A Validation Framework for Non-Point Source Simulation Models: Application to the Southern California Central Valley with Spatio-Temporally Heterogenous Source Rates

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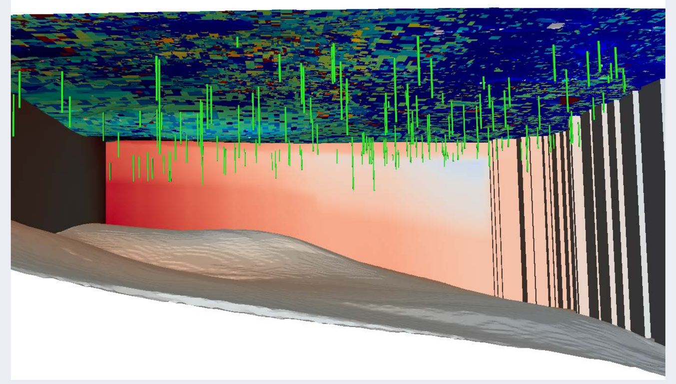
Abstract

Non-point source pollution on groundwater of agricultural regions is an alarming issue of global importance. The very large response times of contaminants which may vary from decades to centuries, require mitigation measures to be based on reliable modeling. Here we present a novel computational framework to assess and evaluate the dynamic, spatio-temporally distributed linkages between non-point sources above a groundwater basin and groundwater discharges to wells, streams, or other compliance discharge surfaces (CDSs) within a groundwater basin. The modeling framework allows for efficient evaluation of NPS pollution scenarios and of their short- and long-term effects on pollutant exceedance probabilities in CDSs

We apply the model to simulate 100 years of nitrate pollution at high resolution in a 2 million hectare semi-arid, irrigated agricultural region with a large diversity of crops, but also natural lands and urban areas, and highly heterogeneous, temporally variable loading landscape in the Southern California Central Valley. Results show that the timing of nitrate breakthrough in wells is significantly controlled by aquifer recharge and pumping rates in NPS areas and by the effective porosity of the aquifer system. Last the model predictions are compared against a highly heterogeneous, spatio-temporally varying in space and time database of historic nitrate records and an attempt is made to compute the spatial distribution of nitrate half-life due to denitrification

Motivation

- ❑ Simulation of Non Point Source (NPS) Pollution in large unconfined groundwater basins
- ❑ Examine the effect porosity uncertainty
- ❑ Compare the simulated with measured data and highlight data gaps .
- ❑ Make future prediction of nitrate contamination due to agricultural activities

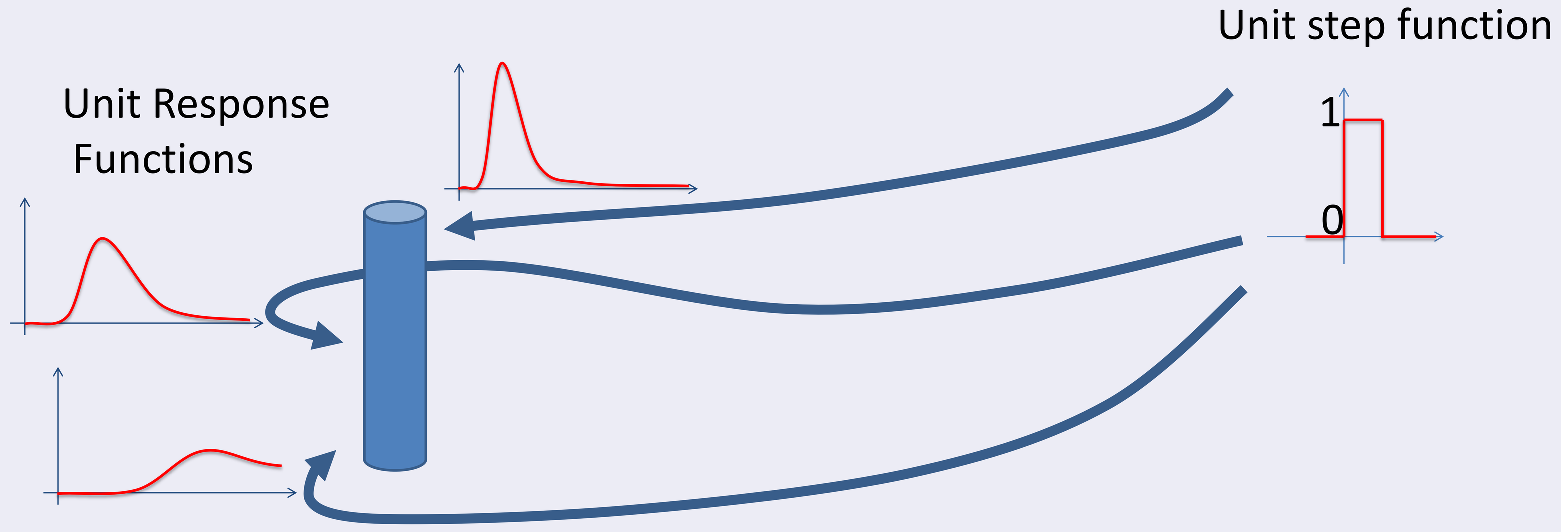


Methods

❑ Non-Point Source Assessment Toolbox (NPSAT) (Kourakos and Harter, *inPress*)

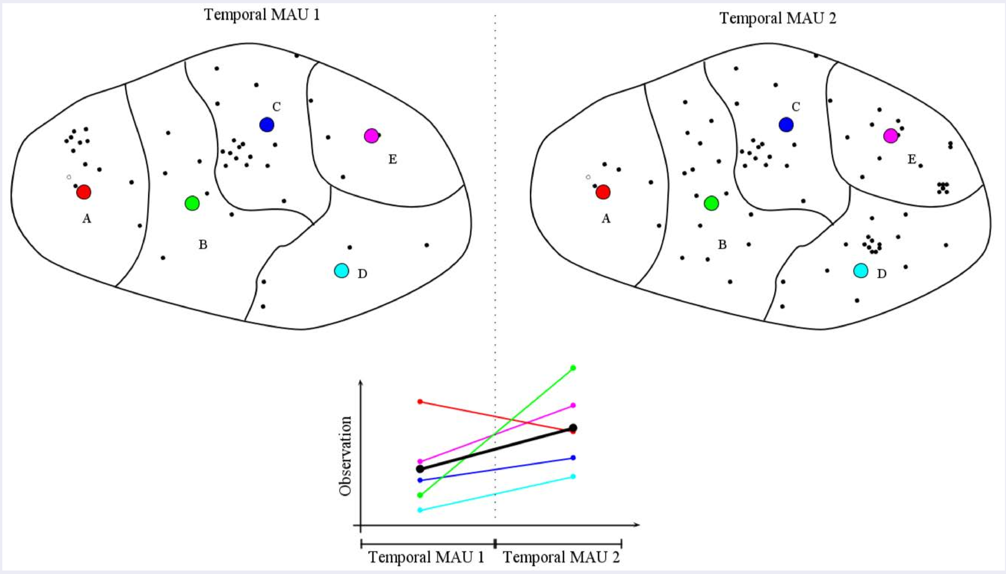
1) Steady State Groundwater Flow Simulation
   - Algebraic Multigrid implemented Trilinos (http://trilinos.sandia.gov).
2) Streamline Transport simulation
   - Backward Particle Tracking
   - 1D Transport simulation along each streamlines assuming unit input concentration (Computation of Unit Response Functions, URF)
3) The predictions of NPS Pollution are based on the convolution of URFs with loading functions

The NPSAT is written in Matlab and is available from www.groundwater.ucdavis.edu/msim



❑ Method to obtain average trends using highly spatio and temporal heterogeneous data

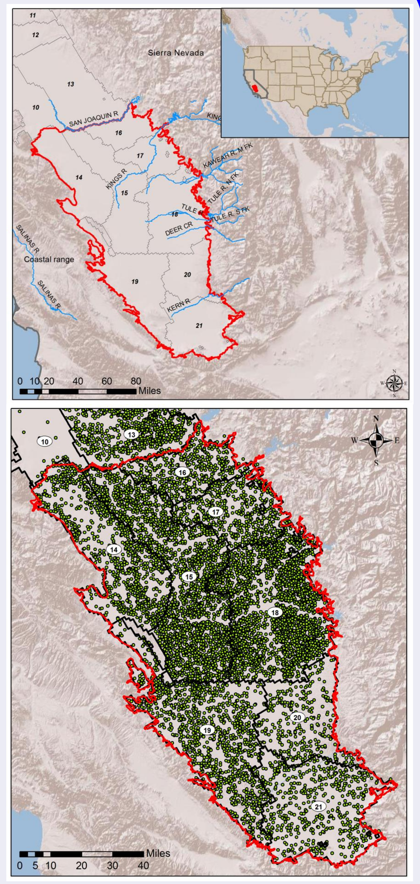
1) Define spatial and temporal Minimum Analysis Units (MAU).
2) For each MAU compute the median of all the observations that fall into the spatial and temporal MAU.
3) Using the medians we compute an unbiased average trend with confidence intervals. Optionally the data may need to be log-transformed.

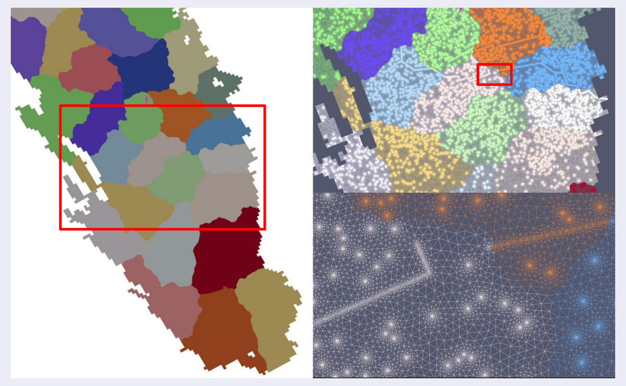


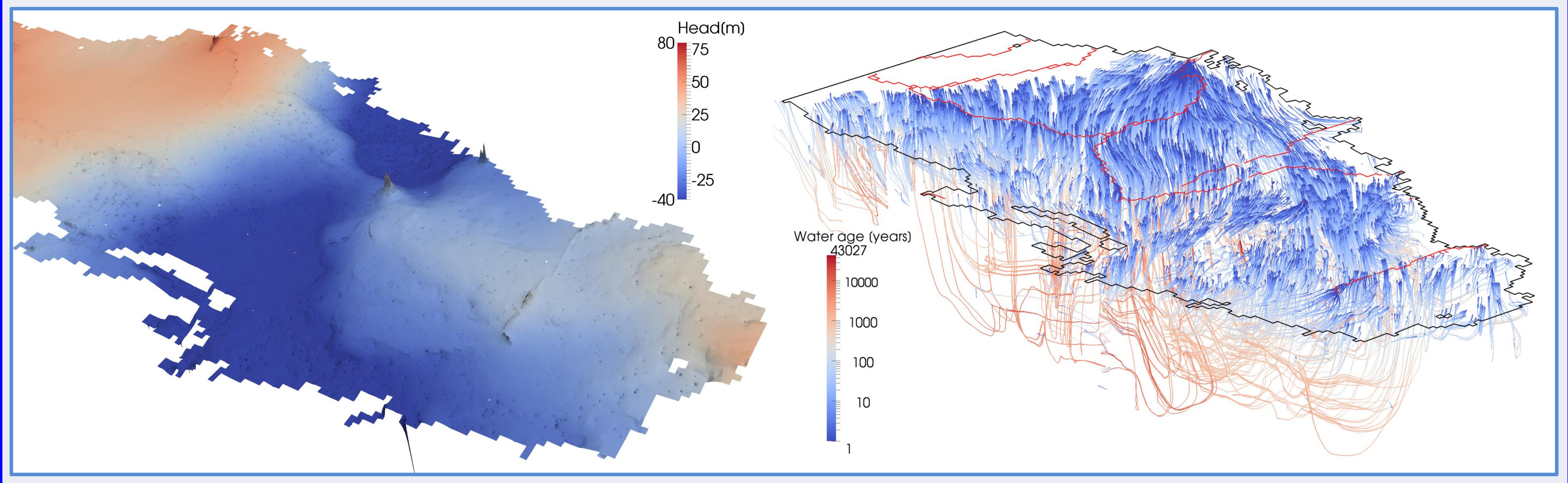
Study Area

The study area is located in south Central Valley, CA.

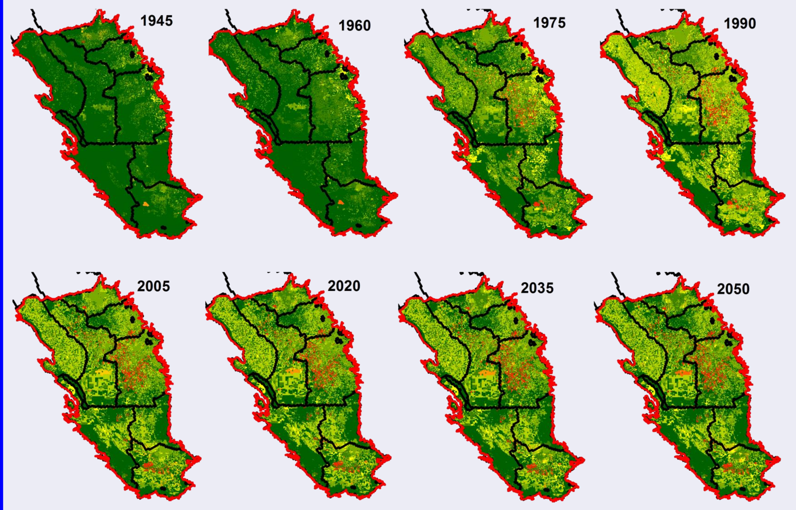
- Domain size : 21,301.40 km^2
- Highly heterogeneous hydraulic conductivity and porosity
- 85 % of total recharge is associated with agricultural
- 15 % of total recharge comes from streams.
- Pumping is simulated by 7790 virtual wells, which correspond to production wells.
- CVHM (Faunt , C.C., ed., 2009) was used as parent model.
- The flow domain was discretized into ~80 million dofs and it was solved using Algebraic Multigrid method, distributed into 64 cores
- For the transport we used 779,000 streamlines



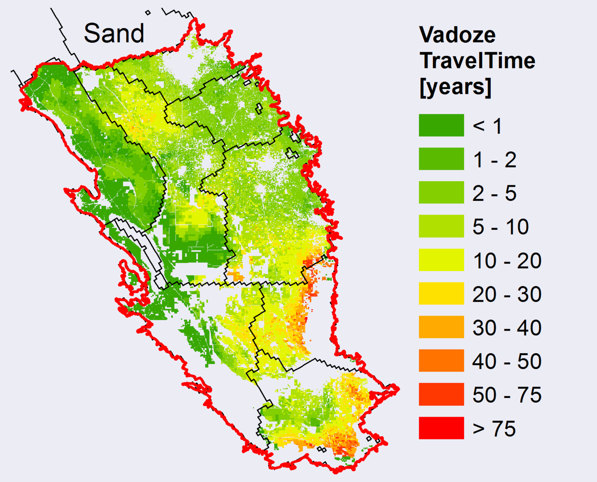




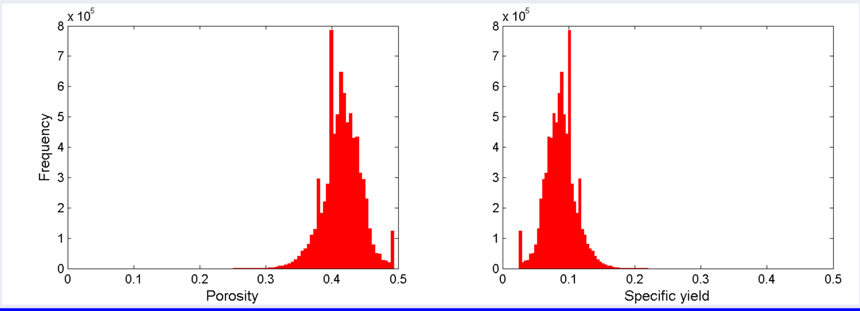
Historic and future Nitrate Loading



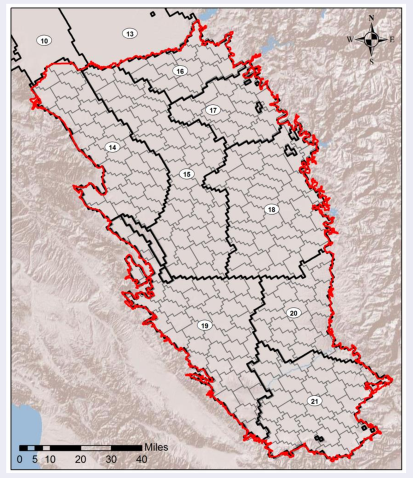
Vadoze travel time distribution



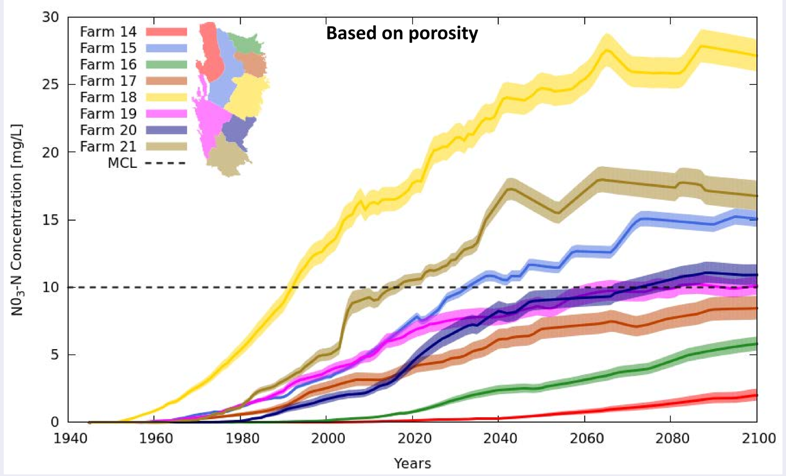
Due to porosity uncertainty the transport was simulated twice based on two different porosity distributions

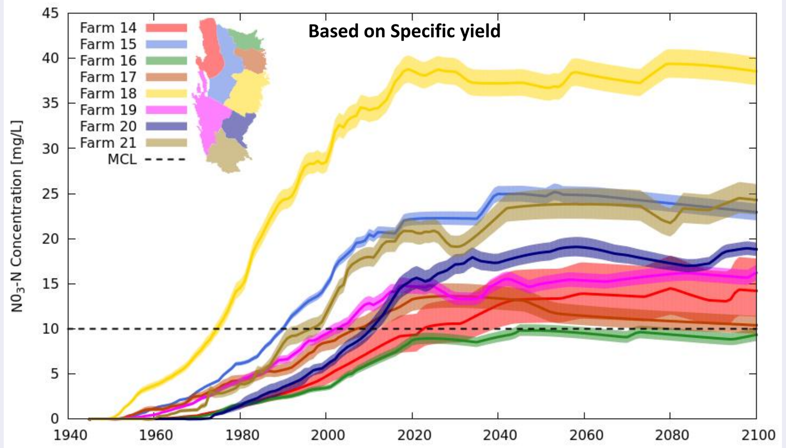


Predictions



- Each sub-basin ("Farm") was divided into a number of equal area MAUs.
- Temporally the data were grouped into decadal time steps.
- For each decade we computed the median for each MAU.
- The MAU medians were found log normally distributed.
- Based on the log-transformed medians we computed the average nitrate concentration trend and confidence intervals.

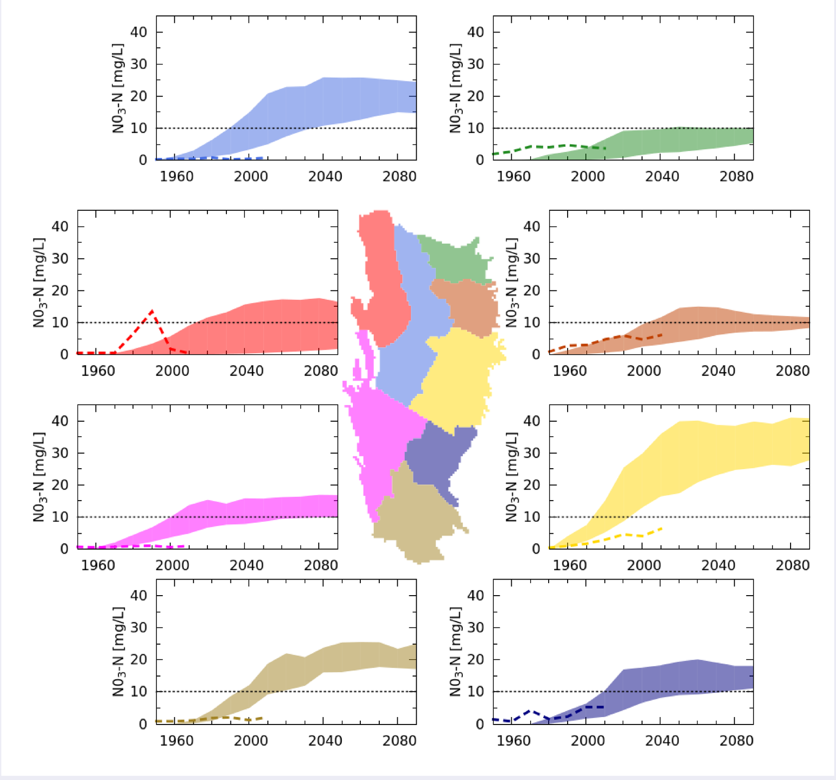




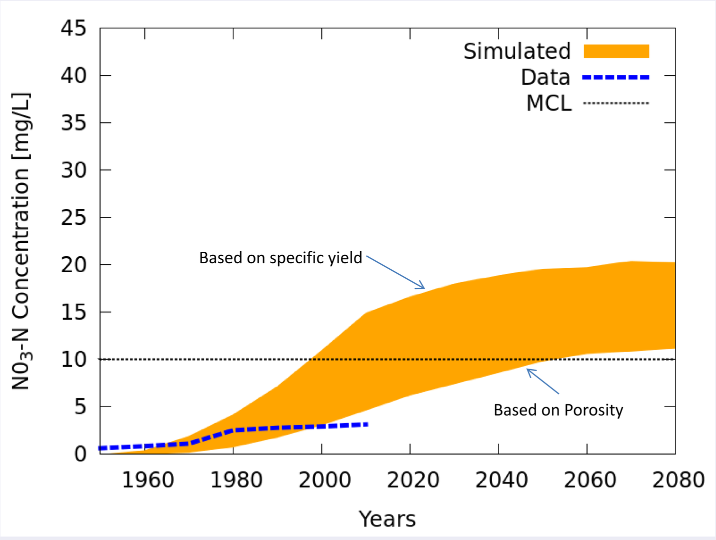
The solid line corresponds to the average trend per farm.
The range corresponds to 95 confidence intervals.
The dashed black line corresponds to Maximum contaminant limit

Simulated vs. measured data per virtual farm

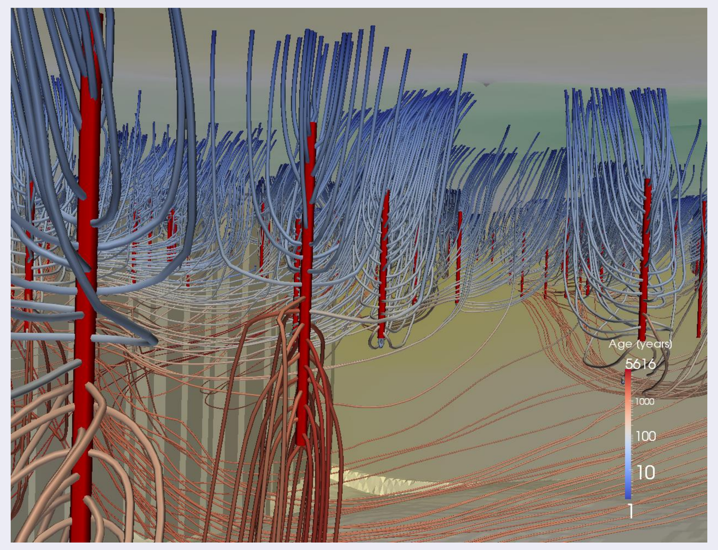
The dashed line corresponds to measured data.
The range of the simulated data is defined by the two different porosity distributions



Simulated vs. Measured data



Mixing effect



References

1) Kourakos, G., F. Klein, A. Cortis, and T. Harter (2012), A groundwater nonpoint source pollution modeling framework to evaluate long-term dynamics of pollutant exceedance probabilities in wells and other discharge locations, Water Resour. Res., 48, W00L13, doi:10.1029/2011WR010813.
2) Kourakos, G., T. Harter (inPress), Vectorized simulation of groundwater flow and streamline transport Simulation Environmental Modelling & Software http://dx.doi.org/10.1016/j.envsoft.2013.10.029.
3) Faunt, C.C., ed., 2009, Groundwater Availability of the Central Valley Aquifer, California: U.S. Geological Survey Professional Paper 1766, 255.

Conclusions

- •A Process-based Non Point Source Assessment Toolbox is used for simulating non-point source pollution in large scale groundwater basins
- •The code is written in Matlab/Octave and is available online http://groundwater.ucdavis.edu/mSim/
- •The porosity is a significant time scaling factor which results in great uncertainties in future predictions
- •The comparison with measure data revealed data gaps and the need for more intensive quality sampling,

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