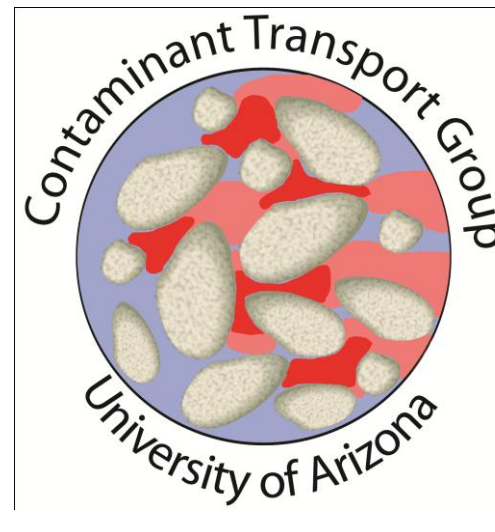




Abstract

The Upper Santa Cruz Basin has experienced population growth and industrial development that has resulted in increasing water demand and greater risk of groundwater contamination. This demand and subsequent pumping that began in the late 1800s have led to ephemeral flow in portions of the river, while effluent discharge from the Nogales International Wastewater Treatment Plant (NIWTP), beginning in 1951, now sustains perennial flow in the downstream reach. In combination, these factors have altered the natural groundwater flow patterns in the basin. The objective of this study is to examine the potential for contaminant transport in the subsurface and associated human-health risks by using a groundwater flow model previously developed for the portion of the aquifer downgradient of the NIWTP. Water-quality data for the area have been compiled from numerous sources (federal, state, consultant, and academic) into a database of sampling events for the area. These data were then aggregated to identify major contaminants and their distribution. Using a numerical model (MT3D), simulations are being conducted for specific contaminants, including nutrients and trace metals, to evaluate their movement in the aquifer. The results of this study will be used to evaluate the potential for groundwater contamination and transport to domestic water supply wells.

Objective

Develop a conceptual and numerical model of the occurrence and levels of contaminants along the effluent-dominated portion of the Santa Cruz River. This was accomplished by:

- Compiling a water quality database of past and current water sampling events
- Determining predominant contaminants and their distributions
- Conducting simulations of transport and fate for representative contaminants (NO_3^- , Cd^{2+})

Site Location

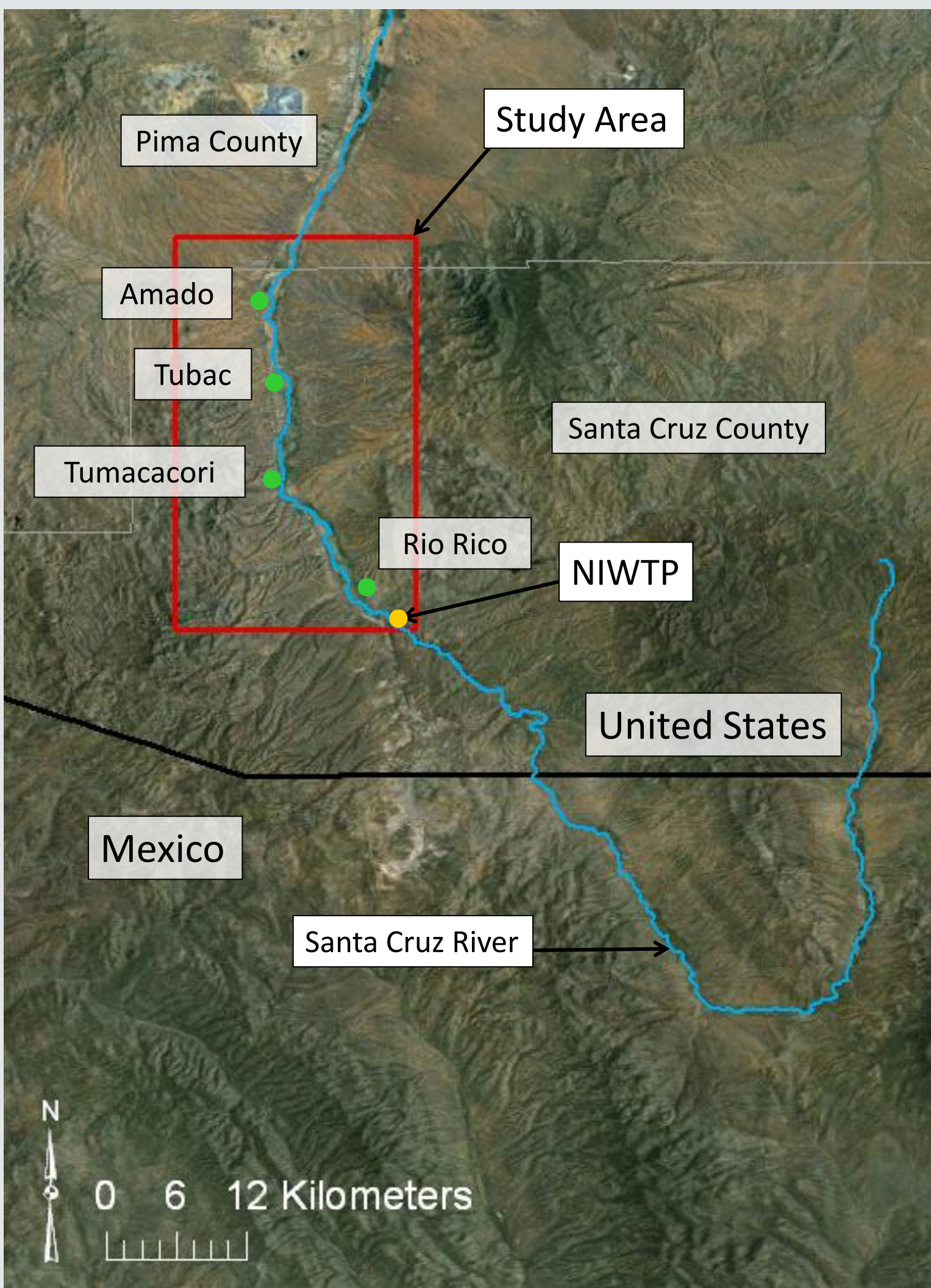


Fig 1. Santa Cruz River basin from the headwaters to the just north of the Santa Cruz Active Management Area (AMA)

The domain in which water quality samples were collected covers the entire Santa Cruz Active Management Area (AMA) and the headwaters of the Santa Cruz River in the San Rafael Valley, with a few samples collected in Mexico. The red boundary in figure 1 outlines the domain of the groundwater-flow model created by ADWR (Nelson, 2007). This model was calibrated to the years 1997 to 2002. The domain covers 230 square miles with a quarter mile by quarter mile cell size. The domain is composed of three layers: young alluvium, old alluvium, and the Nogales formation.

The NIWTP releases effluent into the Santa Cruz River at a rate of 12,000 to 15,000 acre-feet/year and maintains a perennial flow north from the treatment plant for approximately 20 miles, varying with seasons. The aquifer receives a significant portion of total recharge from flow in the Santa Cruz River downstream of the treatment plant, with river recharge to the aquifer ranging from approximately 30 to 70 percent per year.

The river serves as the sole nitrate source for the nitrate simulations. The concentrations are specified at the river cells based on sampling results in the Santa Cruz Water Quality Database.

Methods

- Create a water quality database from the following sources:
 - Arizona Department of Environmental Quality's (ADEQ) Water Quality Database and Reports
 - International Boundary and Water Commission's Binational Nogales Wash United States/Mexico Groundwater Monitoring Program Interim and Final Reports (IBWC)
 - Friends of the Santa Cruz River's RiverWatch (FOSCR)
 - Arizona Department of Water Resources' Groundwater Site Inventory (ADWR GWSI)
 - National Uranium Resource Evaluation (NURE)
 - United States Geological Survey's National Water Information System (USGS NWIS)
 - Academic reports and published data (Treese, 2008)

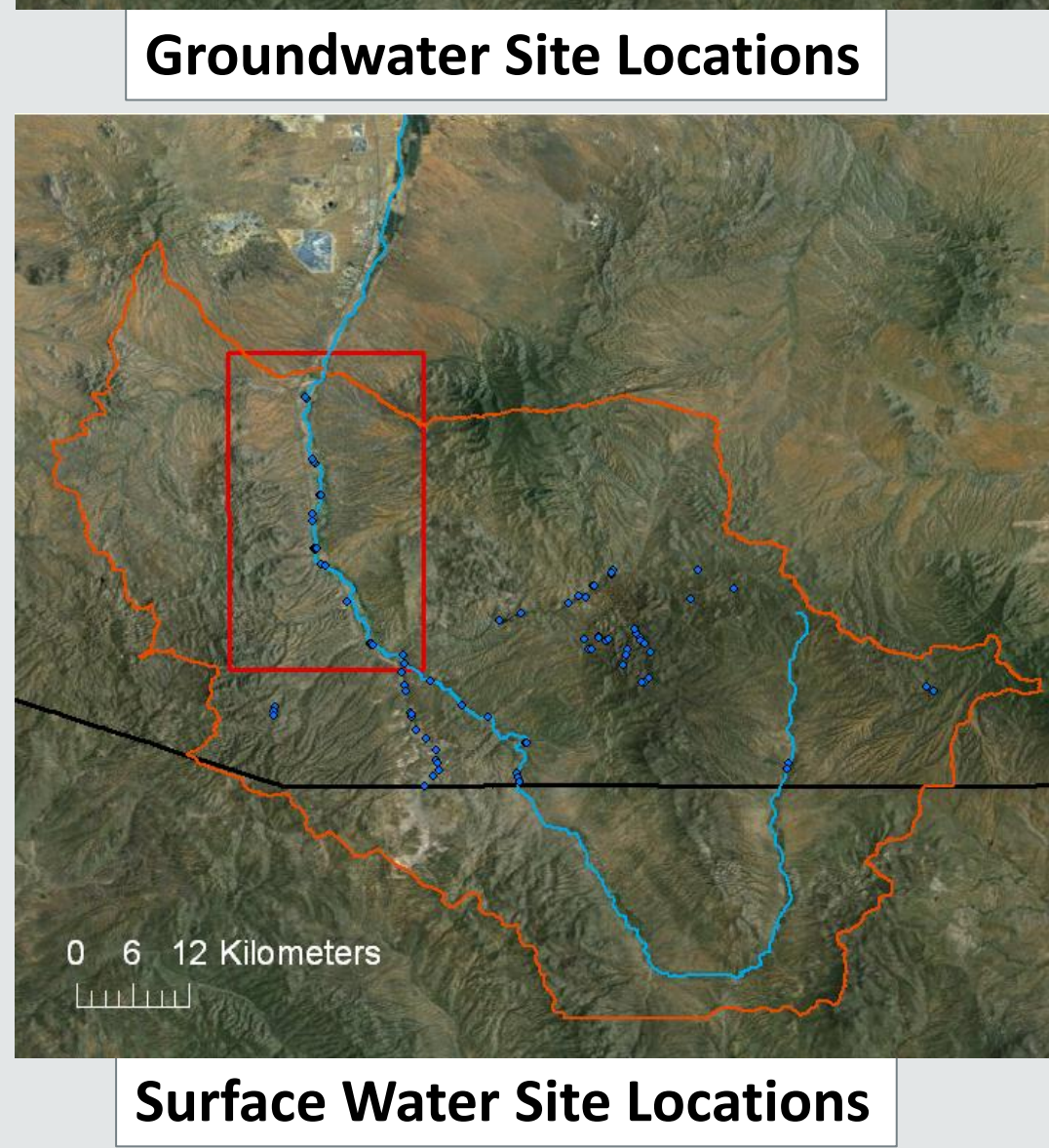
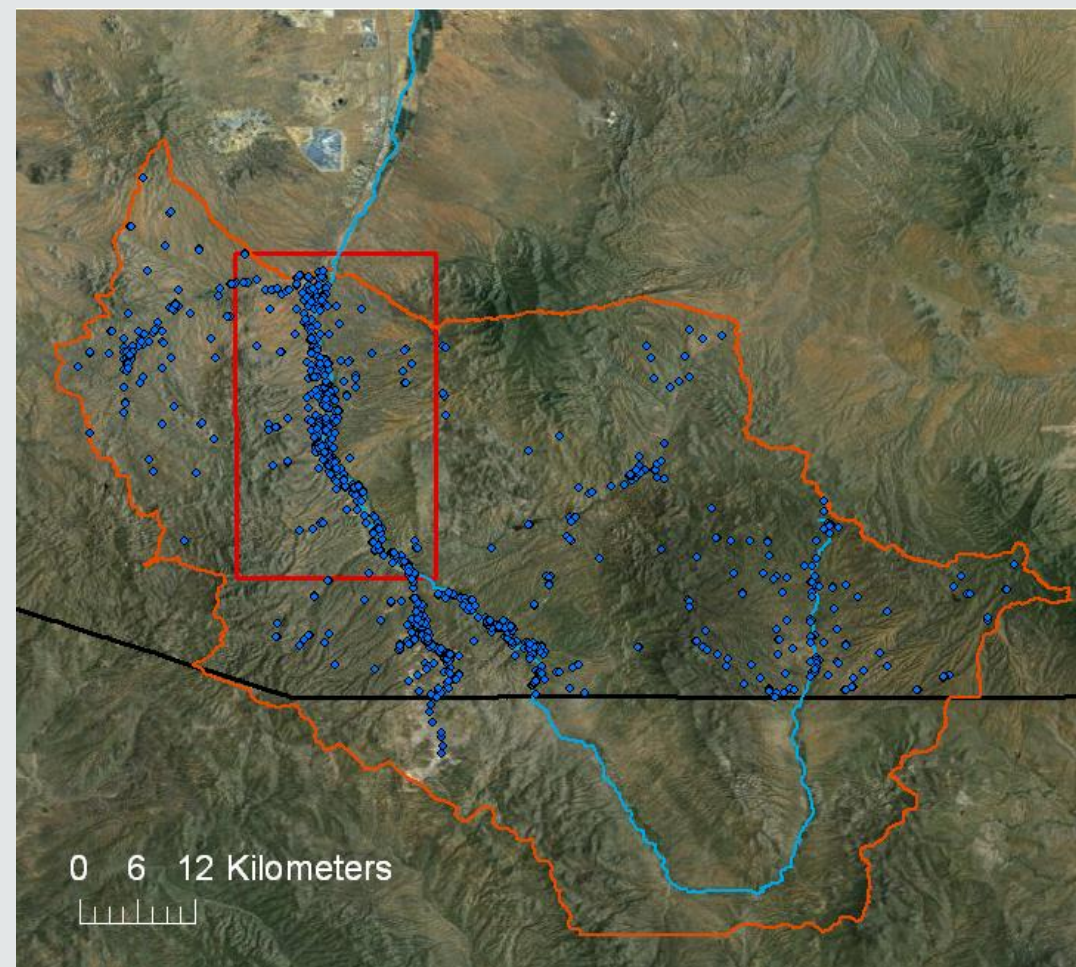
- MT3DMS model coupled with MODFLOW 2000 run in GMS 7.1

$$\frac{\partial(\theta C)}{\partial t} = \frac{\partial}{\partial x_i} \left(\theta D_{ij} \frac{\partial C}{\partial x_j} \right) - \frac{\partial}{\partial x_i} (\theta v_i C) + q_s C_s + \sum R_n$$
$$\sum R_n = -\lambda \theta C$$

Santa Cruz River Water Quality Database

- The spatial distribution of the groundwater sample locations is more dense along the river

In dealing with numerous sources, it was necessary to structure the database in a way that provided some uniformity among the various sources. This was accomplished by separating the site information from the water quality sample results to create two smaller tables that could be structured to minimize repeating information. Additional information for some data files includes depth to water and flow measurements, well logs, and sediment analysis results. Duplication among the sources was present; in such cases the duplicate information was removed.



	Number of Locations	Number of Results*	Sample Type
ADEQ Water Quality Database up to 4-2005	840	14,379	Groundwater
ADEQ Santa Cruz Water Quality Report 1997	69	31,230	Surface Water
IBWC	24	881	Groundwater
FOSCR	3	108	Surface Water
ADWR GWSI	14	2,249	Groundwater
NURE	9	3,726	Surface Water
	224	749	Groundwater
	55	2,691	Groundwater
	2	93	Surface Water
USGS NWIS	79	5,666	Groundwater
	10	8,875	Surface Water
	18	920	Surface Water
Treese, 2008	15	342	Groundwater

*One result represents one parameter analysis result

Additional Modeling Efforts

A news release from ADEQ in October 2010 reported the IBWC was in violation of cadmium water standards in the effluent discharged from the NIWTP and excessive cadmium levels were present in the biosolids that are applied to the land surface. Data review does not show a large number detects of cadmium in the domain; in light of this press release, however, a cadmium transport model is being developed to evaluate where cadmium is found and its potential movement. Initial review shows nonlinear sorption is a primary transport characteristic with rate-limited sorption playing a minor role (Wang et al, 1998).

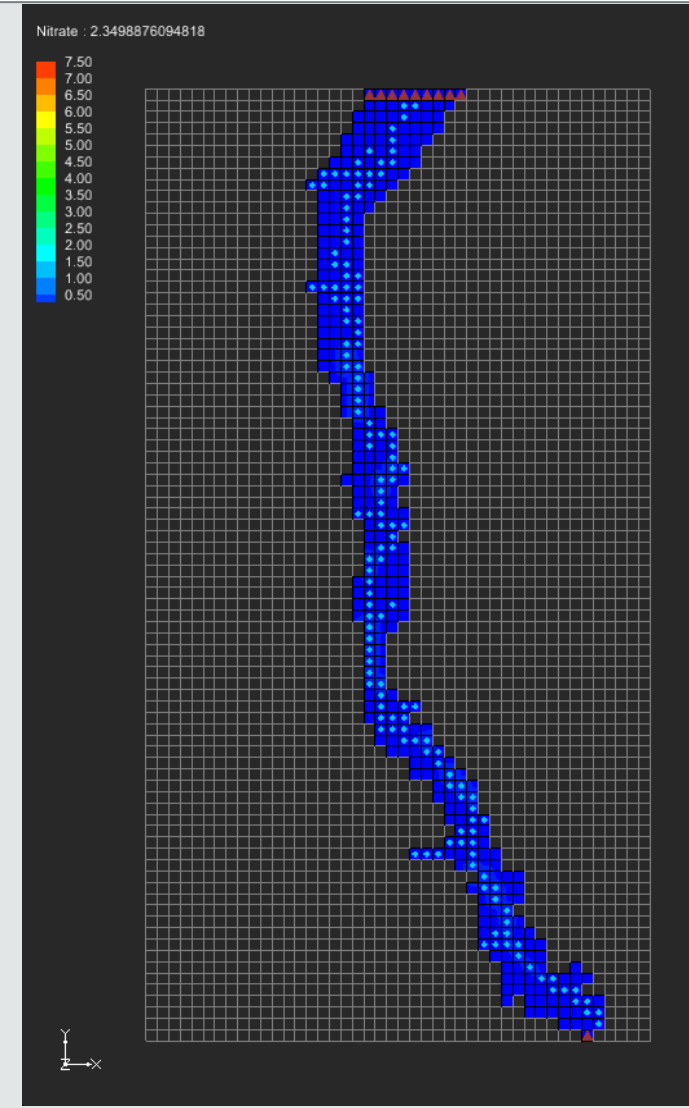
Nitrate Model Results

A review of the database results showed elevated levels of nitrate in the effluent. A literature review of studies in the area and in similar environments produced the parameters included in the following table.

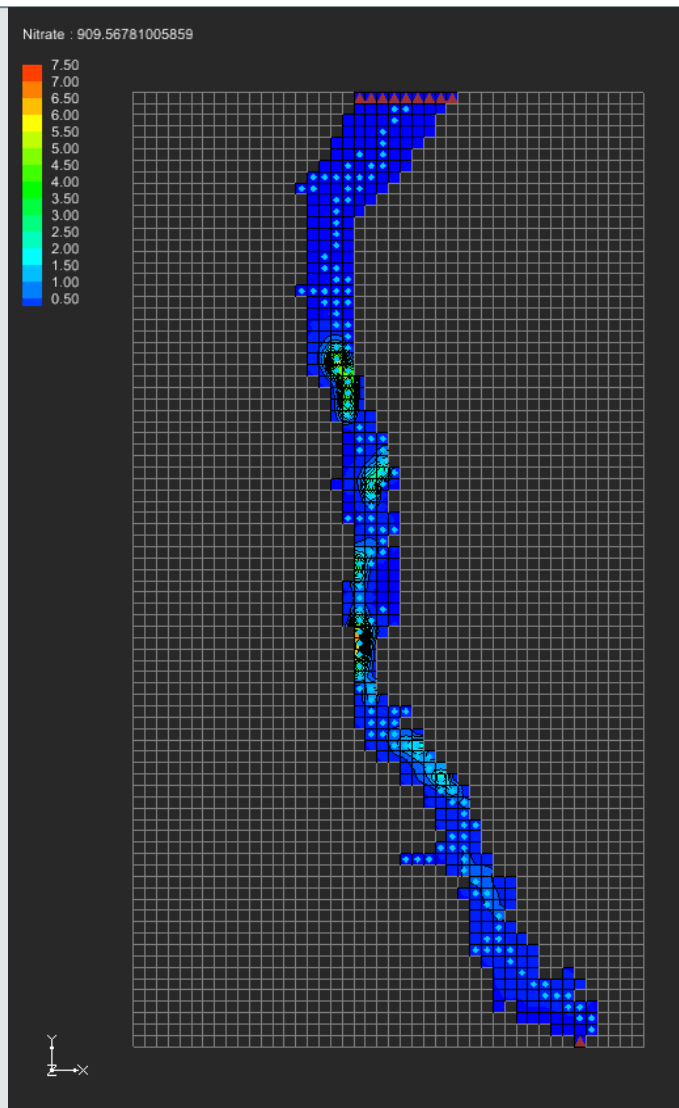
	Young Alluvium	Old Alluvium	Nogales Formation
Porosity (θ) ¹	0.21	0.16	
Bulk Density (ρ_b) ¹	139.8 lb/ft ³	144.8 lb/ft ³	
First-Order Rate Coefficient (λ) ²	0.7 yr ⁻¹		
Longitudinal Dispersivity (α_L) ³	164 ft		

(1) Getting and Houser, 1998, (2) Carroll et al, 2009, (3) Gelhar et al, 1992

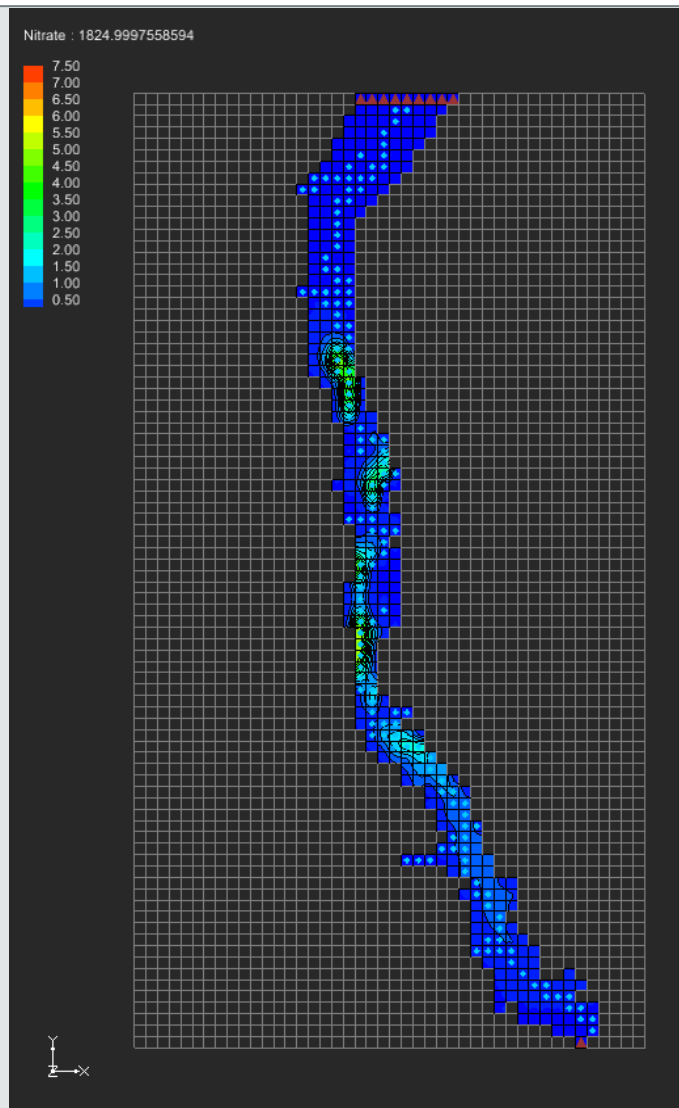
Young Alluvium Initial Condition



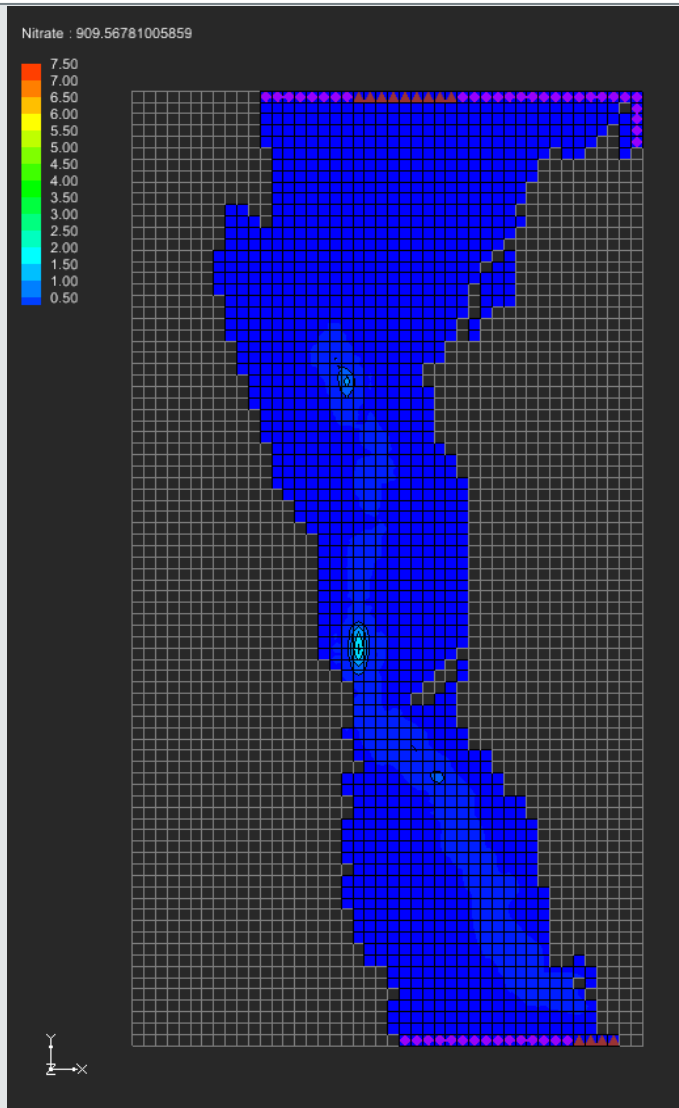
Young Alluvium at 2.5 years



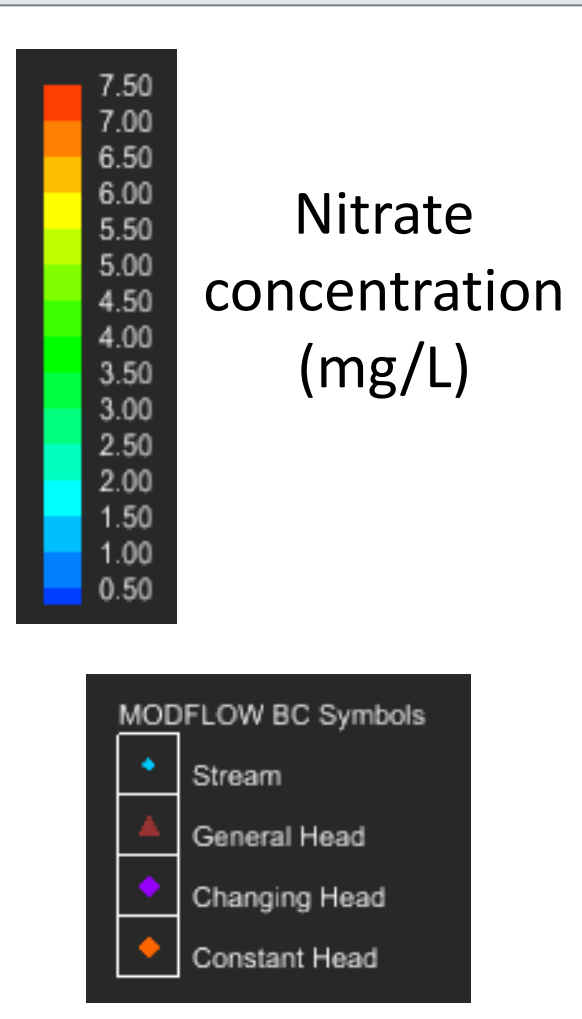
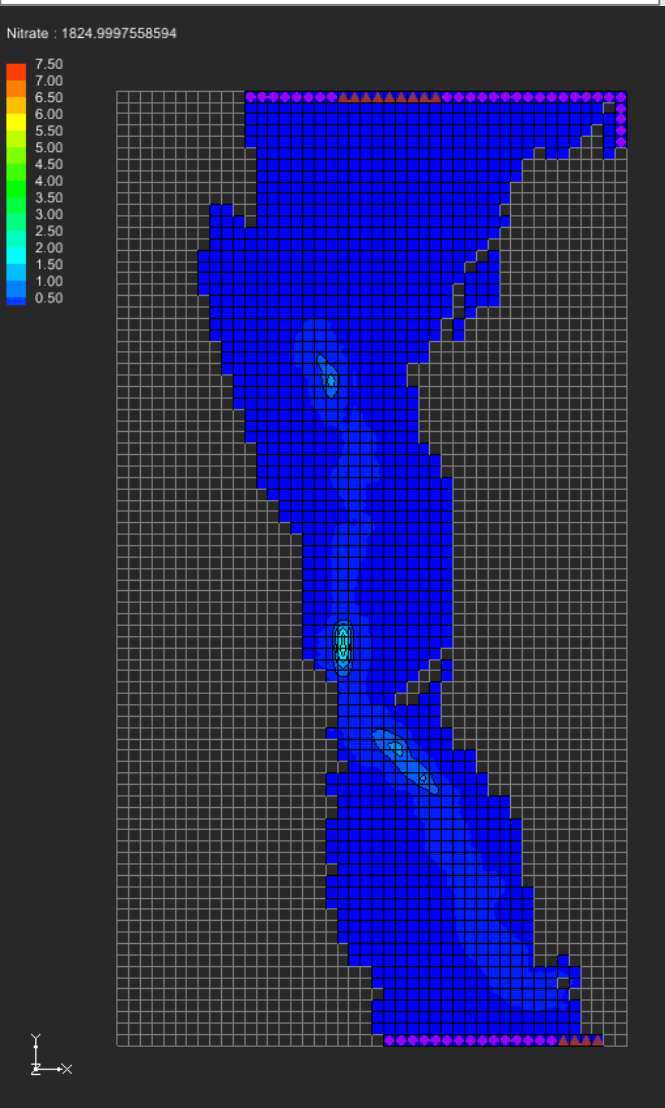
Young Alluvium at 5 years



Old Alluvium at 2.5 years



Old Alluvium at 5 years



- The large hydraulic conductivity and minimal sorption behaviors in the modeled young alluvium, top model layer, led to large areas of transport of nitrate, shown in the top three images, above, including transport into the old alluvium (middle model layer), shown in the lower two images above
- The five year model run showed minimal transport of nitrate to the Nogales formation (bottom model layer), data not shown
- The plume was sensitive to the five-season temporal fluctuations in precipitation, recharge, evapotranspiration, etc.

Acknowledgements and References

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