

Chapter 4

Design of field sampling program

4.1 Introduction

Flowing aquatic ecosystems provide a host of unique challenges and considerations for the design of monitoring programs to detect responses to management interventions (Downes *et al.*, 2002). They face a complex array of direct and indirect stresses, operating over a range of temporal or spatial scales, resulting from man's growing use of water resources. In the Murray-Darling Basin, most rivers are flow-regulated (Sheldon *et al.*, 2000) and are subject to a range of management actions aimed at maintaining or improving their ecological condition (Likens *et al.*, 2009). Management decisions for these river systems are increasingly being made in an adaptive framework, whereby future interventions are based on outcomes from previous ones. This approach provides one of the best mechanisms for ensuring that decisions are defensible and based on best-available knowledge, yet must be underpinned by well-designed monitoring programs if it is to succeed.

Impacts or interventions at an upstream point in a river system will potentially influence downstream reaches over a considerable distance. Yet, in dryland areas, riverine ecosystems tend to behave less in a unidirectional, longitudinal fashion (e.g. Vannote *et al.*, 1980; Cummins *et al.*, 1995) than in a highly temporally-variable manner driven both by the prevailing flow regime and lateral connections between channels and their surrounding floodplain (Young & Kingsford, 2006). This adds further complexity to the monitoring requirements for detecting responses to flow or other events which may be short-lived or whose influence may be highly patchy or occur over an uncertain area or timeframe.

Robust monitoring programs for environmental flow events in dryland river systems need to carefully consider the range of ecosystem components and how each might respond to the anticipated hydrology. Understanding the temporal and spatial scales over which these biota and physico-chemical process function, as well as the likely scales of the 'impact' of interest, is particularly important, and allows a critical matching of indicator variables to the specific study objectives or questions. This information can be derived from prior ecological data on the ecosystem, species, populations or assemblages of interest, or through existing stakeholder knowledge of how the ecosystem may respond. The natural heterogeneity or patch dynamics is also critical, and will assist in the location of study sites, choice of sampling methods, and the scale of sampling units.

In this chapter, we outline the broad principles used in the design of our field sampling program, both in a spatial and temporal sense. We also summarise the rationale behind our choice of ecological parameters in both the in-stream and floodplain wetland components.

4.2 Choice of study watercourses and spatial sampling design

Channels across the Lower Gwydir floodplain comprise a number of westerly-flowing streams, all derived from the Gwydir River within 50 km of Moree. They form a considerable delta system of channels of varying sinuosity, and end in either terminal wetlands (e.g. Gwydir River, Gingham Watercourse) or confluences with the adjacent Border Rivers and Barwon-Darling catchments (e.g. Mehi River, Carole Creek). Aquatic habitat in some older channels is now restricted to isolated floodplain lagoons of varying permanence (e.g. Baroona Waterhole) which connect during significant local rainfall or flooding events. Choice of study channels for the present study was primarily governed by four criteria, namely study objectives, flow regulation, current water use, and access for sampling. These characteristics were reviewed for five Lower Gwydir channels as well as the floodplain lagoons to the north of the Gingham Watercourse (Table 4.1).

As the overarching aim of the study was to provide a stronger understanding of aquatic responses to environmental flow releases, we concentrated our study sites around the Gwydir River and Gingham Watercourse where ECA flows are currently released. They also provided numerous suitable reaches for the study's in-stream component, although access to some areas was anticipated to be difficult following overbank flooding or heavy local rainfall. Despite the presence of numerous in-stream regulating structures in both channels, potential study reaches could still be identified away from their direct influence. There was also a choice of telemetered flow gauges in each channel for access to data on recent hydrological history.

The prior history of research on Lower Gwydir wetland vegetation also influenced our decision to focus on the Gingham Watercourse and Gwydir River portions of the floodplain. Research on the responses of floodplain vegetation to flow variability using a series of grazing exclosures established by the University of New England in 1994, was a key factor in site selection. The four sets of exclosures were split evenly between wetlands along the two channels, and provided a unique opportunity to extend the existing 12-year data set. The remainder of our investigation of vegetation responses examined individual ECA events into the Gingham Watercourse and Gwydir River from 2007 to 2008.

In studies of this nature, the strongest causal inferences of ecological response to a particular environmental signal are possible when 'impact' sites are compared with unimpacted 'control' sites. We wished to be able to characterise responses to flow events in the Gwydir River and Gingham Watercourse through comparison with control sites where similar species or assemblages hadn't been subject to comparable flow conditions. As ECA flows or any in-stream responses to these were likely to be transmitted along much of the two 'impact' channels, our control sites needed to be selected in parallel channels or floodplain lagoons. Accordingly, our choice of control channels and wetland areas was largely governed by whether or not they were likely to receive managed flow events at the same time as ECA events in either the Gingham Watercourse or Gwydir River. Options included the Carole and Moomin creeks, the Mehi River and floodplain lagoons. These three channels are all subject to managed flow releases although largely just for irrigation and stock and domestic flow purposes, and were likely to be broadly similar to the two impact channels in their geology, elevation, slope, water chemistry and aquatic species. The Carole Creek and Mehi River were deemed the most suitable of these for reasons of riparian condition and site access. For logistical convenience, the Mehi River was chosen due to its closer proximity to the Gwydir River and Gingham Watercourse sites.

Table 4.1. Regulation and water-use characteristics of Lower Gwydir floodplain watercourses and the associated advantages and disadvantages for the location of sites in the present study.

Watercourse	Regulation structures	Current water uses	Advantages	Disadvantages
Carole Creek	Booloroo Weir off Gwydir River and associated regulator.	Stock and domestic supply Irrigation throughout.	Potential sites in apparent good in-stream and riparian condition. Good flow gauging. Potential as a control stream – unlikely to receive flows during periods of ECA release elsewhere.	Reduced significance for terminal wetland areas.
Gingham Watercourse	Tyreel Weir. Numerous rock crossings. Constructed offtake channels in lower reaches. Leveed banks in many areas.	ECA releases. Stock and domestic supply. Irrigation in upper reaches.	Ramsar-listed and other extensive wetlands. Reasonable access throughout most reaches. Good flow gauging in upper and middle reaches.	Degraded riparian areas in many areas. Potentially difficult access throughout wetland areas following overbank flows.
Gwydir River (Big Leather)	Tareelaro Weir. Booloroo Weir. Tyreel Regulator. 'Keetah' Weir. 'Cooma' Weir. Numerous rock crossings. 'Wandoona' drop-board weir.	ECA releases. Stock and domestic supply. Irrigation in upper and middle reaches.	Ramsar-listed and other extensive wetlands. Reasonable access to most reaches. Good flow gauging in upper and middle reaches. Potential sites in apparent good in-stream and riparian condition.	Potentially difficult access throughout wetland areas following overbank flows.
Mehi River	Tareelaro Regulator. Moree Weir. Combadello Weir. Smaller structures at offtakes to creeks such as Mallowa Creek.	Stock and domestic supply. Irrigation in upper and middle reaches.	Reasonable access to most reaches. Potential sites in apparent good in-stream and riparian condition. Good flow gauging. Potential as a control stream – unlikely to receive flows during periods of ECA release elsewhere.	Reduced significance for terminal wetland areas. Degraded riparian condition in some downstream reaches.
Moomin Creek	Regulators off Mehi River. Numerous rock crossings.	Stock and domestic supply.	Potential future Ramsar listing of nearby wetlands. Some sites in apparent good in-stream and riparian condition. Some flow gauging. Potential as a control stream – unlikely to receive flows during periods of ECA release elsewhere.	Degraded riparian condition in many areas. Uncertain flow regime throughout study period. Difficult access in many areas. Reduced significance for terminal wetland areas.
Floodplain waterholes	Rock crossing inbetween Baroona and Tillaloo waterholes.	Stock watering.	External control sites above flow height of nearby main watercourses.	Reduced flooding incidence may lead to total drying. Limited (if any) flow gauging. Potentially difficult access to some points.

The floodplain lagoons to the north of the Gingham Watercourse connect during significant overland flows, either from flooding from Carole Creek and/or the Gingham Watercourse or from heavy local rainfall events, and offered a further set of control sites. These were also unlikely to receive flows at the same time of ECA events and were also selected for their proximity to the Gingham/ Gwydir study channels. In early 2006, these waterholes were filled beyond their sill height by rainfall-generated overland flow. They did, however, have the disadvantage of not being the subject of any direct flow gauging and their potential to dry out entirely during the study interval without further inflows.

For monitoring the responses of wetland vegetation to ECA events, 'impact' sites were selected in areas where it was anticipated that inundation would occur from an ECA flow. Control sites were selected outside this influence, either beyond the inundation in the same wetland complex or else in another Lower Gwydir wetland complex nearby. In both ECA events monitored in this way, it was anticipated that ECA flows would not reach all parts of the target wetland complex for a variety of reasons including insufficient flow volume, the presence of diversion structures or upstream 'losses' onto the floodplain. We countered this likelihood by selecting sites in an east—west gradient along the channel(s) where ECA flows were to be delivered, to ensure that at least some impact sites would be inundated. In the case of the grazing-exclosure vegetation monitoring sites, control sites where grazing was unrestricted had already been built into the experimental design in 1994. Other details of the spatial arrangement of vegetation sampling units (transects, quadrats) are given in chapters 5 and 6.

For the in-stream study component, we also established sampling over an east—west gradient, particularly to ensure that any downstream shifts in water chemical load or assemblage structure could be characterised. Three sites were selected over the accessible length of the Gwydir River and Gingham Watercourse and a comparable length of the Mehi River. Further details of the positioning of these sites and the spatial arrangement of sampling units are given in chapter 7.

4.3 Temporal design – sampling specific flow events

The Lower Gwydir floodplain receives surface flow from both regulated and unregulated flow events as well as local rainfall, all of which may have a significant local influence on the ecology of the various channels or floodplain wetlands. Nevertheless, each of these water sources will invariably result in differing hydrograph characteristics in the Lower Gwydir channels, including parameters such as the timing, height, velocity, duration and rates of rise and fall of individual pulses. They will also differ in their availability for abstractive use and so both hydrology and human use will determine the extent to which individual events are likely to reach the western end of the channels and wetland areas.

Given our overarching objective of characterising ecological responses to environmental water releases, we focussed our sampling schedule around a series of planned ECA events, from December 2006 to November 2007. In isolation, these flows are less likely to be lost to agricultural use than natural flows which may still be subject to off-allocation access. As such, these releases are also unlikely to be subject to loss of any ecological response (e.g. nutrient release, drifting larval fish or zooplankton) from the channels. The hydrological characteristics of these releases (e.g. timing, velocity, duration) are also more predictable, which facilitates the planning of associated field work. Nevertheless, ECA releases can be

made to partially compensate for the loss of volume from off-allocation harvesting of natural flows. In these cases, it may be difficult to discriminate any ecological responses to the ECA release from those due to the prior natural flows.

The intent of this study was to include monitoring before and after ECA releases at both 'impact' sites exposed to these events and control sites either not subject to ECA flows or unlikely to receive other flows at the same time as the Gwydir River or Gingham Watercourse. This allowed us to reference any responses to an event against the conditions in the channel or wetland that existed prior to the release as well as against nearby comparable areas or populations. For in-stream work, we aimed to sample sites at the beginning of each field season, prior to a release, and then following the release. However, sampling at the beginning of the season was delayed in 2007 and 2008 due to rainfall and local flooding, and our first sampling was either prior to the ECA release (November 2007) or shortly after a natural flow (December 2008). For the monitoring of floodplain vegetation, sampling was also structured around ECA releases, both within the grazing exclusion sites and in other parts of the study. For each ECA release monitored for vegetation responses, fieldwork was undertaken shortly before the release and twice following the release over a 3–4 month interval.

4.4 Choice of response variables

Dryland river ecosystems such as the lowland portion of the Gwydir catchment comprise a wide range of biotic components, all with specific lifehistory adaptations to flow variability over a range of spatial and temporal scales (Walker *et al.*, 1995; Puckridge *et al.*, 1998; Bunn & Arthington, 2002; Downes *et al.*, 2002). In geomorphological terms, they include 'aquatic patches' from the river channel itself, to features such as in-channel benches or anabranches and various floodplain wetland types. Biotically, they include components such as bacteria, fungi and algae that form the basis of aquatic food webs and undertake critical nutrient processing (Finlay *et al.*, 1997), macrophytes and riparian plants (e.g. Blanch & Walker, 1997), various invertebrate groups (Marshall *et al.*, 2006), fish (Gehrke *et al.*, 1995; Humphries *et al.*, 1999; Arthington *et al.*, 2005; Wilson & Wright, 2005; Balcombe *et al.*, 2006; Grownns *et al.*, 2006; Grownns, 2008) and waterbirds (Roshier *et al.*, 2002). For some of these, relationships between population abundances or community structure and the extreme levels of flow variability within these catchments remain complex and incompletely understood. By contrast, other biota or specific population processes are known to provide useful and measurable insights into the ecological functioning of varying flows for these river systems.

Choice of response variables in any ecological study should be based on a range of criteria, from logistical and technical points to issues concerning the specific ecological or taxonomic objectives. The key aim of the present study, to determine ecological responses to environmental flows into the Lower Gwydir floodplain, meant that parameters needed to be capable of demonstrating responses at the temporal scale of individual flow pulses and spatial scales smaller than individual channels as well as between channels. The range of potential biotic variables and parameters is summarised in Table 4.2. In distilling this list down into a suite of variables and parameters for the present study, we considered a range of factors including:

- stakeholder views;
- technical issues in relation to field sampling and/or laboratory processing;

Table 4.2 Potential aquatic ecosystem variables for use in the present study and their past use as indicators of ecological response to flow variability on the Lower Gwydir floodplain. Continued overpage.

Variable	Potential parameters	Past use in region	Existing data or knowledge	Potential advantages	Potential disadvantages	Recommended for this study?
Water chemistry	pH Dissolved oxygen Temperature Turbidity Conductivity Suspended solids Dissolved organic carbon Phosphorus and nitrogen	NSW Integrated Monitoring of Environmental Flows	Sampling and analytical methods well established. Some data available from Lower Gwydir and nearby catchments.	Public awareness. Relatively rapid responses to flow variability. Ease of sample collection.	Potential logistical difficulties with sample filtration and storage in the field. Expensive laboratory analyses.	All.
Sediment	Particle size composition	None known.	None known.	Potential indicator of bank instability and channel siltation. Potential transport mechanism for nutrients.	Potential logistical difficulties with sample storage and transport from the field. Time consuming laboratory analyses. Response to flow variability potentially over time frames > the study period.	None.
Algae	Chlorophyll a. Diatom cell abundance and taxonomic composition. Pelagic cell abundance and taxonomic composition. Benthic algal biomass and taxonomic composition.	NSW Integrated Monitoring of Environmental Flows	Limited available from Lower Gwydir channels.	Base of aquatic food webs. Public awareness. Relatively rapid responses to flow variability.	Potential logistical difficulties with sample filtration and storage in the field. Expensive time-consuming laboratory analyses.	Chlorophyll a.
Macrophytes	Shoot density. Taxonomic composition. Seedbank germination.	NSW Integrated Monitoring of Environmental Flows	Limited available from Lower Gwydir channels.	Key structural component for aquatic ecosystems. Potential rapid response to flow variability.	Logistical difficulties with sampling over appropriate spatial scales.	As part of floodplain/wetland sampling.
Floodplain vegetation	Species composition, abundance and biomass. Seedbank emergence.	NSW Integrated Monitoring of Environmental Flows. Past UNE studies.	Historical data sets from long-term monitoring sites (UNE). Established grazing-exclusion plots (UNE). NSW government monitoring program.	Key structural component for floodplain ecosystems. Public awareness. Management focus. Availability of historic data sets and long-term monitoring sites. Relatively rapid response to overbank flows.	Logistical difficulties with sampling over appropriate spatial scales.	All.

Table 4.2 continued.

Variable	Potential parameters	Past use in region	Existing data or knowledge	Potential advantages	Potential disadvantages	Recommended for this study?
Bacteria	Taxonomic composition. Enzyme (metabolic) activity. Abundances.	None known.	None known.	Base of food web.	Considerable laboratory effort and prior expertise required.	None.
Zooplankton	Abundances and taxonomic composition.	Limited data from egg-bank emergence experiments.	Limited available from the Lower Gwydir floodplain.	Key food web component. Relatively rapid response to flow variability. Capacity to investigate floodplain inundation history and regenerative capacity through eggbank experimentation.	Considerable laboratory effort and some prior expertise required. Spatial patchiness in populations could mask temporal patterns.	All.
Macroinvertebrates	Abundances and taxonomic composition. Size structure (e.g. shrimps).	NSW Integrated Monitoring of Environmental Flows. MDB Sustainable Rivers Audit.	Some past data available, although many samples reportedly still require sorting.	Public awareness. Some past data available. Key food web component. Relatively rapid response to flow variability.	Considerable laboratory effort required. Spatial patchiness in populations could mask temporal patterns.	None.
Amphibians	Abundances and taxonomic composition. Spawning activity.	NSW Integrated Monitoring of Environmental Flows.	Limited available from the Lower Gwydir floodplain.	Public awareness. Relatively rapid response to flow variability.	Considerable field effort required.	None.
Fish	Abundances and taxonomic composition. Spawning activity. Size structure.	Limited sampling by NSW Fisheries, and for the MDB Sustainable Rivers Audit.	Limited information available through NSW DPI.	Public awareness. Minimal laboratory effort required, apart from otolith analyses of spawning timing. Potentially rapid response to flow variability in spawning activity.	Moderate field effort required.	Abundances and taxonomic composition. Size structure.
Turtles	Abundances and taxonomic composition. Size structure.	None known.	None known.	Public awareness. Low field effort – sampled incidentally during fish sampling. No laboratory effort required.	Unknown short-term responses to flow variability – some species will potentially relocate overland to sites with more favourable flow conditions.	Species composition, abundance and size-structure as incidental catch during fish sampling.

- whether the parameter was likely to show a response to flow events at realistic temporal and spatial scales;
- whether there was already sufficient understanding of the nature of any link with flow variability in the Lower Gwydir; and
- availability of long-term data sets upon which we could build.

We also used our conceptual model as a guide to the likely response of particular variables or parameters.

Water chemistry, water quality, algae. We included a range of physico-chemical parameters in our monitoring, ranging from those typically measured by hand-held meters, as well as other parameters such as suspended solid load, nitrogen, phosphorous, and dissolved organic carbon. Along with chlorophyll a concentration, the latter parameters provide an indication of the short-term availability of nutrients and pelagic primary productivity. Data on some of these parameters have previously been collected in the Lower Gwydir in relation to flow variability by programs such as the NSW Integrated Monitoring of Environmental Flows. However, they are simple to collect in the field and we had good access to laboratory capacity for processing the appropriate field samples.

Invertebrates. The NSW integrated Monitoring of Environmental Flows program has a 2–3 year series of aquatic macroinvertebrate samples, collected to analyse Lower Gwydir wetland responses to flow variability (N. Foster, pers. comm.). At the outset of our study, these samples were still being processed. Aquatic macroinvertebrate samples can also be time consuming to process. For these reasons, we decided not to collect further data on these assemblages. However, data on microinvertebrate responses to flow variability in the Lower Gwydir are unavailable, although the techniques for their field collection and subsequent laboratory processing are comparatively simple. For this reason, we included monitoring of these assemblages in the present study. Any responses to flow variability by microinvertebrates were also anticipated to occur at the temporal scale of our fieldwork.

Our sampling method for fish (fyke nets, chapter 7) also incidentally sampled macrocrustacea such as *Cherax destructor* yabbies and *Macrobrachium* shrimps, and so we included their abundances as further invertebrate parameters.

Fish. Although some data are available on the fish assemblages in the Gwydir catchment, few data were available on the Lower Gwydir channels and no responses to flow variability have been reported. Sampling methods for fish in these dryland river systems are well established (e.g. Arthington *et al.*, 2005; Balcombe *et al.*, 2006), and samples are relatively easy to process in the field. Moreover, any responses to flow variability are likely to be detectable at the spatial and temporal scales at which we could monitor. For these reasons, we included monitoring of fish abundance, species diversity, and size-structure. This complemented parallel studies of the influence of flow variability on fish early growth and condition in Lower Gwydir channels (Heagney *et al.*, 2008; Wilson *et al.*, submitted).

Wetland plants. The NSW integrated Monitoring of Environmental Flows program has also collected data on wetland plant assemblages in the Lower Gwydir wetlands, and maintenance of the core terminal wetland areas is one of the key objectives for which Lower Gwydir ECA releases have been made (NSW DIPNR, 2005a; NSW DECC, 2008). One of the key drivers for these releases is also maintenance of the ecological character of the four privately-managed Ramsar wetland sites. Given these management priorities, we included wetland vegetation in the present study. Furthermore, UNE researchers commenced a

monitoring program on Lower Gwydir wetland plants in 1994, and this provided an opportunity for us to extend an existing data set to gain a unique medium-term perspective on responses to flow variability. These data were collected from a mix of fixed monitoring points and a series of grazing-exclosure sites spread between the Gwydir and Gingham wetland areas. Field methods are also well established for floodplain vegetation (e.g. Reid & Quinn, 2006; Alexander *et al.*, 2008), and any responses are likely to be detectable at the spatial and temporal scales at which we could monitor. We included variables such as the percent cover of species, species composition, and germinant abundance, complementing a parallel study on the Lower Gwydir wetland soil chemistry and seed-bank emergence (Wilson *et al.*, 2008).