Applications of Modeling Non-point Source Pollution in Groundwater

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Abstract

Groundwater modeling is an indispensable tool for understanding subsurface flow and transport processes, enabling informed decision-making in water resource management. Advancements in groundwater modeling provide new opportunities to address critical challenges in subsurface hydrology. This work focuses on the development and application of the non-point source assessment tool (NPSAT) for simulating groundwater flow and transport processes. By integrating regional-scale hydrologic models with particle-tracking and reactive transport frameworks, the NPSAT addresses complexities such as spatial variability and anthropogenic influences. Two novel applications are highlighted: groundwater age modeling, which refines our understanding of aquifer porosities and flow velocities, and nitrate transport modeling, which evaluates contaminant movement and attenuation under varying agricultural practices. These advancements demonstrate the potential of cutting-edge groundwater modeling approaches to tackle emerging issues in water resource sustainability and pollution mitigation.

Methods

The Nonpoint Source Assessment Tool(NPSAT) is applied as the general framework to run the groundwater flow model and transport model.

The steady-state groundwater flow equation is governed by:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)=0$$

where h is the hydraulic head, K is hydraulic conductivity.

NPSAT is a streamline-based model approximating the transport equation using multiple 1D streamlines connected to output surfaces of interest (wells, stream segments), thus greatly reducing computation time.

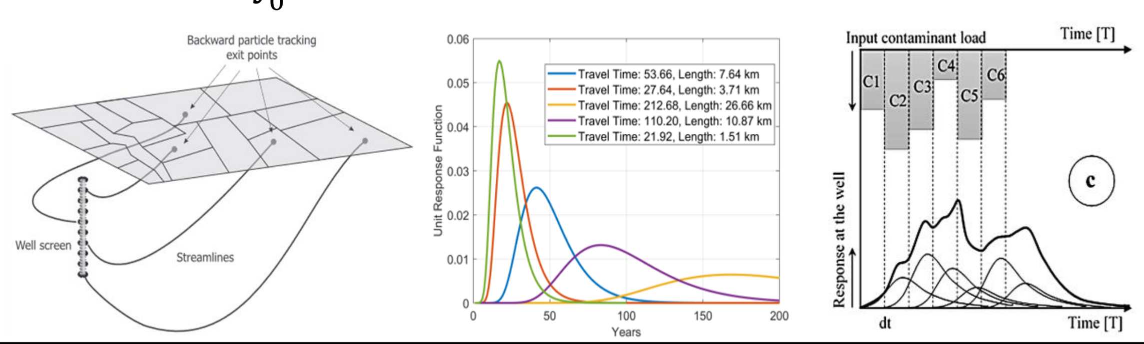
The 1D advection-dispersion-retardation equation (ADE) is governed by

$$R\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial x^2}-v\frac{\partial C}{\partial x}-\lambda RC$$

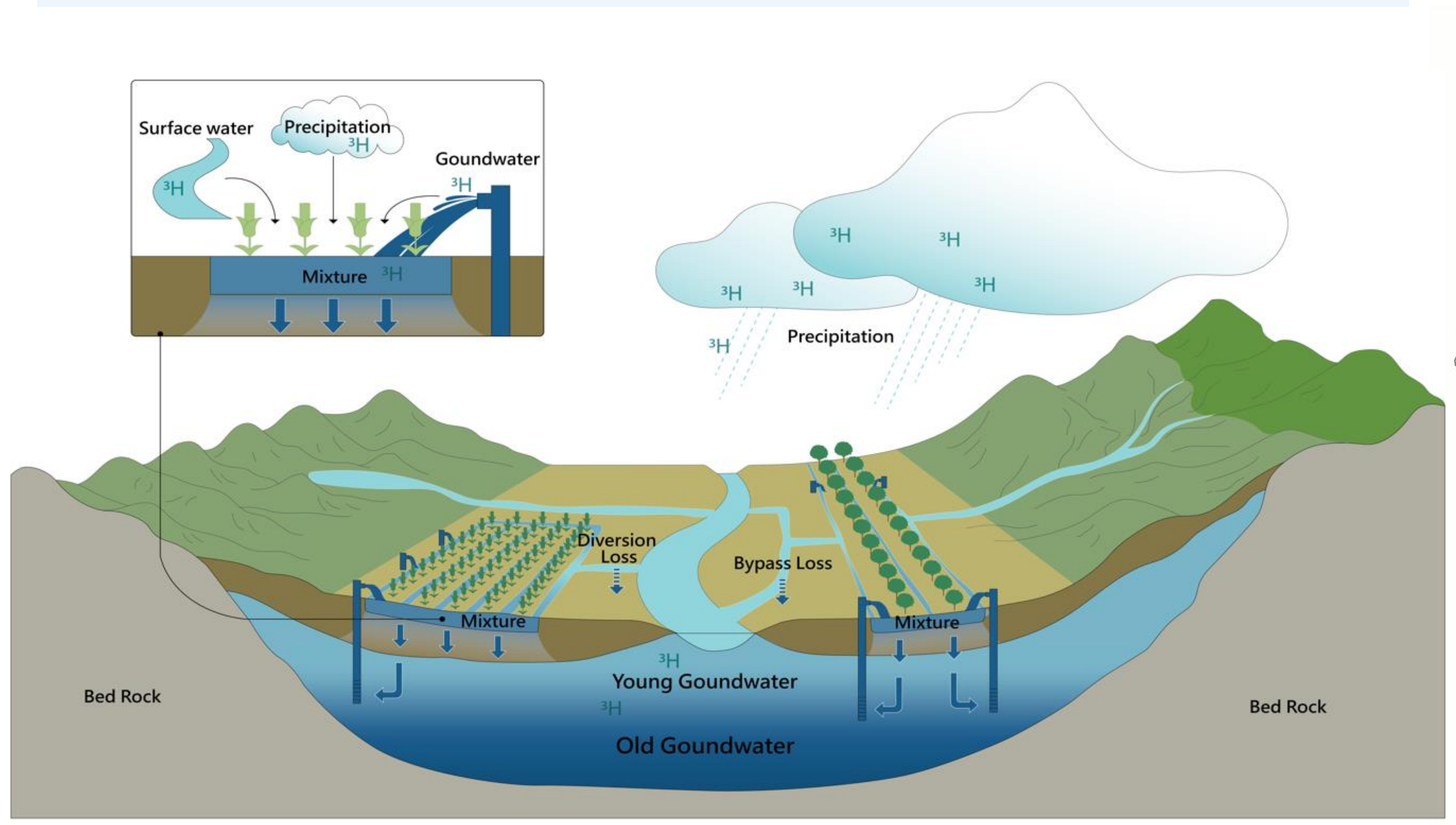
Where R is the retardation factor, v is the velocity of the groundwater flow, D is the dispersion coefficient, λ is the decay rate and C is the concentration. The half life for tritium in this model is 12.63 years .

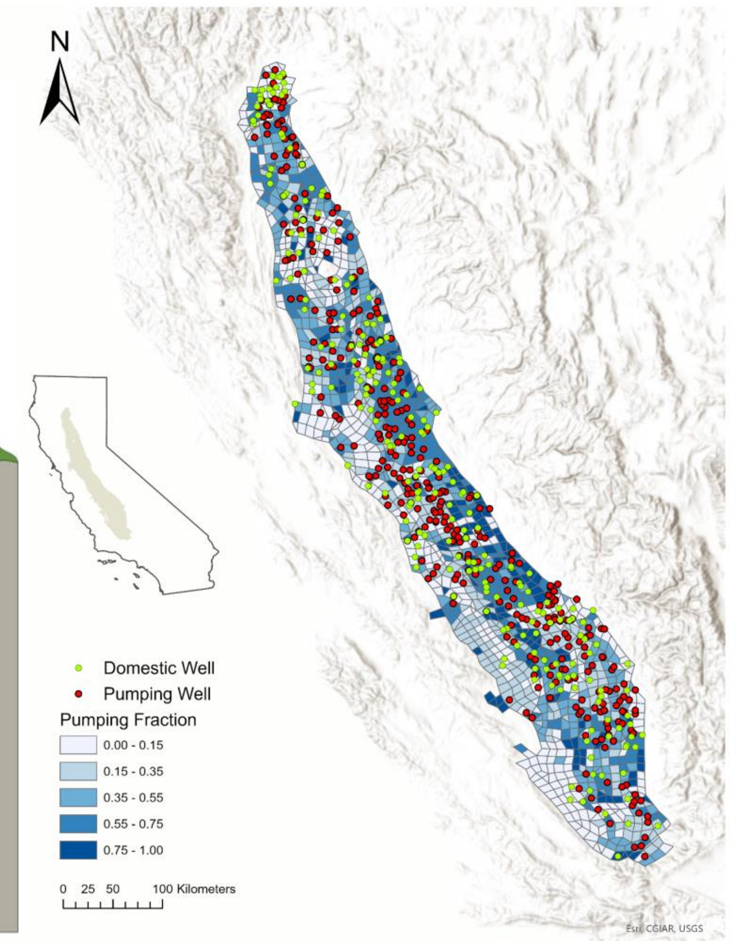
The NPSAT solves the ADE by decomposing the fully 3D domain into multiple 1D streamlines and calculates the Unit Response Function (URF) at each streamline and convolutes the URF based on the source boundary conditions to get the breakthrough curve in the well screen.

$$(f*g)(t) := \int_0^t f(\tau)g(t-\tau)d\tau$$

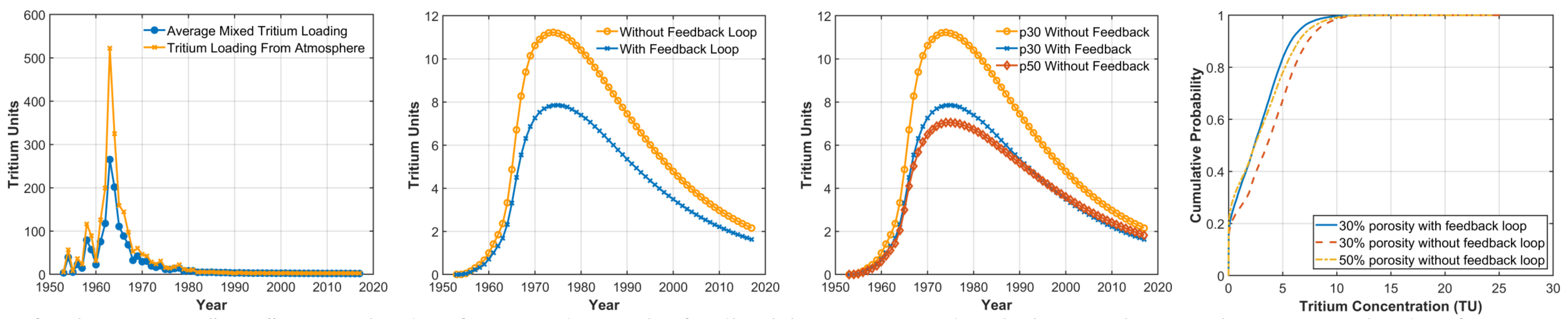


Age Tracer Simulation



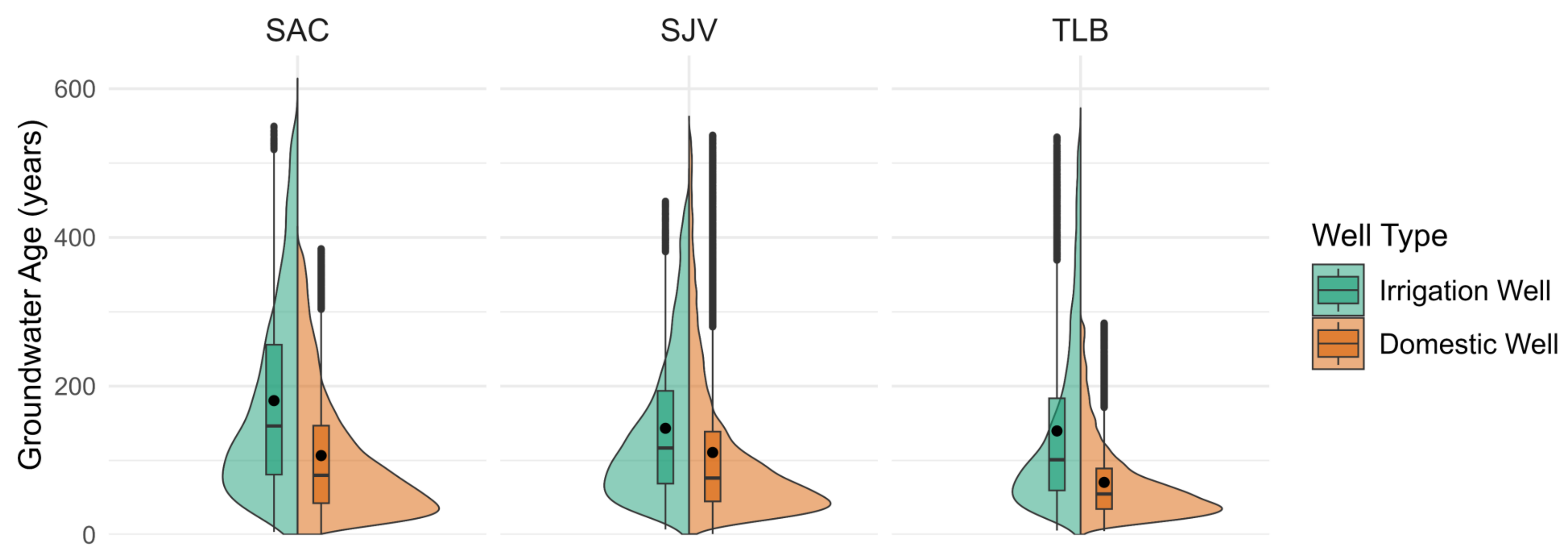


Left: Feedback Loop of groundwater-aided irrigation recharged into aquifer with other precipitation and precipitation-derived surface water sources. Right: Average spatial pumping fraction distribution in 1392 elements (C2VSIM Coarse Grid) from 1922-2015. Domestic and Supply/Irrigation wells distribution from USGS dataset that has measured tritium concentrations.



Left: The average "new" tritium loading function due to the feedback loop compared with the initial atmospheric tritium loading function from 1953-2017. Left middle: Average tritium concentration in the irrigation/supply wells with and without the feedback loop. Right middle: Mean tritium concentration for 30% porosity with feedback loop, 30% and 50% without feedback loop across 65 years. Right: ECDF of tritium concentration for 30% porosity with feedback loop, 30% and 50% without feedback loop in 2006.

Half violin plot for irrigation/supply wells and domestic wells in the Sacramento basin (SAC), San Joaquin Basin (SJV) and Tulare Lake Basin (TLB).



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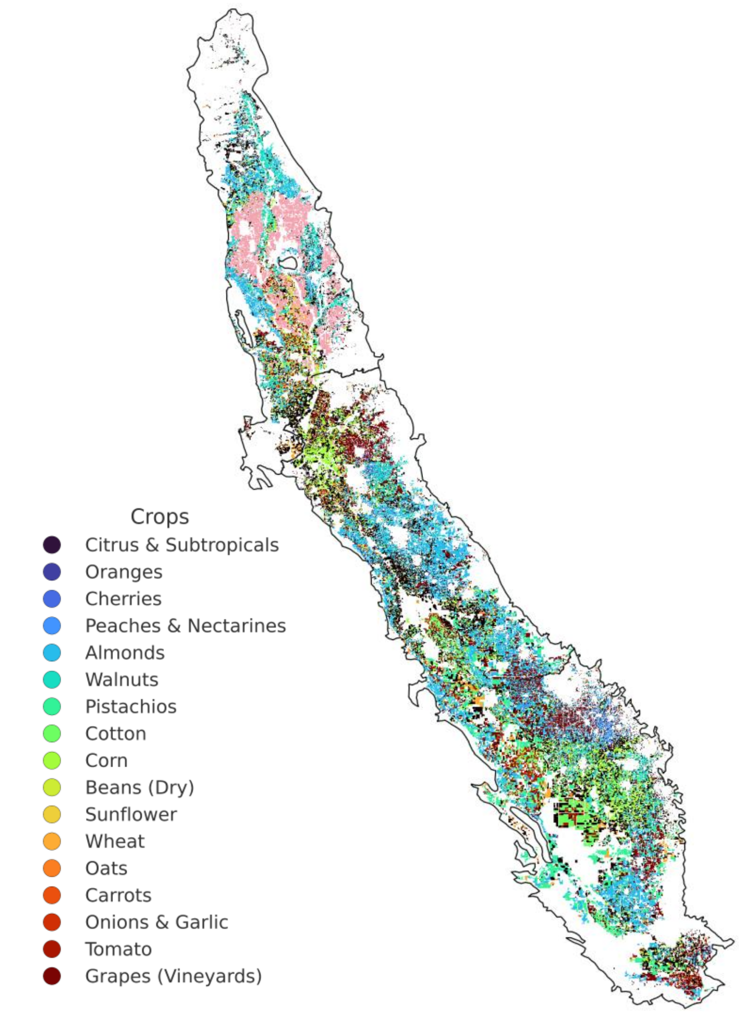
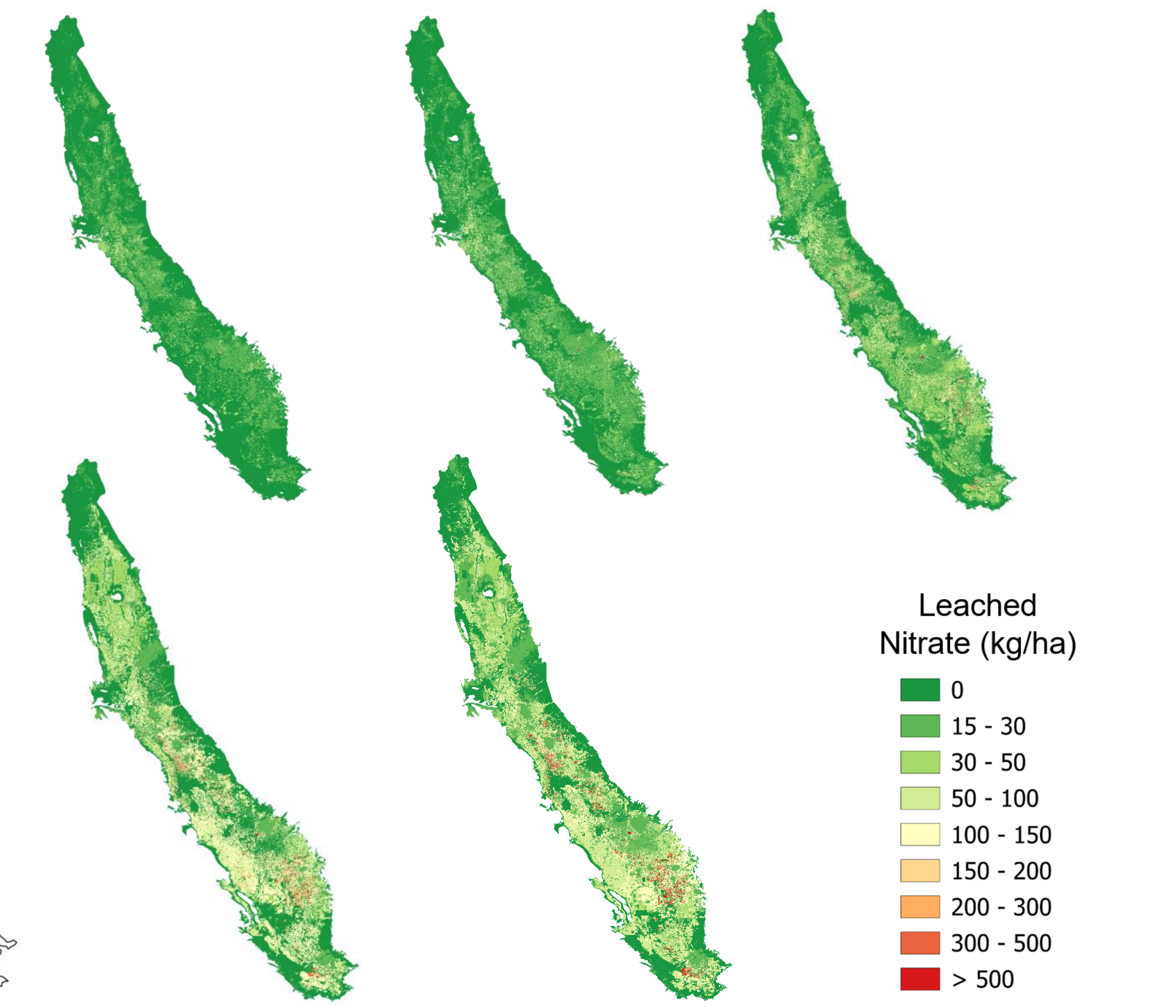
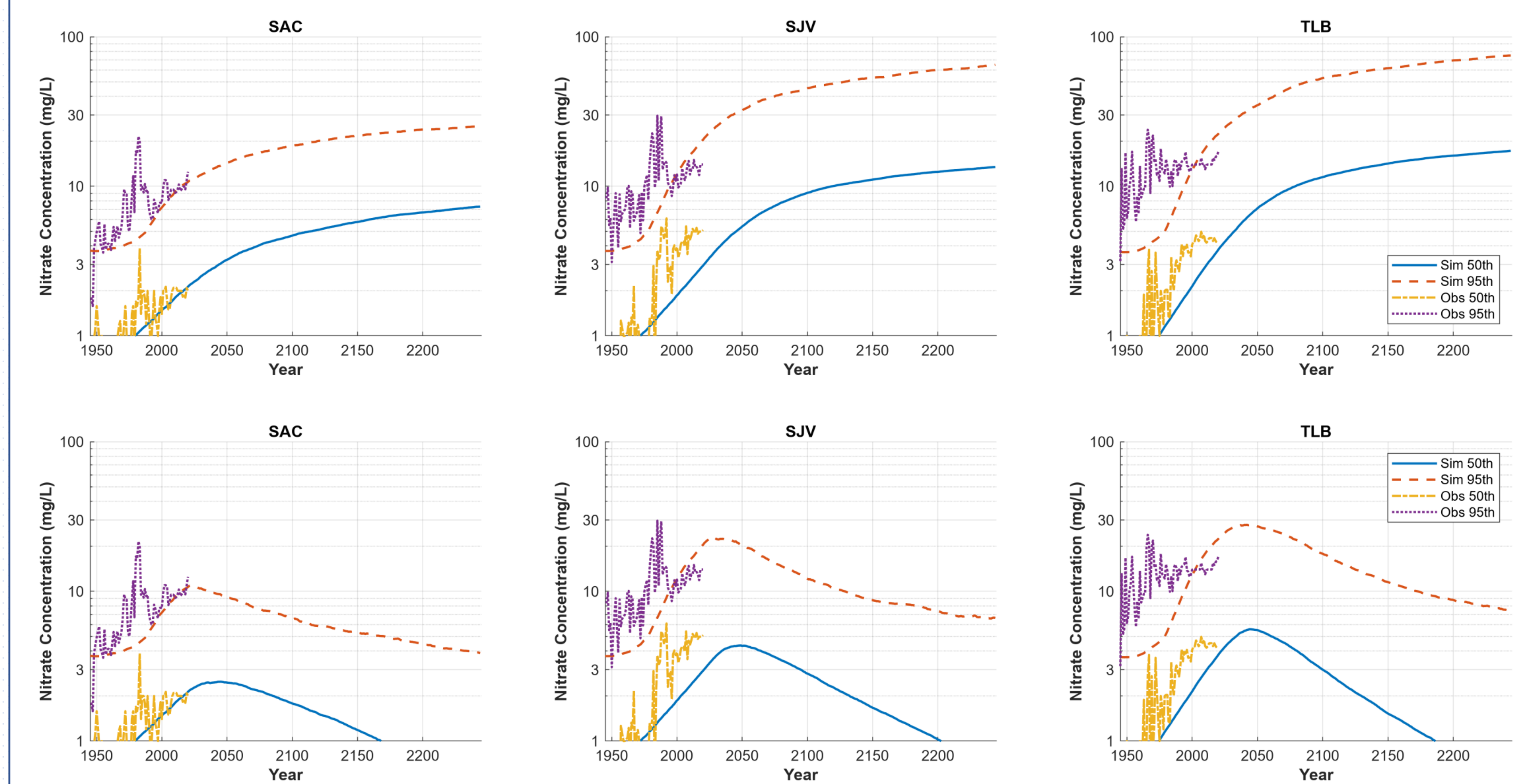
Nitrate Simulation





Left: Land use map in the Central Valley, California. Right: From upper left to lower right are the nitrate leaching maps from 1945-2005 with 15 years increment.



Upper: Groundwater nitrate simulation with NPSAT for 300 years in three subbasins Sacramento basin (SAC), San Joaquin Basin (SJV) and Tulare Lake Basin (TLB). Lower: Simulation result with 100% nitrate reduction from 2025.