Improving BASINS/HSPF predictions of nitrogen export to improve TMDL accuracy using NASA imagery

Estimating nitrate export from Chesapeake Bay watersheds using hypertemporal satellite data (MODIS) and climate inputs

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Background

- Nitrogen: chief nutrient generated from landscapes that leads to eutrophication of receiving waters
- TMDL (total maximum daily load): maximum amount of a pollutant that a water body can receive and still meet water quality standards
  - TMDLs are used for management as a basis to establish an implementation or watershed plan designed to meet water quality standards and/or restore impaired water bodies
- HSPF, BASINS, Chesapeake Bay Model: varieties of a particular model (HSPF) that simulates watershed hydrology and water quality and are used by EPA and the Chesapeake Bay program to develop TMDLs
  - effects of land use, point and nonpoint sources, etc.

Background

- Most models for predicting nitrogen export or loads assume no spatial or temporal variations in N export from large areas of forestland
- Although clearly mixed land use and fertilizer application are major drivers of diminished water quality*, realism in the modeling of export from forest land* is required to properly address land use contributions
- Current assumption of Chesapeake Bay Model is a uniform load: "an acre of 'forests, woodlots, and wooded' land contributes 3.1 lb/year of nitrogen to the watershed."
- The Chesapeake Bay watershed is 60% forested, and this biased assumption has been demonstrated to be problematic in numerous studies.

Objective

- Develop inputs from remote sensing that allow us to better characterize seasonal and inter-annual variability of nitrogen loads from forests
- Implement these inputs within the HSPF (Chesapeake Bay Model) context to improve overall estimates of nutrient loads based on more realistic parameterization of forests

Partners

- EPA
- Chesapeake Bay Program
- BASINS, HSPF community

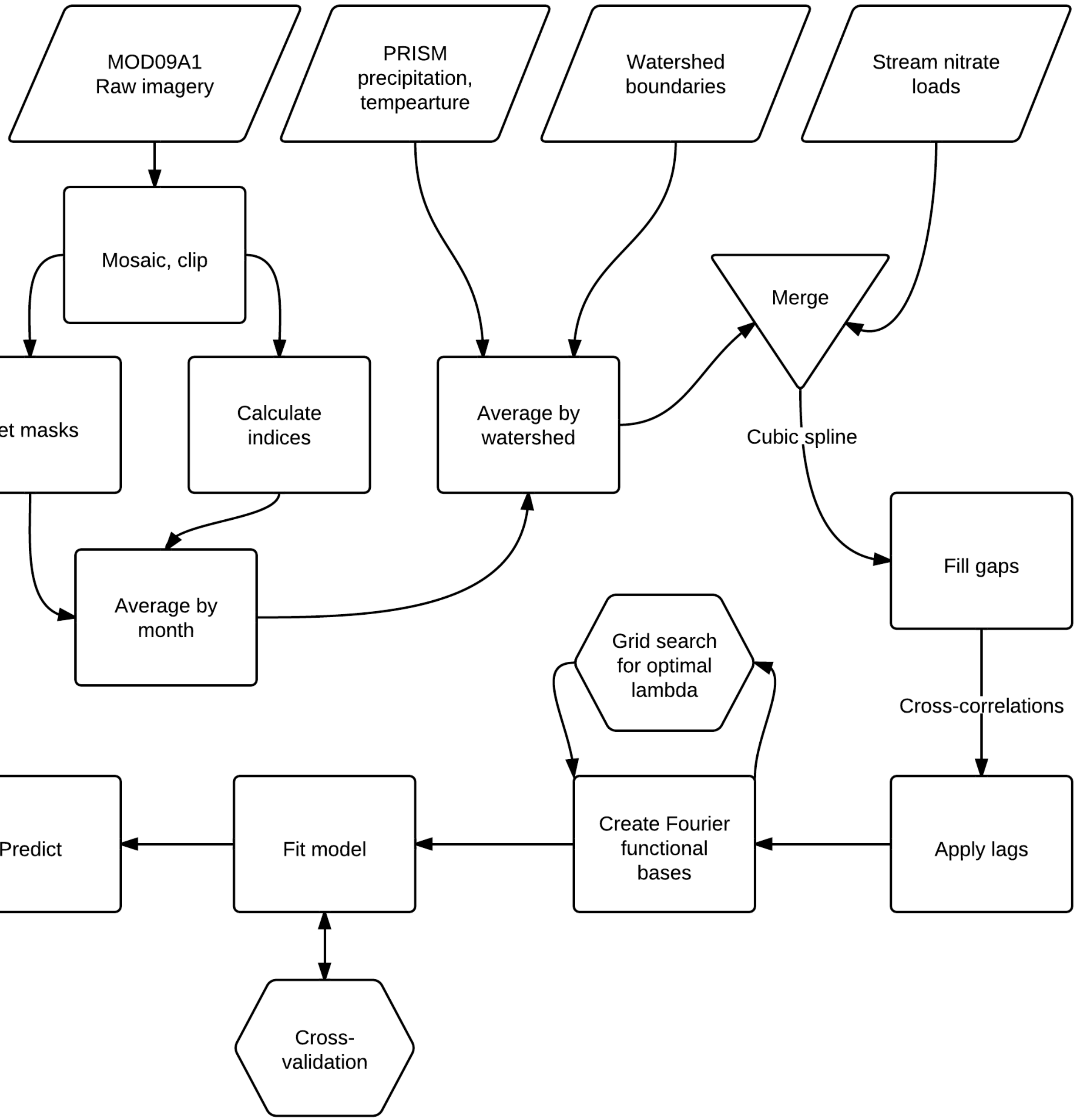
Key Datasets

- Widely available imagery: MODIS
  - MOD09A1: Tasseled cap indices (4), NDII, Simple ratio, NDVI (= 7 MODIS covariates)
  - Tested EVI/NDVI, as well as GPP (gross primary productivity) and PSN (photosynthesis), but:
    - MOD13A1 and MOD17A2 had too much missing data
- Climate data (PRISM monthly)
- Landscape data about watersheds
  - Stream density, stream length, latitude

Approach

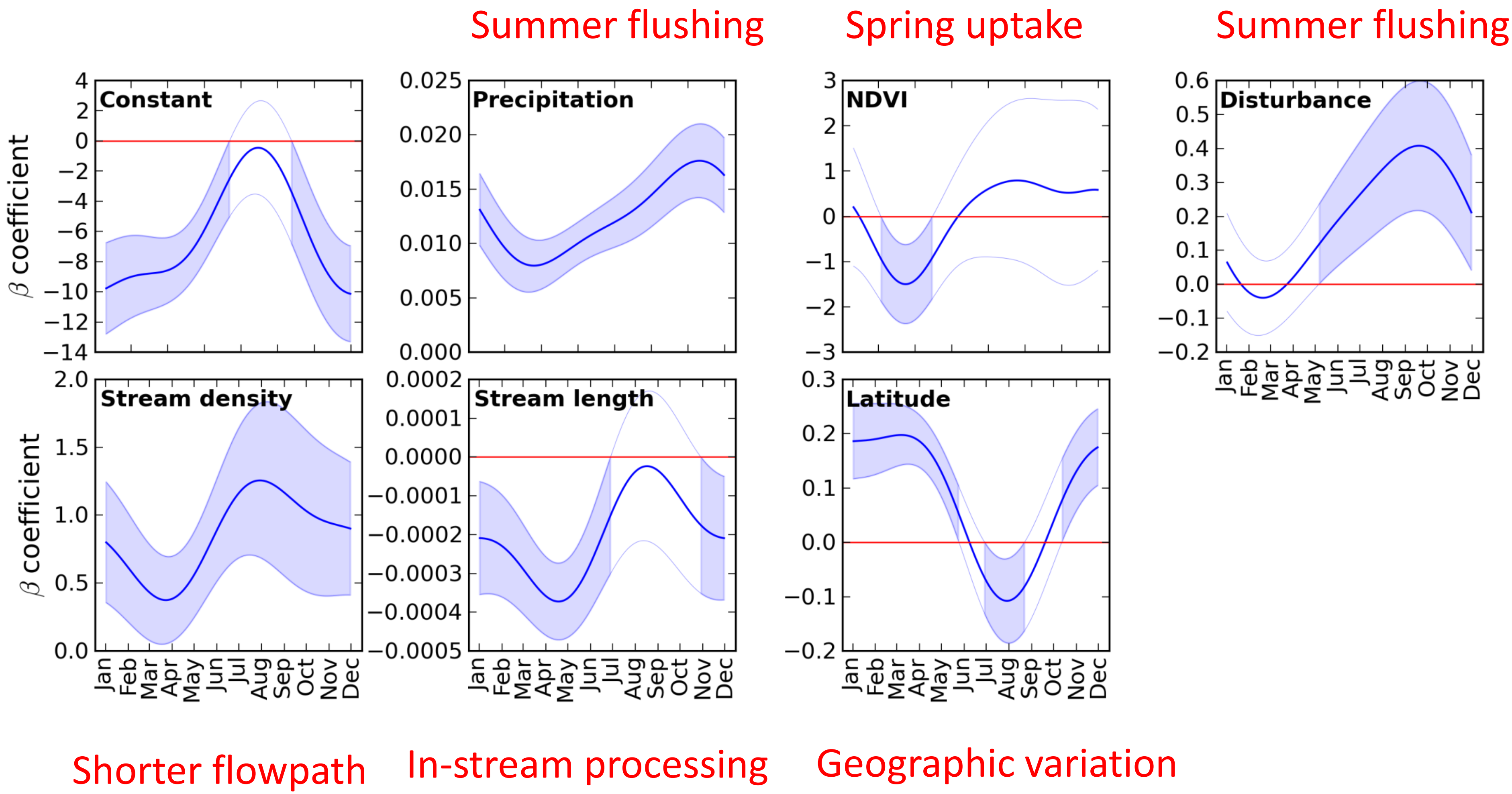
- MODIS imagery summarized by watershed to characterize variation in forest condition
- 2001-2005 water quality data from forested watersheds and HSPF simulations, used to estimate nitrogen loads from remote sensing data
- Functional concurrent linear models (FLCMs) to predict N loads from forests as a function of imagery
  - FLCMs can use time series for predictors and responses and therefore allow continuous-time predictions
  - similar to regression: uses multiple predictors
  - we incorporate lag effects

Method:



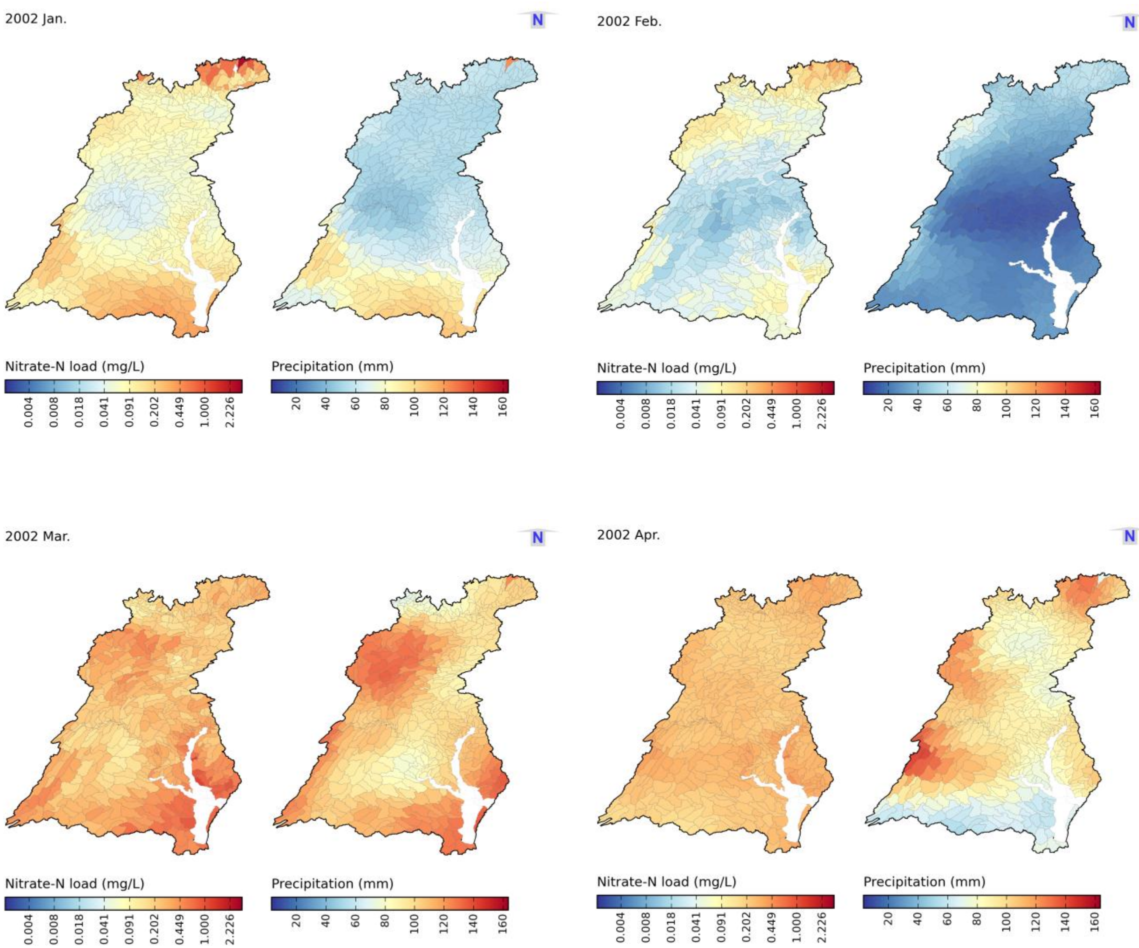
MOD09A1
Raw imagery
PRISM
precipitation,
tempearture
Watershed
boundaries
Stream nitrate
loads
Mosaic, clip
Merge
Get masks
Calculate
indices
Average by
watershed
Cubic spline
Average by
month
Fill gaps
Grid search
for optimal
lambda
Cross-correlations
Predict
Fit model
Create Fourier
functional
bases
Apply lags
Cross-
validation

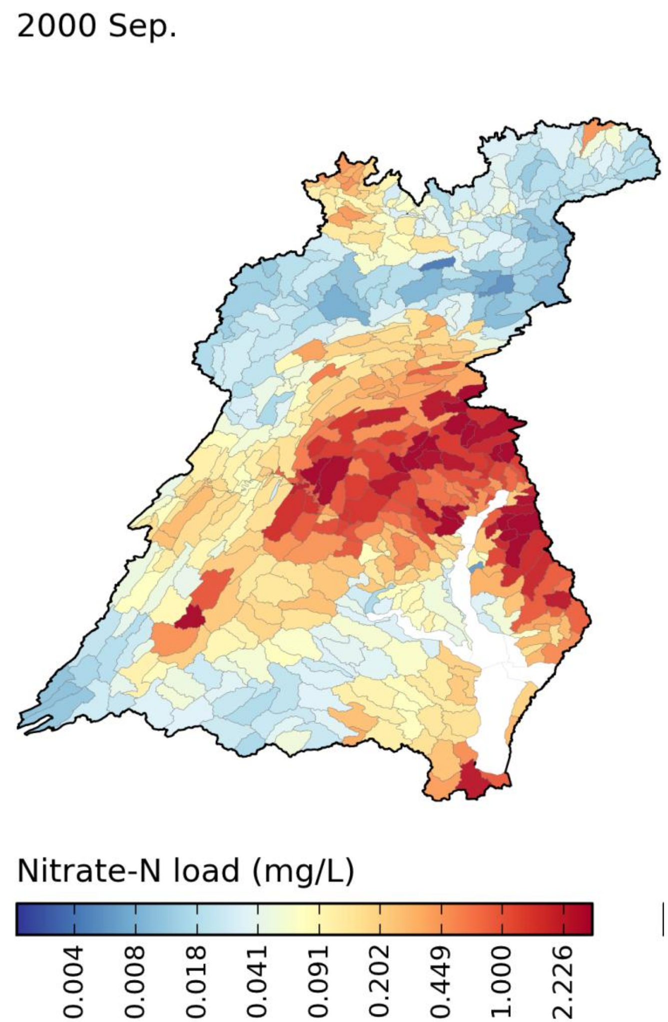
Results:



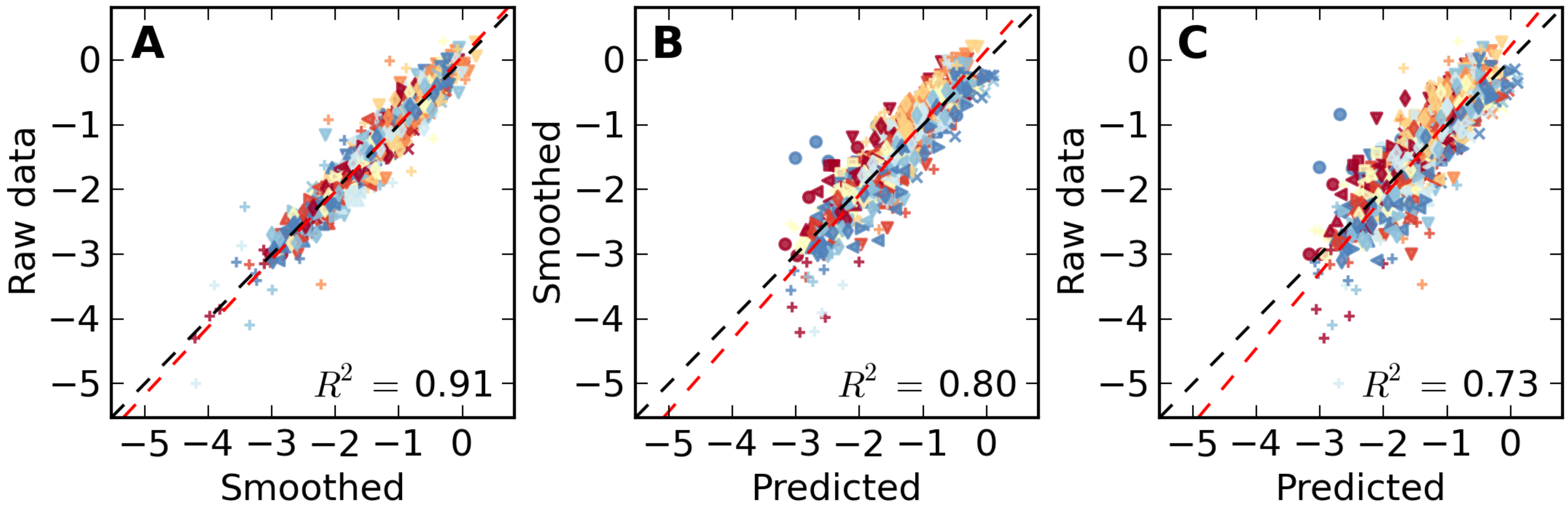
Summer flushing
Spring uptake
Summer flushing
Constant
Precipitation
NDVI
Disturbance
Stream density
Stream length
Latitude
β coefficient
β coefficient
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Shorter flowpath
In-stream processing
Geographic variation

Image-Derived Nitrate-N Loads from Forests





Better model fits with fewer (remote sensing) predictors:



YEAR	R^2model	R^2valid	Bias
2001	0.818	0.701	-0.130
2002	0.804	0.779	0.091
2003	0.800	0.553	-0.086
2004	0.816	0.614	-0.186
2005	0.794	0.881	-0.063
2006	0.812	0.719	0.069
2007	0.792	0.838	0.135
2008	0.811	0.765	0.159

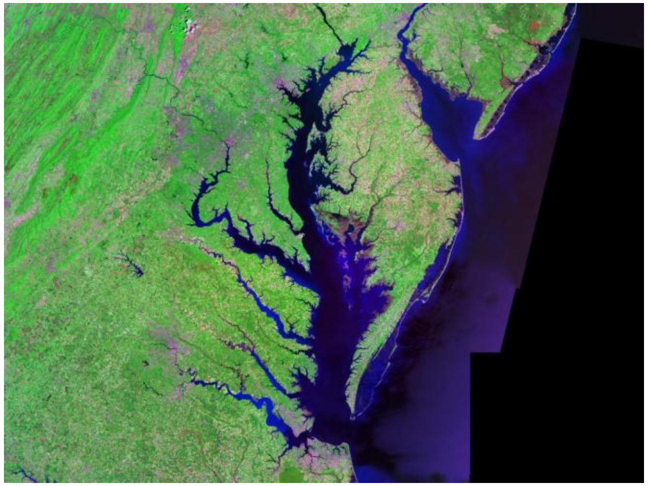
Watershed	R^2model	R^2valid	Bias
Upper Big Run	0.828	0.781	-0.583
Blacklick Run	0.819	0.503	-0.201
Cedar Creek	0.816	0.726	-0.058
Cowpasture river	0.797	0.781	0.048
Deep Run	0.829	0.764	0.405
Sinnemahoning Creek	0.799	0.867	0.201
Jackson River	0.813	0.469	0.084
Kettle Creek	0.794	0.858	0.004
Pine Creek	0.811	0.585	-0.319

Impacts

- We have finalized our algorithms
- Angélica Gutiérrez-Magness at University of Maryland is using FLCM “forest N loads” to calibrate the selected sites of the CBP-HSPF model
- We then will test model performance using the revised data against the current implementation of CBP-HSPF
- Early 2013: demonstration with EPA and Chesapeake Bay Program
  - Goal: implementation into the Bay Model!

Strategy for Quantifying Impacts

- More accurate model predictions and better data to set strategic goals for N load reduction/ watershed loading management.
- Ultimately: adoption by modeling community



Questions?