SPAtially Referenced Regressions On Watershed Attributes

Sources of Suspended Sediment in the Chesapeake Bay Watershed

A Regional Application of the SPARROW Model

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Introduction to SPARROW
Model specification
Model accuracy and estimation
Model applications

John W. Brakebill
Scott W. Ator
Gregory E. Schwarz

The Goal is to Gain a Comprehensive Understanding of the Long-Term Steady State of Sediment Supply and Transport in the Chesapeake Bay Watershed

- Regional approach
  - Identify the spatial variability and magnitude of sediment sources
  - Quantify the contributions
  - What are the factors affecting transport
- Although SPARROW models provide a regional perspective, additional information may be required at the local scale to gain a detailed understanding

SPARROW Mass-Balance Model

Nonlinear regression

$$\text{Load}_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \beta_n \underbrace{\exp(-\alpha' Z_j)} \right] \underbrace{\exp(-\delta' T_{i,j})} \right\} \underbrace{\exp(\epsilon_i)}$$

Load leaving the reach	=	Load generated within upstream reaches and transported to the reach via the stream network	+	Load originating within the reach's incremental watershed and delivered to the reach segment

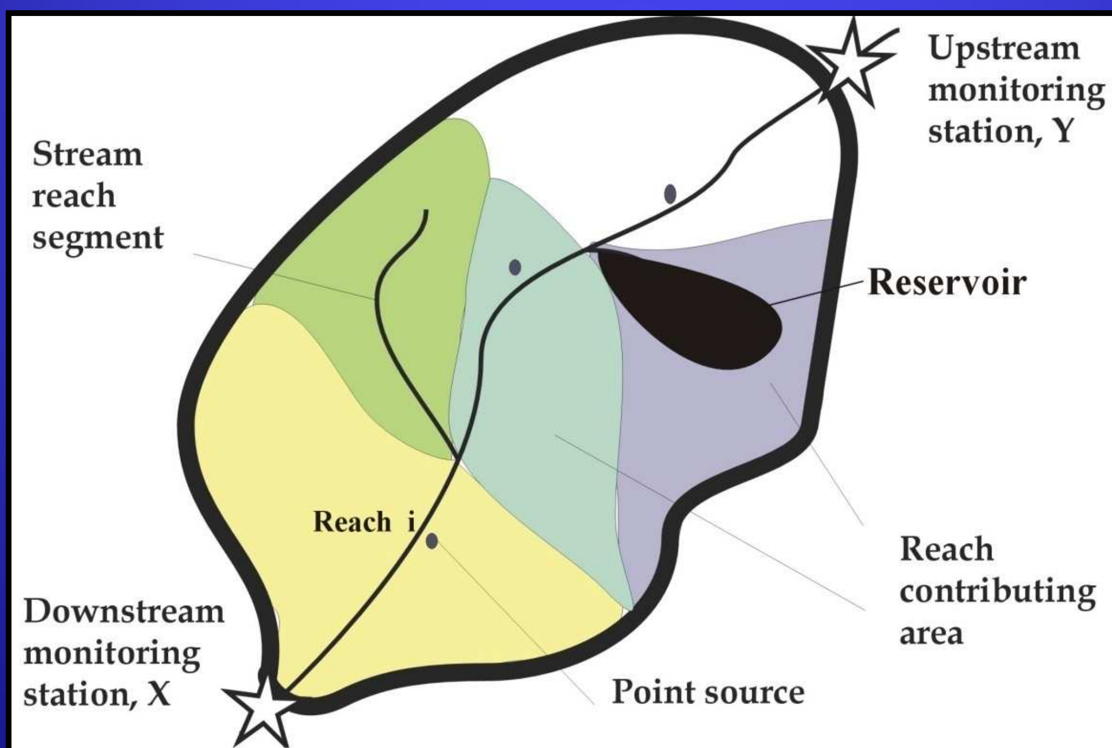
Source

Delivery

Decay/storage

- in-stream
- reservoir

Monitoring



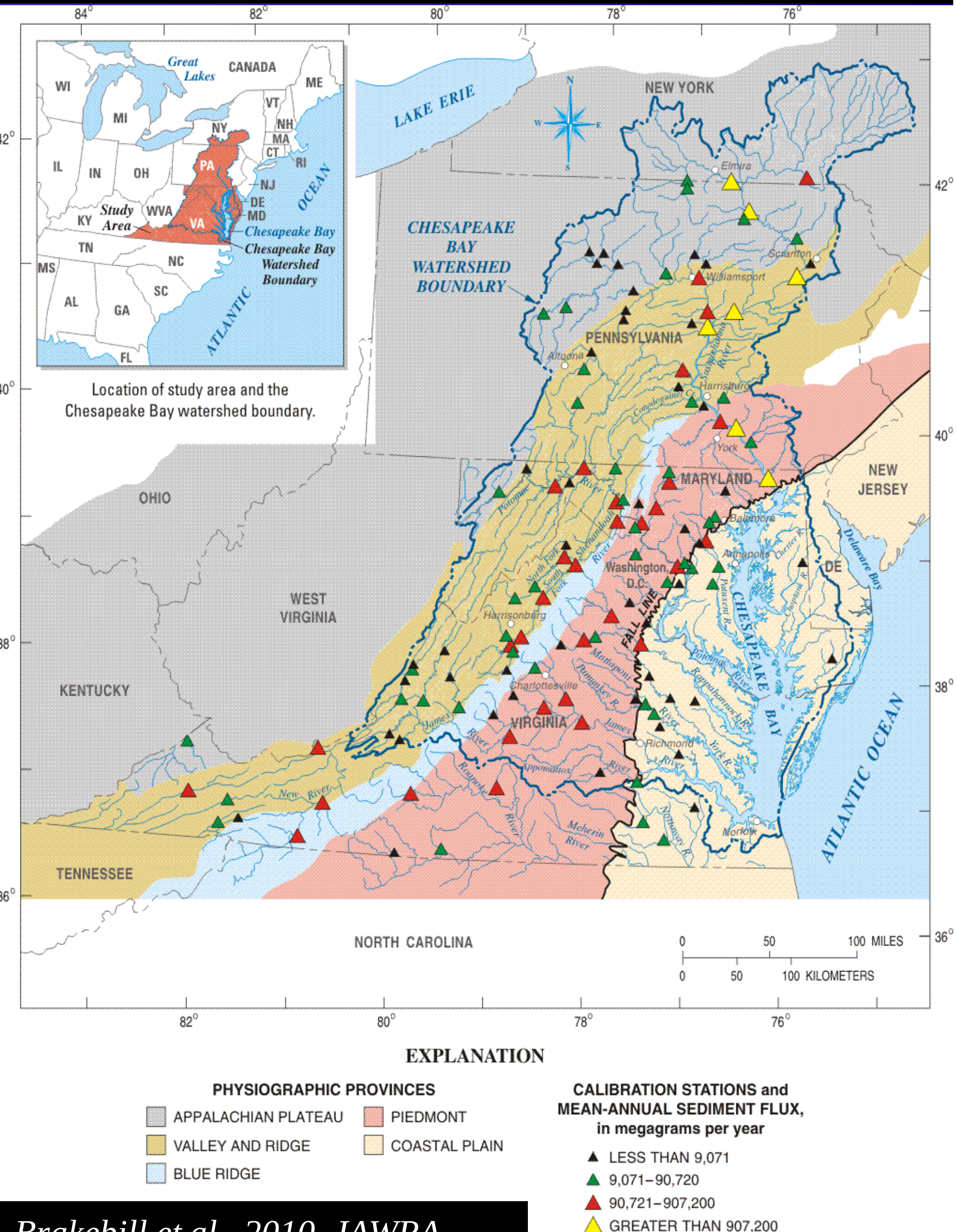
Nonlinear model structure includes topography and water routing; provides separation of land and water processes

Steady-state, mass-balance structure gives improved interpretability of the model coefficients and predictions

Schwarz et al., 2006

Chesapeake Bay Sediment SPARROW Model

- The geographic extent of the model includes the Chesapeake Bay watershed and adjacent areas of southern Virginia and northern North Carolina
- Area is 57% forest, 22% ag, 9% urban and suburban
- Calibrated to 129 estimates of mean-annual flux for a base year of 2002
  - Flux estimates are developed by relating sediment concentration (SSC and TSS) to continuous streamflow and time
  - Period of record -1970 - 2004
- Monitoring is referenced to 1:500k reaches, ~3,500 reaches
- Mean catchment area 75 km^2



Brakebill et al., 2010, JAWRA

Calibration Station Distribution

129 stations	MEAN	MAX	Q3	MEDIAN	Q1	MIN	IQR
Area (km^2)	4,345	70,005	1,997	799	342	62	1,655
MEANQ (CFS)	2,168	37,451	990	429	172	25	818
LOAD (Mg/yr)	18,442	3,612,188	145,057	17,590	3,508	236	141,549
Yield (Mg/km^2)	65	1,453	55	19	8	.9	47

Flux ranges 4 orders of magnitude
Monitored area ranges 3 orders of magnitude

Explanatory Variables

Sediment Source Parameters (Supply)

- Small Stream Channels < 35 CFS (*meters of stream length)*
  - Represents bank, bed, and flood-plain erosion
- 2002 Total Agriculture Area (*km^2*)*
- Net increase of Imperviousness Area (*km^2*)*
  - Area in 2002 minus area in 1992
- 2002 Forest Area (*km^2*)*

Factors Affecting Transport

- Mean Basin Slope (percent)
- Reservoir Density (fraction)
- Piedmont Uplands *(7.5 million scale, Fenneman and Johnson)*
- Soil Permeability (*inches/hour*)

Aquatic Transport

- Stream attenuation *(Storage)*
  - *First order Decay*
- Reservoir transport/storage *(On Network Reach)*
  - *Mean settling Velocity*

USGS Model Statistics R^2=0.83, Yield R^2=0.57, RMSE = .96, N = 129

EXPLANATORY VARIABLE				
Sources	Units	Estimate	Std. Error	P-value
Agriculture Area, 2002	Mg/km^2	56.96	11.99	<0.001
Forested Area, 2002	Mg/km^2	0.98	1.44	0.495
Urban Development, 1992-02	Mg/km^2	3,928.41	1,370.07	0.004
Stream Channel < 35cfs, Coastal Plain	Mg/m	0		----
Stream Channel < 35cfs, Other Prov.	Mg/m	0.29	0.13	0.030
Land-To-Water				
Watershed slope		0.06	0.04	0.083
Soil permeability		-1.19	0.52	0.022
Piedmont Province		0.96	0.31	0.002
Off-reach impoundment density		-22.96	9.82	0.021
Aquatic Storage				
CP Streams (120 – 250 ft^3/sec)	Day^{-1}	2.54	1.02	0.007
CP Streams (> 250 ft^3/sec)	Day^{-1}	1.92	0.86	0.014
On-reach reservoirs	m/yr	234.91	127.34	0.034

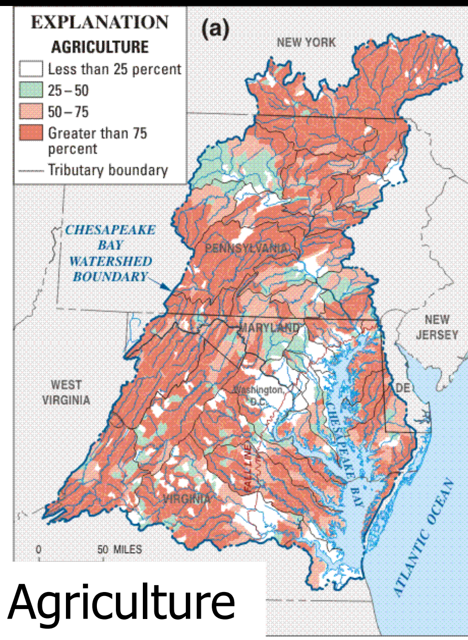
Applications – Individual source contributions

Source Shares

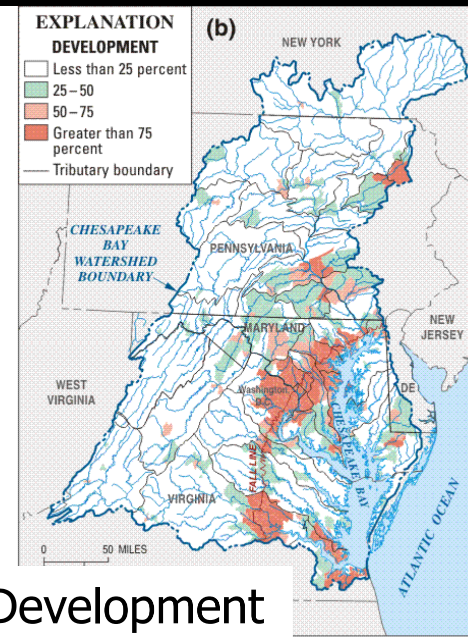
- Incremental (local) sources
  - how much is generated in each catchment?

Source Share (%)	Mean	Median
Agriculture	62	74
Urban Development	26	14
Forest	5	3
Small streams	7	0

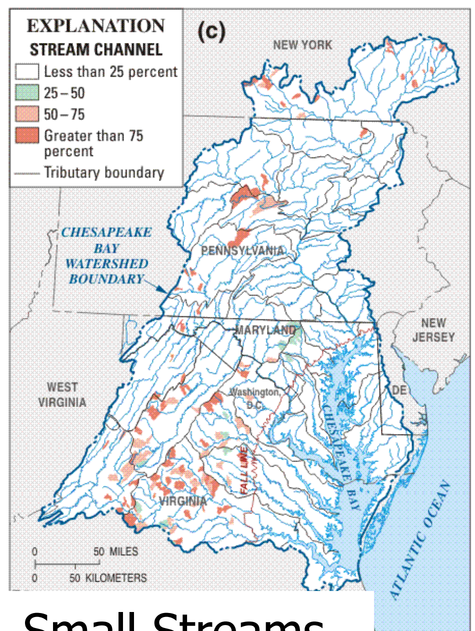
* Forest mapped 1 order of magnitude less than other sources



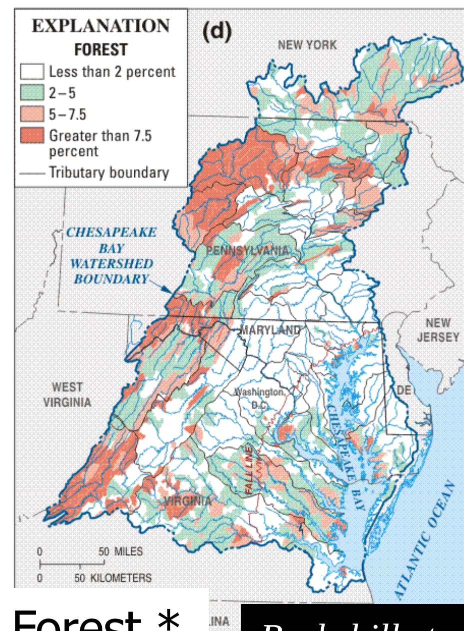
Agriculture



Development



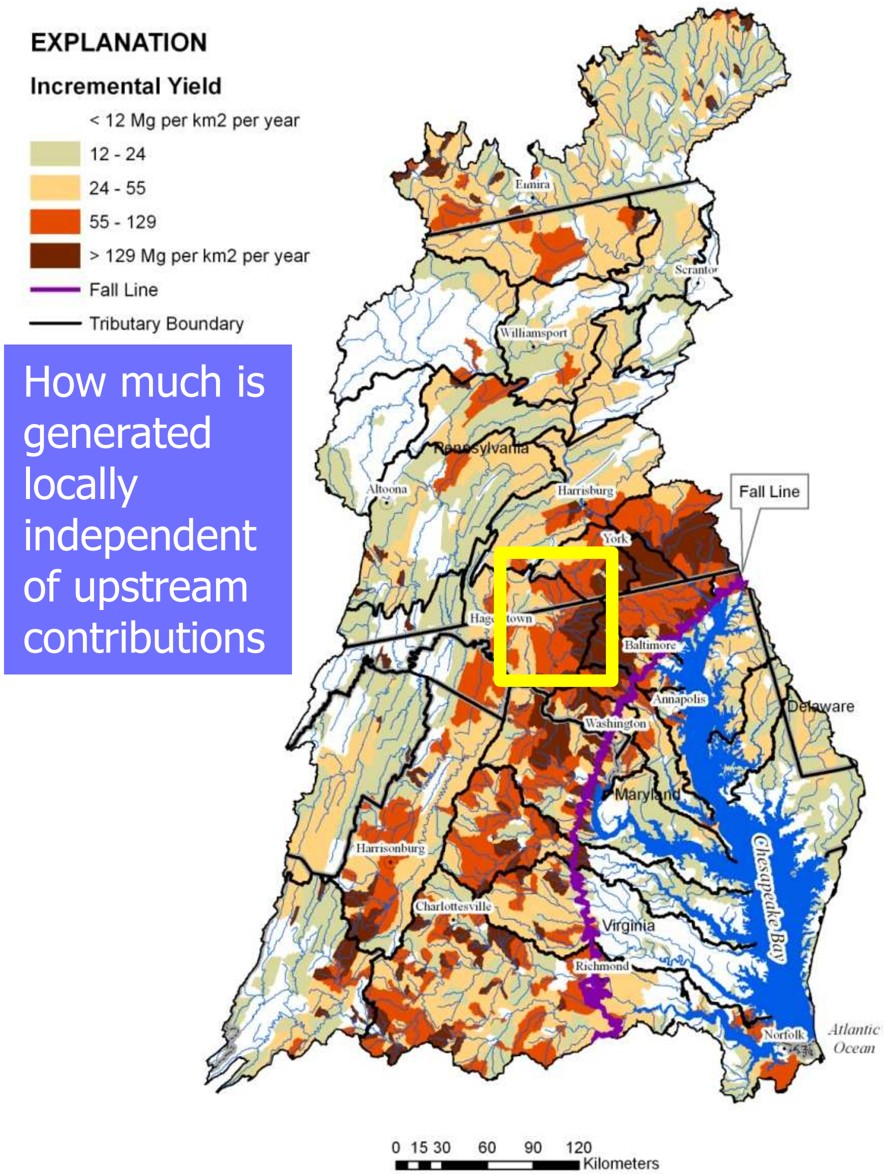
Small Streams



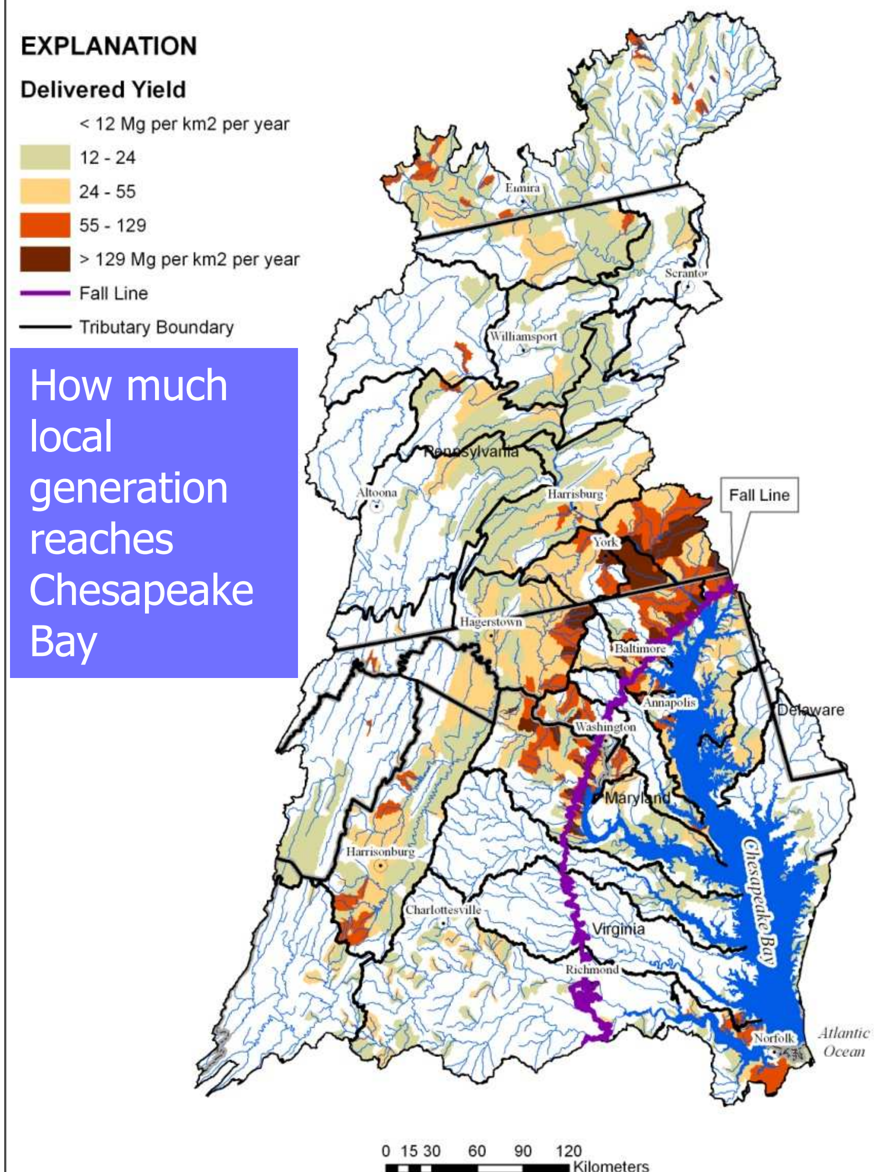
Forest *

Brakebill et al.

Applications – Geographic targeting



How much is generated locally independent of upstream contributions



How much local generation reaches Chesapeake Bay

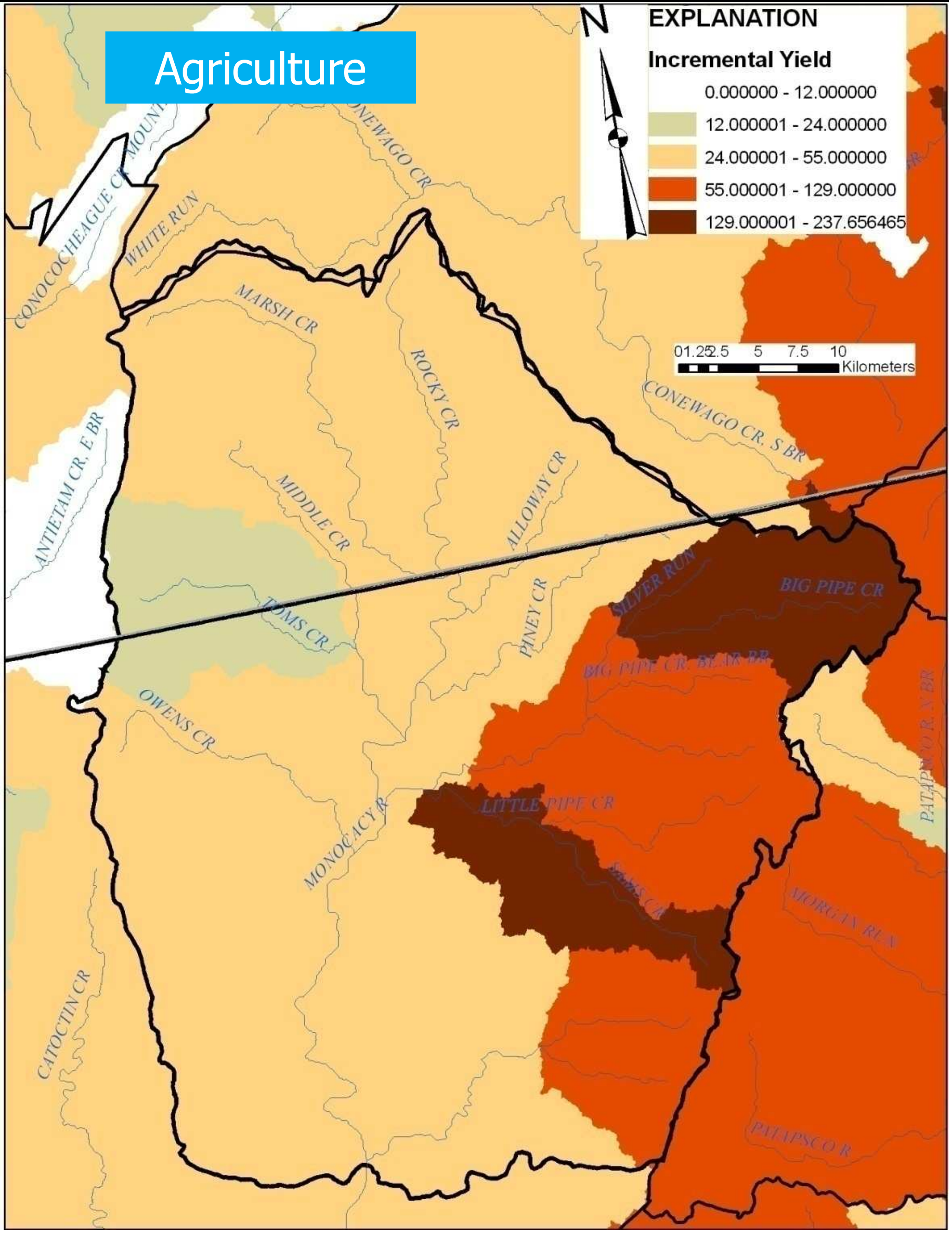
Incremental Yield

Modified from Brakebill et al., 2010, JAWRA

Delivered Yield

Additional information required?

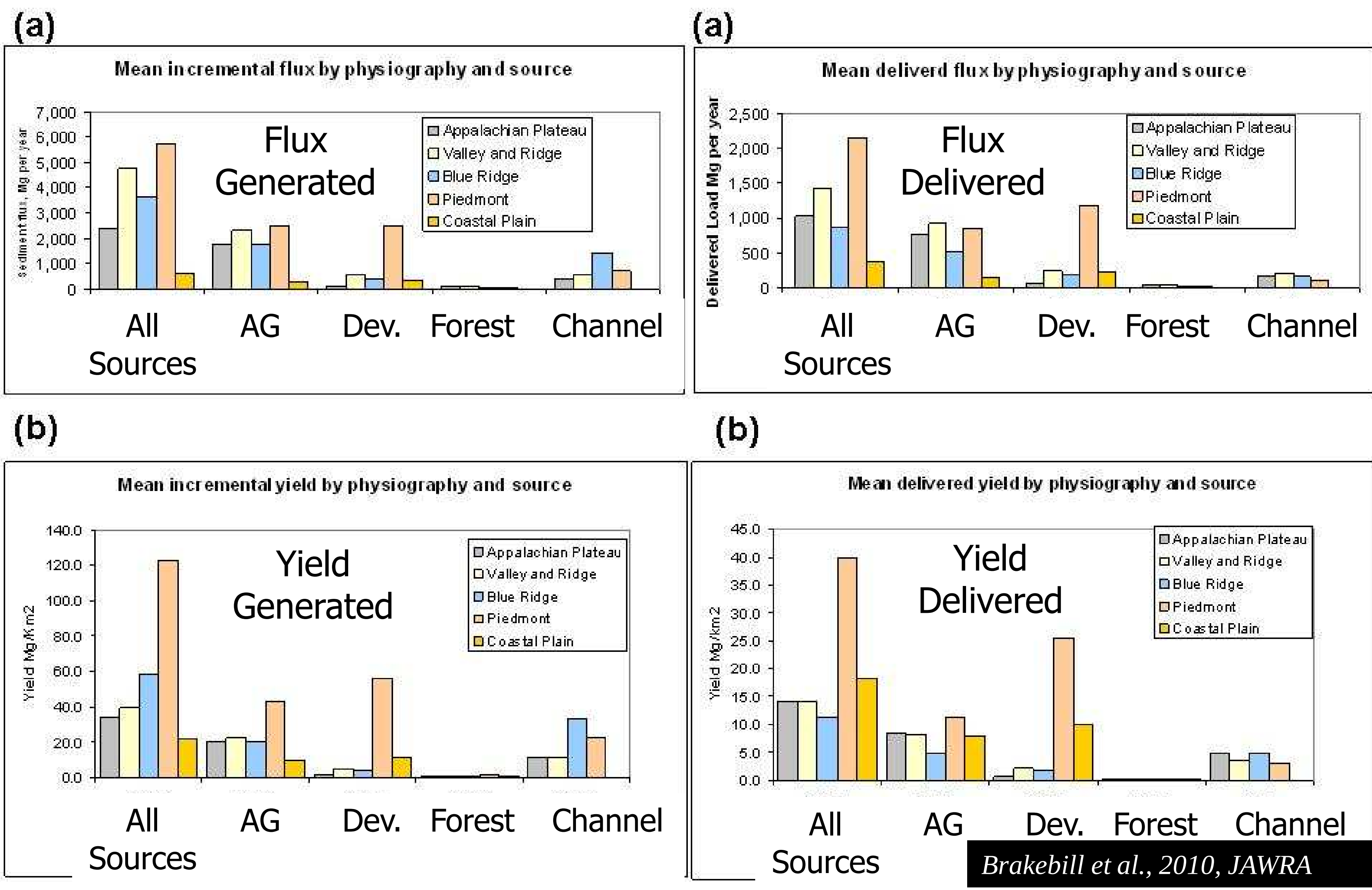
- Ability to look at each source individually
  - Is sediment yield related to urbanization?
  - Is sediment yield related to agriculture?
- Other sources?
- Other factors?



Upper Monocacy River Basin

Application – Quantifying Sediment Supply

Sediment Source Distribution *By Physiography*



Brakebill et al., 2010, JAWRA

Delivery to the Bay

Sediment Source Distribution

- Quantified amounts of each sediment source transported to the Bay
- Can be quantified and mapped at any location on the network

Source	Flux (10^6 Mg/year)	
Agriculture	51%	1.50
Urban Development	39%	1.16
Forest	08%	0.25
Small Streams	02%	0.05
TOTAL		2.96

Brakebill et al., 2010, JAWRA

Applications – Land-to-water delivery

Factors affecting overland sediment transport

- Combined effects of overland transport
- Properties suggest areas more or less vulnerable to erosion

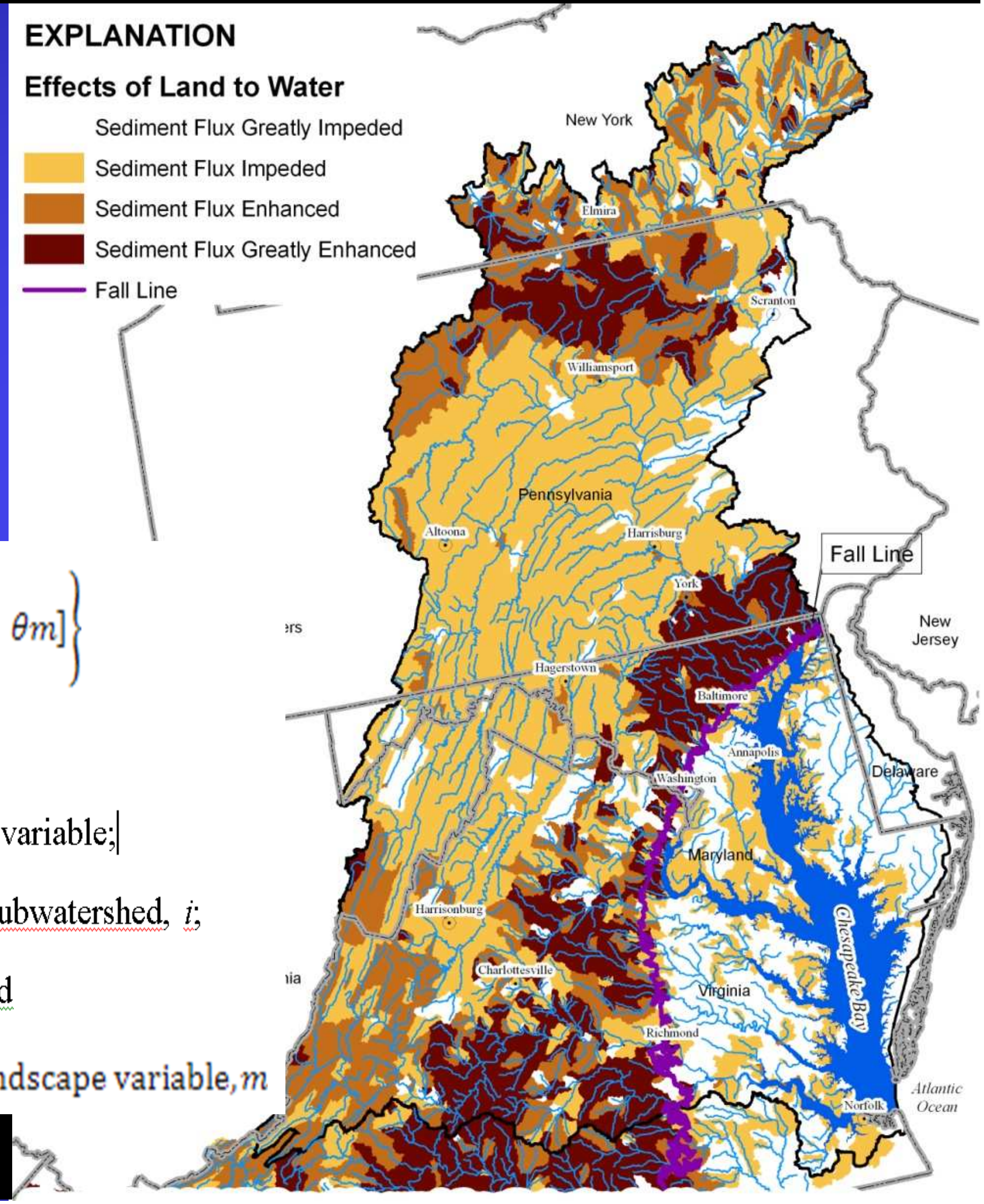
$$\mathrm{RUEV}_i = exp\left\{\sum_{m=1}^{4}\left[\left(Zm_i - \overline{Zm}\right) * \theta m\right]\right\}$$

m = significant overland transport landscape variable;

Zm_i = the value of landscape variable, m, in reach subwatershed, i;

$\overline{Zm}$ = the mean of Zm over all i; and

θm = the mean model – estimated coefficient for landscape variable, m



Modified from Brakebill et al., 2010, JAWRA
And Ator et al., 2010, FISC

Conclusions

- Applying the SPARROW model provides the ability to gain a regional understanding of sediment supply, fate, and transport within the Chesapeake Bay watershed
  - The SPARROW model demonstrates reasonable relations between the response variable (long-term water-quality conditions) and selected exploratory data representing supply, transport, and storage.
- SPARROW predictions can be used for:
  - Identifying individual source contributions and their relative importance
  - Identifying important transport factors and their relative importance
  - Quantifying relative amounts of sediment generated and transported to Chesapeake Bay
  - Geographic targeting for further study, additional monitoring, or management actions

Brakebill et al., 2010, JAWRA

Conclusions

- Sediment yields *(export coefficient)* are greatest from areas of urban development *(represented by an increase in impervious surface)*
- Agriculture is widespread and a significant source of sediment to local streams and Chesapeake Bay
- In-stream sources *(bank, bed, or flood plain erosion)* are also significant in small streams above the Fall Line
- The Piedmont province generates and delivers more sediment than any other physiographic province, where agriculture and urbanization are the dominant sources
- Upland sediment transport to streams is greatest in areas with greater slope, fewer reservoirs, less permeable soils, and in the Piedmont
- Net retention (storage) of sediment occurs
  - Within the stream network in large Coastal Plain streams
  - In reservoirs

Brakebill et al., 2010, JAWRA

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Thank You.

John Brakebill, jwbrakeb@usgs.gov
Scott Ator, swator@usgs.gov
Greg Schwarz, gschwarz@usgs.gov