Discussion Paper:
Options for assessing the river health implications of flow scenarios in the Namoi and Gwydir catchments

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Introduction

This document reviews some methods for catchment-scale environmental flow assessment, for potential inclusion in a decision support system.

River Health concepts

Ecological theory generally states three necessary conditions for natural river functioning:

- habitat heterogeneity — the biotic community is structured by the availability of habitat and at a broad level there is a relationship between biodiversity and habitat heterogeneity;
- connectivity — along the river, with the floodplain and riparian vegetation, and with groundwater;
- metabolic functioning — the source and amount of organic matter produced will have a significant effect on the food web.

(Whittington *et. al.*, 2004, p. 11)

The Sustainable Rivers Audit defined river health as:

> “the degree to which aquatic ecosystems support and maintain processes and a community of organisms and habitats relative to the species composition, diversity, and functional organisation of natural habitats within a region.” (Whittington *et. al.*, 2004, p. 9)

This definition is consistent with the more specific concept of Gawne (2001), who defined “ecological integrity” as:

> “the degree to which biological processes incorporate similar amounts of material into the food web as reference systems (productivity); and maintain a food web of similar complexity to that of reference systems (ecological processes).”

These definitions are not easily used in practice. Instead, most studies focus on particular species, or the presumed drivers of river health, such as habitat and fluxes of water and nutrients. Such specific aims may also be more consistent with community values.

Target & Reference States

The target state in multiple-use systems is a sustainable balance; for example The Living Murray initiative aims for “a healthy working river”. Apart from the river health concepts described above, important considerations in flow management may include

- aesthetic & amenity value (e.g. channel form, water quality)
- infrastructure and property (e.g. bank erosion, flooding impacts)

The natural flow paradigm is a fundamental scientific principle: the integrity of river systems depends largely on their natural dynamic character (Poff et al, 1997). Native species are adapted to the natural regime, whereas exotic species tend to be at a disadvantage (Bunn & Arthington, 2002).

The natural flow regime is a useful reference because of its historical and evolutionary significance to the river. Even so, it is **not** equivalent to the typically desired state: sustainable human use. Rivers can be incrementally restored with consequent benefits to ecological processes (Poff et al, 1997).

While a non-natural flow regime could be designed to benefit particular species, it is possible that this would have an impact on other species, or “new and unforeseen problems may develop” (Arthington, 1998).

Flow is the primary driver of river-floodplain ecosystems (Figure 1). Of course, other factors are important and may limit the response to flow restoration. Equally, an ecologically inappropriate flow regime will limit the effectiveness of non-flow management actions. Indeed, supplying natural flow elements is “likely to be the most successful and least expensive way to restore and maintain the ecological integrity of flow-altered rivers” (Poff et al, 1997).

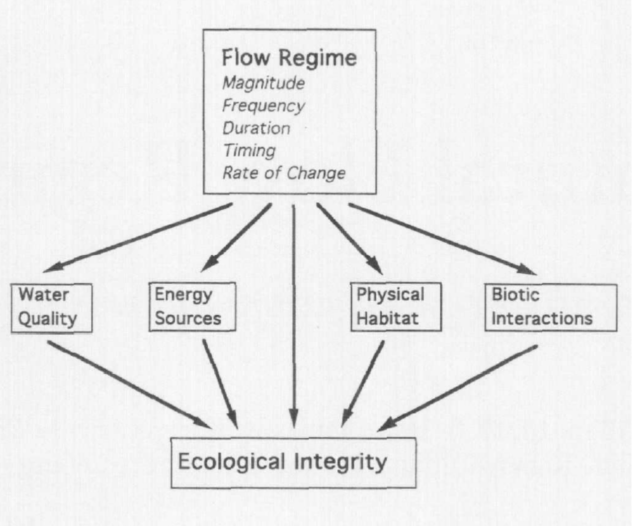


Figure 1: The flow regime as a direct and indirect driver of river systems (from Poff et al, 1997).

Flow-related Issues

The IMEF program is investigating the hypotheses that: "protecting or restoring a portion of freshes and high flows, and otherwise maintaining natural flow variability [through off-allocation use restrictions and implementation of the North West Unregulated Flow Plan]" will improve the following issues (Box 1).

Environmental Issues in the Namoi River Addressed by Current Flow Rules

- Blooms of cyanobacteria (so-called blue-green algae) occur periodically in summer in the weir pools and some other areas of the lower Namoi River and Pian Creek. These blooms cause discolouration and are hazardous to human and animal health.
- Stony substrata in the Namoi River downstream of Keepit Dam may be accumulating silt and associated mature biofilms during low-flow periods. The reduction in freshes and small floods caused by river regulation and water abstraction may be preventing natural scouring and consequent resetting of biofilms to early successional stages favoured by invertebrate scrapers. This may be reducing the supply of invertebrate food to carnivorous fish.
- The reduction in freshes and small floods caused by river regulation and water abstraction may be retarding the natural exchange of organic matter between the river channel and the riparian zone and flood plain, resulting in a reduced supply of terrestrial energy sources to the river. This may be causing an imbalance between production and respiration in the river.
- Littoral zones in the Namoi River may be developing mature biofilms during low-flow periods. The reduction in freshes and small floods caused by river regulation and water abstraction may be preventing natural water level changes and consequent resetting of biofilms to early successional stages favoured by invertebrate scrapers. This may be reducing the supply of invertebrate food to carnivorous fish.
- The reduction in freshes and small floods caused by river regulation and water abstraction may be preventing adequate wetting of anabranches and riverine wetlands, thus inhibiting the exchange of organic matter between the wetlands and the river and failing to provide adequate habitat for wetland flora and fauna.
- The reduction in freshes and small floods caused by water abstraction may be reducing breeding opportunities for native fish and hampering their migration. The steady flow conditions may also be to the advantage of alien pest species such as gambusia and carp.

(**Box 1:** IMEF Operations Manual, Namoi Valley, 1999, Box 4)

Other flow-related effects are also relevant. Bank erosion is a widespread problem (Thoms et al, 1999). Alterations to flow and sediment regimes have led to fundamental changes in river styles (Olley & Scott, 0000). Water quality is a major problem in these basins (CNWWQMS, DLWC, 2001), with clear examples being turbidity, salinity, nutrients and temperature.

Dams typically have a wide range of impacts on river systems, notably anoxic and cold water pollution, constancy of flow levels (reduced variability of low flows), reduction in medium-sized pulses, barriers to sediment movement, barriers to fish passage, and unseasonal flows. The operational rules of dams are typically used to specify environmental flows. However, unregulated rivers should also be included in environmental flow assessment (Brizga, 1998).

It is important to remember that response to alteration occurs over a range of time scales. Geomorphic response can take many decades following regulation. Reduced connectivity (downstream or with floodplain) can alter ecosystems over long time scales, especially long-lived species such as large fish and trees. For this reason the full implications of flow regime alteration may not yet be visible.

Table 1, below, describes different flow attributes as they relate to riverine ecology. Table 2 gives an example set of flow statistics that was used in a recent environmental flow assessment, together with an ecological interpretation of each.

Table 1. General role and importance of flow types (from King et al, 2003)

Flow	**Importance to ecosystem**
Low flows	These are the daily flows that occur outside of high-flow peaks. They define the basic hydrological nature of the river: its dry and wet seasons, and degree of perenniality. The different magnitudes of low-flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and water-quality conditions, which directly influence the balance of species at any time of the year.
Small floods	Small floods are ecologically important in semi-arid areas in the dry season. They stimulate spawning in fish, flush out poor-quality water, mobilize and sort gravels and cobbles thereby enhancing physical heterogeneity of the riverbed, and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronizing activities as varied as upstream migrations of fish and germination of riparian seedlings.
Large floods	Large floods trigger many of the same responses as do the small ones, but additionally provide scouring flows that influence the form of the channel. They mobilize coarse sediments, and deposit silt, nutrients, eggs and seeds on floodplains. They inundate backwaters and secondary channels, and trigger bursts of growth in many species. They re-charge soil moisture levels in the banks, inundate floodplains, and scour estuaries thereby maintaining links with the sea.
Flow variability	Fluctuating discharges constantly change conditions through each day and season, creating mosaics of areas inundated and exposed for different lengths of time. The resulting physical heterogeneity determines the local distribution of species: higher physical diversity enhances biodiversity.

Table 2. Hydrological statistics and their relevance, as used in the Condamine-Balonne WAMP process. (from Thoms & Dyer, 2004)

Key statistic	**Primary features of importance**
Proportion of natural median annual flow	• Annual discharge • Sediment transport • Availability of aquatic habitat
Annual Proportional Flow Deviation (APFD)	• Overall modification of the flow regime • Reproduction of native fish and water birds • Abundance of alien fish species, e.g. carp
Proportion of natural monthly flow variability	• Daily variation in flow, and seasonal patterns • of flow variability • Natural disturbance
Proportion of natural "high flow" event frequency	• Flooding, and near bank-full flow events • Floodplain inundation • Natural disturbance • Movement of native fish over weirs
Proportion of natural "medium flow" event frequency	• Within-channel flow events • Maintenance of channel complexity • Inundation of channel benches
Proportion of natural "low flow" duration	• Connectivity of riverine pools • Movement of native fish • Maintenance of riffle habitat
Proportion of natural "no flow" duration	• Drying of the in-stream environment • Natural disturbance • Maintenance of in-stream vegetation • Oxidation of nutrients
Proportion of river inundated by dams and weirs	• Loss of natural riverine habitat

Spatial and temporal scales of assessment

The spatial scale of assessment should be relevant to both management decisions and ecosystem dynamics.

Hydrological approaches include the distinction between regulated and unregulated, and statistical analysis of hydrologically similar regions (Thoms & Parsons, 2003). Subcatchments based on tributary confluences may also correspond to changes in the physical and biological environment (Rice et al, 2000).

Geomorphic approaches include Functional Process Zones (Thoms et al, 1999) and River Styles, a hierarchical framework. Off-river environments may also be defined, such as floodplains and wetland storages.

Problem

- We know how changes in water allocation management affect flows but what does this mean to river health?
- Flow is the primary driver of river-floodplain ecosystems
- How can we improve the environmental suitability of river flows?

River Health

- What do we care about?
  - Fish, riparian trees, river channel, water quality…
  - What is required to sustain these over large scales of space and time?
- Scientific evidence shows that a healthy river requires maintenance of:
  - the natural physical and biological processes (e.g. nutrient and energy dynamics)
  - the natural linkages – downstream, river-floodplain, and river-groundwater
  - the natural diversity of habitats for plants and animals (Young, 2001)

DSS: pros and cons

- A structured, transparent and repeatable method of assessment (MDBC, 2003)
- "The constrained nature of a Decision Support System […] may be an impediment to creative, lateral thinking, a key element in the difficult process of constructing modified flow regimes to achieve defined ecological outcomes." (Arthington, 1998)

Beyond passive assessment

- The most rigorous approach includes a specification of environmental flows – addressing flow requirements directly
- Sophisticated operational rules can be simulated to achieve more natural flows (e.g. Flow Restoration Methodology)
- More natural flows may not be enough: need to identify constraints to recovery

Environmental Flow Assessment

- Basic approach:
  - compare current, natural and proposed river flows
  - relate changes to physical, ecological and biological outcomes
  - rank scenarios on various criteria
- How much water does a river need?
  - Bottom-up approaches: what are the flow requirements of ecosystem components?
  - Top-down approaches: how much (or what kind of) change from the natural regime causes major impact?
  - Most robust method is to use both: bottom-up design followed by top-down assessment (Brizga, 1998)

EFA methods

- Arthington et al (2003) defines:
  - Level 1: Hydrological methods
  - Level 2: Holistic scientific panel approaches
  - Level 3: Modelling of system components
- Higher levels, generally:
  - are more resource- & knowledge-intensive
    - Take more time and money
  - have a stronger scientific basis (less risk)
  - are better targeted
- All assessments are hypotheses which should be tested and revised

Hydrological methods

- Calculate **important** attributes of flow scenarios and compare to natural
- Attributes (statistics) should be chosen carefully
- Many different statistics have been proposed
  - Often based on conceptual models of how rivers work
  - Some have been shown to be biologically meaningful (in specific regions)
  - Recent emphasis on characterising flow diversity and predictability in floodplain systems
- Simple, interim, broad-scale assessments

Range of Variability Approach (RVA)

- Uses a set of 32 statistics for each year
  - Duration & magnitude of extremes
  - Timing of extremes
  - Frequency & duration of high/low pulses
  - Monthly magnitude…
- Identify natural range of variability of each, as targets
- Example: range of natural regime in 80% of years
  - "low pulse count" should be between 6 – 16
  - "low pulse mean duration" should be between 4 – 10 days

Holistic approaches

- Address requirements of the whole river system
- Multi-disciplinary structured workshop: a key mechanism to integrate current state of knowledge
- Use fieldwork, data, models and judgment to estimate flow requirements and sensitivities
- Typically flexible frameworks – can be applied with varying degrees of rigour

- (+) Intensive process gives deep understanding and summary of system
- (-) Comprehensive assessments may be expensive; rapid ones subjective?

Flow Events Method

- Relatively simple; uses hydraulic modelling
- Identify critical aspects of flow regime; e.g.
  - Disturbance by bed exposure
    - Minimum wetted area
  - Sediment entrainment; formation of channel features
    - Duration of effective flow
  - Floodplain inundation
    - Magnitude above bankfull level
- Events which occur much more/less frequently than natural are problematic
- May require expert interpretation to rank scenarios

WAMP Benchmarking Methodology

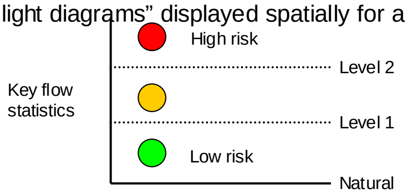
- Rapid, basin-wide process
- Data sets and information collated, but no new field study

- Technical Advisory Panel (TAP) workshop
- Identify critical water levels for habitats or species, e.g. inundation of gravel bars
- Key flow statistics chosen describing each

WAMP Benchmarking Methodology

- Estimate ecological condition at similar sites
  - On a scale of 1 to 5
  - Several methods to assess components of ecosystem
- Develop benchmark levels of alteration by linking changes in key statistics to observed condition

- “traffic light diagrams” displayed spatially for a scenario.



DRIFT

- Comprehensive, holistic, scenario-based
- Best-practice methodology other than long-term research and detailed modelling
- “a data-management tool, allowing data and knowledge to be used to best advantage in a structured process” (King et al, 2003)
- Develop predictive capacity for ecosystem components
  - nature & direction of change
  - a qualitative rating of severity

DRIFT

- Modelling of hydaulics and habitats at representative sites
- Field studies estimate requirements of ecological components
- For each specific type of change to flow:
  - Geomorphologists describe physical changes
  - Aquatic chemists (chemical & thermal)
  - Vegetation specialists (aquatic & riparian)
  - then Fish, Invertebrates, etc
- Build a structured database of “consequences” – allows assessment of scenarios and interpretation of impacts

MFAT

- DSS using simple models: minimal data requirements
- Relates flow to suitability for fish groups
- Simple wetland storages driven by overbank flow – gives inundated area, depth over time
  - Assessment of suitability for vegetation, birds
- Risk of algal blooms in weir pools
- “Preference curves”, weightings etc: defined and documented by regional expert groups
  - Hydrology-related parameters are site-specific
- ‘Incremental’ method suitable for trade-offs
- Requires further development for general application

Ecological Modelling

- Both empirical and process-based models have been used for biological communities
  - Project (CRC FE/CH): database of hydraulic requirements of particular fish & invertebrates
- Research groups are developing relationships between flow and
  - Physical habitat
  - Ecological processes (e.g. production/respiration)
  - These are strongly linked to river health
- Modelling of floodplain environments is improving

Physical & Chemical modelling

- Geomorphic modelling: bank erosion, channel shape, sediment transport
- Salinity, Turbidity, Nutrients, Temperature
- Dilution effect of flow
- Complex interactions of flow with floodplain, groundwater…
- Intensive quantitative modelling effort would be needed
- Integrating flow management and catchment management remains a challenge

Possible ways forward

- Flow requirements of each system are different and should be estimated
  - An integrated framework can guide the process towards a predictive capacity
  - What flow management decisions would be likely to improve river health?
- Assessment problems:
  - Defining a set of representative sites
  - Hydraulic modelling: sensitivity to channel shape
- River Styles™ may be a useful template?

Summary of approaches

Note: these are rough estimates and opinions based on limited knowledge. Those listed are obviously a small subset of the 200+ documented methods. Reference to the original papers is encouraged, as well as these reviews:

- (Arthington, 1998)
- (Arthington & Zalucki, 1998)
- (Tharme, 2003)

Name and Reference	**Type**	**Spatial focus**	**Confidence**	**Investment**
Range of Variability Approach (Richter et al, 1997)	Hydrological	Catchment	Low	Low
Flow Events Method (Stewardson & Gippel, 2003)	Holistic / Hydraulic	Reach – Catchment?	Medium	Medium
WAMP Benchmarking Methodology See: (Tharme, 2003) and (Whittington, 2000)	Holistic	Catchment	Medium	Medium
DRIFT (King et al, 2003)	Holistic (Best Practice)	Reach – Catchment?	Medium – High	Medium – High
MFAT (Young et al, 2003)	Holistic?	Catchment	Medium	Medium
Ecological models	Modelling	Reach – Catchment?	Medium – High	High?
Physical / Chemical models (Brizga, 1998) (Letcher et al, 2002)	Modelling	Catchment	Medium – High	High?

Any results from an environmental flow assessment should be treated as hypotheses only. All outputs (predictions and recommendations) should explicitly acknowledge their degree of uncertainty. As research continues, new data and models will allow a more reliable assessment of flow regimes.

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