Nutrient Uptake and Cycles of Change: The Ventura River in Southern California

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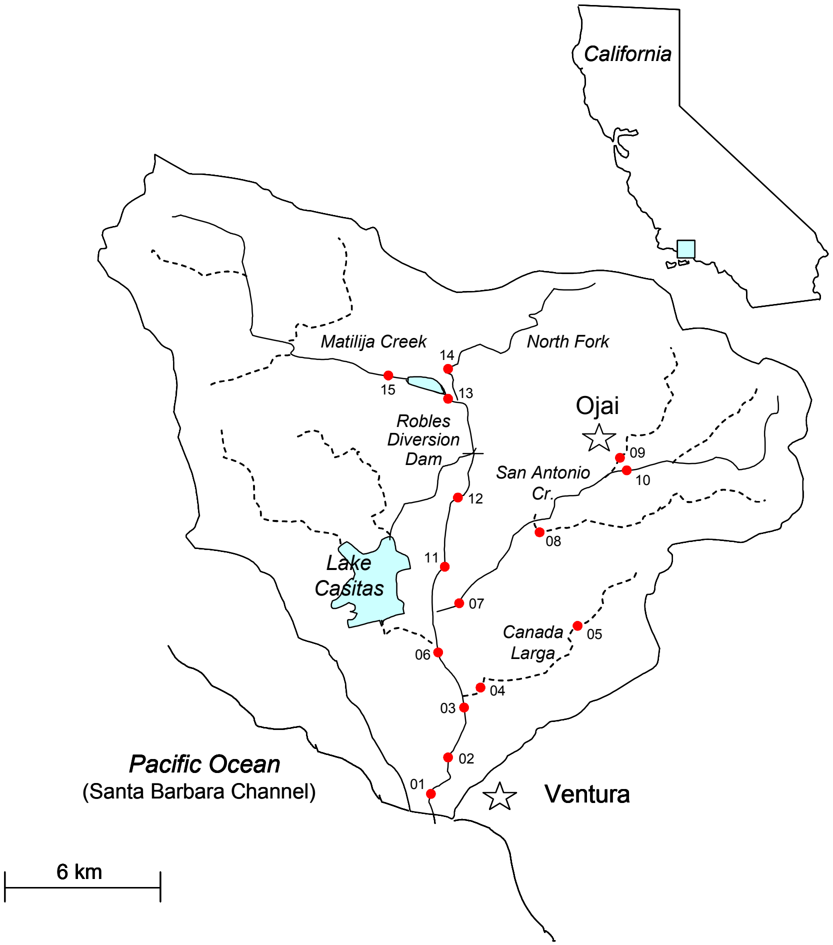
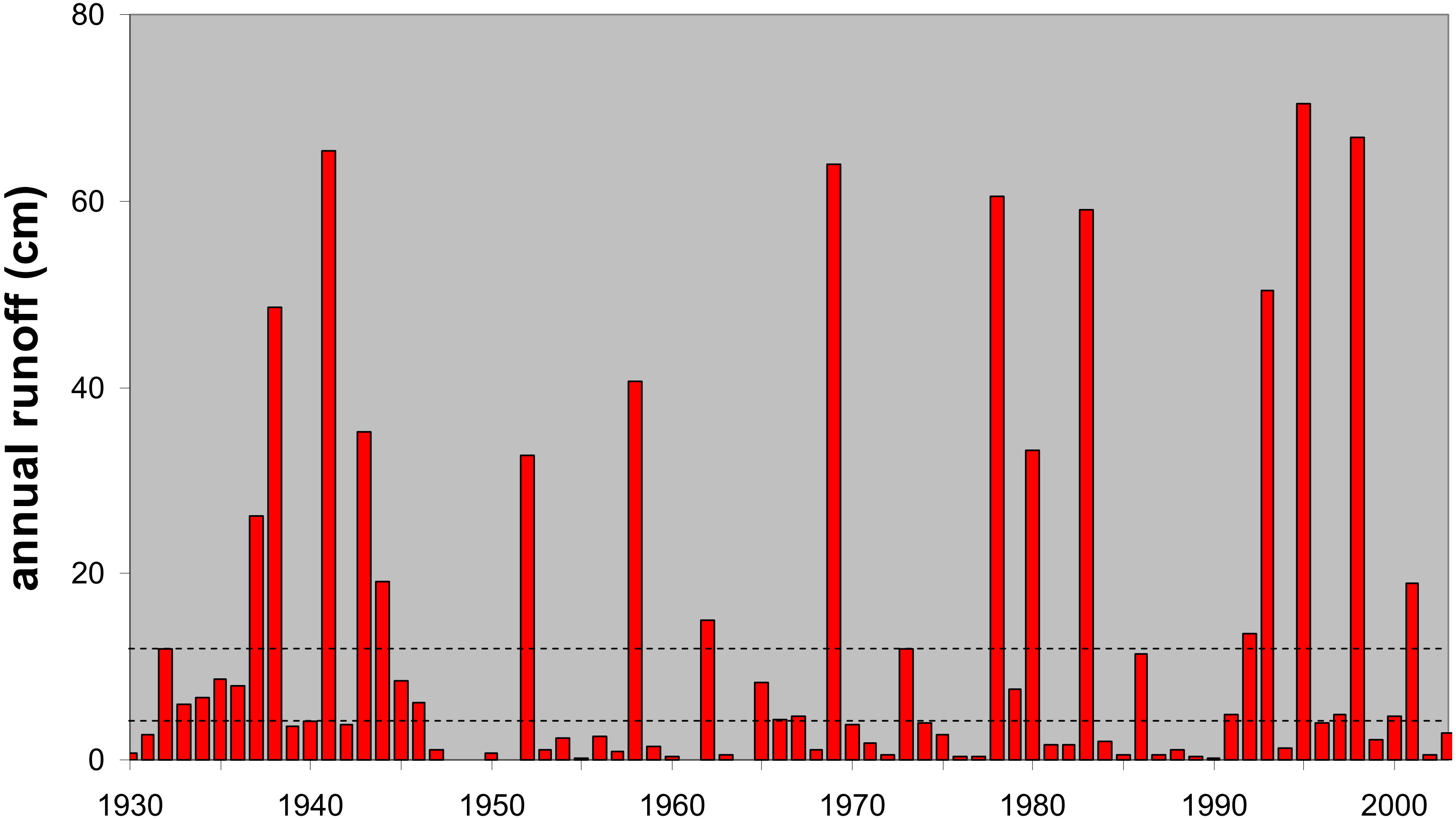


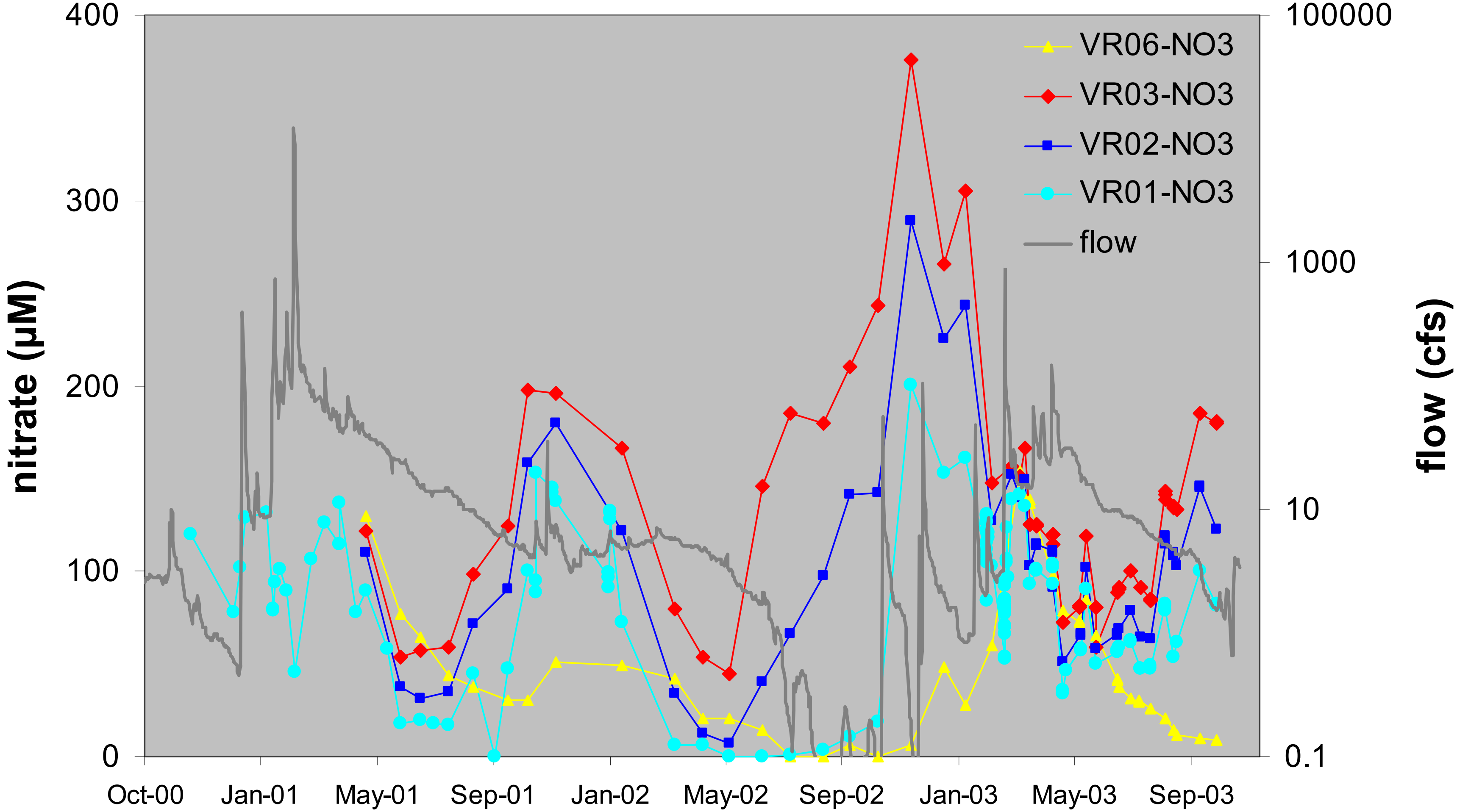
This study, presented at the 2003 AGU winter session in San Francisco, and at the ACS summer meeting in Philadelphia, concerns inter-annual variations in river channel functioning and their effect on nutrient uptake at the lower 4 river locations shown on the map.

Watersheds in Mediterranean climates are characterized by extreme seasonal and inter-annual rainfall variability. This variability engenders cycles of sediment deposition and removal, algal growth, and the advance and retreat of riparian and aquatic vegetation. In turn, these changes dramatically alter the appearance and biological functioning of rivers and streams, regulating the uptake of nutrients.

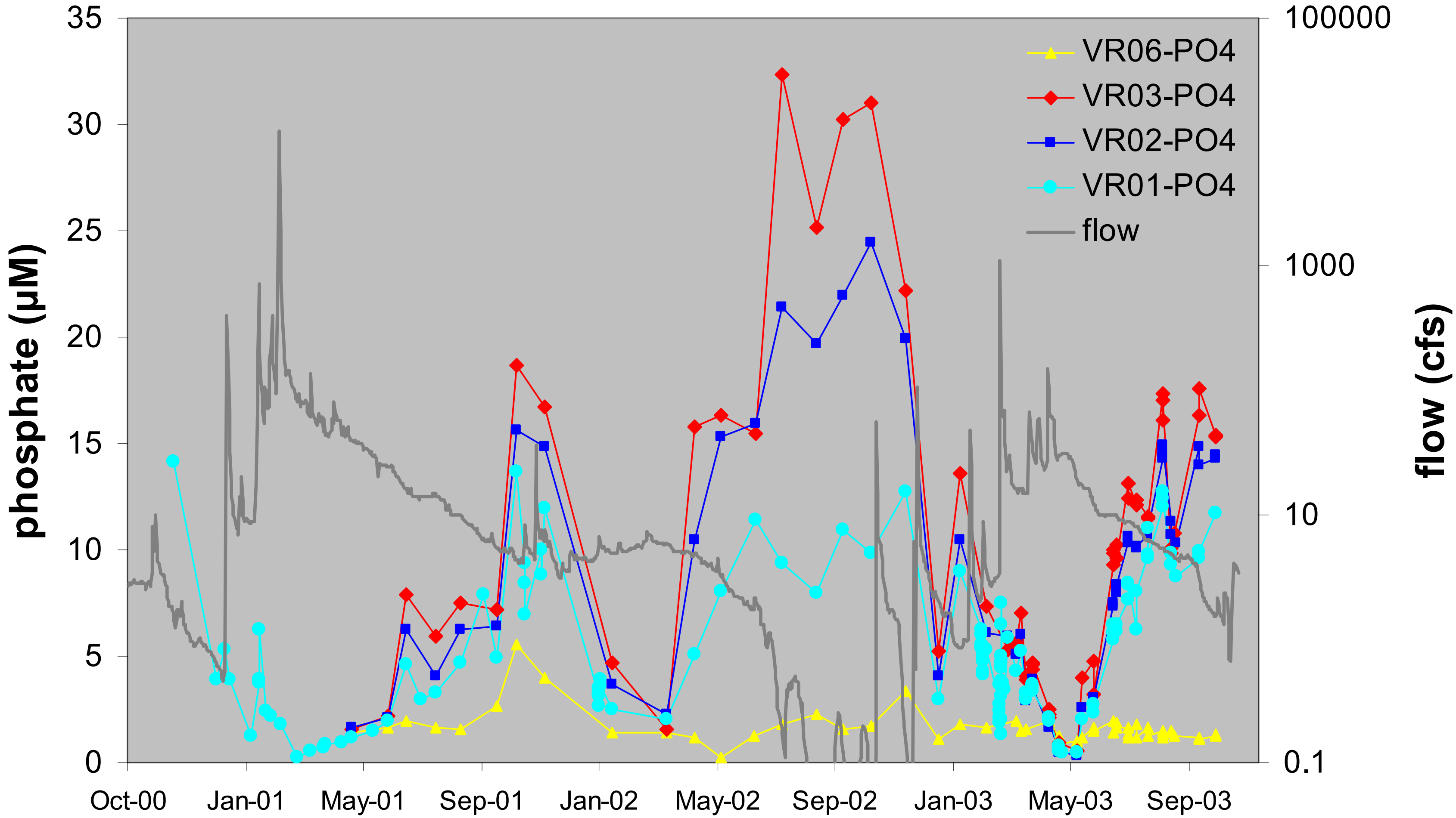
Major winter storms, such as occur during severe El Nino years begin a transformational cycle by completely scouring the channel of vegetation and fine sediment; this occurs, on average, once every 10 to 12 years (the interval has varied from 3 to 30 years). The scoured channel, with warmer water temperatures, the absence of shade and a nutrient rich environment, becomes dominated by filamentous algae (principally *Cladophora, Rhizoclonium*, *Enteromorpha* and *Spirogyra* spp.). In contrast, drought years occasion exuberant plant growth and the competitive replacement of algae by aquatic vegetation. Absent scouring winter flows, perennial aquatic plants become established, trapping fine sediment and narrowing the wetted channel; the rapid growth of riparian vegetation (*Arundo donax* and *Salix* spp.) provides increased shade to the narrowed waterway. These processes increasingly stabilize the channel and elevate the threshold flow of a scouring storm; the major storm of 2003, following the 2002 drought year, produced appreciably less channel transformation than a similarly-sized storm in 2001.



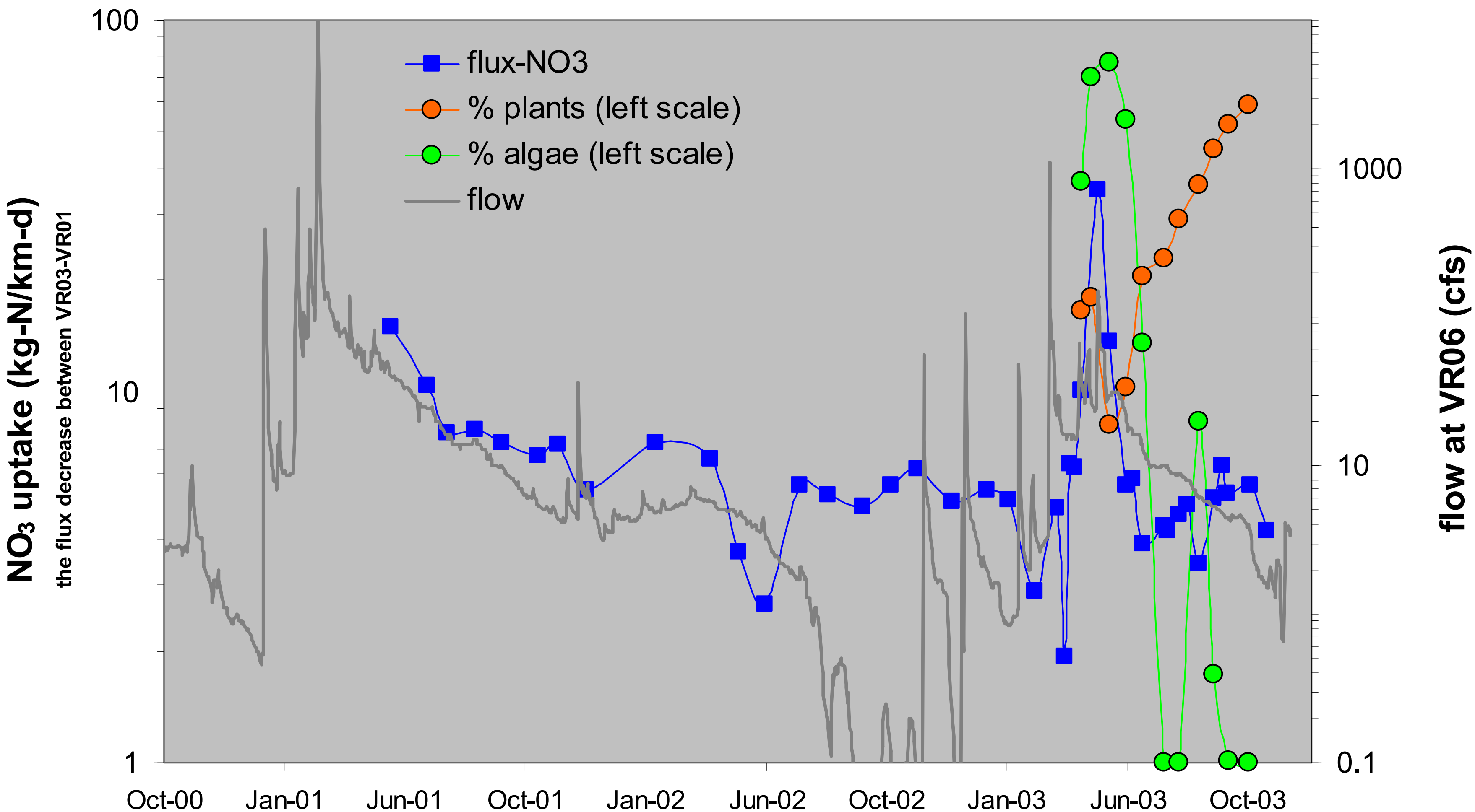
The Ventura River, a 580 sq. km mountainous coastal watershed 100 km northwest of Los Angles, CA., has a Mediterranean climate with an average annual rainfall of 500 mm. More than 90 % of the rain falls between November and April, and most of the annual discharge occurs over a few days. The seasonal and inter-annual variations are extreme – dashed lines represent the mean (12.1 cm) and median (3.8 cm) annual runoff. Since 2001 we have been measuring dissolved nutrient concentrations at four locations on the lower 9 kilometers of the river (annual runoff of 19, 0.6 and 14 cm, for 2001, 2002 and 2003, respectively) and quantifying the relative abundance of plants and algae during 2003. A subsequent decrease in nutrient concentrations below a treated sewage outfall at km 8 provides estimates of nutrient uptake under changing conditions.



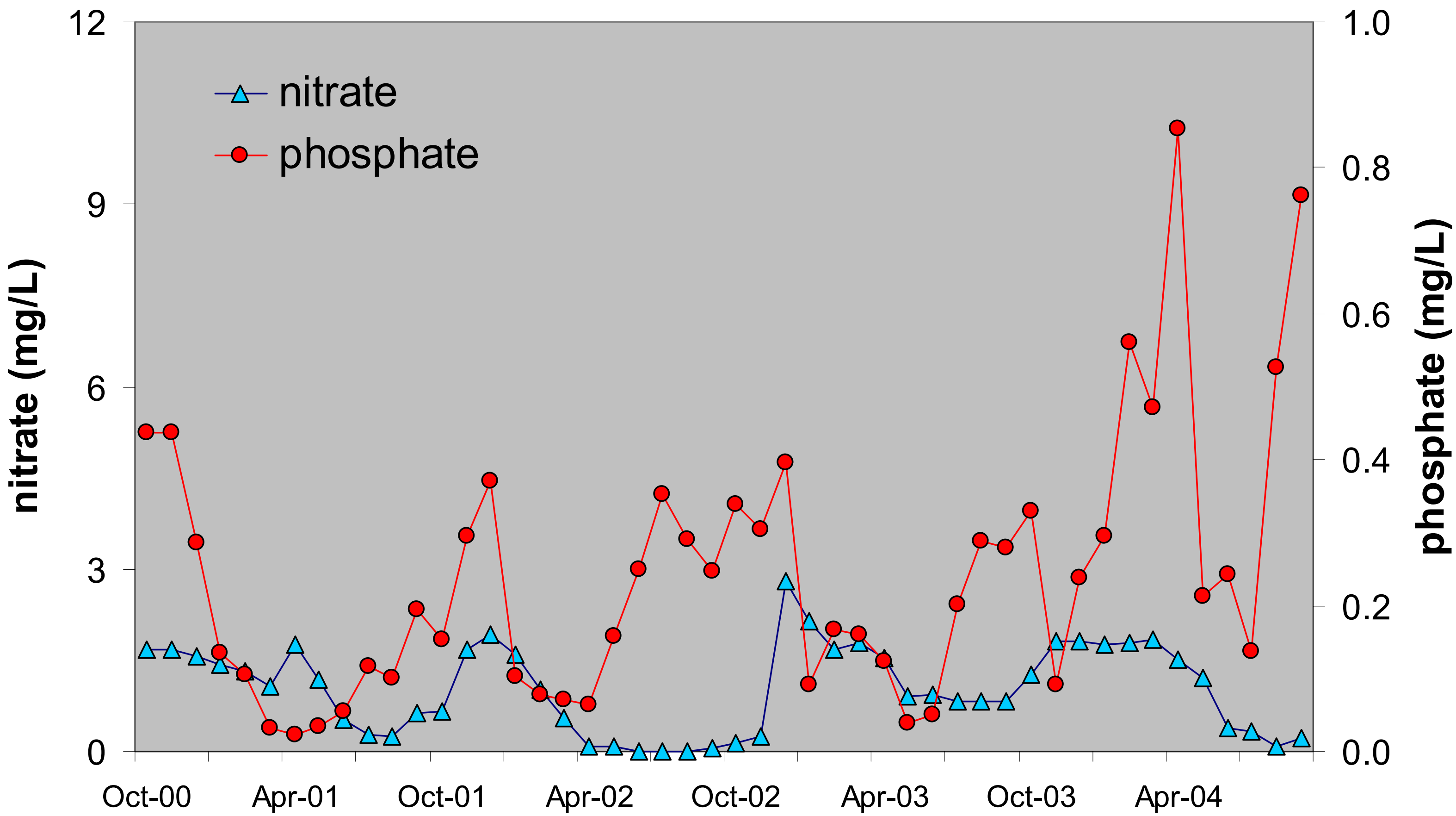
Nitrate concentrations typically peak in late winter, presumably from rainy season mineralization and mobilization, and decrease to a minimum by late summer, i.e., they follow the variation of the annual hydrograph. Concentrations at VR06 – yellow symbols – represent this pattern. Between VR06 and VR03, a sewage outfall, contributes high nitrate effluent to the river. The nitrate variation below the outfall, controlled by dry-season effluent discharge, is of increasing concentrations as normal river flows decrease throughout summer and into the fall. During dry years, more than 90 % of lower river flow originates as effluent. The blue shading on the graph marks the mid-November to mid-March rainy season.



Phosphate concentrations on the natural river remain relatively constant throughout the year, perhaps peaking slightly at the beginning of the rainy season. VR06 – yellow symbols – represents this pattern. Below VR06 the sewage outfall contributes high amounts of phosphate, as well as nitrate, to the river. As for nitrate, the phosphate variation below the outfall, controlled by dry-season effluent discharge, increases in concentration as normal river flows decrease throughout summer and into the fall. The blue shading on the graph marks the mid-November to mid-March rainy season.

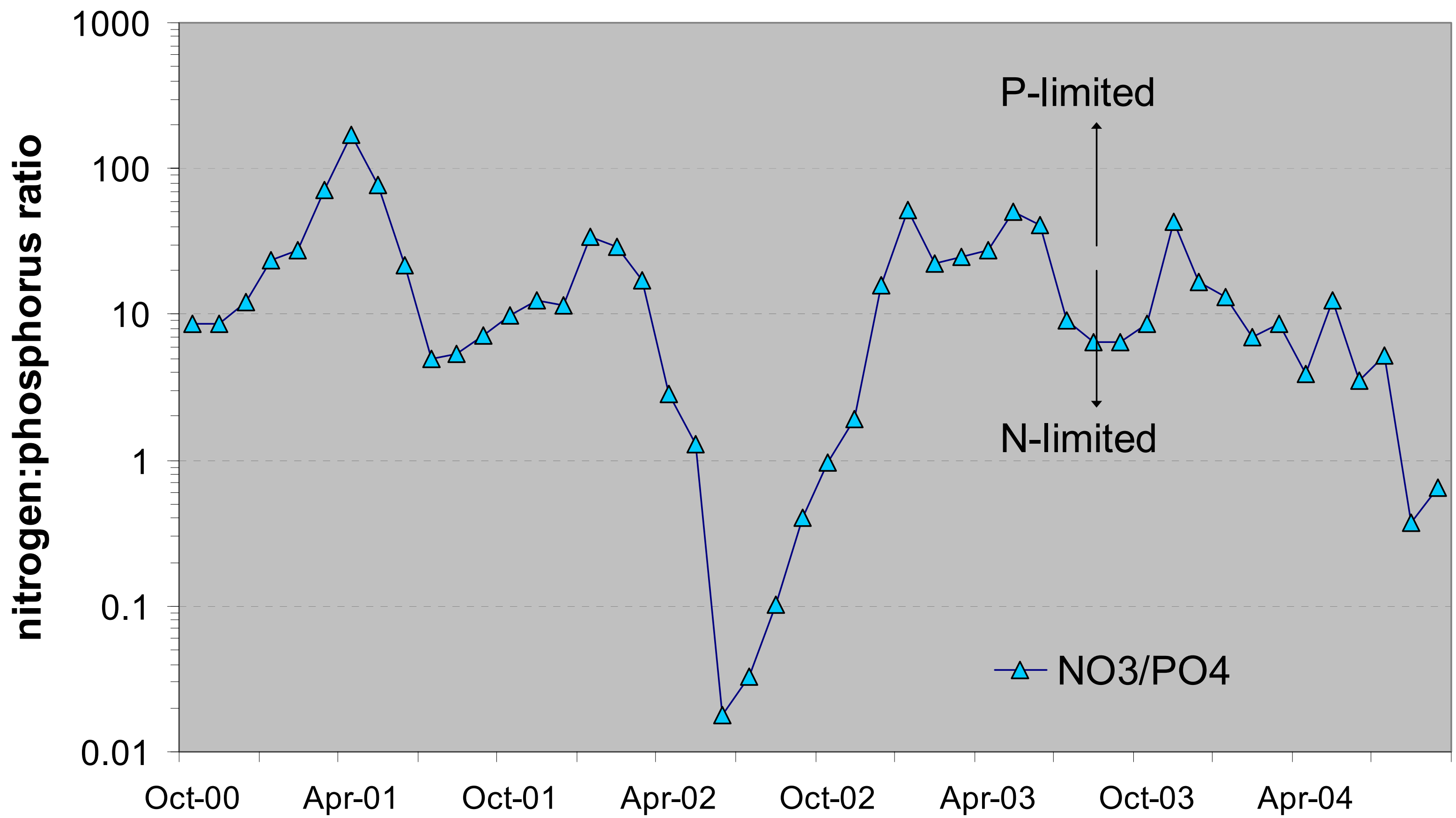


Nitrate uptake (the flux decrease between the sewage outfall and estuary) is surprisingly consistent, except during periods of heavy algal growth (the summer of 2001 and late spring 2003; "percent cover" is a rough measure of abundance derived from the average of 15 lower river transects). Algal dominance increases nitrate uptake 2 to 4-fold over periods of aquatic plant domination. While algae appear to be more effective in removing nutrients from the river, this may simply be an artifact of higher nutrient availability at the end of the rainy season when more open and deeper waters give faster growing algae a competitive advantage. Later in the season, when river levels drop and plants begin to over-shadow the river surface, the situation is reversed.



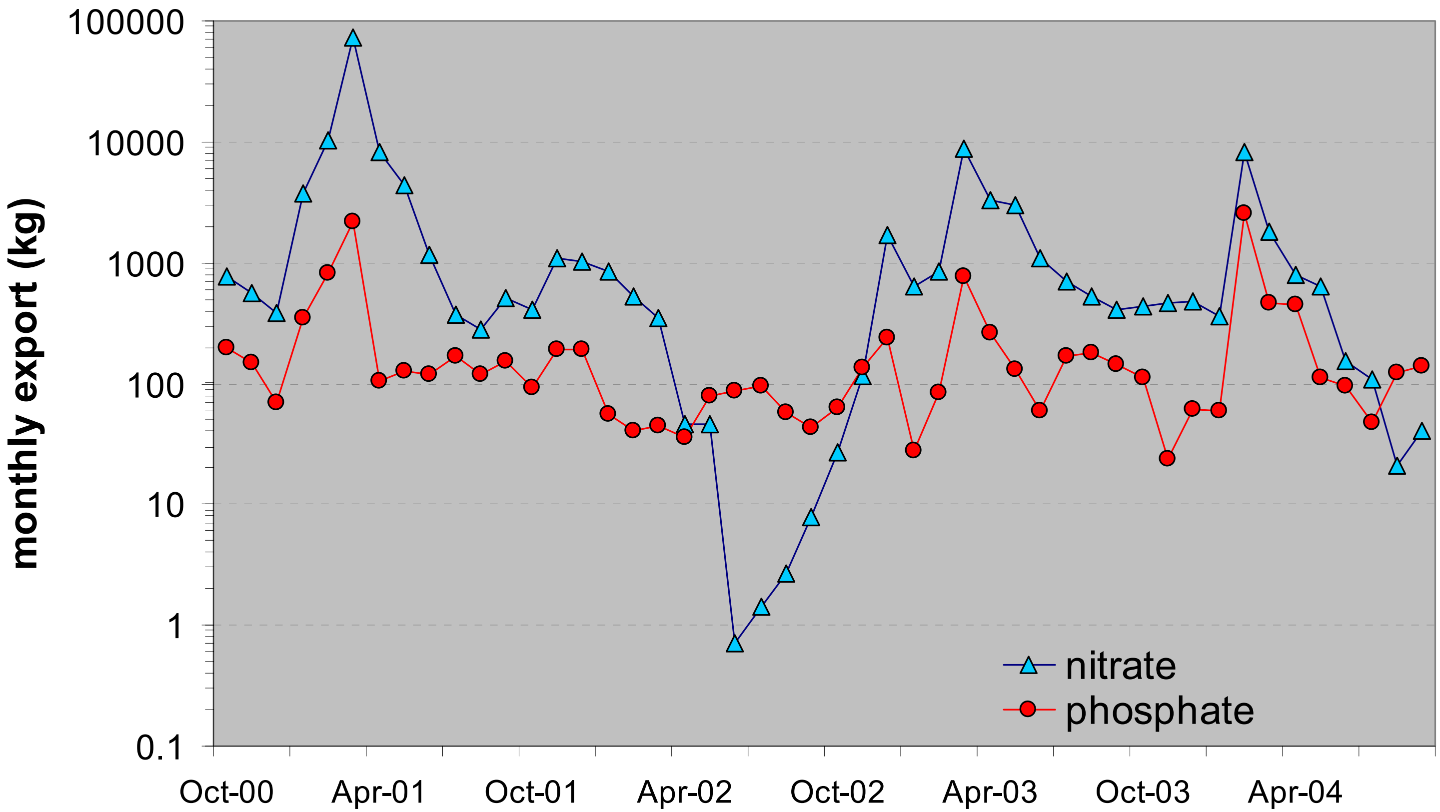
The Ventura, like most southern California coastal streams, ends in a tidal estuary. The EPA has proposed N and P limits for the prevention of eutrophication in this area: they are 0.38 mg/L for nitrogen and 0.03 mg/L for phosphorus. The graph shows nitrate and phosphate concentrations at the tidal limit (VR01). Nitrate is sometimes above this limit; phosphate is *always* above. The limits are for nitrogen and phosphorus and the graph shows nitrate and phosphate, so the actual situation is a slightly worse than portrayed; nitrate and phosphate make up most of the nitrogen and phosphorus in the river (especially during the dry season), but not all.

"Bluish" areas mark the typical rainy season (mid-November to mid-March) and we have chosen to show the respective nitrate and phosphate axes in a proportion of 12:1 (in mg/L); this represents a molar ratio of approximately 30:1, i.e., the general ratio of molecular N and P uptake by freshwater aquatic primary producers. When phosphate appears above nitrate in the graph, nitrogen becomes the limiting nutrient; when nitrate appears above phosphate, phosphorus is limiting; when roughly equal, they are in balance and neither is limiting growth. Notice that the river at this location, while sometimes P-limited, is mostly N-limited, especially during the dry season.



The graph shows the nitrate concentration divided by the phosphate concentration for each month's sampling data at the river mouth (VR01) and illustrates the nutrient status of river water going into the Ventura estuary. Bluish vertical bars show rainy seasons and the thick horizontal green bar represents a molecular ratio of 20 to 30:1; the zone where both nutrients are in balance. If the ratio is above the line, water going into the lagoon is phosphorus limited, if below the line, nitrogen limited. Winters and early spring are mostly in-balance or phosphorus limited, while the remainder of the dry-season is nitrate limited. And in some years, drier, low-rainfall years, freshwater supplying the lagoon becomes severely nitrogen deficient.

The impact of these freshwater fluctuations in nutrient flux and status on the estuary are, as yet, unknown. However, we suspect them to be reasonably dramatic as ocean water is usually nitrogen-limited. Low stream flows and drifting sand along the coast often close off these small estuaries from ocean inputs for extended periods of time (often half a year or more).



Finally, concentrations and the nutrient balance are only part of the story. More important may be the *amount* of nutrients entering the Ventura estuary. The amount (or *flux*) from the river is the product of river *concentration* and *flow*. The graph shows amount, in kilograms per month, of nitrate and phosphate entering the estuary below VR01. Again, vertical bars indicate rainy seasons. To say that nitrate varies substantially would be a severe understatement: the difference between the highest and lowest monthly fluxes is five orders of magnitude. The inter-annual variation is also extreme: in 2002 and 2004, nitrate just about disappeared as a river input. Notice that the phosphate variation is substantially different: the phosphate flux, particularly during the dry-season, is relatively consistent – roughly around 100 kg/month.

While phosphate inputs to the estuary remain steady, nitrate usually becomes either mildly or strongly limiting as the growing season develops; and in drought years lack of nitrogen is probably extremely limiting. As the years since the last big flood pass, and vegetative dominance of the channel and flood plain increases, flows will decrease (due to increased uptake, evaporation and lower groundwater inflows) and the reduction of the nitrate flux is likely to become even more severe.