Design of Water Quality Monitoring Programs and Automatic Sampling Techniques

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SUMMARY: An important means of characterising the health of streams is through the measurement of the sediment and nutrient fluxes that they transport. Cost effective and targeted water quality monitoring programs are required to properly quantify both the total loads and temporal distribution of these fluxes at catchment scales. Careful analysis of data from such programs ensures ameliorative efforts to reduce the biological, chemical and physical impacts of high loads are targeted to have the best effect.

This paper reports on the development of a monitoring program in tributaries of the upper Murrumbidgee River. The aim of the program is to provide data for the modelling of both nutrient and sediment loads transported from upland catchments. The objective of the modelling is to spatially identify sediment transport and storage dynamics together with source strength variations in upland catchments. A brief review of design considerations for water quality programs is made with reference to the Murrumbidgee case study. The tools, techniques and sites of an alternative monitoring program in tributaries of the upper Murrumbidgee River are detailed. Included in the paper are modifications to the design of Graczyk et al. (2000) for an inexpensive, rising-stage water quality sampler, suitable for Australian conditions and currently in use. The research demonstrates that water quality data can be collected simply and cost effectively if programs are appropriately designed.

THE MAIN POINTS OF THIS PAPER
- Water quality data spanning a range of hydrologic conditions are required for effective stream health management.
- Current water quality sampling programs are not providing data commensurate with investment.
- Better design of sampling programs and sample collection methods, for example the use of an inexpensive rising-stage samplers, can improve the utility of the data collected.
- The design of a rising-stage siphon sampler, modified for Australian conditions is presented.

1. INTRODUCTION
Monitoring stream water quality is an important tool for the quantification of the health of a stream. Effective water quality monitoring programs provide the basis to calculate loads of material exported from catchments including sediments, nutrients, pesticides and other pollutants. This information is important for effective siting of ameliorative effort and for associated research and modelling. Collection and analysis of water quality data is expensive. Unfortunately much investment in collection and analysis is ineffective in providing information to assist in reaching management outcomes.

Using the upper Murrumbidgee catchment as a case study this paper will demonstrate the inadequacies of present monitoring programs for estimation of total loads of sediments, nutrients and other pollutants. The paper will then describe a cost-effective alternative for the provision of high quality data for accurate load estimation. That part of the paper will show the design of an event based water quality sampling program and the use of low cost siphon sampling equipment in the Molonglo and Gudgenby Rivers of the Canberra region. Results from a prototype sampler and a discussion of the program will then be presented.

2. WATER QUALITY MONITORING: MURRUMBIDGEE CASE STUDY
The Murrumbidgee River catchment upstream of the Burrinjuck Dam is used as a case study for evaluation of stream water quality monitoring. The upland catchment has an area of 13,090km² and a population of approximately 390,000. There is growing concern over reduced water quality in the catchment, which is part of the Murray-Darling basin (Murrumbidgee Catchment Management Committee, 1998).

Water quality data is collected over the catchment by a variety of organisations for multiple purposes. Examples of the programs in place include:
- The NSW Department of Land and Water Conservation has funding of $1.6 million over six years for the unregulated parts of the Murrumbidgee River catchment (Nancarrow, pers com 2001). For the upper Murrumbidgee catchment, this represents an investment of approximately $95,238 per annum for physical and chemical water quality sampling and analysis.
- Environment ACT invests $25,795 in monitoring chemical and physical water quality of streams and rivers within the upper Murrumbidgee annually. A further $25,731 is invested in monitoring the water quality of the ACT urban lakes and $11,411 is spent on macroinvertebrate monitoring (Wilkinson, pers com 2001).

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• Environment ACT is improving the utility of the data they collect by shifting from a predominantly routine sampling program to include more event-based sampling.
• ActewAGL’s activities in water quality monitoring are primarily concerned with the provision of residential water supply to the Canberra region.
• The ACT Department of Health, Housing and Community Care has a water quality testing program in place to assess the quality of water for recreational purposes primarily in the urban lakes of the ACT.
• The National Capital Authority conduct water quality monitoring in Lake Burley Griffin and inflows. Their testing includes physical, biological and chemical analysis. Selected swimming sites are targeted with additional bacteriological sampling.
• The catchment is also an important study area for research by organisations that do not have direct management roles. A number of universities and organisations such as the CSIRO and Landcare collect water quality information in the catchment however, it is difficult to quantify their total investment.

Each of the organisations has a predominantly routine stream sampling program presently in place. Routine samples are collected at set intervals and generally take no account of the hydrologic or antecedent conditions. According to Letcher et al. (1999) less confidence may be placed on loads estimated using data with a wide sampling interval or a sampling interval that does not characterise flood events. Routine sampling is thus largely ineffective for the purposes of sediment and nutrient load estimation due to the predominance of sampling at low flow conditions. Only the prevailing ambient quality of a water body is determined by these means.

In summary, more than $150,000 is invested annually in water quality investigations for the catchment. The catchment has fewer than ten sites with data of an appropriate quality for effective estimation of sediment and nutrient loads. This is because of the generally routine sampling program in place and the fact that some sampling sites are not located in the vicinity of stream gauges. This result is unacceptable and alternate approaches are needed.

3. AN ALTERNATE APPROACH

The remainder of this paper illustrates potential methods available to overcome some of the methodological and design inadequacies of current water quality programs for the estimation of pollutant loads and assessment of stream health. This is approached by description of an alternate water quality sampling program at a scale and budget commensurate with a PhD study.

3.1 Aims and Objectives

Clear objectives for water sampling programs need to be established prior to commencement of sampling (Sanders et al., 1983). The aim of the program presented in this paper is to provide data for accurate calculation of loads of sediments and nutrients for testing SedNet - a landscape-based sediment and nutrient estimation model. A secondary aim of the program is to illustrate alternate sample collection methods and design of water quality programs.

The SedNet model has been developed to spatially identify transport and storage dynamics together with source strength variations of catchments, see Prosser et al. (in prep). Research into the structure and parameterisation of the SedNet model is in progress. Long-term estimates of sediment and nutrient loads are required to assess the accuracy of the SedNet model. To develop these estimates a function relating sediment and nutrient concentrations to flow will be developed from the data collected in this monitoring program. A long-term hydrologic record will be reconstructed using the IHACRES rainfall-runoff model calibrated for each site. Sediment and nutrient loads will then be calculated using the aforementioned function and long-term streamflow reconstruction. The testing of the SedNet model will be supplemented by geochemical tracing of materials, fieldwork and other spatial analysis. See Newham et al. (in prep) for a more detailed discussion of associated accuracy assessment and model sensitivity trials.

In the Australian context – a continent with highly variable rainfall and streamflow, there are two crucial design factors in the construction of water quality monitoring programs. These are the location of sampling stations (Sanders et al., 1983) and the type or frequency of sampling. The following sections consider these in turn.

3.2 Site Selection

For the program presented here sites for monitoring of water quality were selected based on the following criteria:

• it was necessary that sites be co-located with a continuously recording stream gauge. This was to ensure that streamflow could be determined at the time of sampling and hence loads calculated;
• it was preferable that sites were telemetered and access to this data was available. The reasons for this will become apparent in the following section, which discusses an event-based sampling regime;
• it was necessary that sites have vehicular access in wet weather;
• preference was given to sites close to Canberra; and
• it was preferable that sites be nested to investigate pollutant transport of individual river reaches.
A short list of catchments was then made. To ensure variety in physical characteristics, attributes such as topography, land use and preliminary results of a landscape based modelling exercise were considered in selection from this shortlist. Four sites were selected. A map showing the locations of the sites is shown in Figure 1. Fortunately with the cooperation of our industry partners we are able to access telemetered stream level data at or nearby each of the sites. This will enable timely collection of water quality samples.

3.3 Sampling Strategy

The sampling program is expected to run for a maximum of 18 months. For a program of this length it is suggested by Robertson and Roerish (1999) to have a combined event-based and monthly routine sampling. This has been established. Event-based sampling programs collect discrete samples throughout runoff events and comprise both rising and falling limbs of the stream hydrograph. The aim of event monitoring is to measure the water quality of a stream during or following a runoff-producing rainfall event. Rising stage conditions, in particular, are generally not sampled adequately with a manual-sampling program due to their rapid rise. In the Australian context, the rationale for the collection of samples during runoff events is that the majority of material is exported from catchments during these periods (Croke and Jakeman, 2001). The approach of our program is to collect rising stage samples using a siphon sampler (described in the following section); routine and falling stage samples are to be collected by manual ‘grab’ samples. The routine sampling program also enables maintenance of the samplers including removal of any fouling of the intake or sample collection bottles however, this has not been a problem to date.
4. RISING STAGE WATER QUALITY SAMPLER

Siphon samplers are low-cost alternatives to automatic mechanical samplers used to collect event-based water-quality samples. This section describes a rising-stage siphon water sampler. The design of the sampler was modified for Australian conditions from Graczyk et al. (2000). This new design of the sampler is shown in Figure 2. The approximate cost of each of the samplers is $60, mechanical automatic samplers are expensive generally priced from around $2000 (not including installation). The siphon samplers are easy to construct and secure instream using simple tools. The operation of the samplers is also simple. As water level rises to the elevation of the intake tube, water enters the 8mm-vinyl tube. As the stream continues to rise, water continues to move up the intake tube until it reaches the top of the loop; at this point a siphon is created and the bottle starts to fill. The sample collection bottle fills rapidly under a hydraulic head with displaced air escaping through the exhaust tube. Once full, changes in the water level do not significantly affect the contents in the bottle. Following an event, the bottles are collected and the contents analysed. Several samplers can be installed at different levels at each site to collect samples throughout the anticipated range in water levels with a bias toward high flows. Samplers were positioned at stream gauge sites with continuous monitoring of streamflow. Figure 3 shows the height of samplers marked on a stage height recurrence interval plot for each of the catchments of this study. Five samplers are installed at each site. At the site, the height at which each of the samplers takes a sample has been determined accurately using a dumpy level from marked stream gauge heights. By use of a rating curve, instantaneous streamflow at the time of sampling can be determined and this data used to calculate pollutant loads.

Figure 3: Stage height recurrence interval plots. The height of individual samplers are marked on the plots and labelled with their corresponding sampler number. Gauge numbers correspond to sites in Figure 1.
Unfortunately siphon samplers do not collect water samples when the stream stage is decreasing and therefore manual samples are required for analysis of the water quality during this period. Decreases in stage, however, are generally more protracted than increases in stage and can be adequately manually sampled (Graczyk et al., 2000). A simple comparison of the water quality data collected by mechanical automatic samplers and siphon samplers was made in the study of Graczyk et al. (2000). No systematic biases are evident in the comparison of data and the methods of that study suggests that variation in samples were predominantly due to timing of siphon and mechanical sampling.

A prototype of the sampler has been trialed successfully in the Sullivans Creek catchment of the ACT for a runoff event (see Figure 4). Lessons from the experience in the Sullivans Creek have led to some design modifications for Australian conditions and the sampling program presented here. These include:

- increasing the length of the intake loop to 150mm to increase the depth at which the sample is taken; this also has the desirable effect of decreasing the sample collection time resulting from the greater hydraulic head;
- securing the intake loop for a better estimation of the height at which a sample is taken thus reducing errors in corresponding estimation of streamflow;
- increasing the size of the collection bottle to 1L to allow a greater range of attributes to be analysed;
- adding a screw cap and coupling at each end to strengthen the unit and allow ease of access;
- strengthening of the intake and exhaust tube connections; and
- painting of the body of the sampler to protect from ultraviolet light deterioration and to assist in concealment.

Figure 4: Sample collected by the siphon sampler prototype in Sullivans Creek ACT following a streamflow event.

5. RESULTS OF SAMPLING
The samplers have been positioned in-stream since early March 2001; in this time there have been no significant streamflow events. As noted previously, the prototype sampler has successfully collected a single sample. Analysis of results for any events that occur prior to the Healthy Streams Conference (late August 2001) will be included in the associated conference poster.

6. DISCUSSION
The alternate program described in this paper is presented to stimulate improved methods of water quality sampling. The cost and importance of these programs necessitates that good quality data is collected, for the appropriate purposes, at the appropriate sites, over a sufficient range of hydrological conditions.

The alternate program presented here is a step towards better water quality sampling. The salient features of the program presented are:

- data are collected with a specified objective;
- sampling sites have been selected to achieve the objective of the program;
- rising stage samples are collected automatically;
samples that are to be collected will be of use; and
the program is cost effective.

A shortcoming of the alternate program is that falling stage water quality samples need to be collected manually. Research into the design of cost effective, simple falling samplers is continuing. The limitations to designing these devices are that they require a double trigger to start sample collection; they must be robust enough to be deployed in stream for long periods; they must be simple to construct from readily available materials; and they must be inexpensive to produce.

The variability of the Australian climate has been demonstrated in this study. To date no samples have been collected in the study catchments. This illustrates that samples collected as part of a routine program over this period would give information over only a very narrow range of hydrologic conditions. The implication is that there would be a high level of uncertainty in loads estimated from this routinely sampled data.

The only sample that has been collected as part of this study has been by the design prototype in a non-study catchment. The collection of that sample resulted in improvements to the design of the sampler that has made it more robust and reliable for installation in the field. Further improvements to the design of the sampler will stem from experience in the new catchments studied.

7. CONCLUSION

Water quality programs are necessary for the quantification of stream health and to improve research and extend our understanding of riparian systems and landscapes. However, programs presently in place in the upper Murrumbidgee catchment are not delivering results commensurate with investment. It is suspected that this may be the case over much of Australia.

This paper has described an alternate approach to the collection of water quality samples that attempts to overcome some of the design inadequacies of existing programs. It is hoped that through presentation of this paper that alternate approaches are sought for water quality collection within the Murrumbidgee River catchment and more broadly.

8. REFERENCES


