Report as of FY2006 for 2006AZ149B: "An Investigation in the Upper Santa Cruz River 2005 Riparian Vegetation Die-off"

Publications

Project 2006AZ149B has resulted in no reported publications as of FY2006.

Report Follows

A. Problem and Research Objectives

The overall objective of this research project was to conduct a preliminary investigation into the potential causes, observed consequences, and management implications of a sudden and widespread mortality of woody riparian and bosque vegetation along a 16-km stretch of the Upper Santa Cruz River in southeastern Arizona. Our proposed objectives were to document the spatial and temporal context within which the die-off occurred and assess strong candidate causes associated with water quality and tree pathology. Given the nature and significance of this problem, we anticipated that this preliminary investigation will provide the foundation for a larger, interdisciplinary research initiative addressing the dynamics of coupled natural and human systems within the context of riparian ecosystems and riparian ecohydrology.

Key Findings

Our research suggests that the Upper Santa Cruz River tree mortality occurred in response to a combination of individual stressors, primarily decreased levels of groundwater, reduced infiltration from streamflow and flood events due to a five year drought, and the formation of an impervious streambed clogging layer from increasingly high nutrient levels in effluent discharged from the Nogales International Wastewater Treatment Plan (NIWTP). Each of these individual impacts converged in the Rio Rico sub-basin of the Santa Cruz Active Management Area due to the unique hydrogeology and streambed dynamics along that stretch of the river.

High transmissivity within the Rio Rico sub-basin normally allows for tightly coupled interactions between streamflow and groundwater levels that support both gaining and losing reaches, depending upon the frequency of flood events and groundwater levels. However, drought conditions have greatly impacted precipitation patterns in the region and there were no significant flood events from 2001 through 2005. During this time, groundwater levels dropped precipitously as pumping rates were maintained and mountain front and streambed recharge rates decreased. High nutrient levels in the effluent simultaneously supported the formation and growth of a clogging layer in the stream channel of the Santa Cruz River. Under favorable climate conditions, this clogging layer is routinely scoured by high intensity flood events. However, due to the drought conditions, the clogging layer continued to grow and expand in the absence of floods from 2001-2005 and increasingly prevented infiltration from the stream channel into the groundwater tables and floodplain that supports the riparian forest. Cumulative impacts from the drought and the clogging layer likely combined to cause a threshold event in the riparian forest along the Rio Rico sub-basin of the Upper Santa Cruz River. Within approximately six months, the health of the riparian forest crashed and there was widespread mortality along the length of the Rio Rico sub-basin.

This event highlights a number of future research needs. There are numerous unresolved ecohydrological issues regarding the release of effluent, a third source of water, into ground-water dependent riparian systems. Studies to date have not addressed the role of flooding as a natural disturbance process in these partially unnatural systems. While natural systems are adapted to disturbance and highly resilient during and after floods and droughts, it is not known whether effluent-dominated stream ecosystems exhibit a comparable recovery capacity, or even if disturbance events are important to the functional integrity to the ecohydrological processes of an effluent-dominated riparian ecosystem (Patten et al. 1998). Few if any studies have studied how native riparian vegetation responds to continued inflows of nutrient-rich effluent and the possible associated changes in riparian community composition and structure. No studies have examined this from the perspective of climate variability and the potential for prolonged droughts and rising temperatures to increase freshwater demands, further degrade riparian systems, and potentially increase the number of streams reliant upon effluent to maintain surface flows and associated riparian habitats. Ultimately, a lack of understanding about the dynamics of effluent-dominated streams has created a void in ecological methods and policy responses suitable for evaluating and protecting the ecological integrity of these systems (Brooks et al. 2006).

B. Methodology

Much of the die-off occurred on 35,000 acres of private land within the floodplain of the Upper Santa Cruz River. The majority of that private land is owned by one landowner. We met on at least six occasions with the landowner to discuss this research project and took two field trips with the landowner and associated colleagues into the most severe areas of the die-off prior to June 2006. However, in June 2006 the landowner officially denied us access to the land by sending a letter to the University of Arizona. We initially proposed to conduct water quality and tree pathology tests directly on the riparian floodplain land impacted by the die-off, however since much of our proposed testing sites were on the private land that we could not access, we had to adjust our means of analysis to comply with these restrictions. As a result, we were unable to take water quality and tree pathology samples from the affected areas and we were unable to ground-truth our estimations of the extent and patterns of the die-off. We will discuss our alternate methods of analysis in the narrative that follows.

Landscape Analysis

To delineate the spatial extent and pattern mosaic of the die-off, we developed a map of the affected region showing the degree of mortality throughout the floodplain. Initially we compared a Quickbird satellite image taken on September 1, 2006 with 2004 DOQQ imagery and aerial photographs from the past decade to identify areas of tree mortality that occurred in 2005. However, we found that the resolution of the imagery was not fine enough to delineate the boundaries and varying degrees of mortality along the river. We therefore created a base map of the river and conducted a hilltop visual assessment of the die-off region from the Tumacácori Mountains west of the river and from the San Cayetano Mountains east of the river. To augment this visual assessment, we took an overflight of the river on October 11, 2006 with EcoFlight to conduct an aerial assessment of the die-off region. From these land and air-based vantage points, we were able to visually determine the areas of mortality with some degree of accuracy, despite our inability to groundtruth the maps due to landowner access restrictions (Figure 1).

Plant Pathogens and Insect Infestations

The role of plant pathogens and insect pests in a sudden and widespread mortality of woody plants may indicate cause or consequence, but very little information is available to determine their contribution. We were furthermore limited in our analysis of the potential role of plant pathogens or insect infestations in the die-off due to the land access restrictions. To accommodate this limitation, we were able to make one field visit to the site before June 2006 with three professional plant pathologists from the University of Arizona and the U.S. Forest Service. We conducted on-site investigations of affected cottonwoods (*Populus freemontii*), Goodding willow (*Salix gooddingii*), and Netleaf hackberry (*Celtis reticulata)* trees to determine the presence or absence of insects and/or diseases.

Water Quality

Our water quality analysis was greatly limited by the restrictions on land access and we were unable to take water quality samples from wells in the die-off area as we proposed. To accommodate this restriction, we analyzed readily available water quality monitoring data from the RiverWatch program of Friends of the Santa Cruz River (FOSCR) and from Arizona Department of Environmental Quality (ADEQ). We analyzed the data for water quality trends that may have a bearing on the health, vitality, and composition of the riparian forest.

C. Principal Findings and Significance

Landscape Analysis

The *Upper Santa Cruz River riparian Mortality and Severity Index* map (Figure 1) depicts three levels of mortality:

Low = less than 30% mortality
Medium = 30% - 80% mortality
High = more than 80% mortality

These levels represent not only the degree of mortality within a gradient along the river, but also depict the variable pattern of mortality. From the map, it is apparent that the mortality is highest in the south at Rio Rico Road and tapers off as it extends north to the boundary of Tumacácori National Historical Park. The mortality appears to be distinctly bound on the south and on the north thus suggesting a difference in hydrological and/or ecological conditions in the areas adjacent to the die-off. In addition, the pre-2005 imagery did not indicate that the riparian vegetation was exhibiting usual physical responses to drought or groundwater decline, such as canopy die-back or leaf senescence (Stromberg et al. 1996, Scott et al. 1999, Rood et al. 2000, Shafroth et al. 2000, Amlin and Rood 2002, Shafroth et al. 2002, Rood et al. 2003). This apparent lack of well-documented drought responses exhibited by the Upper Santa Cruz River riparian corridor is both notable and surprising and may indicate a threshold change between alternative riparian conditions, or states, that has yet to be described in published research.

We considered this gradient of mortality in the context of the hydrogeology of the river basin. The Santa Cruz River is a tightly coupled groundwater and surface water system. Small and geologically constrained micro-basins within the younger alluvium form a series of cascading water tables along the Santa Cruz River. These microbasins can be rapidly depleted by groundwater pumping as well as rapidly re-filled during significant storm events. Their dynamic nature can provide some buffer against prolonged drought if at least one yearly storm event continues through a prolonged drought period. However, the dynamic nature of the microbasins can also leave the region vulnerable to depleted water supplies if groundwater pumping and prolonged drought combine to lower groundwater levels.

Observational studies have shown that the Rio Rico Sub-area represents a subsurface reservoir that stores water from storm recharge events, effluent inflows, and subsurface flow (Nelson 2007). High transmissivity within the younger alluvial aquifer along this stretch of the river allows for rapid and highly efficient recharge (Nelson 2007). This can be seen in Figure 2 where there is a tight correlation between flood events and spikes in aquifer recharge. These shallow water tables depend, in part, on regular storm events during the monsoon and winter precipitation seasons for adequate recharge. However, the current drought conditions throughout the Sonoran Desert region have significantly reduced the number and intensity of storm and flood events.

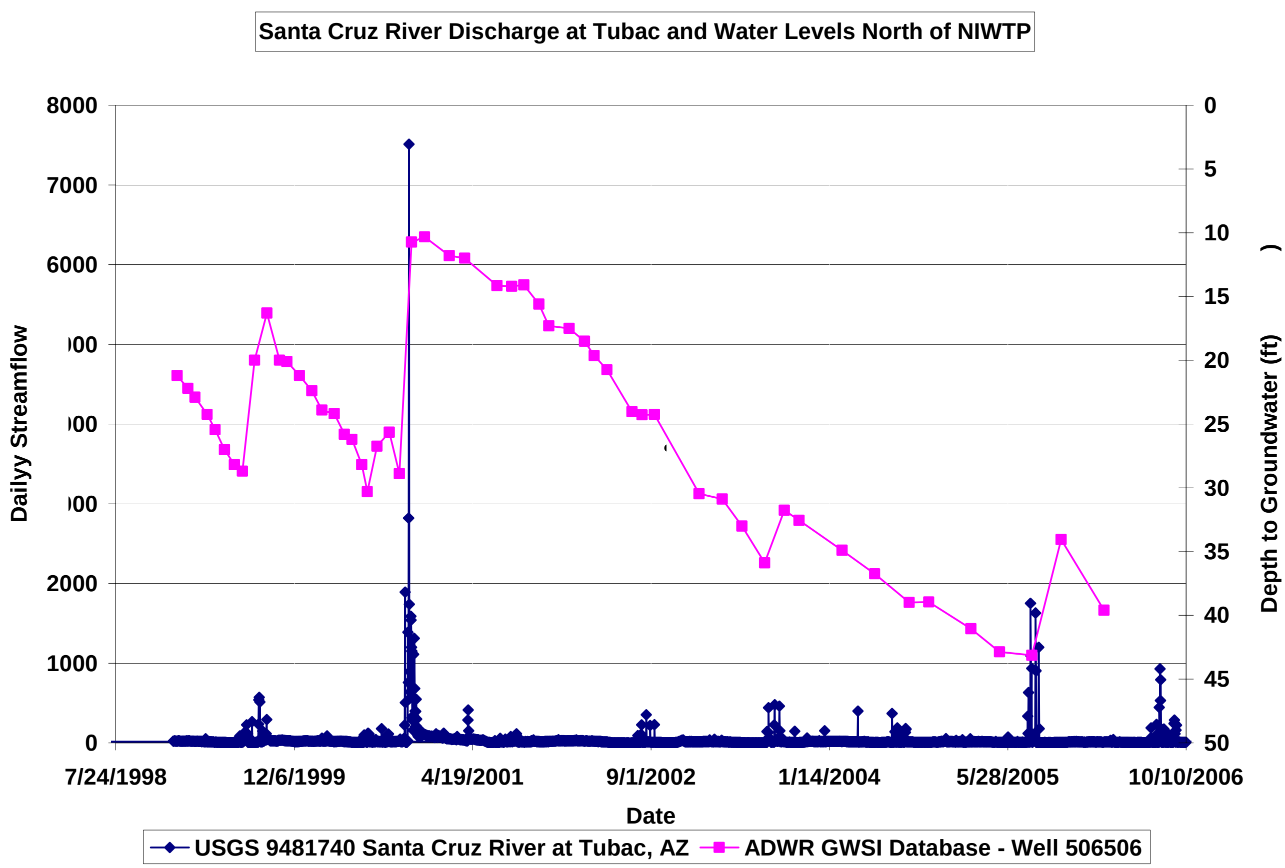

Figure 2. Correlation between streamflow and groundwater levels (Colleen Filippone, unpublished data)

An analysis of recent precipitation trends shows that the drought in this region has been severe. Precipitation at Tumacácori NHP has fallen to approximately 50%-60% below average (Figure 3). In addition, there were no significant flood events between 2001 and 2005 at the Tubac USGS streamflow gauge, as seen in Figure 4. The relationship between the riparian vegetation and the natural flow regime of the river is integral to healthy and functional riparian ecosystems. The Santa Cruz River native riparian forest is dominated by pioneer species (primarily *Populus* and *Salix* spp.) that rely upon physical disturbances such as floods to re-set successional stages (Stromberg 1993). Alterations to the natural hydrologic flow regime result in significant changes to the vegetation composition of the riparian system. Native riparian species that depend upon pulsed and seasonal flooding for seed germination have been shown to have decreased recruitment when flood pulses are eliminated from the system, and as a result are replaced by more opportunistic, and often non-native, species (Nagler et al. 2005). The Santa Cruz River die-off could have been partially triggered by the severity and length of this current drought event.

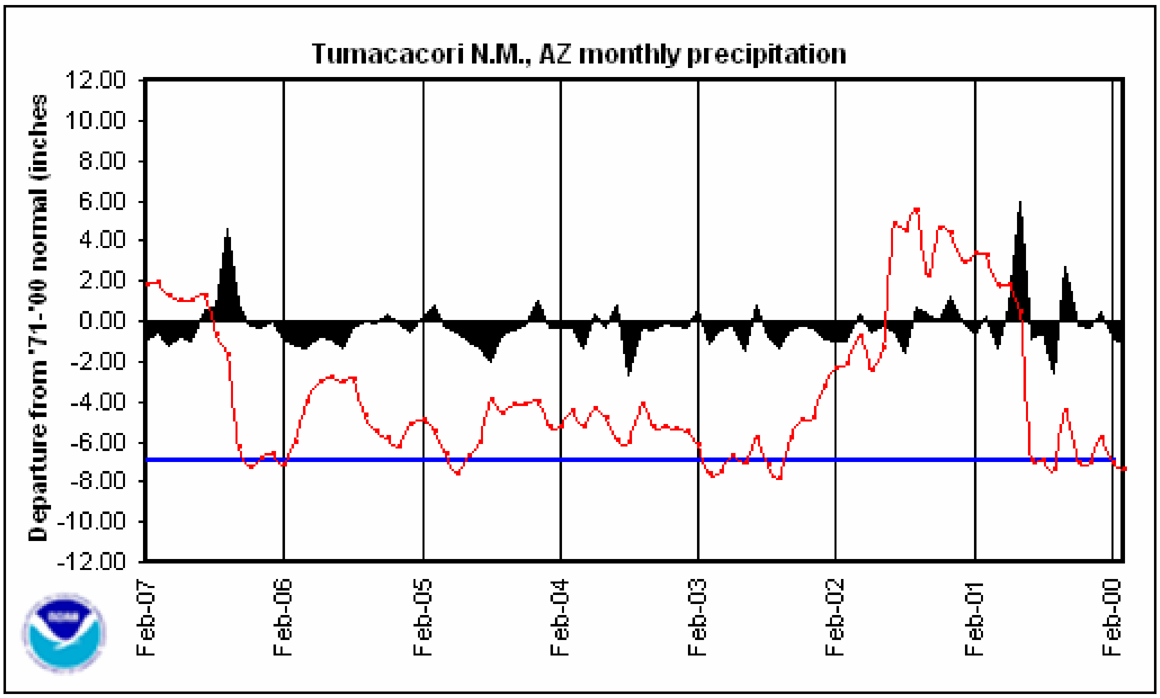

Figure 3. Tumacácori NHP monthly precipitation trends

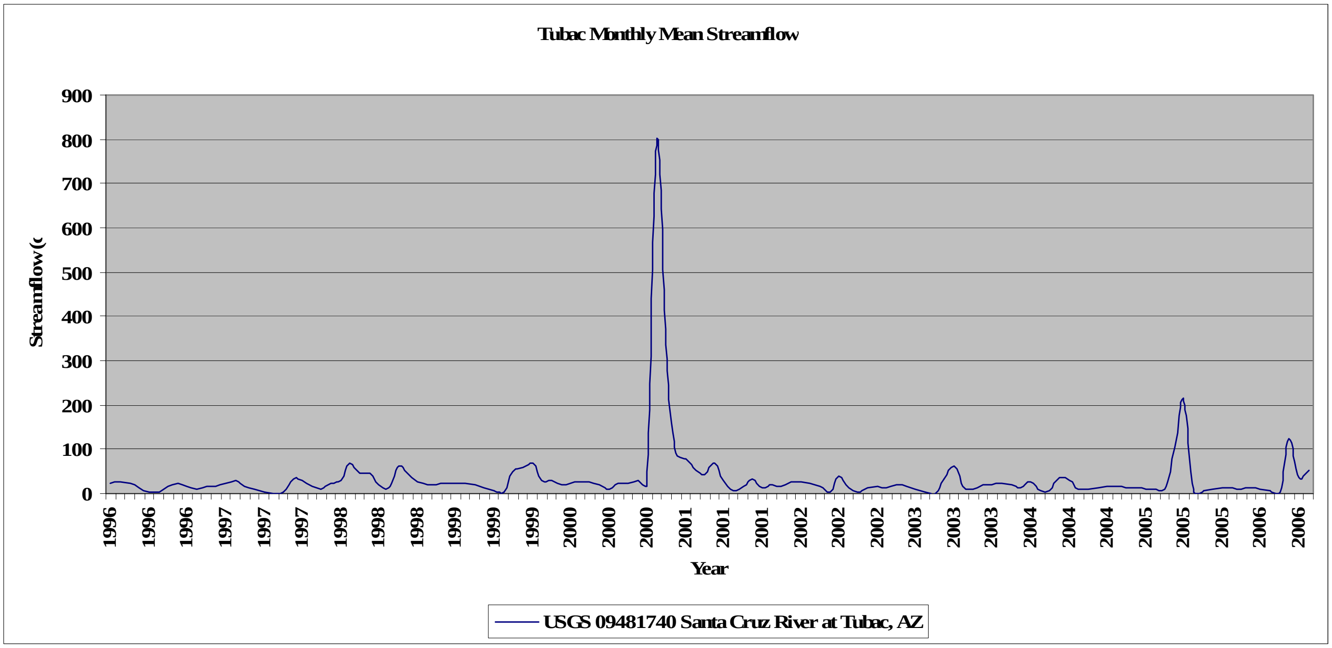

Figure 4. Streamflow at the Tubac USGS gauge

Plant Pathogens and Insect Infestations

Frequently, the activity of pathogens and insects may be an indication of plant health that in turn may be an important part of any equation for dynamic management strategies in riparian ecosystems. Pathogens of plant species common to the Santa Cruz River basin have been described in other habitats (University of Arizona 2006, Streets 1969), and records of wood rotting fungi that cause heart rots of living trees are housed in The University of Arizona's Robert L. Gilberstson Mycological Herbarium. Several pathogens are problematic on cottonwood trees that have been planted in landscapes or reforestation sites (University of Arizona 2006), but none has ever been the single cause of large scale mortality. In our investigation, *Inonotus munzii* was found to be very common in mature living and dead cottonwood trees in the affected area. It is not known if this is a distribution common to unusually stressed areas or whether it is common to healthy areas as well, however it is frequently found in dead or mostly dead trees. As a result, the plant pathologists did not feel that the presence of *Inonotus munzii* was a significant contributing factor to the die-off.

Known insect infestations have historically occurred in the Santa Cruz River riparian corridor and are mostly known through observations by long-time residents. It is possible that an insect infestation has not yet been detected and that such an impact is affecting the area presently, though this is unlikely. We did notice that several dead Netleaf Hackberry's in Calabasas County Park (located about one-mile south of the southern die-off boundary) displayed woodboring insect patterns under the bark. It is currently unknown whether or not these patterns are normal or are an indication of a potentially deadly infestation, however since only 5 hackberries appeared affected in this region we again felt that this was not a major contributing cause of the die-off. The following beetles could be the species found in the hackberries.

- A longhorn beetle *(Anelaphus villosus)* (Figure 5, left photo) occurs westward into Arizona. Longhorn beetle larvae typically leave rounded holes in the wood due to the shape of their heads. However, not all longhorn beetle larvae bore into the wood. They may feed only in the cambium-phloem region lightly scoring the sapwood.
- Hackberry bark beetle (Figure 5, right photo) has been reported as far east as N.M. They feed under the bark producing distinctive horizontal adult galleries & vertical larval galleries best described as a two-sided comb.
- Redheaded ash borer *(Neoclytus acuminatus)* (Figure 5, lower photo) has been reported in Colorado & N.M. on hackberry. Larvae feed almost entirely in the sapwood. More than one generation may occur in warmer climates. Parasitic wasps & predatory beetles are commonly associated with this borer.

Figure 5. Potential wood-boring insects affecting Netleaf Hackberry trees

Water Quality

In the Upper Santa Cruz River, discharges of effluent, or treated wastewater, can augment surface flow in ephemeral or intermittent streams and enhance riparian habitat (Tellman 1992, Marler et al. 2001, Bouwer 2002, Brooks et al. 2006). In addition to providing additional water to riparian systems, effluent is also high in nutrients and supplies additional nitrogen to the river system (Stromberg et al. 1993). In our analysis of the water monitoring data from FOSCR, we found that ammonia levels have been increasing at Rio Rico and Chavez Crossing from 1993-2004, with substantially higher ammonia levels detected at Rio Rico (Figure 6). As a corollary to that increasing trend, nitrogen levels have been increased from 1993-2004, with substantially higher nitrogen levels detected at Chavez Siding reflecting the breakdown process of the ammonia as it moves downstream through the riparian corridor (Figure 7).

In a review of riparian nutrient literature, we found that Marler *et al.* (2001) demonstrated in a controlled environment along several Arizona streams, including the Upper Santa Cruz River, that Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), and exotic saltcedar (*Tamarix ramosissima*) increased their shoot:root biomass ratio as nitrogen increased from effluent inflows. In a field experiment, Adair and Binkley (2002) demonstrated that cottonwood germinants were co-limited by both water and nitrogen, indicating that nitrogen may play an important role in riparian vegetation productivity and composition. Therefore, additional inflows of N into the

Upper Santa Cruz River may impact the rate of nutrient cycling as well as contribute to increased phreatophytic growth and abundance.

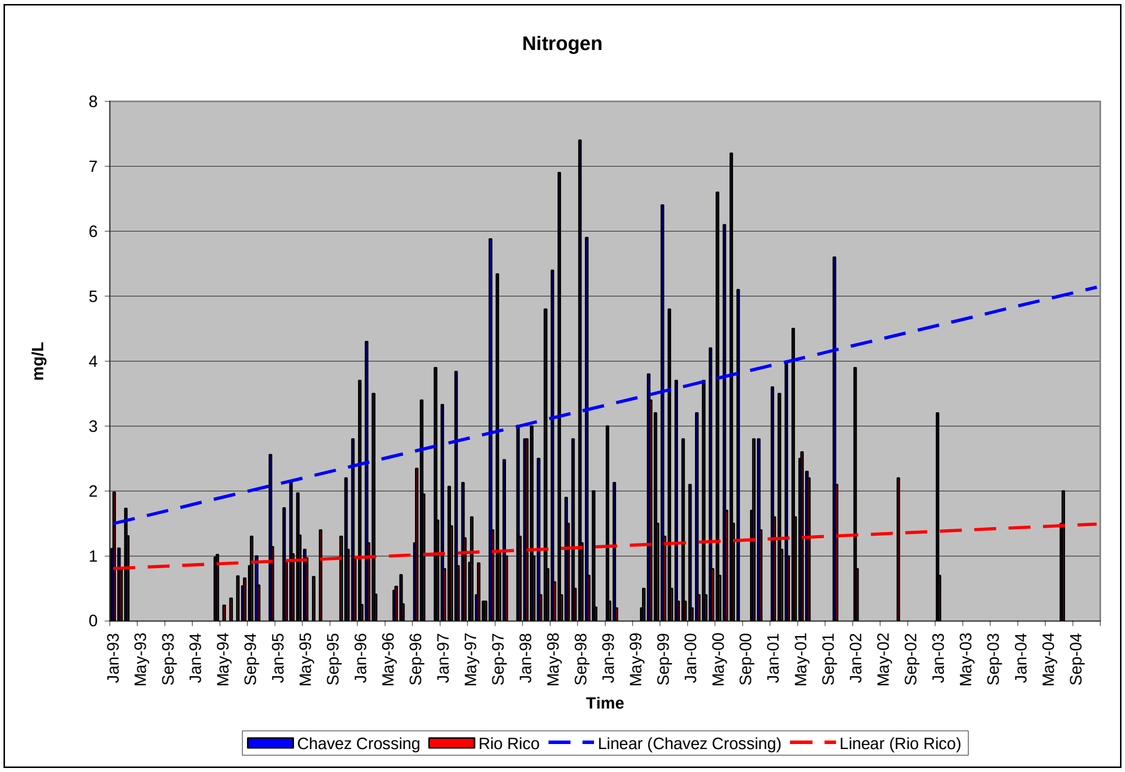

Figure 6. Nitrogen levels at Chavez Crossing and Rio Rico from 1993-2004

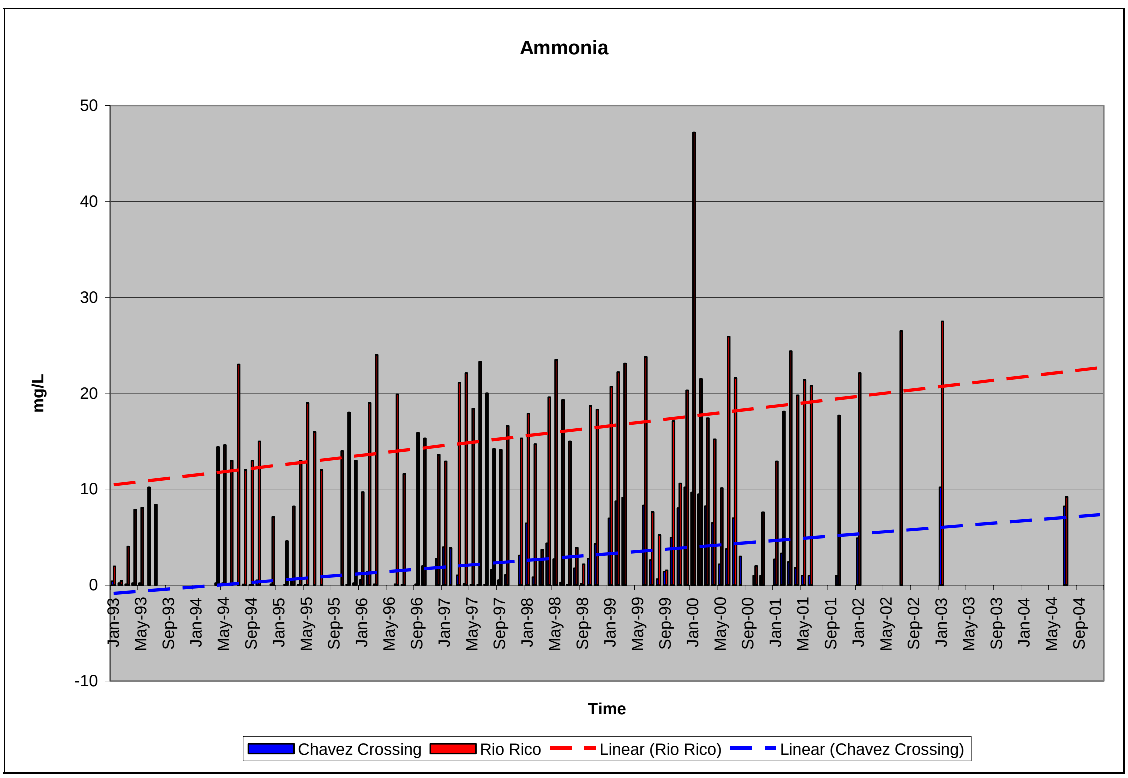

Figure 7. Ammonia levels at Chavez Crossing and Rio Rico from 1993-2004

Early research on nutrient cycling in stream systems predicted that the rate of uptake of essential nutrients is proportional to the rate of organic matter accretion in the system (Vitousek and Reiners 1975). This prediction was made in light of successional vegetation stages that occur after a flood event. During this successional time, early stages will show little uptake, middle stages of high biomass accretion will demonstrate high uptake rates, and later steady-state systems will once again exhibit low uptake as the inputs and outputs of nutrients equilibrate (Figure X) (Vitousek and Reiners 1975, Fisher et al. 1982). While this analysis applies to stream systems that sustain a natural flow regime, it is not known how an effluent-dominated stream system will accommodate consistent nutrient availability or how a constant nutrient supply will impact the successional stages of vegetation or if there are nutrient loading rates above which biotic structure and function are degraded (Stromberg et al. 1993). It is possible that increased amounts of N could “overload” the system by temporarily providing a water and nutrient buffer against drought and supporting an increasingly robust riparian vegetation community until the energy requirements of the system exceed available resources. In this scenario, the system would not have adapted to the drought conditions through the linear and progressive mechanisms usually exhibited, but could instead experience a threshold crash under the weight of its own energy requirements.

This possibility is support by E.P. Odum’s theory that explains how systems are impacted by “subsidies”, or supplemental additions such as effluent to a certain ecosystem (Odum et al. 1979). While many subsidies may have beneficial results, such as additional nitrogen in a nitrogen-limited system, at some point those additions may allow the system to increase its energy demands beyond what can be sustained by the functions and processes in place, particularly simultaneous with a disturbance or perturbation, such as drought (Figure 8).

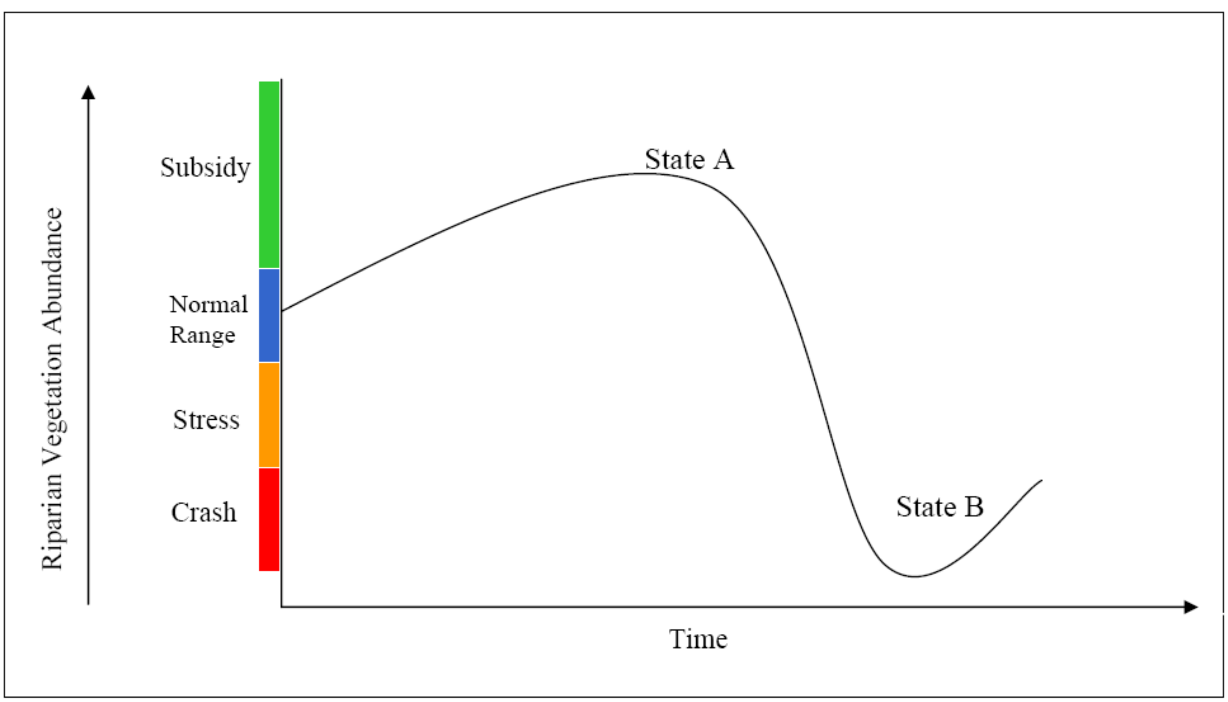

Figure 8. Subsidy-stress curve for an effluent-dominated system. Modified from Odum (1979)

In the case of the Upper Santa Cruz River, the effluent flows provided additional water and nitrogen to a system co-limited by both. The vegetation was bolstered and streamflow was augmented concurrent with a drought and declining groundwater tables. Under normal conditions, the riparian vegetation would adjust its energy demands to accommodate a balance between water conductance and evapotranspiration demands. According to past research, all riparian cottonwoods display leaf senescence that visibly precedes branch and crown die-back following drought stress (Rood et al. 2003), however current satellite imagery data does not indicate such a conspicuous drought response in the Upper Santa Cruz River.

Furthermore, natural hydrologic regimes in riparian forests tend to create heterogeneity in riparian ecosystems that enables the system to adapt and recover from perturbations like floods and water stress. Effluent, on the other hand, due to its consistent delivery of nutrients and water, homogenizes the system and potentially diminishes its resilience to perturbations and stress. This is likely the case in the Upper Santa Cruz River where supplemental nutrients and water provided by the effluent masked the impacts of the drought and muted the normal physiological response to water stress. Nutrients from the effluent bolstered vegetation production and ultimately shifted the energy requirements beyond that which the ecohydrological system could support. The riparian system was therefore less resilient and crossed a threshold into a new alternative state.