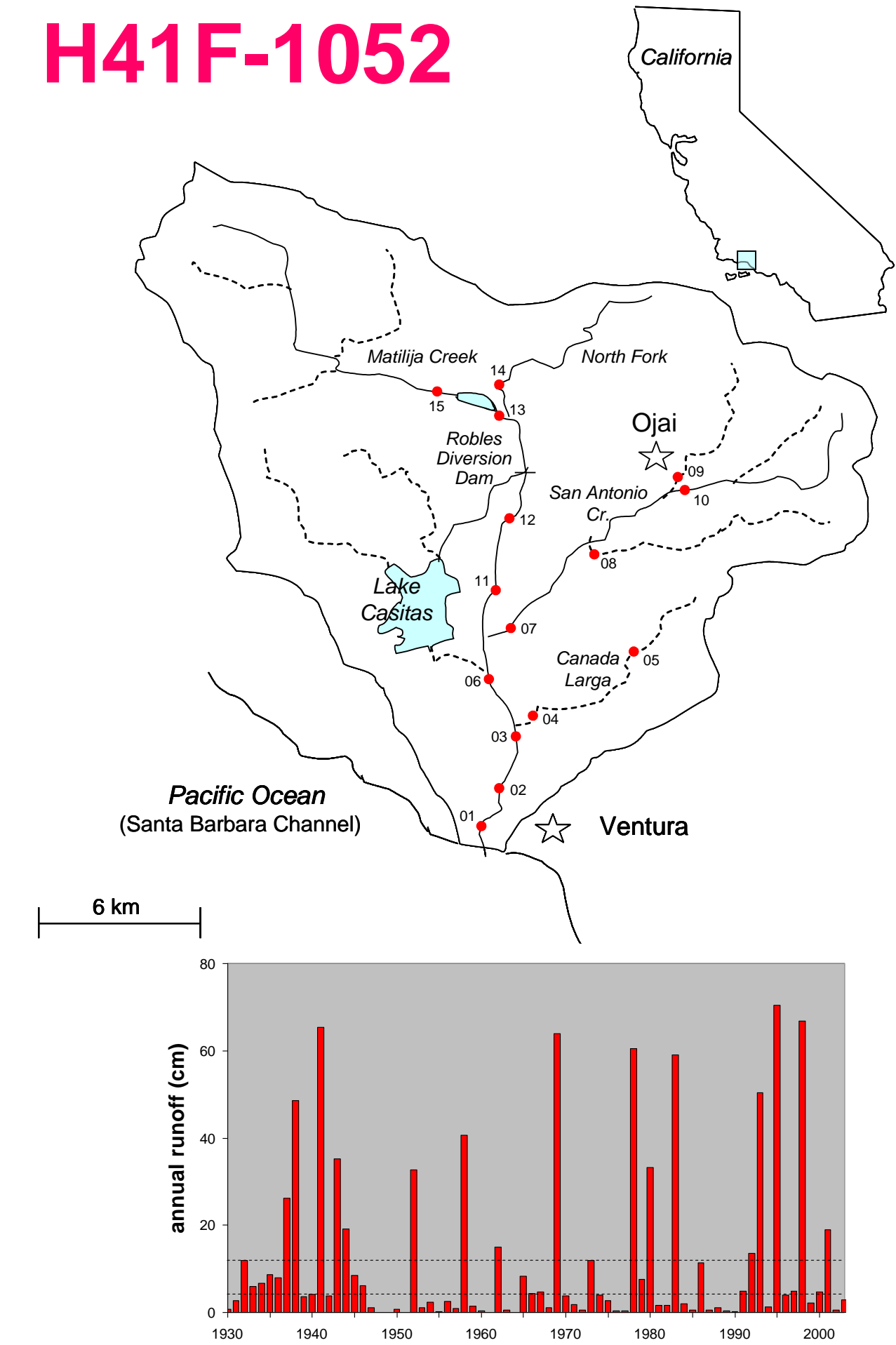


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1

The Ventura River, a 580 sq. km mountainous coastal watershed 100 km northwest of Los Angeles, Ca., has a Mediterranean climate with an average annual rainfall of 500 mm. More than 90 % of the rain falls between Nov. and Apr., 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 the spring of 2001 nutrient concentrations have been sampled monthly at 15 locations, 3-times a month on the lower river (VR01, 02, 03 and 06) since March 2003. A sequential decrease in concentrations below a sewage treatment plant outfall between sites VR06 and VR03 provides estimates of nutrient uptake under changing conditions.



2

Highly variable annual runoff engenders **cycles of sediment deposition and removal, algal growth, and the advance and retreat of riparian and aquatic vegetation**. Major El Niño winter storms (every 10 to 12 yrs. on average) begin a transformational cycle by completely scouring the channel of vegetation and fine sediment. The photos show the Ventura River upstream of sampling site VR02 in July 2001, August 2002, March 2003 and Sept. 2003 (left to right). In 2001 the river, still recovering from the scouring of the river bed during the El Niño of 1998, was open and relatively free of vegetation. Algae were abundant in the open water with little competition from plants. Aquatic plants began to supersede algae by the end of summer, 2001. By 2002, after a winter of low flows and no storms large enough to uproot them, plants came to dominate the entire river channel. Winter storms in 2003 scoured the center of the channel and re-established deeper flows, allowing algae to briefly reappear, but plants, surviving along the channel edge, soon recovered.



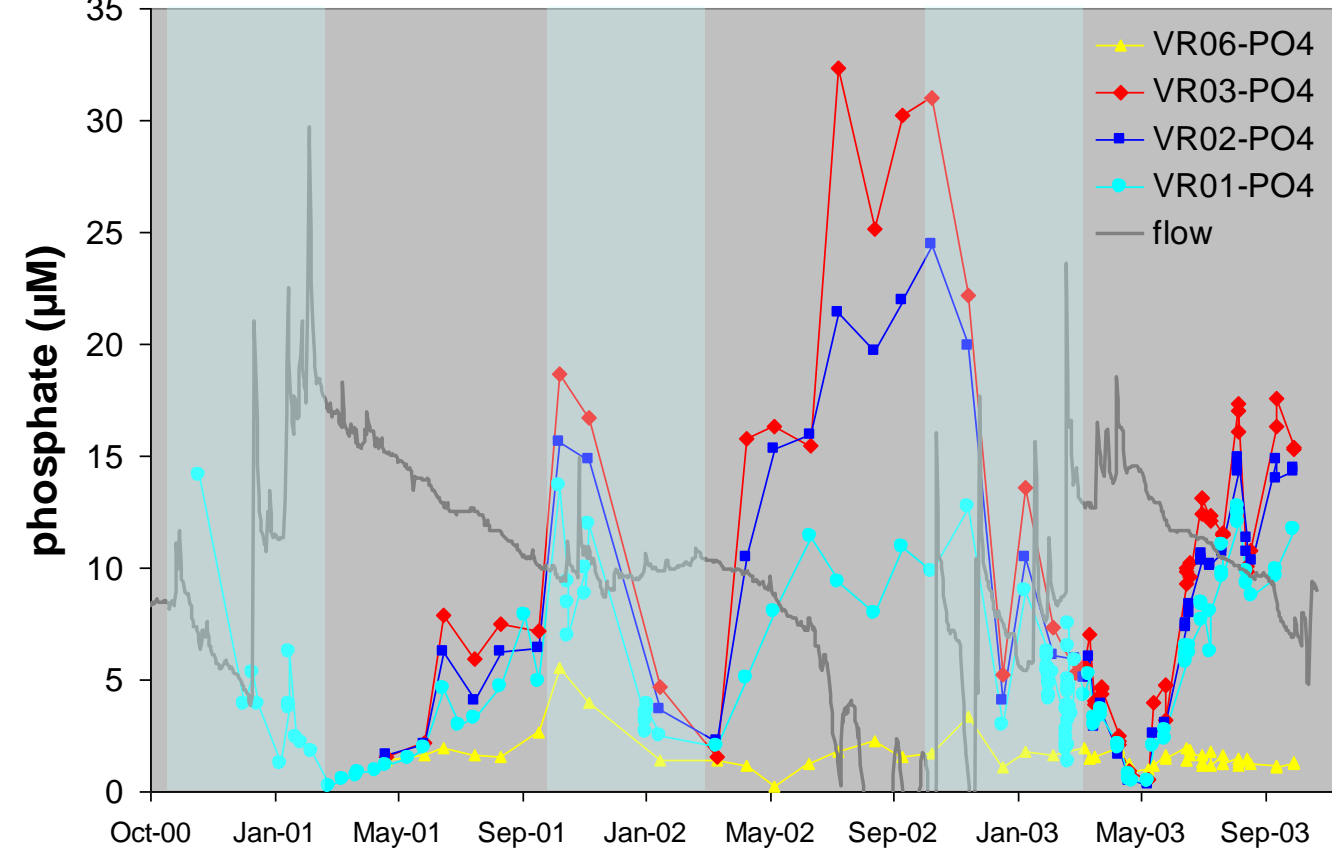
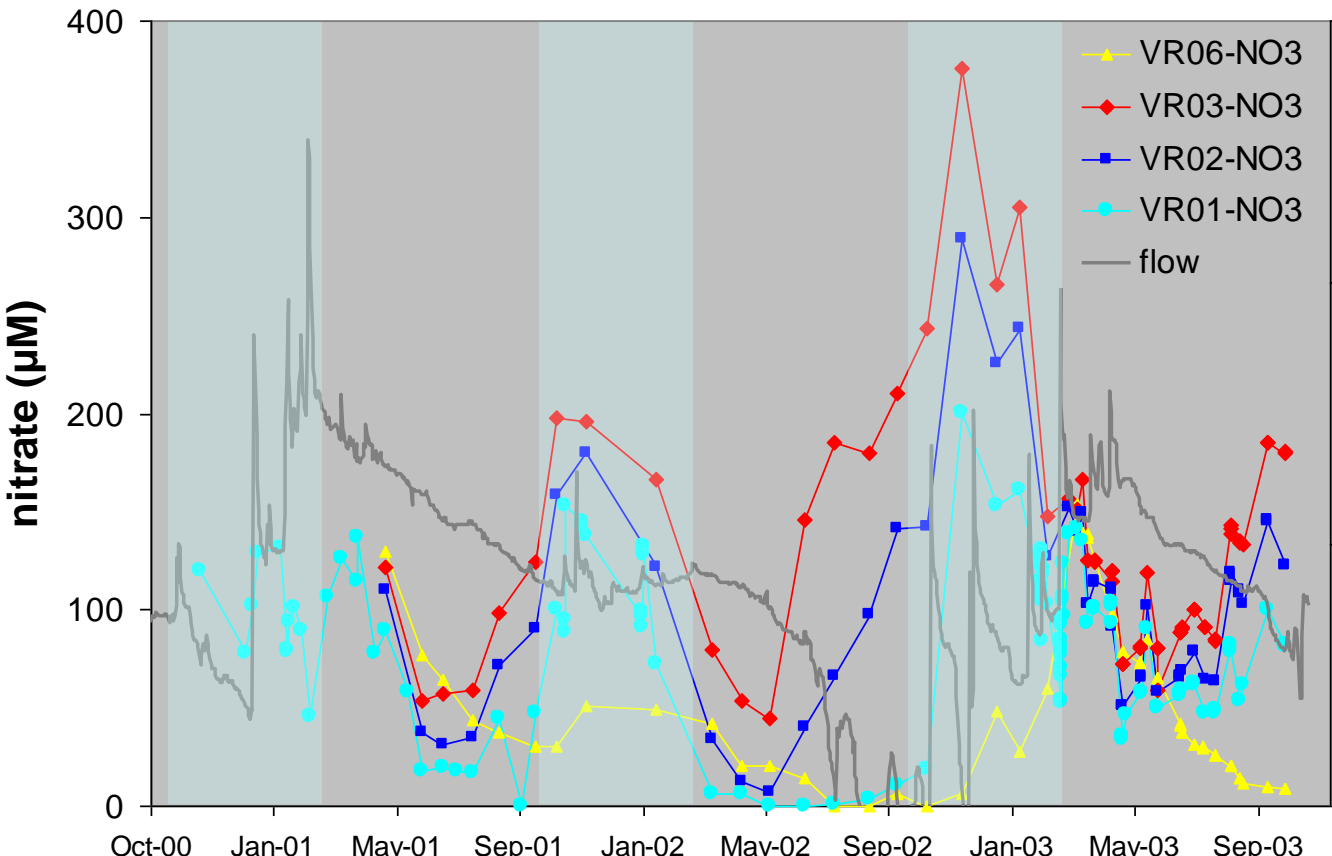
3

Riparian Vegetation (downstream of VR03 in June 2001, June 2002, Mar. 2003 and Sept. 2003 (clockwise from the upper left): Winter storms of 2003 removed aquatic plants and sediment from the center of the channel, but taller and deeper rooted riparian species (willows and arundo, visible in early stages of establishment in 2001) were relatively undisturbed. The replacement of aquatic by riparian vegetation increases the threshold size of a channel-scouring storm. Ending the riparian growth cycle will require another El Niño year such as 1995 or 1998.



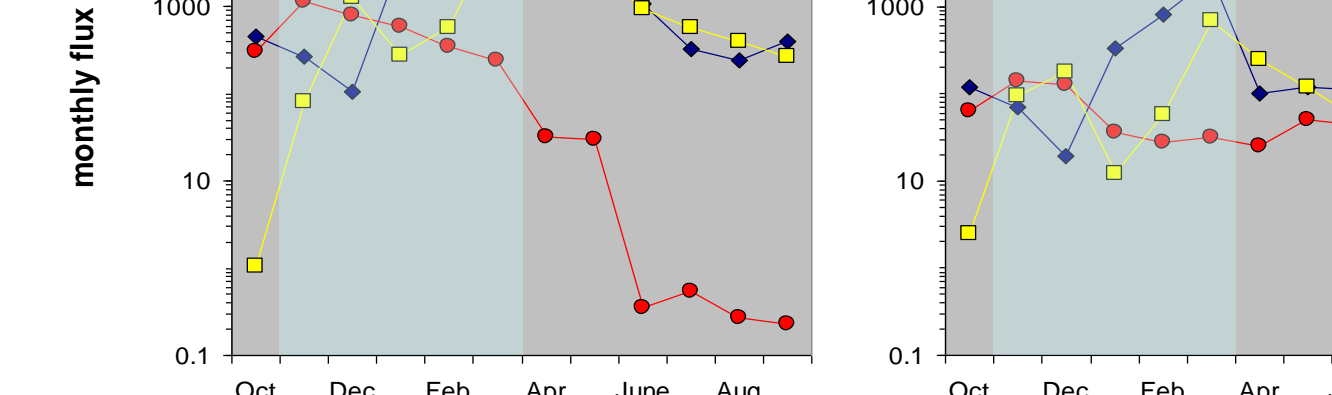
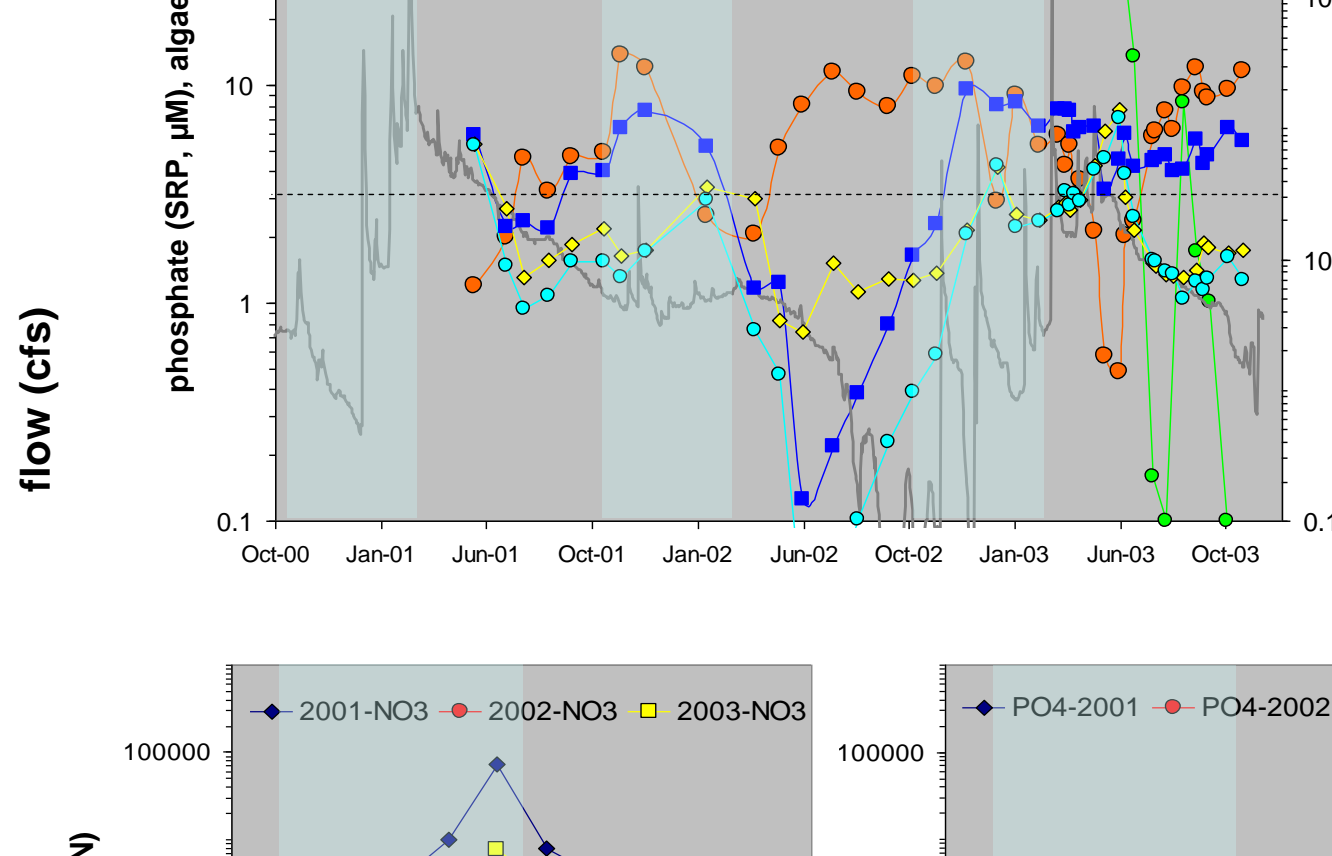
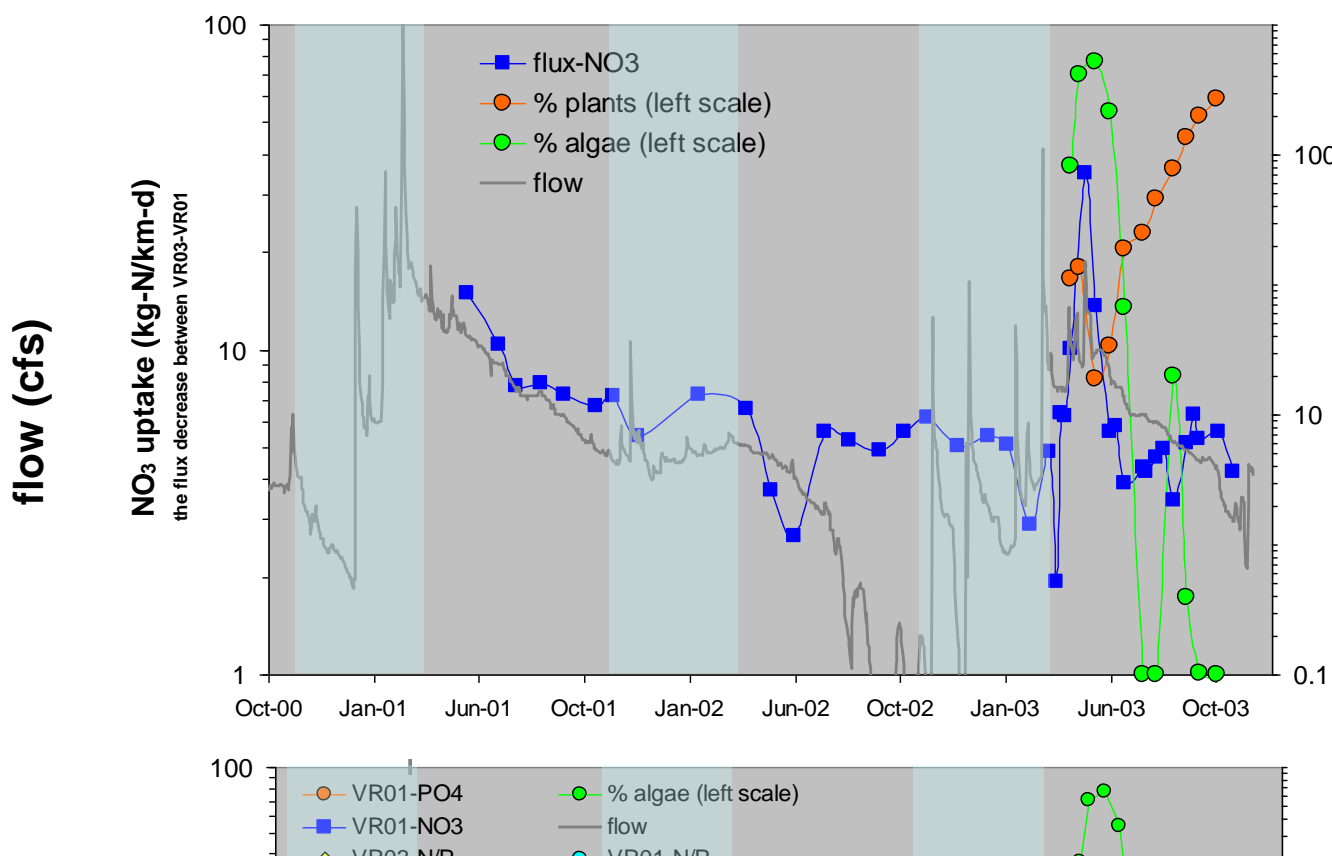
4

Channel Transformation (VR02 in Oct. 2002, and March, May, June, Sept. and Nov. 2003 (left to right, top to bottom): The plant is water primrose (*Ludwigia hexapetala*) and it dominates the lower river from VR03 to the estuary. By the fall of 2002 the river was essentially a slow moving current through a sea of *Ludwigia*. Storms in the winter of 2003 partially opened up the channel, but also deposited sediment among the roots of the remaining plants, creating confining banks in what had been an open waterway (the May photo shows this process during a small storm). Deeper, faster flows in the now confined stream slowed, but didn't stop, plant expansion during the summer of 2003. In the last photo the process begins anew with this year's rains. Channel narrowing, aquatic plants and the shading of the waterway by growing riparian vegetation end the cycle of dry-season algal dominance.



5

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 path of the hydrograph, while phosphate remains relatively constant. Concentrations at VR06, above the sewage plant – yellow symbols – represent this variation. Below the sewage outfall, the pattern, controlled by dry-season effluent discharge, is of increasing concentration 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 marks the mid-Nov. to mid-Mar. rainy season.



occurs during the rainy season and phosphate conc. are closely coupled with sediment load. The relative ratios of runoff to nitrate to phosphate for annual export in **2001, 2002 and 2003** were **31:1:5, 29:1:5** and **7:1:3**, respectively.

6

Nitrate uptake (the flux decrease between sewage outfall and estuary; upper panel) is surprisingly consistent, except during periods of heavy algal growth (the summer of 2001, 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. The shift from algal to plant dominance also causes a change from P-limitation to N-limitation. When plants dominate, N/P ratios are well below 30 (the estimated Redfield ratio for terrestrial aquatic systems shown as a dashed line in the lower panel) and the ratio decreases going downstream (from VR03 to VR01), nitrate concentrations are often at minimum values, and the effluent driven increase in dry-season nitrate concentrations below the sewage outfall is preceded by the phosphate increase – all evidence of N-limitation. Conversely, during algal periods phosphate concentrations are at a minimum and N/P ratios near or above 30.

7

Differences in annual runoff in Southern California coastal streams, magnified by riverine processes, can produce greater than 3 order-of-magnitude differences in monthly nutrient export fluxes to receiving estuaries. Differences are greatest for dry-season nitrate concentrations and export. In contrast, annual export differences are greatest for phosphate – the great majority of annual export