5 4 3	2 1 0
9. Bank stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent small areas of erosion mostly healed over; 5–30% of bank in reach has areas of erosion.	Moderately unstable; 30–60% of bank in reach has areas of erosion; high erosion potential during floods	Unstable; many eroded areas; “raw” areas frequent along straight sections and bends; obvious bank sloughing; 60–100% of bank has erosional scars.
Score	Left bank 10 9	8 7 6	5 4 3	2 1 0
Score	Right bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative zone width (score each bank)	Width of riparian zone >18 m; human activities (i.e. roads, lawns, crops etc.) have not impacted zone.	Width of riparian zone 12–18 m; human activities have impacted zone only minimally.	Width of riparian zone 6–12 m; human activities have impacted zone a great deal.	Width of riparian zone <6 m; little or no riparian vegetation due to human activities.
Score	Left bank 10 9	8 7 6	5 4 3	2 1 0
Score	Right bank 10 9	8 7 6	5 4 3	2 1 0

Total score _____

Site features Comments**Sheet 5**

Recorder _____

Site name _____

River _____

Site number _____

Flow type	
Site features	
Substrate	
Channel structure	
Riparian structure	
Floodplain	
Instream habitat	
Other comments	

Flow bands**Sheet 6**

Recorder _____

Site name _____ River _____ Site number _____

Flow band	Flow band description	Key functions of flow band	Duration, seasonality

Observations

Photo record

Sheet 7

Recorder _____

Site name _____ River _____ Site number _____

[illegible]

Observations

Sheet 8

Recorder _____

Site name _____

River _____

Site number _____

Linkages	
Knowledge gaps	
Monitoring	
Management actions	
Land use	
Instream disturbances	
Other	

Cross-section profile

Sheet 9

Recorder _____

Site name _____ River _____ Site number _____

Cross-section number _____ Cross-section location _____

Planform

Cross-section profile

Appendix E Water-dependant species



The Department of Environment and Primary Industries has current lists of aquatic or riparian flora and fauna considered threatened in Victoria and nationally. These lists can be found at:

<www.dse.vic.gov.au/plants-and-animals/native-plants-and-animals/threatened-species-and-communities/threatened-species-advisory-lists>.

Panels should make their own assessment of this list and adjust it if necessary.

As described in the main body of the report, the list of species which must be considered in identifying environmental assets is much broader than threatened biota, and includes:

- threatened aquatic invertebrates
- all fish
- all frogs
- all aquatic reptiles
- all aquatic mammals
- colonial water birds
- threatened water birds
- threatened aquatic and riparian plants.

Appendix F Calculating performance

F

F.1 Preamble

Assessing the percentage of time or years that environmental flow recommendations are met is useful for:

- Checking that the environmental flow recommendations are realistic (e.g. are they met in the unimpacted flow series?).
- Understanding how often flow recommendations are met under the historic, current or possible future flow regimes.

F.2 Using daily data

Daily data should be used wherever possible to assess performance against flow recommendations. This is because many flow recommendations have durations of a few days or less.

There is more than one way to assess performance against environmental flow recommendations. What is important therefore is that the assessment reflects the intent of the EFTP flow recommendations, and assumptions in the performance assessment are made explicit.

As an example, Table 5.1 shows flow recommendations for a reach of the Tarago River. Table 5.2 shows one possible way of assessing performance against the flow recommendations using a daily time-series of recorded streamflow. This approach assumes flow events only comply with environmental flow recommendations if they meet each aspect of the recommendation (threshold, duration and timing). An independence criterion of seven days was used to differentiate events, and it has been assumed that recommendations are not independent of each other. That is, if a flow of 600 ML/day occurs in October, it can be counted as a winter high and bankfull event.

F.3 Summer low and winter low

Performance has been calculated by assessing how often flows are equal to or above the recommended magnitude, in the relevant months. Results are presented in three ways: the percentage performance for a given year, the average within year performance over the period of record, and the percentage of years where flows complied with the summer low or winter low recommendation for the whole year. The volumetric shortfall in meeting the low flow recommendations is also shown.

F.4 Summer fresh and high; winter fresh and high

Performance has been calculated by assessing the frequency of events above the required threshold that last the recommended duration, in the relevant months.

Results are presented in three ways: the percentage performance for a given year, the average within year performance over the period of record, and the percentage of years where flows complied with the fresh and high recommendations. This approach is only applicable when assessing performance for recommendations with frequency of one or more per year.

Table 5.1: Environmental flow recommendations, reach 2, Tarago River.

Summer low	12 ML/day (Dec–May)
Summer fresh	100 ML/day (Dec–May, 5/year, 4day)
Summer high	200 ML/day (Apr–May, 1/year, 1day)
Winter low	100 ML/day (Jun–Nov)
Winter fresh	280 ML/day (Jun–Nov, 4/year, 3day)
Winter high	280 ML/day (Oct–Nov, 1/year, 1day)
Bankfull	600 ML/day (1/year, 1day)
Overbank	1000 ML/day (1 in 2 years, 1day)

F.5 Bankfull and overbank

Performance has been calculated for the whole period of available record as the number of years with the recommended number of complying events, divided by the number of years expected to have complying events. For example, a performance of 50 per cent over the period of record for a bankfull recommendation of 1700 ML/day for one day, one in two years in June to November, would mean that for a record of (say) 20 years, 10 years were expected to have bankfull events between June and November inclusive, but only five years did. This approach is only applicable when assessing performance for recommendations with frequency less than once per year.

F.6 Cease to flow

Table 5.2 does not include a cease-to-flow recommendation, but where there is such a recommendation, performance could be calculated as the percentage of years where the number of days equal to or below the cease-to-flow threshold is within the recommended range in the relevant months. For example, a performance of 75 per cent over the period of record for a cease-to-flow recommendation of 5–24 days for December to May would mean that there were 75 per cent of years with between five and 24 days of cease to flow. If more than one cease-to-flow event was recommended, performance could be calculated in the same manner as for fresh and high events, based on a spells analysis for events below rather than above a threshold.

The main disadvantage of this 'strict' approach to assessing performance for reaches with only one set of frequency and duration recommendations is that performance is likely to be poor in 'wet' years where flows are above recommended thresholds for long periods of time (thus reducing the number of events observed in a year). Another possible approach to assessing performance is therefore to consider the number of days above the recommended flow thresholds, and compare this with the product of recommended frequency and duration. Table 5.3 shows the performance for summer and winter freshes in reach 2 of the Tarago River reworked using this approach. This method results in higher estimates of performance. For example, performance with the summer fresh recommendation in 1993 is 20 per cent in Table 5.2 and 100 per cent in Table 5.3. It is therefore important to use a method to assess performance that reflects the intent of the EFTP flow recommendations.

F.7 Assessing performance using monthly data

The only time it is acceptable to estimate performance using data with a time-step longer than one day, is when daily data is not available. However, many of the water resource models used in Victoria still operate on a monthly time-step, and therefore if performance needs to be assessed for future possible scenarios, using monthly data may be inevitable.

When estimating performance using monthly data, the following needs to be kept in mind:

- performance estimated using monthly data tends to be higher than performance estimated using daily data (Neal et al, 2011);
- monthly data is more amenable to performance assessments for summer low, winter low, bankfull and overbank recommendations than fresh and high recommendations (Neal et al, 2011); and
- it is not possible to use monthly data to assess performance against cease-to-flow recommendations, unless the recommended cease-to-flow duration is multiple months.

There are a number of methods that have been previously used to estimate performance against environmental flow recommendations when only monthly data is available. These are summarised below.

Approaches applicable when assessing how well flow recommendations are met under different water resource scenarios

- 1) Using daily time-series of recorded or modelled streamflow, a relationship can be developed between the volume of water flowing through a reach in a given season and the number of days above the flow threshold of interest. An example is provided in Figure 5.2. This relationship can then be used to estimate the number of days above environmental flow thresholds under the different water resource scenarios modelled. This approach works best for large flow thresholds, such as bankfull or overbank recommendations, and less well for fresh recommendations.
- 2) Using a daily time-series of unimpacted flows, a daily time-series of environmental water demand can be created using the algorithm described in Neal et al (2005) (an example is provided in Figure 5.3). This time-series of environmental water demand is then aggregated, and compared with flows modelled for each monthly time-step for the water resource scenarios being considered. Performance is then assessed as the percentage of months where the modelled flow is greater than the modelled environmental water demand. Each month of the environmental water demand can also be given a label (e.g. bankfull, summer fresh, winter high) corresponding to the largest component of the environmental water demand in that month. Performance can then be assessed separately for the different flow components.

Under both these approaches, performance against environmental flow recommendations is post-processed for the assumed inflow and consumptive use scenarios being modelled. That is, the water resource model is not configured to restrict consumptive demand or release water from storage to meet the environmental flow recommendations.

Table 5.2: Worked example – calculating performance with environmental flow recommendations for reach 2 of the Tarago River.

Season	Summer fresh				Winter fresh				Summer high				Winter high				Bankfull				Overbank				Summer low			Winter low		
	No. of days	No. of events	Complying events	Yearly performance	No. of days	No. of events	Complying events	Yearly performance	No. of days	No. of events	Complying events	Yearly performance	No. of days	No. of events	Complying events	Interval w/o event	No. of days	No. of events	Complying events	Interval w/o event	Complying days	Shortfall (ML)	Yearly performance	Complying days	Shortfall (ML)	Yearly performance				
1981	2	1	0	0%	12	3	2	50%	1	1	1	100%	2	1	1	0	5	2	2	0	41	7785	22%							
1982	0	0	0	0%	2	2	0	0%	0	0	0	0%	0	0	0	2	0	0	0	2	16	12276	9%							
1983	0	0	0	0%	12	4	2	50%	0	2	2	100%	5	2	3	0	3	3	0	3	37	7889	20%							
1984	5	2	0	0%	30	5	3	75%	2	1	1	100%	13	3	2	0	10	2	2	0	74	5382	40%							
1985	1	1	0	0%	14	3	2	50%	0	1	1	100%	2	1	1	1	0	0	0	1	80	4427	44%							
1986	50	2	2	40%	27	4	2	50%	3	1	1	100%	6	1	4	0	6	4	4	0	95	3461	52%							
1987	12	3	1	20%	4	3	0	0%	0	0	0	0%	0	0	1	0	1	1	0	1	41	6710	22%							
1988	3	1	0	0%	4	2	1	25%	3	1	1	100%	3	1	1	0	1	1	0	2	10	10451	5%							
1989	10	6	1	20%	14	4	1	25%	0	0	1	100%	9	1	3	0	5	3	0	0	78	3609	43%							
1990	4	1	1	20%	9	3	2	50%	1	1	1	100%	3	1	2	0	2	1	1	0	56	6463	31%							
1991	2	2	0	0%	22	5	5	100%	0	0	0	0%	0	0	3	2	2	2	0	1	93	4463	51%							
1992	28	3	3	60%	31	2	1	25%	0	0	2	100%	18	2	3	0	7	3	0	0	129	1424	70%							
1993	53	3	1	20%	24	3	3	75%	0	0	2	100%	15	2	4	0	7	4	0	0	96	3559	52%							
1994	16	4	1	20%	6	3	0	0%	0	0	2	100%	4	2	1	0	1	1	0	1	67	5156	37%							
1995	17	5	2	40%	26	6	6	100%	5	3	3	100%	7	2	5	0	8	5	0	0	144	730	79%							
1996	27	7	4	80%	26	6	2	50%	6	2	2	100%	5	2	4	0	5	4	0	0	95	2665	52%							
1997	1	1	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	1	0	0	1	18	6135	10%								
1998	3	1	0	0%	5	3	0	0%	0	0	0	0%	5	3	2	0	0	0	2	182	3862	27%								
1999	16	7	1	20%	4	2	1	25%	1	1	1	100%	1	1	3	0	0	0	3	182	5237	11%								
2000	8	3	0	0%	13	5	2	50%	2	1	1	100%	3	1	4	0	0	0	4	71	3301	39%								
2001	6	1	1	20%	6	3	1	25%	3	1	2	100%	3	2	5	0	0	0	5	55	6162	30%								
2002	9	3	1	20%	0	0	0	0%	0	0	0	0%	0	0	6	0	0	0	6	12	6605	7%								
2003	0	0	0	0%	5	1	1	25%	0	1	1	100%	5	1	1	0	1	0	7	38	8867	21%								
2004	5	1	1	20%	12	4	2	50%	0	0	2	100%	6	1	2	0	2	0	8	109	1477	60%								
2005	11	2	1	20%	3	2	0	0%	0	0	0	0%	0	0	3	0	3	2	9	21	7944	11%								
2006	3	3	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	1	0	0	10	2	12211	1%								
2007	7	2	1	20%	1	1	0	0%	1	1	1	100%	1	1	2	0	0	0	11	5	13140	3%								
2008	8	3	1	20%	0	0	0	0%	0	0	0	0%	0	0	3	0	0	0	12	12	9869	7%								
2009	4	1	1	20%	10	2	2	50%	0	2	2	100%	6	2	2	0	7	2	3	25	10989	14%								
2010	2	1	0	0%	23	4	3	75%	0	0	0	0%	9	2	2	0	6	2	0	65	6091	36%								
Total	0% of years				7% of years				30% of years				73% of years				63% over record				73% over record				47% of years			0% of years		
Average yearly performance	16%				34%				30%				73%				92% of days				92% of days				30% of days			30% of days		

Table 5.3: Table 5.2 re-worked, with performance based on the number of days above the recommended threshold, rather than the number of complying events.

Season	Summer fresh				Winter fresh			
	No. of days	No. of events	Complying events	Yearly performance	No. of days	No. of events	Complying events	Yearly performance
1981	2	1	0	10%	12	3	2	100%
1982	0	0	0	0%	2	2	0	17%
1983	0	0	0	0%	12	4	2	100%
1984	5	2	0	25%	30	5	3	100%
1985	1	1	0	5%	14	3	2	100%
1986	50	2	2	100%	27	4	2	100%
1987	12	3	1	60%	4	3	0	33%
1988	3	1	0	15%	4	2	1	33%
1989	10	6	1	50%	14	4	1	100%
1990	4	1	1	20%	9	3	2	75%
1991	2	2	0	10%	22	5	5	100%
1992	28	3	3	100%	31	2	1	100%
1993	53	3	1	100%	24	3	3	100%
1994	16	4	1	80%	6	3	0	50%
1995	17	5	2	85%	26	6	6	100%
1996	27	7	4	100%	26	6	2	100%
1997	1	1	0	5%	0	0	0	0%
1998	3	1	0	15%	5	3	0	42%
1999	16	7	1	80%	4	2	1	33%
2000	8	3	0	40%	13	5	2	100%
2001	6	1	1	30%	6	3	1	50%
2002	9	3	1	45%	0	0	0	0%
2003	0	0	0	0%	5	1	1	42%
2004	5	1	1	25%	12	4	2	100%
2005	11	2	1	55%	3	2	0	25%
2006	3	3	0	15%	0	0	0	0%
2007	7	2	1	35%	1	1	0	8%
2008	8	3	1	40%	0	0	0	0%
2009	4	1	1	20%	10	2	2	83%
2010	2	1	0	10%	23	4	3	100%
Total	13% of years				47% of years			
Average yearly performance	39%				63%			

Approaches applicable when assessing how much consumptive demand needs to be reduced to meet environmental flow recommendations

- 1) In Victoria, the software used to run water resource models is called REALM. Recently, a REALM plug-in was developed to enable environmental flow recommendations to be described using an equation editor. The environmental flow recommendations as described using mathematical equations are then modelled as a demand for the relevant reach, and other consumptive demands are restricted or water (when available) is called out of storage to meet those environmental demands. This approach allows the impact of meeting environmental demands on other consumptive users to be modelled.
- 2) Alternatively, if an environmental water demand time-series has been created using the Neal et al (2005) algorithm described above; this can be assigned to relevant reaches as a demand time-series, instead of using the environmental water demand plug-in.

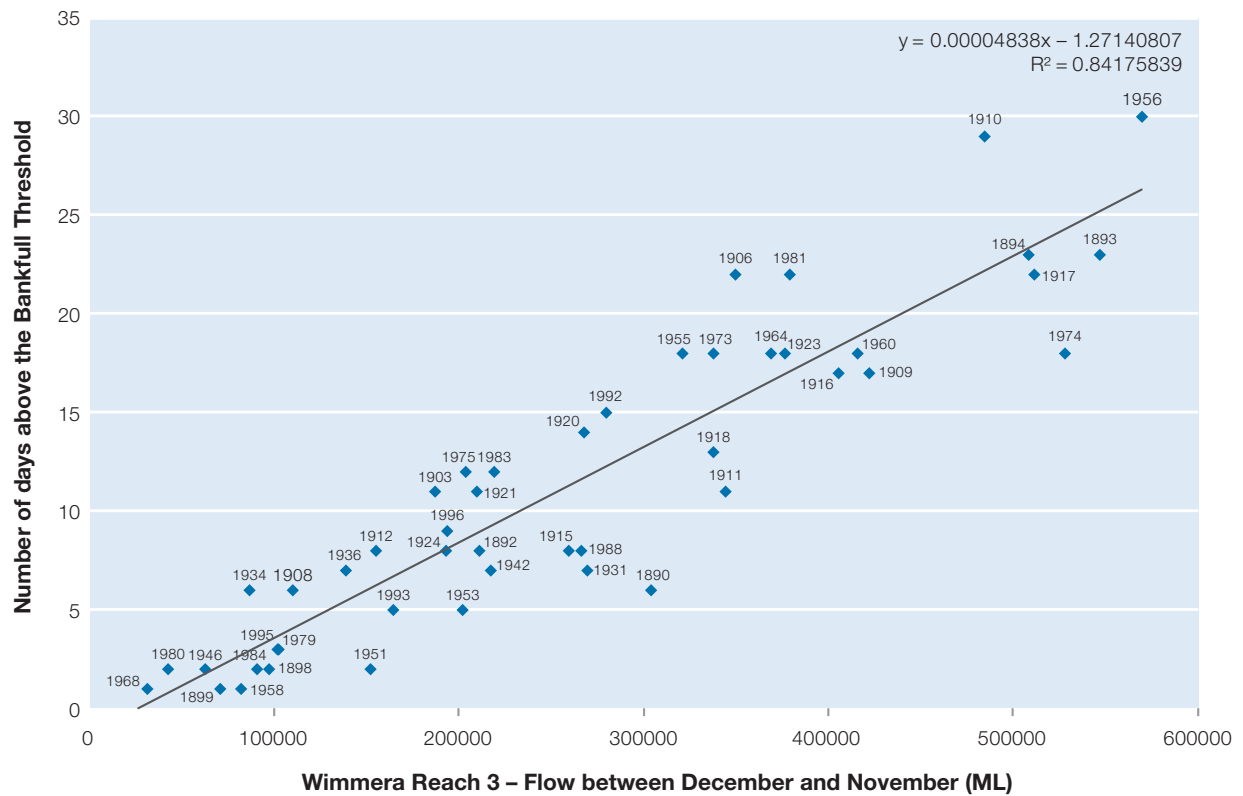


Figure 5.2 Estimating the number of days above the bankfull threshold in reach 3 of the Wimmera, based on the volume of flow over 12 months

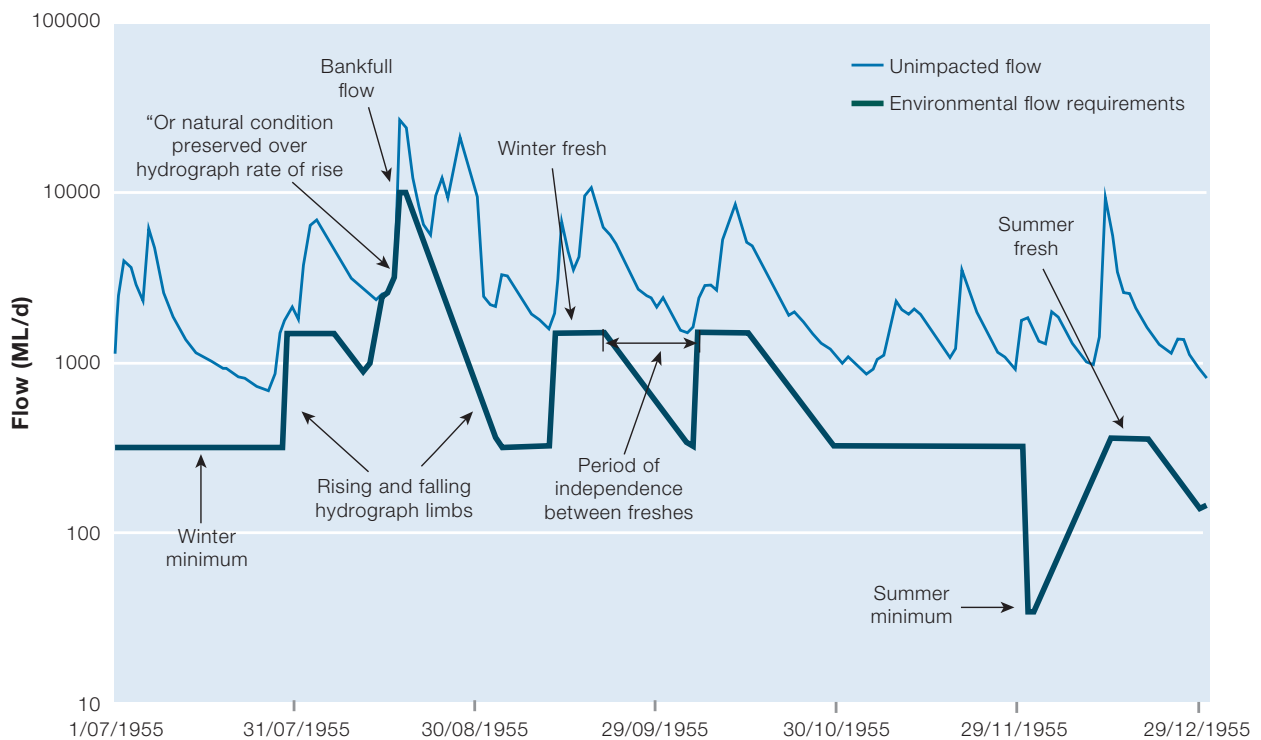


Figure 5.3 Creating a time-series of environmental water demand from a time-series of unimpacted flows (Neal et al, 2005).



For more information call the DEPI
Customer Service Centre **136 186**

www.depi.vic.gov.au