8. RIVER INPUTS OF NUTRIENTS

Discharges from rivers (Figure 6) constitute the major pathway for the transport of terrestrial and anthropogenic nutrients to waters of the central GBR. While watershed areas, daily flows and annual discharges from most of these rivers are reasonably well characterized (Table 3), relatively little is known regarding the temporal dynamics of nutrient speciation concentration variability and delivery in or from particular watersheds. Sampling to quantify nutrient fluxes from the major north Queensland rivers was initiated in 1987 (Table 20), with the sampling network being progressively expanded and temporally intensified since then.

Table 20. River sampling sites, sampling frequencies and analyses carried out.

River	Site	Frequency	Started	DIN	DON	PN/PP	S.S.	Chl
Barron	Lower	3 mo.	1989	+	+	+	+	1
	Estuarine	3 mo.	1989	+	+	+	+	1
Mulgrave	Lower	3 mo.	1988	+	+	+	+	1
	Estuarine	3 mo.	1988	+	+	+	+	1
Russell	Lower	3 mo.	1988	+	+	+	+	1
No. Johnstone	Lower	3 mo.	1988	+	+	+	+	1
So. Johnstone	Lower	Daily 1	1987	+	+	+	1	1
Tully	Upper	Monthly +	1987	+	+	+		
	Lower	Monthly +	1987	+	+	+	1	1
	Boulder Ck.	Monthly +	1987	+	+	+		
	Jarra Ck.	Monthly +	1987	+	+	+		
	White's X	Monthly +	1987	+	+	+		
	Banyan Ck.	Monthly +	1987	+	+	+	1	1
Murray	Lower	3 mo.	1987	+	+	+		
	Estuarine	3 mo.	1987	+	+	+		
Herbert	Yamani Falls	Daily 2	1989	+	+	+	+	+
	Abergowrie	Daily 2	1989	+	+	+	+	+
	Lower	Daily 2	1987	+	+	+	+	+

Seasonal flow patterns in all of the rivers sampled (e.g. Figure 34 Bottom) are characterized by substantial short-term variability associated with large and small flood events. The largest seasonal flow events are usually associated with the occurrence of cyclones or the monsoonal depressions following a cyclone. The intensity of seasonal flow variability from a particular watershed depends in turn on whether the cyclone directly affected that watershed and the amount of rainfall associated with particular storms. Over multi-decadal time periods, the frequency of cyclonic storms is highly variable and likely coupled to processes like ENSO (Lough, 1993).

Seasonal flow dynamics in the So. Johnstone River, as revealed by frequent, often daily sampling, were quite different, even though a tropical cyclone (Ivor - March 24, 1990; Joy - December 25, 1990) occurred both years. Cyclone Ivor crossed the coast near Cooktown (15°S), then degenerated into a tropical depression which moved southward. The resulting rainfall produced a maximum instantaneous flow exceeding 800 m^3 sec^{-1}. With several small peaks, river flow then declined progressively over the remainder of the 1989-90 wet season. In contrast, Cyclone Joy was the first major storm of the 1990-91 wet season. After striking the coast near Cairns, most of the rainfall was delivered by an extended monsoonal depression. As a result, there was no single massive flood event in the South Johnstone River catchment associated with Cyclone Joy. Overall flow peaked during February. The 1991-92 summer

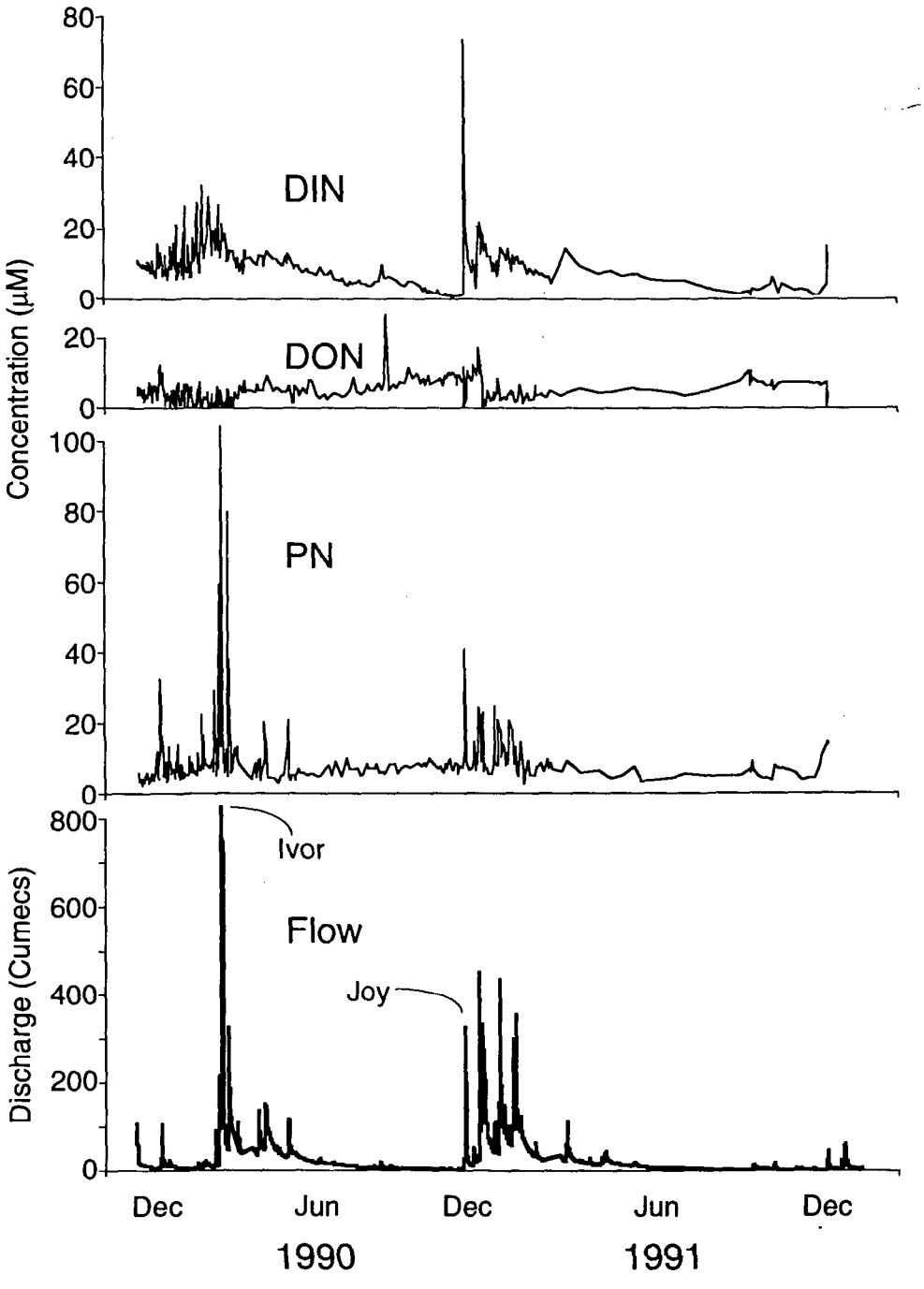

Figure 34. Temporal changes in concentrations of dissolved inorganic nitrogen (NH_4+NO_2+NO_3), dissolved organic nitrogen (DON) and particulate nitrogen (PN) in the lower South Johnstone River during 1990 and 1991 in relation to the temporal pattern of discharge at South Johnstone.

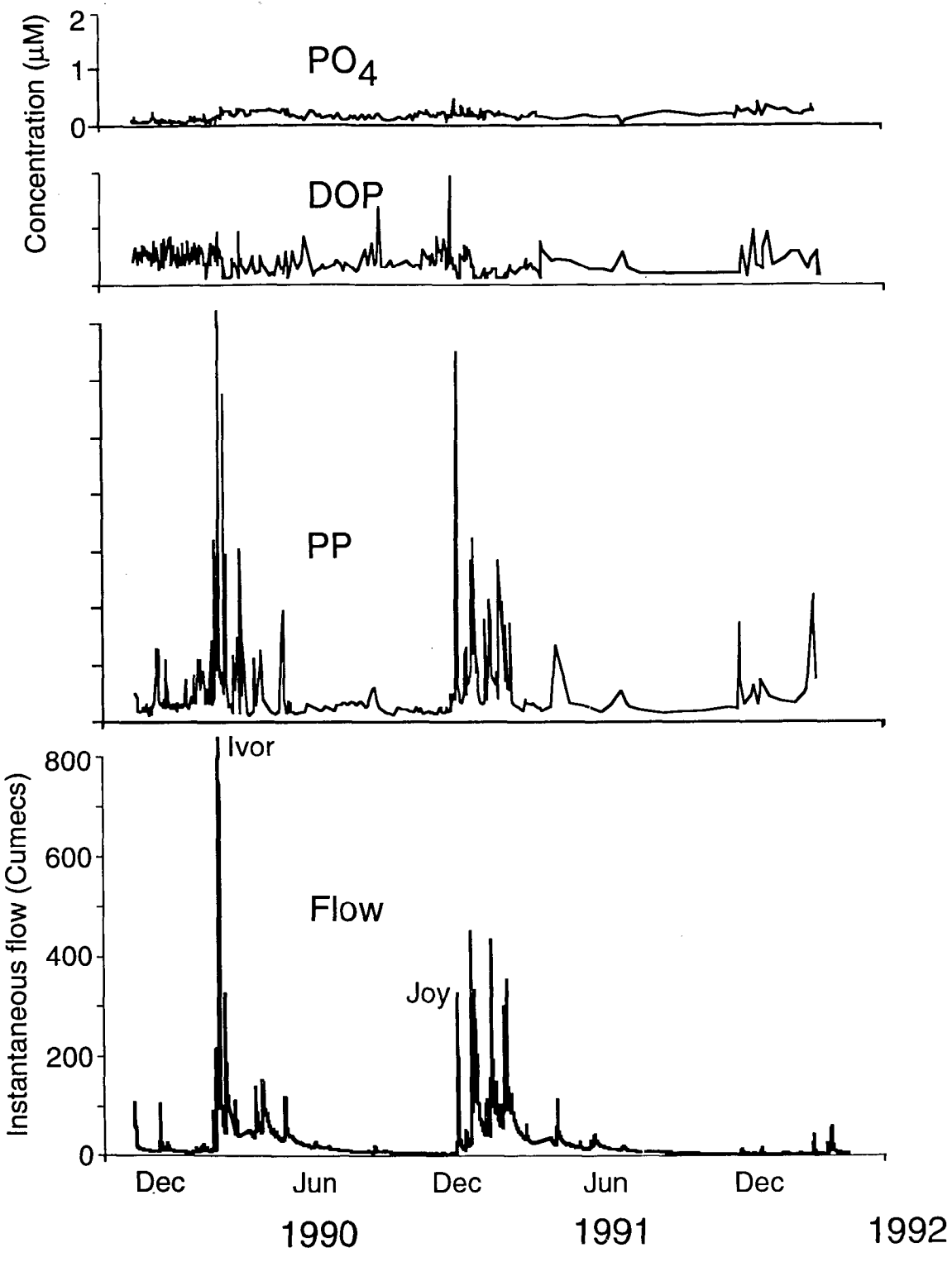

Figure 35. Temporal changes in concentrations of dissolved inorganic phosphorus (PO_4), dissolved organic phosphorus (DOP) and particulate phosphorus (PP) in the lower South Johnstone River during 1990 and 1991 and their relation to discharge measured at South Johnstone.

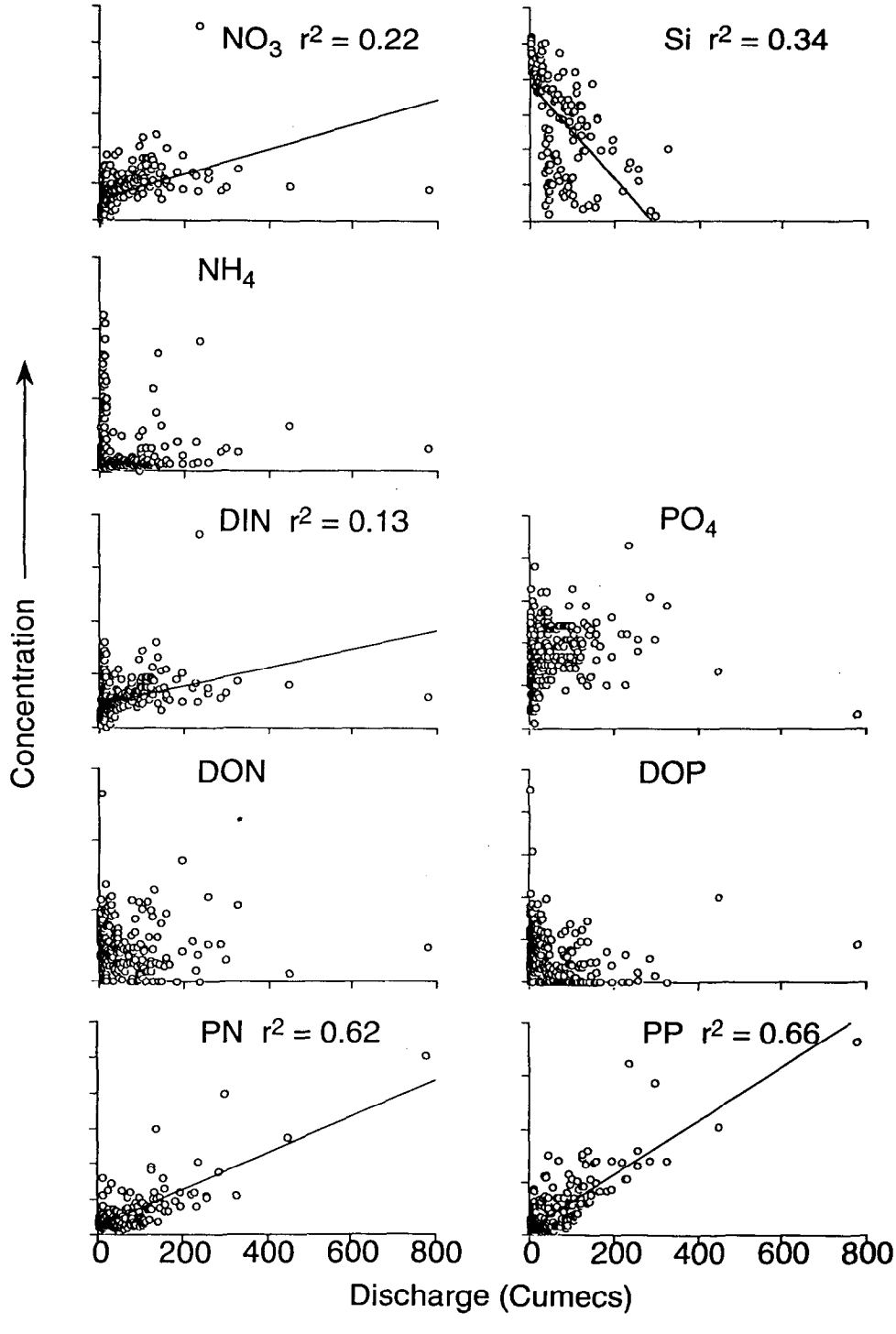

Figure 36. Scatter plots showing relationships between measured water column concentrations of individual nutrient species and the contemporaneous discharge rate of the South Johnstone River as measured at South Johnstone. Fitted linear lines indicate significant correlations.

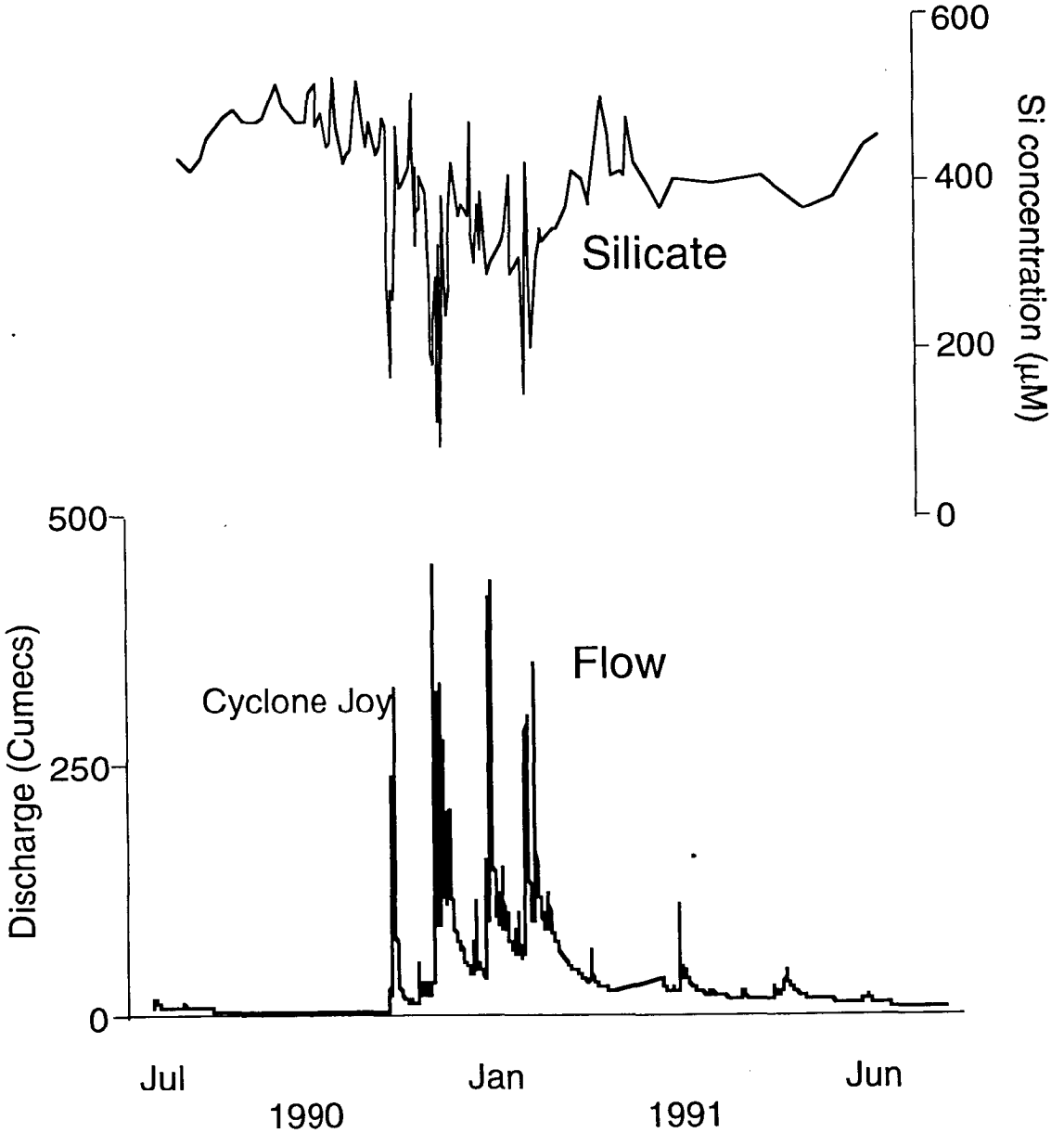

Figure 37. Temporal changes in concentrations of dissolved silicate [$Si(OH)_4$] in the lower South Johnstone River during 1990 and 1991 and their relation to discharge measured at South Johnstone. Silicate concentrations measured prior to July, 1990 are considered unreliable.

Compared to DIN and PN, concentrations of dissolved organic nitrogen (DON) in the So. Johnstone River fluctuated within a fairly narrow range (0-20 μmol N l^{-1}) over the period of intensive sampling. Following a broad seasonal low during the summer wet seasons, DON concentrations in So. Johnstone River waters tended to increase gradually over the duration of the dry season. While there is no statistical correlation between contemporaneous river discharge rates and DON concentrations, the general pattern was of declining DON concentrations in relation to increasing river discharge is suggestive of dilution during the wet season, and during high flow events. A particular example is the first flush flood associated with Cyclone Joy (December, 1990).

Dissolved phosphorus (PO_4, DOP) concentrations in the So. Johnstone River were low and consistent throughout 1990 and much of 1991 (Figure 35). In contrast to the pattern observed for nitrogen, peaks or dilution troughs of dissolved organic and inorganic phosphorus were not associated with flood events. No statistical correlation between concentrations of dissolved phosphorus species and river flow rate was observed.

With the exception of brief periods during flood events, total water-borne nitrogen concentrations in the So. Johnstone River were on the order of 20 μmol N l^{-1} and were relatively constant over the two-year period (Figure 38 Top). The balance between individual nitrogen species in the river water shifted on a short-term basis, though collectively, DIN and DON contributed similar proportions of the total annual export: 55 and 38 percent, respectively (Figure 38 Middle). PN was a major contributor to total export (ca. 43%). The temporal pattern of cumulative nitrogen export from the watershed was characterized by one to several abrupt steps in integrated discharge associated with individual flood events. A significant proportion of the annual discharge flux (ca. 25,000 kmol nitrogen or 340 metric tonnes) occurred during high-flow periods only a few days in duration (Figure 38 Bottom).

The temporal pattern of phosphorus export from the So. Johnstone River (Figure 39 Top) was similar to that observed for nitrogen. Unlike nitrogen, phosphorus fluxes were overwhelmingly dominated (81%) by particulate phosphorus (Figure 39 Middle). Integrated annual export of phosphorus was on the order of 2.26 kmol (35 metric tonnes; Figure 39 Bottom).

Several conclusions can be drawn from the results of the high frequency nutrient sampling program carried out in the So. Johnstone River. The first and most obvious is that most of the nitrogen and phosphorus export from the watershed occurs within one or a small number of discrete events during the wet season which are usually only a few days in duration. Any effort to quantify nutrient export from the watershed must be structured to catch and resolve these events. Sampling programs structured around regular collections at intervals of several days to weeks will almost surely miss the important export events. This makes it difficult to confidently estimate nutrient exports from other north Queensland rivers where intensive day-to-day sampling is lacking. All such estimates (including those made herein) should therefore be treated with the appropriate degree of caution. Sampling programs designed to estimate annual discharge from particular watersheds should be seasonally stratified, with high frequency sampling during the summer wet season to resolve brief discharge and export events, particularly floods associated with cyclonic storms and monsoonal depressions, with a relaxation to more infrequent sampling during the dry season, when events are largely absent and nutrient concentrations fairly constant.

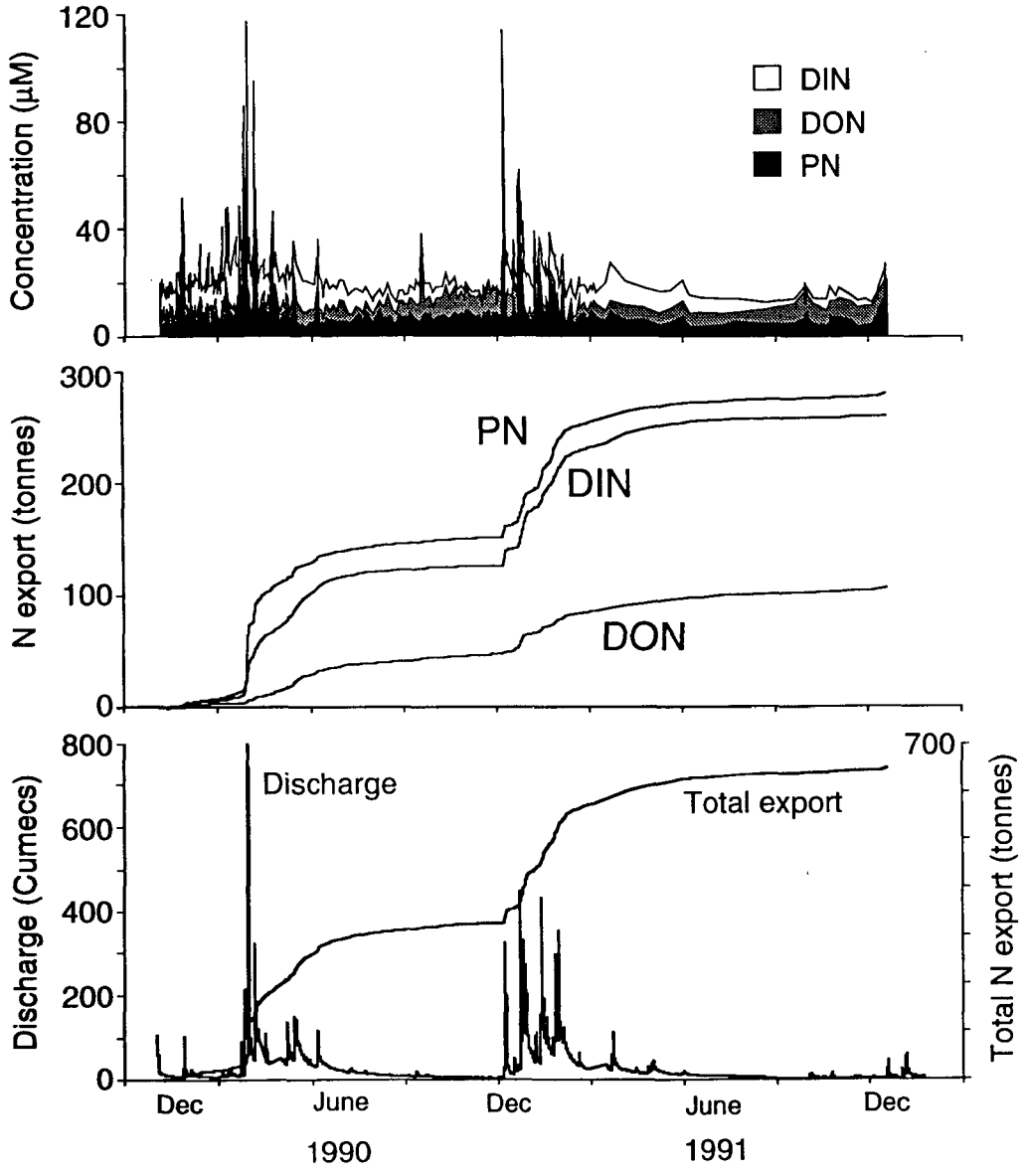

Figure 38. Top: Relative contributions of dissolved and particulate nitrogen species to total water-borne nitrogen concentrations and fluxes in the So. Johnstone River. Middle: Cumulative export of dissolved and particulate nitrogen from the So. Johnstone River. Bottom: Cumulative export of total nitrogen from the So. Johnstone River in relation to discharge measured at South Johnstone.

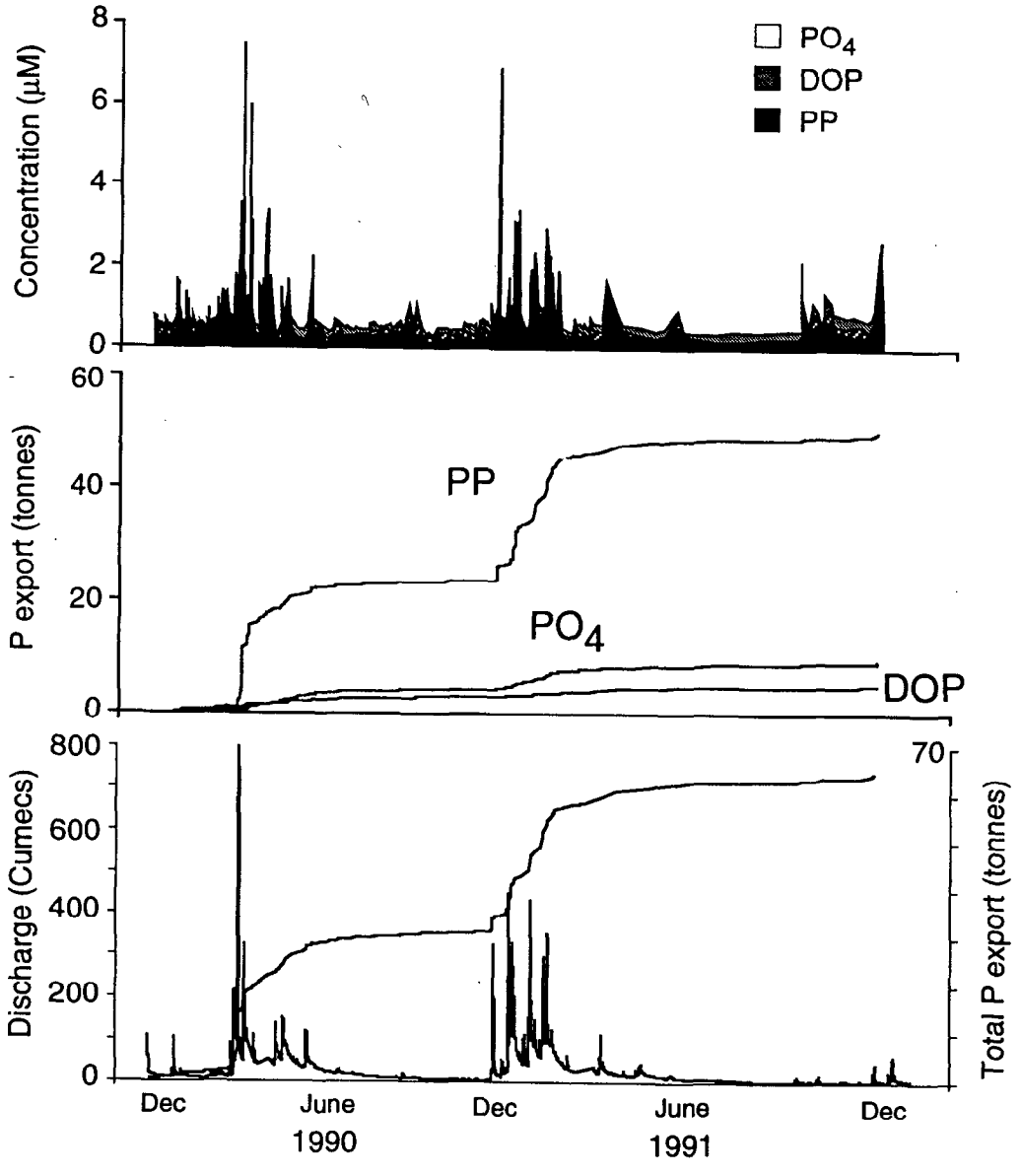

Figure 39. Top: Relative contributions of dissolved and particulate phosphorus species to total water-borne phosphorus concentrations and fluxes in the So. Johnstone River. *Middle:* Cumulative export of dissolved and particulate phosphorus from the So. Johnstone River. Bottom: Cumulative export of total phosphorus from the So. Johnstone River in relation to discharge measured at South Johnstone.

A second important conclusion, as noticed elsewhere, is that a significant fraction (ca. 80%) of the total flux of phosphorus from north Queensland rivers occurs in particulate form. A smaller but significant proportion (~40%) of total nitrogen is exported in particulate form. The transport of particulate material is concentrated during flood events, especially the large floods associated with cyclones. Efforts to resolve nutrient export must therefore include analyses of nutrients in the particulate fraction, using modern instrumental methods appropriate for those analyses. It should be noted, however, that no measurements have been published to date regarding nutrient transport in sediment bedload.

With the exception of PN, PP and silicate, concentrations of all the soluble nutrient species measured were uncorrelated with instantaneous flow rates. This indicates that modelling of soluble nutrient exports from watersheds on the basis of flow records will not be a straight-forward process and will need to incorporate more elaborate functional parameterizations of watershed nutrient behaviour.

Despite the obvious differences between the temporal patterns of flow over the two years of intensive nutrient monitoring of the So. Johnstone River, integrated annual nitrogen and phosphorus exports for the two years. Both wet seasons contained a single cyclone, though the magnitude of the associated flood event was quite different. Analyses have not been carried out on all of the nutrient samples from the El Nino 1991-92 wet season, which lacked a major flood event in order to make a comparison with riverine exports under dry conditions. Given the considerable variability of flow in all north Queensland rivers, it is therefore still uncertain to what extent total annual nutrient export is related to average discharges over long periods.

8.1 Longitudinal Variations of Nutrient Concentrations within Catchments

8.1.1 Herbert River

Dissolved and particulate nutrient concentrations were measured at three sites along the Herbert River between December 1989 and February 1992 (Figures 40-42): Yamani Falls - a mid-catchment site situated just below the Yamani Falls National Park and above the sugar-cane dominated coastal floodplain; Abergowrie, a lower-catchment site in the upper portion of the floodplain with extensive sugar-cane culture surrounding; and at the John Row Bridge, a lower catchment site nearer to the mouth of the river. A considerable amount of grazing and some alluvial mining activity occurs within the Herbert River catchment above the Yamani Falls site. Sampling was largely carried out at weekly to monthly intervals; some daily sampling was carried out during flood events.

As in the South Johnstone River, PN, PP and suspended solids concentrations peaked during early season high flow periods. At other times, water-borne concentrations of PN, PP and suspended solids were low and stable, with little or no difference between concentrations measured at upper and lower catchment sites. Interestingly, peaks in PN and PP did not occur during the large late-summer flow peak of 1991, suggesting possible exhaustion of mobile PN and PP stocks within the watershed. This effect, however, requires corroboration. During flood peak events, there were no clear longitudinal trends in concentrations of particulate materials. The highest concentrations of PN, PP or suspended solids were sometimes measured at the Yamani Falls site, sometimes at Abergowrie or John Row Bridge.

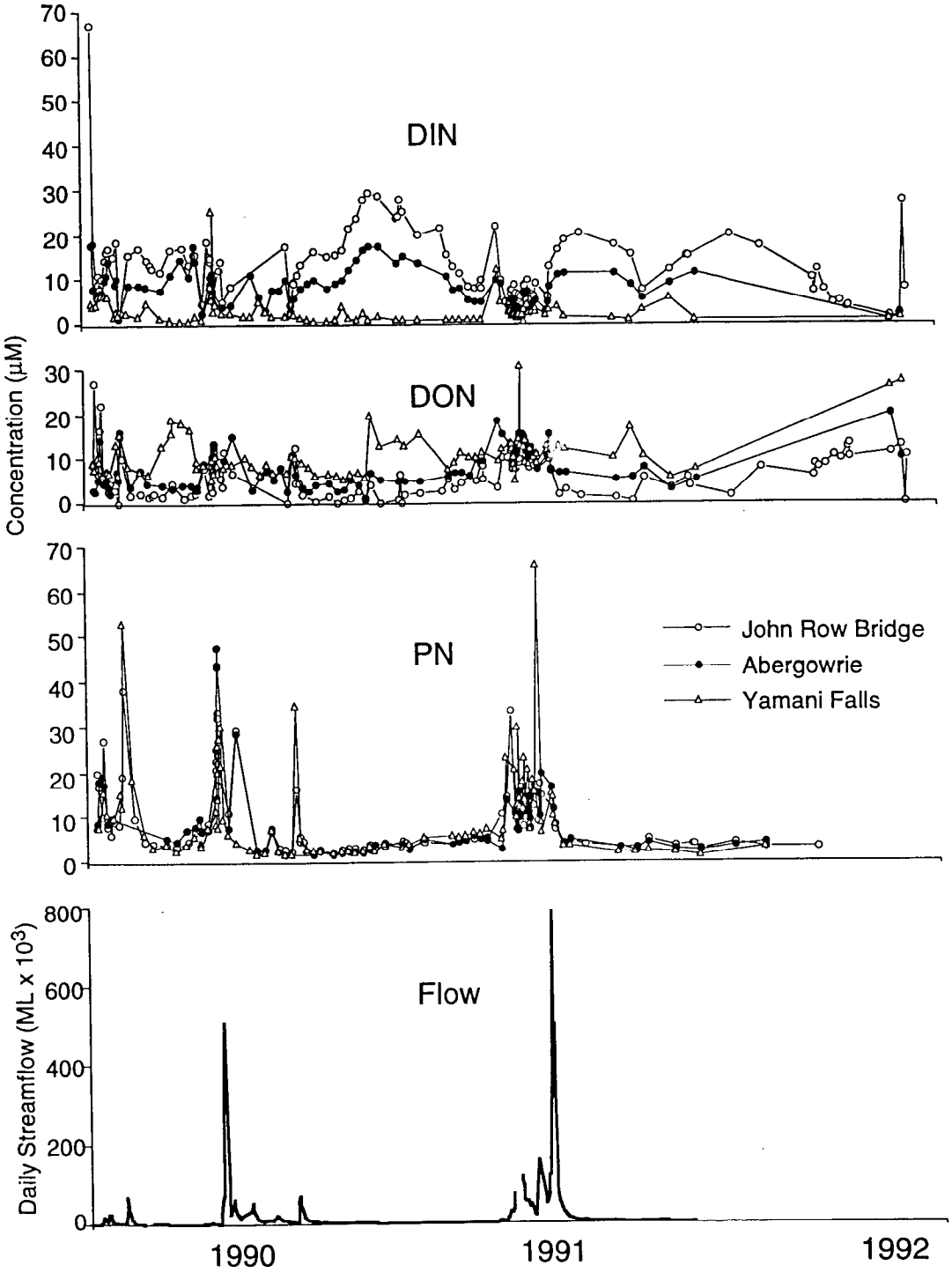

Figure 40. Temporal and longitudinal changes in concentrations of water-borne dissolved and particulate nitrogen in the Herbert River (1990-1992). The Yamani Falls sampling site is located above sugar-cane cultivation activity. The John Row Bridge site is located within the agricultural area of the lower catchment. The Abergowrie site is between the two.

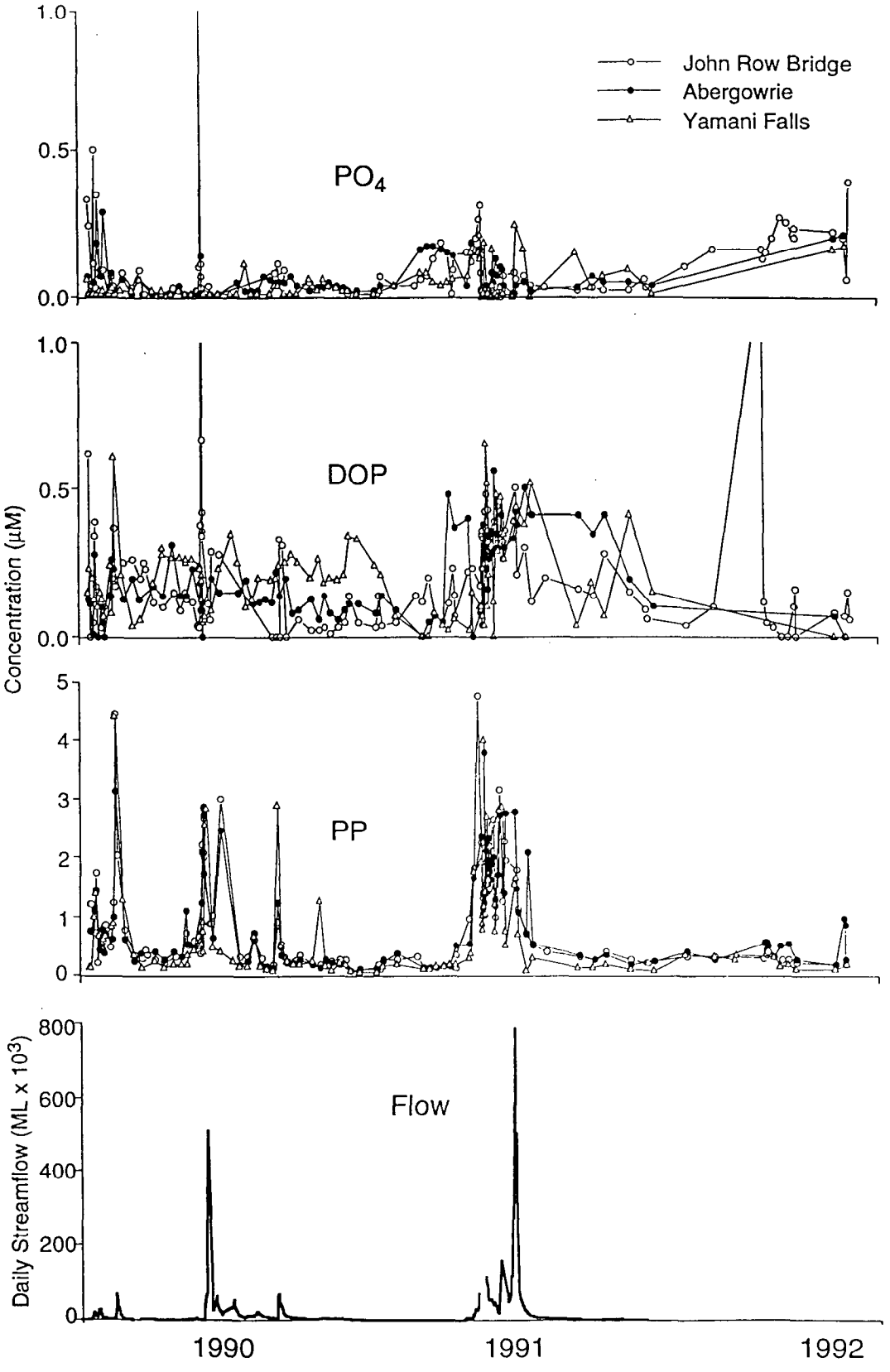

Figure 41. Temporal and longitudinal changes in concentrations of water-borne dissolved and particulate phosphorus in the Herbert River (1990-1992). The Yamani Falls sampling site is located above sugar-cane cultivation activity. The John Row Bridge site is located within the agricultural area of the lower catchment. The Abergowrie site is located between the two.

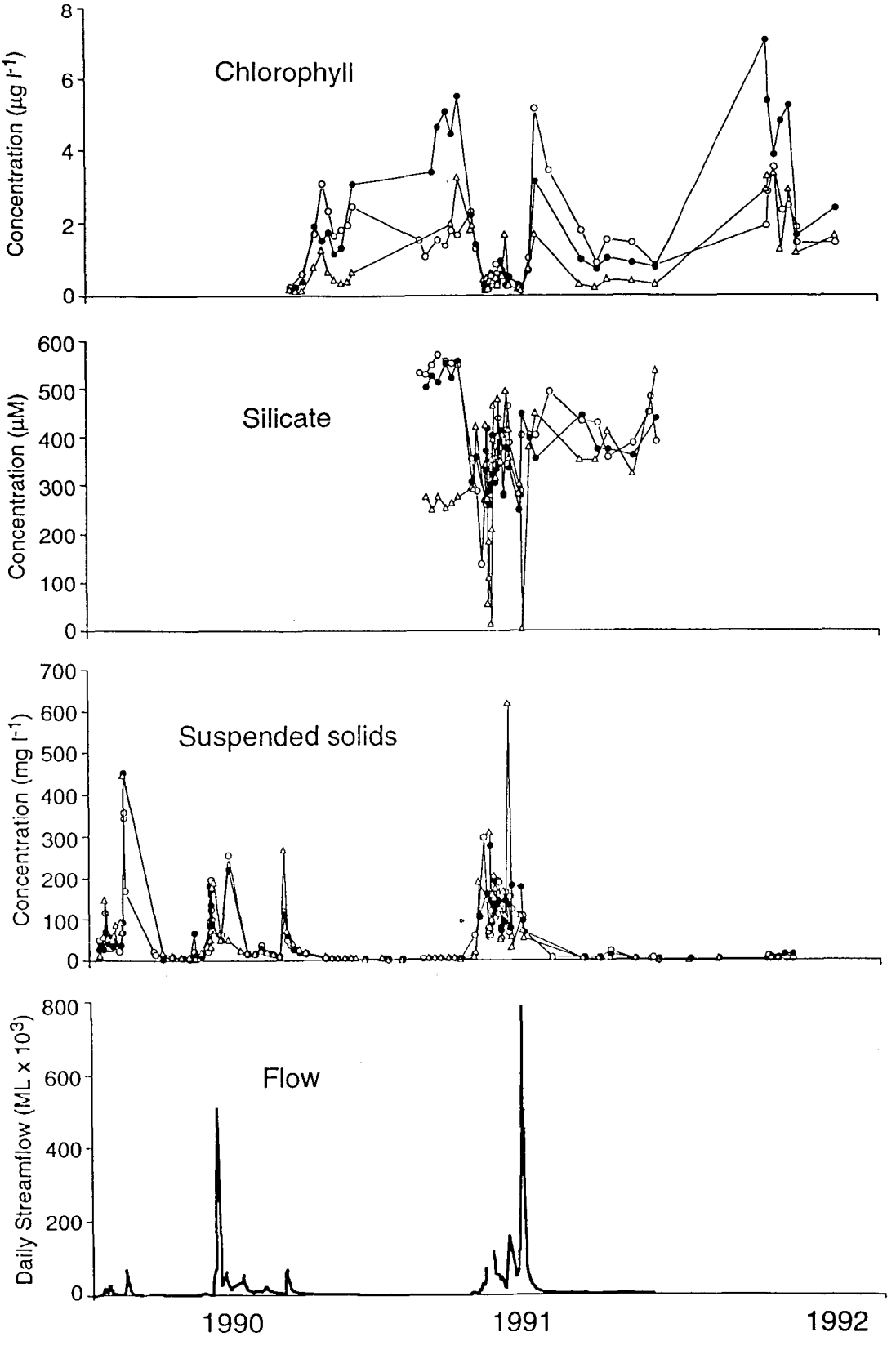

Figure 42. Temporal and longitudinal changes in concentrations of water-borne chlorophyll, dissolved silicate and suspended solids in the Herbert River (1990-1992). The Yamani Falls sampling site is located above sugar-cane cultivation activity. The John Row Bridge site is located within the agricultural area of the lower catchment. The Abergowrie site is between the two.

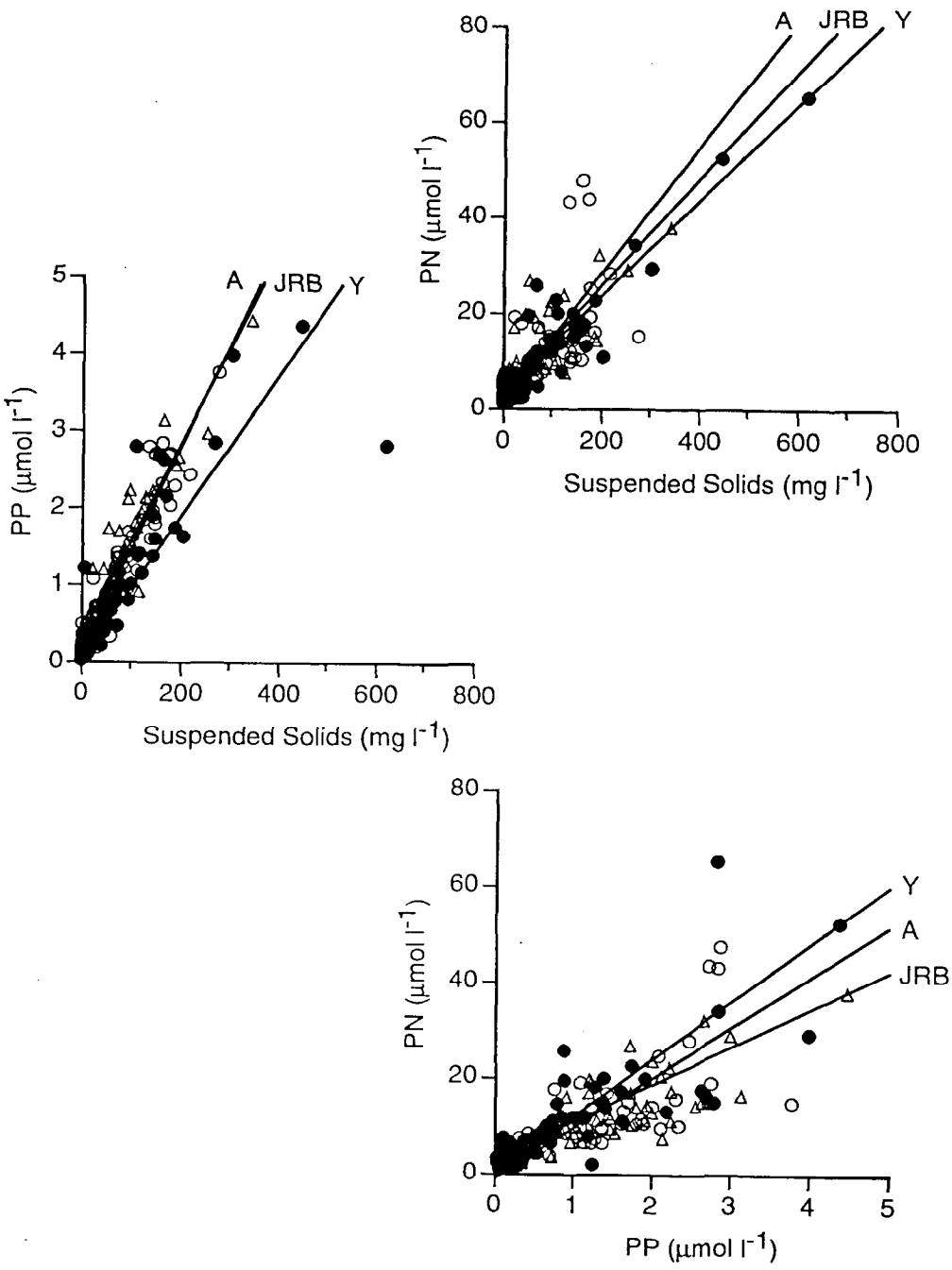

Figure 43. Functional relationships between particulate nitrogen, particulate phosphorus and suspended solids concentrations at three sites in the Herbert River. The regression lines shown are GM functional regressions (Ricker, 1973) with outliers excluded.