Impact assessment tools for determination of environmental flows in water resource planning

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ABSTRACT: Environmental impact assessment approaches are useful in water planning and environmental flow determination to identify water resource development and remediation strategies that meet multipurpose requirements for consumptive use and for environmental protection. Impact assessment tools introduced here (the development and remediation framework for water resource planning, the cause-effect relationship for development pressures and bio-physical condition, and the double field pressure-effect-impact matrix) will help water planners and managers to understand how a stream's bio-physical condition is affected by water resource and other development pressures, to predict the suitability of various water resource development or remediation scenarios in meeting flow or non-flow related objectives, and to define indicators and criteria to be used in performance monitoring.

1 INTRODUCTION

Water resource planning policies and practice in Australia, like many other countries, now recognise the environment as a legitimate water user, defining water allocations both for consumptive use and for environmental purposes (see Arthington & Pusey 2003, Brizga et al. 2002, Naiman et al. 2002). Provision of water for the environment (environmental flows) attempts to redress alterations to natural river flow regimes and other threats to river ecosystem health resulting from water resource development (e.g. impoundments, flow supplementation, water extractions) and other development pressures in and adjacent to watercourses (e.g. urbanisation, infrastructure encroachment, channel modifications). River flow regimes are key drivers sustaining the biological diversity and ecological integrity of rivers, wetlands, estuarine and near shore marine environments (Poff et al. 1997, Bunn & Arthington 2002). The object of providing environmental flows is to sustain the ecological values of aquatic ecosystems at an acceptable level of risk.

Water resource planning strategies to meet multipurpose requirements of water for consumptive use and the environment are, in effect, environmental impact assessment studies that examine present water resource development and future water management scenarios from bio-physical, socio-cultural and economic perspectives. To determine environmental flows in the context of the whole river ecosystem, and to predict the manner in which various water resource development or remediation scenarios may further impact ecological values, water planners need to understand how a stream's bio-physical condition is presently affected by water resource and other development pressures. Impact assessment approaches can be used effectively here.

Environmental flow determination for water resource planning in Queensland, Australia uses the Benchmarking Methodology (Brizga et al. 2002), a whole of system (holistic) approach that establishes relationships between water resource and other development pressures and the geomorphological and ecological condition of the entire waterway from source to sea. The Benchmarking Methodology defines condition indicators for flow (hydrological statistics) and how water is taken, and using risk assessment and conceptual link models (based on literature and professional experience), assesses the performance of various environmental flow scenarios by examining the ecological implications of different levels of departure of the flow indicators from natural values. The link models depict relationships between flow indicators (and other environmental factors) and riverine ecosystem components and functions, and describe interactions between the various ecosystem components. The risk assessment models provide a means of relating risk of ecological impacts to quantitative measures of flow regime change (flow indicators), and form the basis for setting targets for achievement of environmental flows (Brizga et al. 2002).

This paper introduces several other impact assessment tools, which we believe will augment the Benchmarking Methodology and assist water resource planning and environmental flow determination. The proposed development and remediation framework and associated cause-effect relationships for water resource and other developments show the sequence of human-environment interactions that relate water planning and management to bio-physical impacts on streams. The double field pressure-effect-impact matrix relates water resource and non-water resource development pressures to bio-physical impacts, through condition indicators for flow and how water is taken.

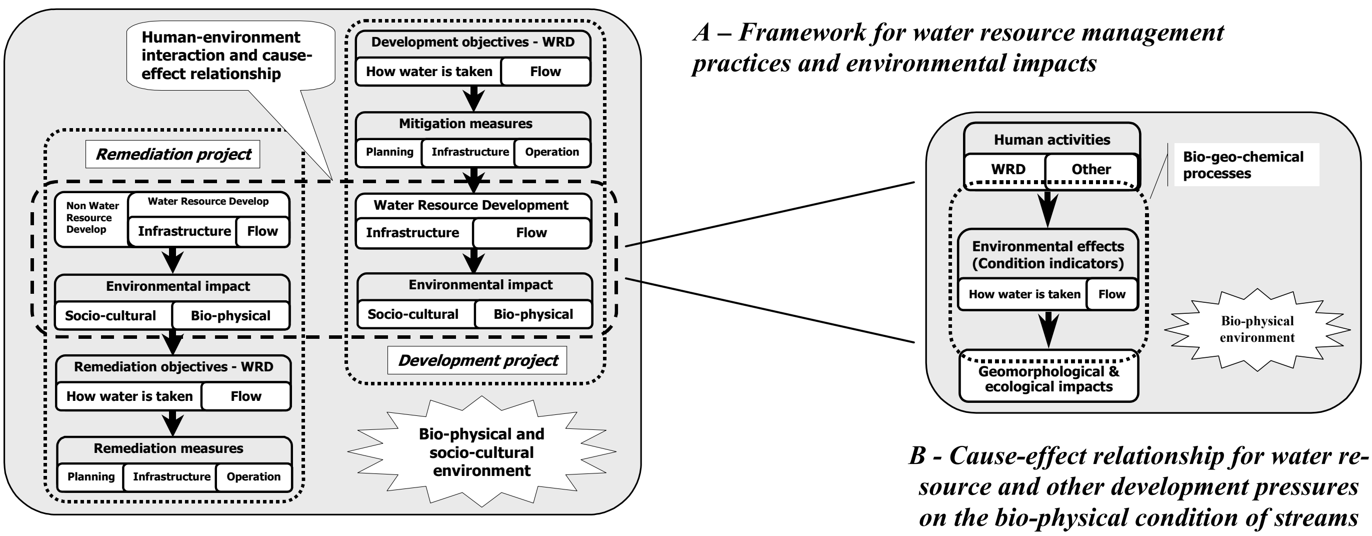
2 WATER RESOURCE DEVELOPMENT, REMEDIATION AND MANAGEMENT

Water planning and provision of water for the environment, like other areas of sustainable resource management, may encompass mitigation of impacts to protect riverine ecosystems in new water resource development projects, or remediation of degraded ecosystems through restoration of flows in existing schemes (Naiman et al. 2002). Figure 1 (after Kapitzke 2003) shows a development and remediation framework for water resource planning, which links the sequence of human activities, environmental impacts, development and remediation objectives, and mitigation and remediation measures within the context of the bio-physical and socio-cultural environment. The following discussion illustrates the framework components and introduces a formal process to document and assess cause-effect relationships that are central to this form of human-environment interaction.

A remediation project (e.g. irrigation area rehabilitation) usually starts with identified environmental impacts (bio-physical – e.g. wetland habitat degradation; or socio-cultural – e.g. inundation of road), which have resulted from existing water resource development (e.g. dam construction, water harvesting), or from non-water resource development pressures (e.g. urbanisation, invasion of exotic species). Remediation objectives relating to flow (e.g. reinstate seasonality), and how water is taken (e.g. reduce habitat inundation) are then addressed through remediation measures for planning (e.g. identify redundant impoundments), infrastructure (e.g. provision for fish passage), and operations (e.g. flow release timing, blue-green algae management).

On the other hand, a new water resource development project (e.g. water for agriculture or township) starts with a need or aspiration, and development objectives related to flow (e.g. capture flood flows) and how water is taken (e.g. draw water from variable level intake). Mitigation measures relating to planning (e.g. water use efficiency), infrastructure (e.g. offstream storages), and operations (e.g. emulating natural water levels) may be embodied in the adopted water resource development infrastructure (e.g. flood harvesting storage) and flow regime (e.g. storage release strategies for improved water quality). Nevertheless, some environmental impacts will remain (bio-physical – e.g. degraded riparian vegetation; or socio-cultural – e.g. loss of agricultural land), and these in turn may require remediation.

The central zone on the framework diagram (Fig. 1A) depicts the fundamentals of human-environment interactions, where human activity and the bio-physical and socio-cultural environment intersect, resulting in some form of bio-physical or socio-cultural impact. The cause-effect relationship diagram (Fig. 1B) links human activities (water resource – e.g. dam construction; and other development – e.g. urbanisation) with bio-physical impacts (e.g. altered sediment processes, change in riffle macrophyte abundance, loss of fish species) by way of environmental effects relating to flow and how water is taken (e.g. changes in total flow volume, barriers to fish migration).



A – Framework for water resource management practices and environmental impacts

B - Cause-effect relationship for water resource and other development pressures on the bio-physical condition of streams

Figure 1. Development and remediation framework and cause-effect relationship for water resource planning

Water planners and managers must understand these interactions to meet multipurpose requirements for human use and protection of environmental processes and function in water resource remediation or development projects.

3 LINKING PRESSURES, CONDITION INDICATORS & BIO-PHYSICAL IMPACTS

As the bio-physical condition of streams is affected by flow and non-flow related pressures, a major challenge in water planning and the determination of environmental flows is to separate impacts related to modified flow regime from impacts associated with how water is taken and other development pressures (Brizga et al. 2002). Several interrelated causal mechanisms operate over different temporal and spatial scales, and it is often difficult to determine which attributes of an altered flow regime or other forms of human intervention are directly responsible for observed or predicted impacts, and the ecological condition of a stream. Environmental impact assessment (EIA) tools such as matrices are beneficial here to scope human-environment interactions and to understand cause-effect relationships. A double field matrix based on the Sanchez & Hacking (2002) activity-aspect-environmental impact model can be used to evaluate pressures (human activities), bio-physical impacts and their causes from an holistic or synoptic perspective, and to help identify appropriate mitigation or remediation measures.

Table 1 is an abridged version of the double field pressure-effect-impact matrix, which depicts the relationship between water resource and other development pressures and bio-physical impacts on the stream. It introduces the notion of environmental effects, which are processes set in motion or accelerated by human actions (e.g. altered flow regime). Whereas Table 1 deals only with hydrological [flow related] effects (e.g. total flow volume, seasonality, zero flows, low flows, high flows, floodplain flows), a more complete double field matrix could include non-flow related effects and associated condition indicators dealing with how water is taken (e.g. water level variations, water quality, habitat inundation, wetland quality, fish barriers).

The left-hand field of the matrix shows flow related environmental effects associated with water resource development (e.g. dams, weirs, water harvesting) and other catchment development pressures (e.g. grazing, forestry, urbanisation). The matrix can be expanded to include riparian (e.g. encroachment, exotic species invasion) and instream development pressures (e.g. river works, aggregate extraction), which will primarily affect stream bio-physical condition through non-flow related effects.

The right-hand field shows how bio-physical impacts relate to particular flow related environmental effects. Table 1 limits this relationship to a selection of bio-physical impacts that includes geomorphology (e.g. altered channel morphology), hydraulic habitat (e.g. altered longitudinal connectivity), terrestrial vegetation (e.g. riparian zonation change), aquatic invertebrates (e.g. lotic species community change), and fish (e.g. flood spawners community change). These impact categories can be expanded to encompass other ecosystem components including subsurface water, water quality, aquatic vegetation, and water dependent vertebrates. Similarly, expansion to include non-flow related environmental effects would more completely present the relationship between development pressures and impacts.

Each pressure may cause one or more effects, and each effect may have one or more impact. A three level ranking, showing *pressure-effect* and *effect-impact* relationships as very important, important, and minor, defines links between pressures and impacts, and identifies significant pathways via flow (and non-flow) related environmental effects. Each environmental effect has an associated condition indicator for flow and other impacts (e.g. flow volume in ML/year, water level variation in metres/day) that provides a measure of how stream condition is presently affected by water resource and other development pressures. The condition indicator can also be used in setting targets for environmental condition and monitoring performance under various water resource development or remediation scenarios.

4 ENVIRONMENTAL FLOW OBJECTIVES & WATER MANAGEMENT MEASURES

The development and remediation framework for water resource planning, the cause-effect relationship for pressures and condition, and the double field pressure-effect-impact matrix will assist in the strategic water planning process and in operational water planning and management. Water planners and managers can use the relationships developed through these impact assessment tools to establish appropriate water management measures to meet various flow or non-flow related objectives, and in the definition of indicators and criteria for use in monitoring performance against these objectives. The double field pressure-effect-impact matrix can also provide a formal basis for the development of detailed conceptual models to illustrate how various water resource and other pressures affect the waterway-riparian-estuarine ecosystem by way of the various types of flow regime change (or other environmental effects).

Table 1. Abridged double field pressure-effect-impact matrix showing impacts of water resource and other development pressures on geomorphological and ecological condition of streams (example pressures and impacts and indicative relationships only)

Pressures - Human activities									Environmental effects (Condition indicators)	Geomorphological and ecological impacts on streams																	
Water resource development					Catchment development					Geomorphology			Hydraulic habitat			Terrestrial vegetation			Aquatic invertebrates			Fish					
Dam	Weir / barrage	Low flow extraction / diversion	Water harvesting	Supplementation	Grazing	Cropping	Forestry	Urbanisation	Hydrological effects - Flow related	Altered channel morphology	Altered sedimentation processes	Altered channel-floodplain processes	Change in timing & extent of wetting	Altered hydraulic diversity	Altered longitudinal connectivity	Zonation change for riparian species	Community change for riparian species	Community change for floodplain species	Community change for obligate lotic species	Community change for aerial species	Community change for estuarine / marine	Community change for flood spawners	Community change for low flow spawners	Community change for estuarine / marine			
◆	✡	✡	◆	✡	✡	✡	✡	✡	Total flow volume	✦	✦	✦		✦	✦	■	■	■	■		■	■	■	■			
◆	✡	✡	◆	✡					Annual variability	✦	✦	✦		✦	✦	■	■	■	✦	✦	■	■	✦	■			
◆	◆	✡	✡	◆	✡	✡	✡	✡	Seasonality		✦		■		✦	✦	✦	✦	✦	✦	✦	■	✦	■			
◆	◆	✡	✡	◆		✡		✡	Zero flows		✦		■	■	■	✦	✦	✦	✦	✦	✦	✦	■	✦			
✡		◆	◆	◆	✡	✡	✡	✡	Low flows	✦	✦		■	■	■	✦	✦	✦	■	■	■	✦	■	✦			
◆			◆						High in-channel flows	■	■	✦	✦	✦		✦	✦	✦	✦	✦	✦	■	■	■			
◆	✡		◆		✡	✡		✡	Floodplain flows	✦	✦	■	✦	✦	✦	✦	✦	■	✦		■	■	✦	■			

Legend						
	◆	very important effect	✡	important effect		minor effect
	■	very important impact	✦	important impact		minor impact

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