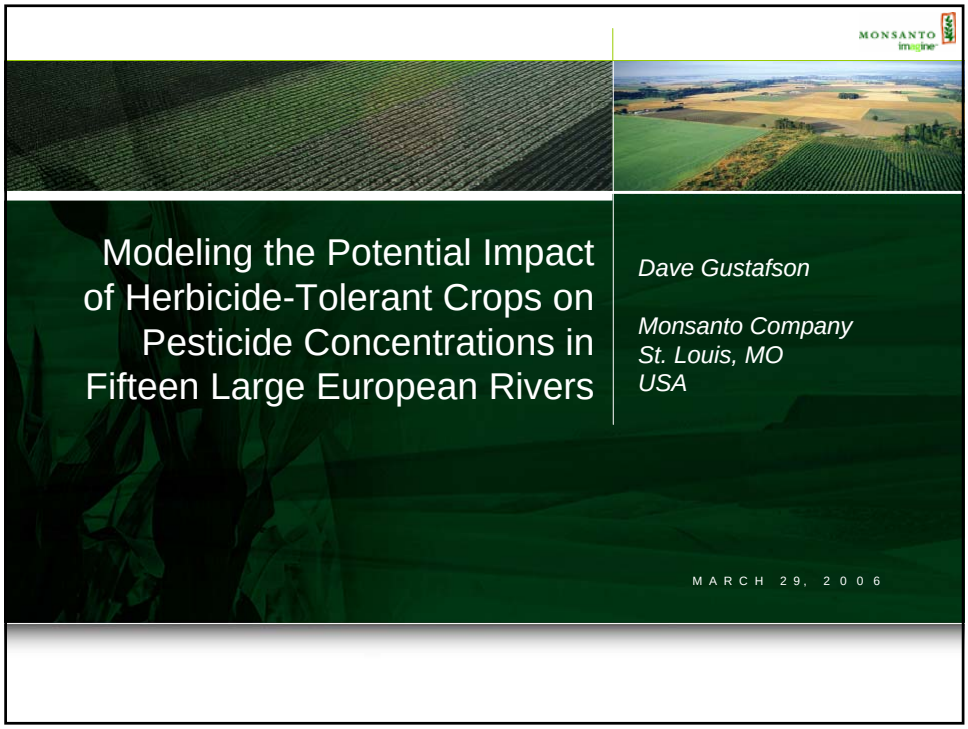
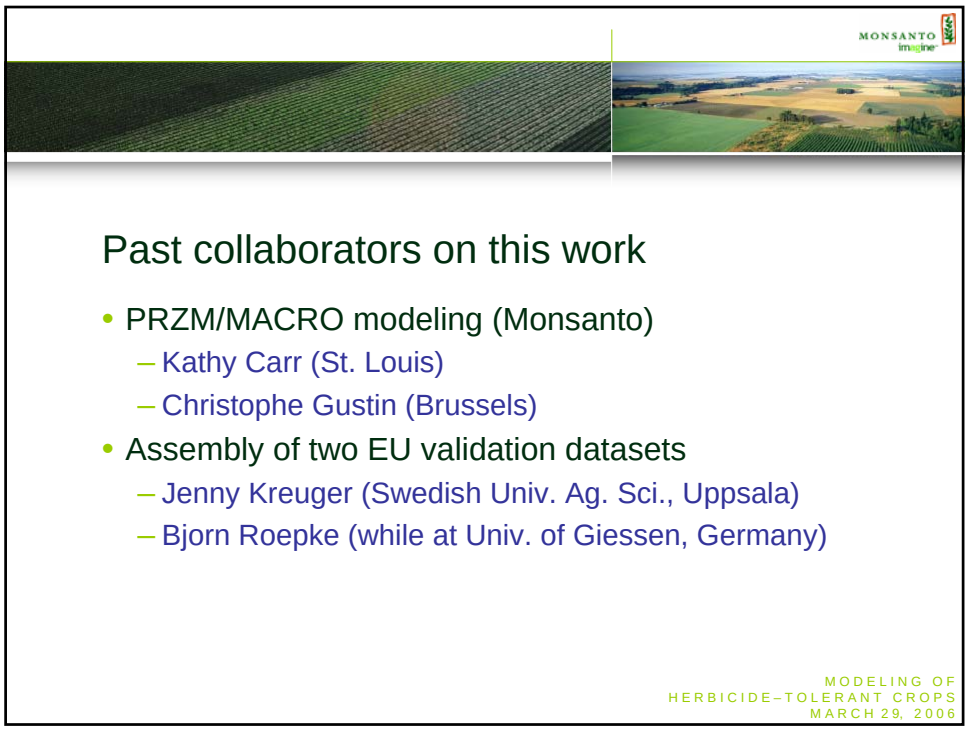

MONSTANTO
imagine
Modeling the Potential Impact of Herbicide-Tolerant Crops on Pesticide Concentrations in Fifteen Large European Rivers
Dave Gustafson
Monsanto Company
St. Louis, MO
USA
MARCH 29, 2006


MONSTANTO
imagine
Past collaborators on this work
• PRZM/MACRO modeling (Monsanto)
– Kathy Carr (St. Louis)
– Christophe Gustin (Brussels)
• Assembly of two EU validation datasets
– Jenny Kreuger (Swedish Univ. Ag. Sci., Uppsala)
– Bjorn Roepke (while at Univ. of Giessen, Germany)
MODELING OF HERBICIDE–TOLERANT CROPS
MARCH 29, 2006

Outline for Presentation

- Brief introduction to this landscape-scale model
  - US datasets used in its development
  - Preliminary validation work in the EU
- Application of model to two HT-crops
- Summary of results and future plans

Motivation Behind the New Model

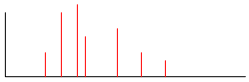
- A key regulatory question is the following:
- *What is the "peak" pesticide concentration to which humans and aquatics are exposed via surface water?*
  - The answer depends largely on scale
  - Catchments exhibit fractal-scaling properties
- This new approach was recently published
  - Fractal-based scaling and scale-invariant dispersion of peak concentrations of crop protection chemicals in rivers, *Environ. Sci. & Technol*., **38**:2995-3003 (2004).

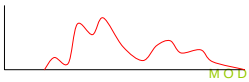
Schematic of New Modeling Approach

- Determine daily edge-of-field concentrations and flows using an existing regulatory model
- Feed these into a simple analytical model to approximate scale effects

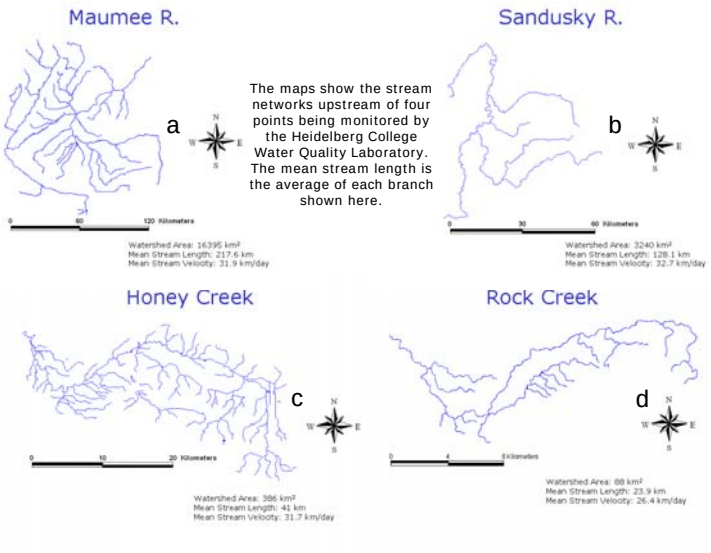
PRZM
or
MACRO, etc.

A Scale Dependent Analytical Solution to the Convective-Dispersion Eq.



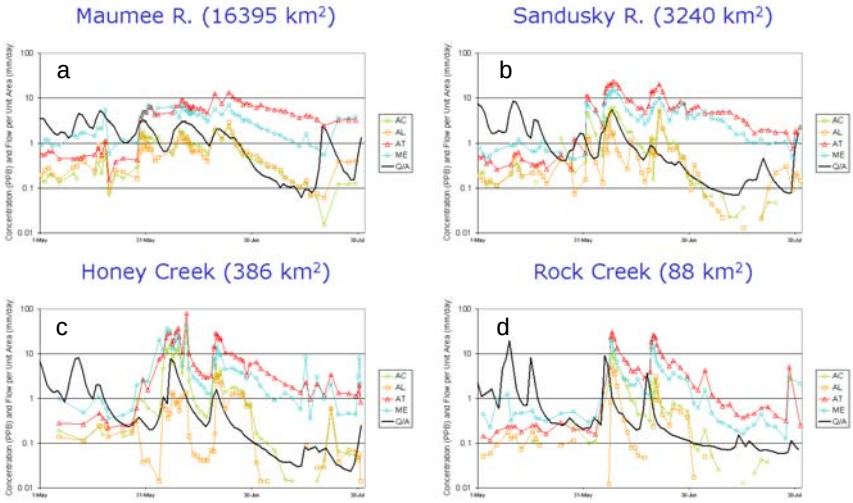


WQL Catchment Data Used in Model Development



The maps show the stream networks upstream of four points being monitored by the Heidelberg College Water Quality Laboratory. The mean stream length is the average of each branch shown here.

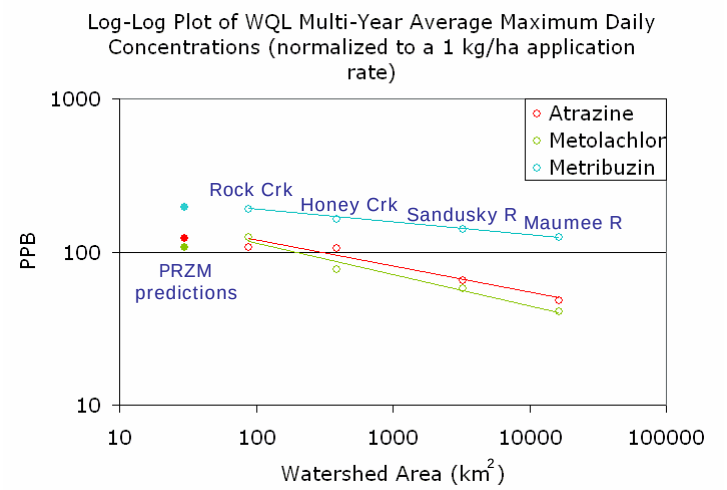
Temporal Intensity of the WQL Dataset



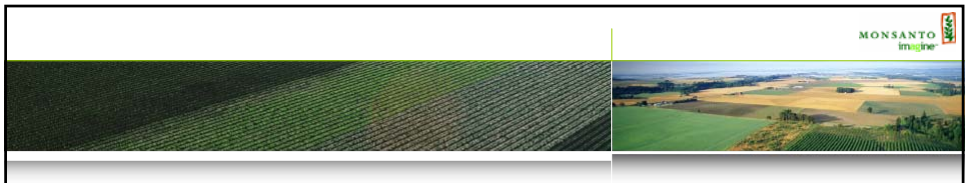
Surface water monitoring results from the Water Quality Laboratory. Each plot shows daily streamflow per unit area (Q/A) and concentrations of four herbicides: acetochlor (AC), alachlor (AL), atrazine (AT), and metolachlor (ME) during 1996, a high runoff year.

Practical Definition of "Peak" Concentration

- According to fractal theory, the "true" peak is a function of sampling frequency
- As a practical matter, we defined the "peak" to be the maximum daily concentration over the year
  - Corresponds to 99.7th percentile
  - Directly available from WQL data



- Solid circles are PRZM-predicted values (area-weighted average of four soils: Hoytville, Blount, Mermill, Toledo). They are somewhat arbitrarily plotted at a Catchment area of 30 km² in order to simply convey the fact that they represent edge-of-field estimates with no scaling effect included.
- Open circles are multi-year averages across years which had observed MDC values for all 4 WQL Catchments. Ten years met this criterion for all three of these pesticides: 1985, 1988-91, 1994-8. Observed maximum daily concentrations are adjusted to a use rate of 1 kg/ha through the assumption that concentration is linearly proportional to use intensity within a site and year.



Uses a Particular Analytical Solution to CDE

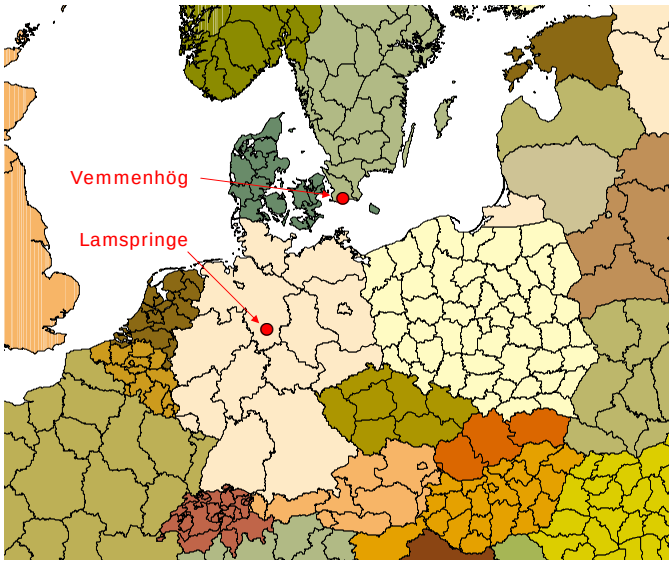
$$\phi = \phi_0 * \left(\frac{e^{-(z-vt)^2 / 2kv_w vt^2}}{\sqrt{0.5\pi k v_w v t^2}} \right)$$

- One-dimensional solution to the Convective Dispersion Equation with D_L increasing linearly with mean distance traveled

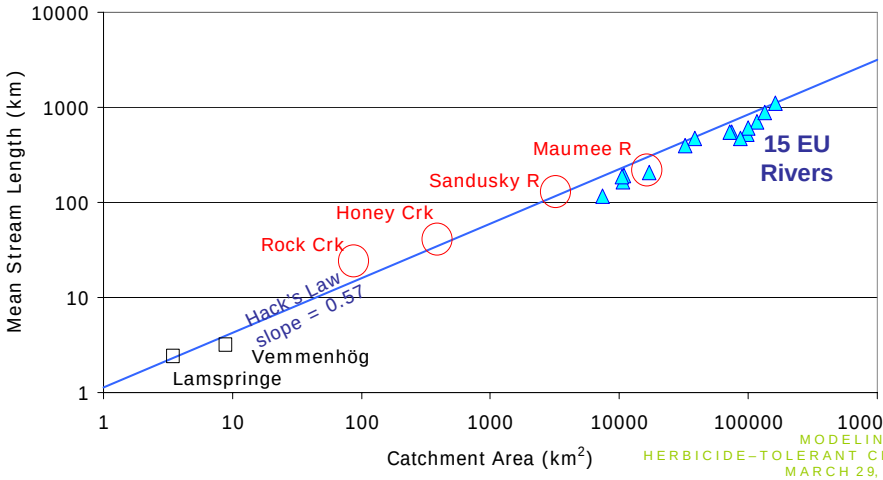
$$t_{\max} = \frac{-(vL) + \sqrt{(vL)^2 + 4kv_w vL^2}}{2kv_w v}$$

- Substitute this time into above CDE solution in order to calculate the maximum concentration for catchment with mean stream length, *L*

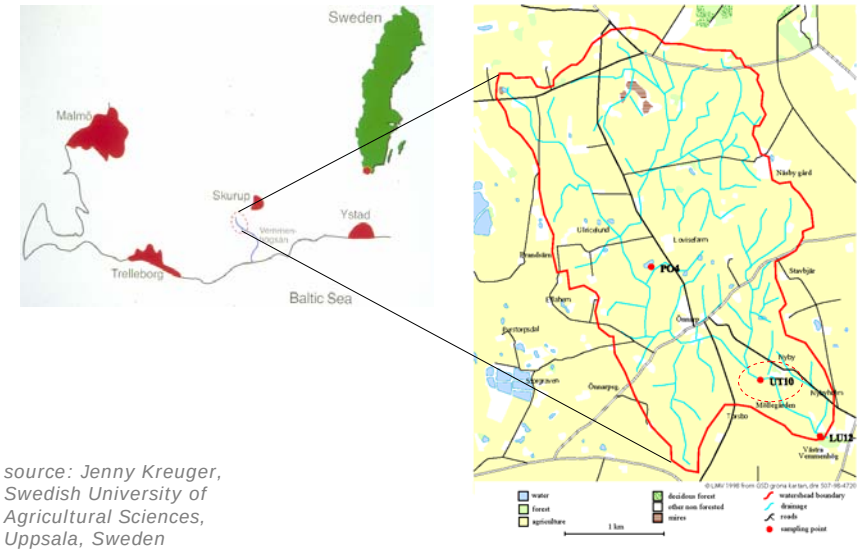
EU Catchment Datasets Used for Validation



Size of Catchments Modeled

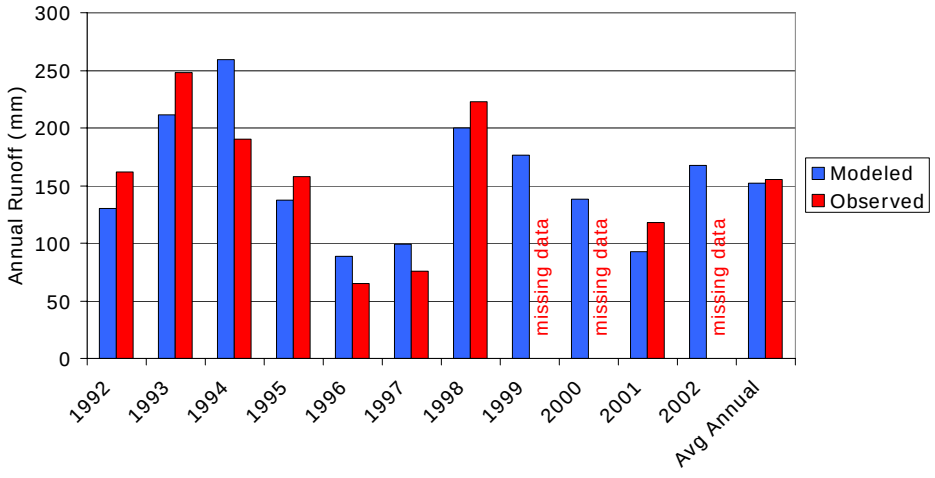


Map of the Vemmenhög Catchment



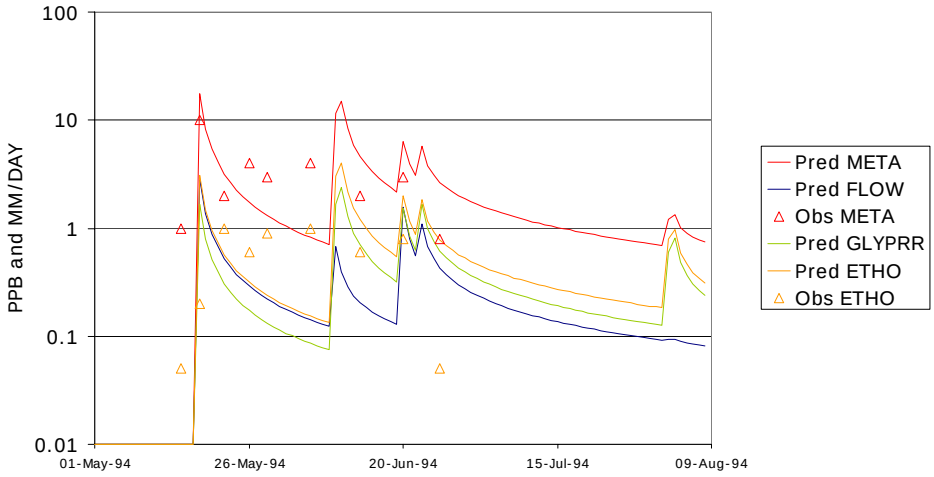
source: Jenny Kreuger, Swedish University of Agricultural Sciences, Uppsala, Sweden

Calibration of PRZM Hydrology (RCN) in the Vemmenhög

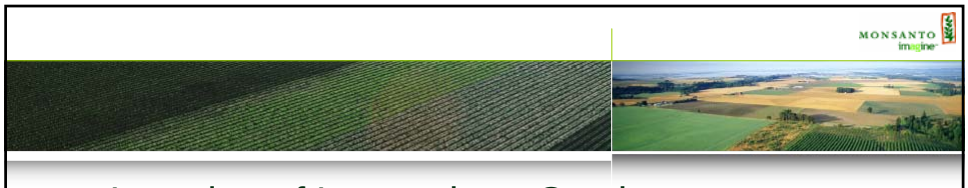


source of monitoring data: Kreuger et al., Swed Univ Ag Sci, Uppsala

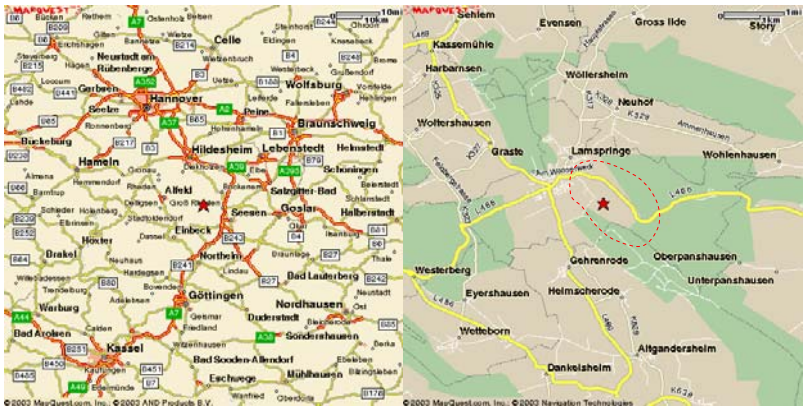
Observed and Predicted Concentrations in the Vemmenhög



source of monitoring data: Kreuger et al., Swed Univ Ag Sci, Uppsala

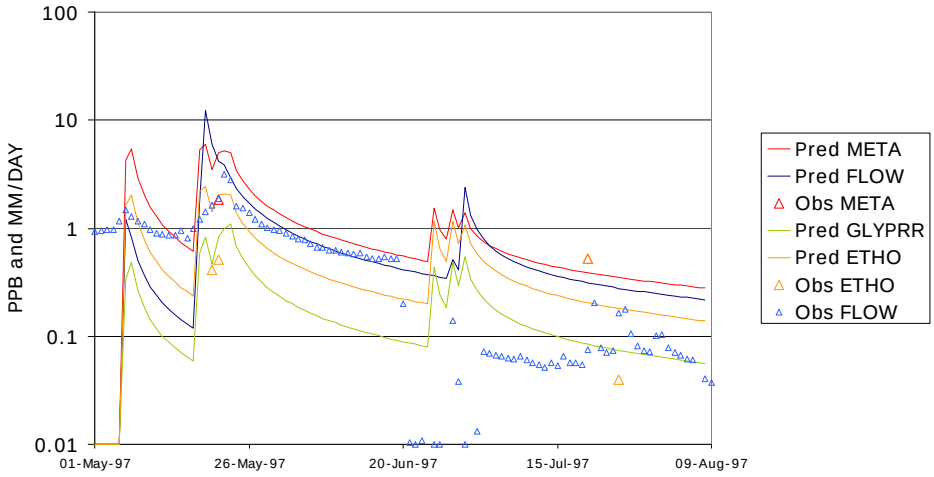


Location of Lamspringe Catchment

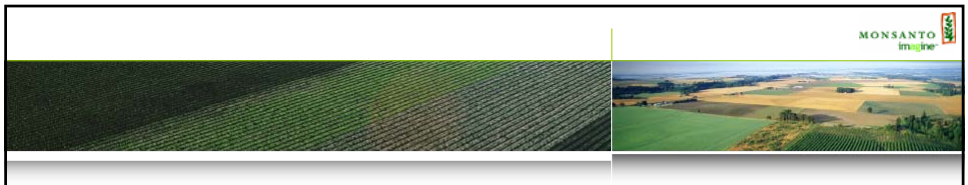


source: BBA, 2000

Observed and Predicted Flows and Concentrations in the Lamspringe



source of monitoring data: BBA, 2000



Application to Herbicide-Tolerant Crops

- Glufosinate and/or glyphosate tolerance now available as GM varieties in several crops, eg.
  - Canola
  - Cotton
  - Maize (field corn)
  - Soybeans
  - Sugar Beet

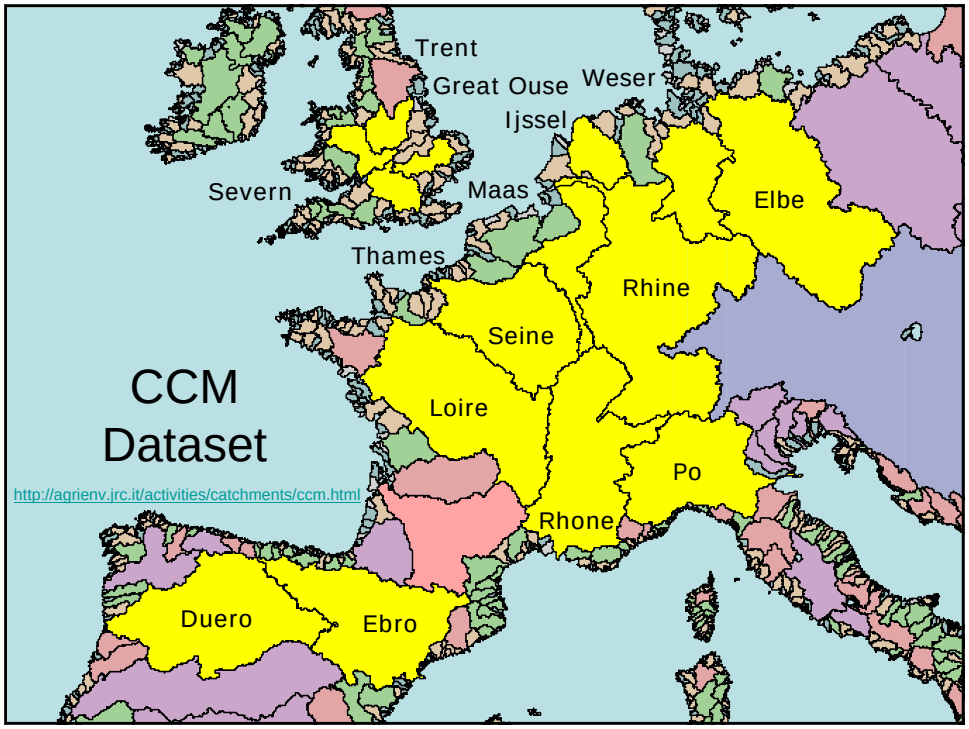
  Examples chosen for this work
- Previous modeling and monitoring work has shown that major reductions in surface water concentrations can occur with HT crops
  - Predicted impact of transgenic, herbicide-tolerant corn on drinking water quality in vulnerable watersheds of the Midwestern United States," *Pest Mgt Sci*, **58**:146-160 (2002).

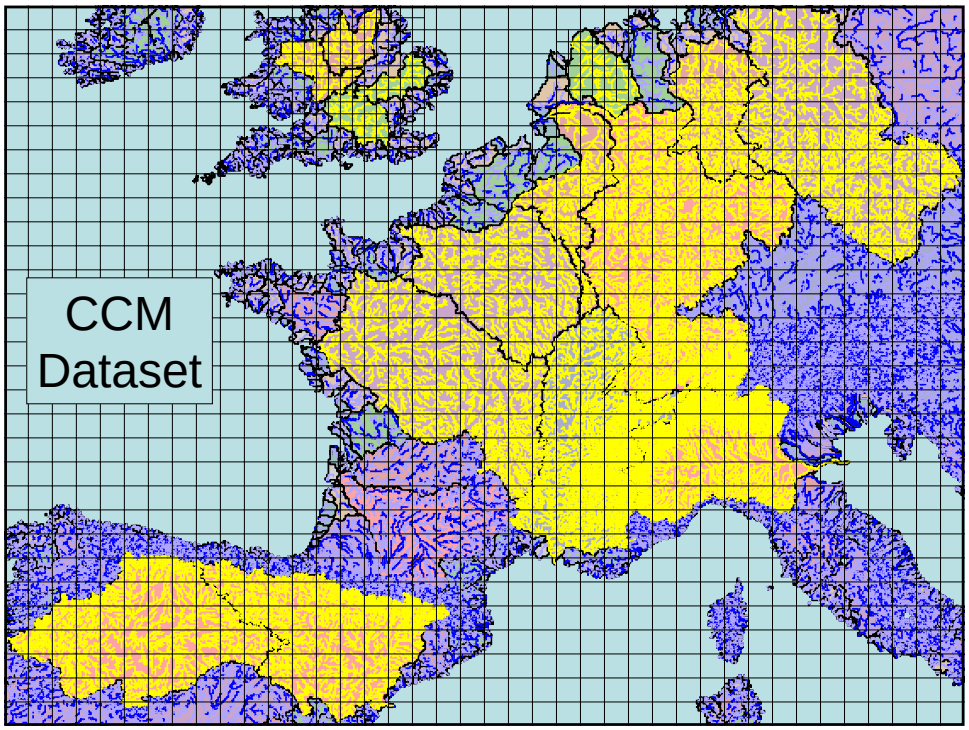
Herbicides Modeled

Active Ingredient	CAS Number	Koc (L/kg)	DT50 soil (days)	Assumed Annual Use Rate (kg/ha)
Ethofumesate	26225-79-6	147	97	0.25
Glufosinate	77182-82-2	600	16	0.91
Glyphosate	1071-83-6	9890	49	2.16
Metamitron	41394-05-2	172	28.2	2
S-Metolachlor	873921-9	170	36	1.25
Terbuthylazine	5915-41-3	220	60	0.75

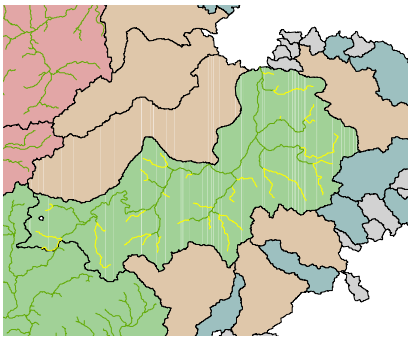
Countries Included in the HT-Crop Modeling

Country	Total Area (km^2)	Area Planted to Maize (ha)	Area Planted to Sugar Beet (ha)	Percent of Country Planted to Maize	Percent of Country Planted to Sugar Beet	Maximum of a Catchment Planted to Maize	Maximum of a Catchment Planted to Sugar Beet
France	546,729	3,179,000	427,000	5.81%	0.78%	40%	10%
Germany	356,109	1,519,000	470,000	4.27%	1.32%	40%	15%
Italy	300,979	1,310,000	220,000	4.35%	0.73%	40%	10%
Netherlands	35,493	230,000	120,000	6.48%	3.38%	40%	40%
Spain	498,118	450,000	112,000	0.90%	0.22%	10%	3%
UK	243,137	100,000	175,000	0.41%	0.72%	5%	10%


Trent
Great Ouse
Weser
Ijssel
Severn
Maas
Elbe
Thames
Rhine
Seine
CCM
Dataset
Loire
Po
http://agrienv.jrc.it/activities/catchments/ccm.html
Rhone
Duero
Ebro


CCM
Dataset

Close-up of Great Ouse Catchment (UK)



- Mean stream length is defined as the average distance from outlet to the upper end of each headwater segment (Stahler order 1, shown in yellow at left)
- GIS tools useful here

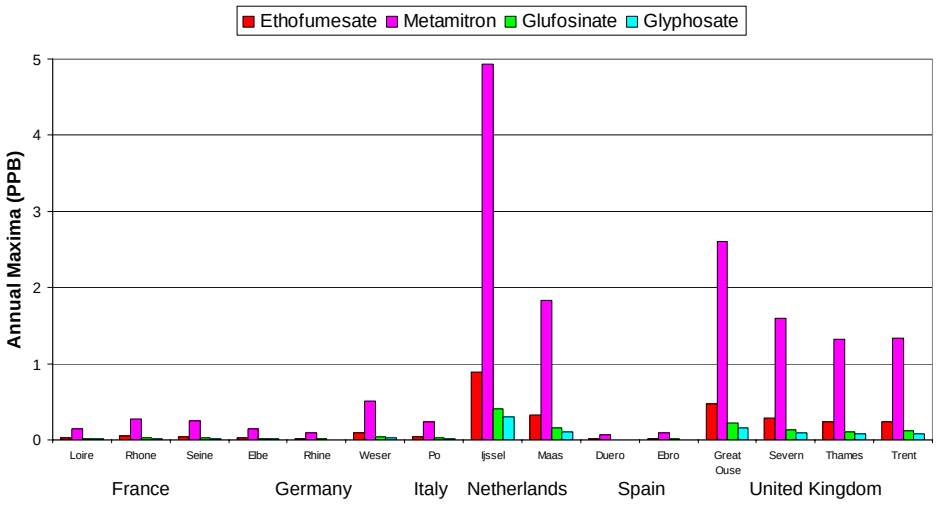
Catchment Areas and Mean Stream Lengths for Fifteen European Rivers

River Name	Country	Area (sq km)	L (km)
Loire	France	115,944	698
Rhone	France	97,944	519
Seine	France	73,833	553
Elbe	Germany	134,933	892
Rhine	Germany	161,570	1,100
Weser	Germany	38,390	476
Po	Italy	72,137	550
Ijssel	Netherlands	17,113	205
Maas	Netherlands	32,578	392
Duero	Spain	99,638	600
Ebro	Spain	87,489	474
Great Ouse	United Kingdom	7,442	117
Severn	United Kingdom	10,574	167
Thames	United Kingdom	10,771	191
Trent	United Kingdom	10,485	189

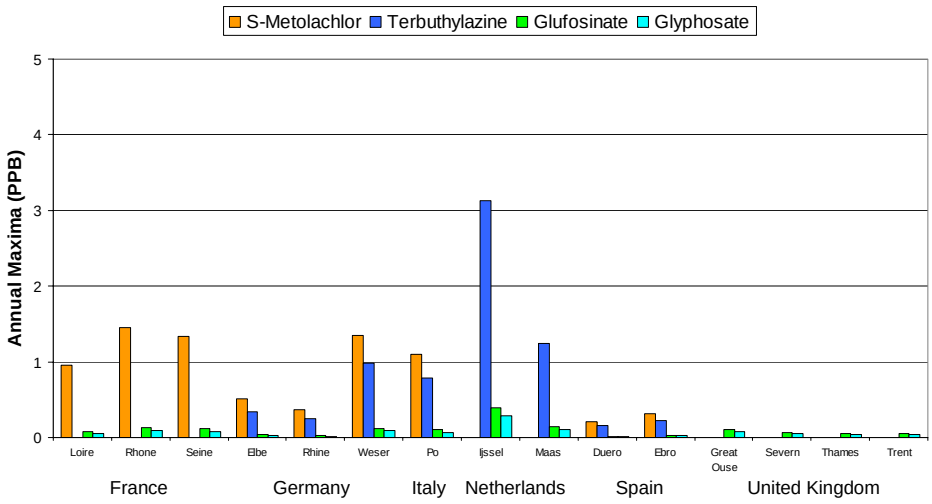
Example Application Rate Assumptions (Germany)

Mean Stream	Catchment	Assumed Catchment-Scale Application Rate (kg/ha)			
Length (km)	Area (km2)	S-Metolachlor	Terbuthylazine	Glufosinate	Glyphosate
1	0.8	0.500	0.300	0.364	0.864
2	2.6	0.459	0.274	0.331	0.787
4	8.9	0.417	0.249	0.299	0.710
8	30	0.376	0.223	0.266	0.632
16	100	0.334	0.197	0.234	0.555
32	334	0.293	0.171	0.201	0.478
64	1120	0.251	0.146	0.169	0.401
128	3754	0.210	0.120	0.136	0.324
256	12586	0.168	0.094	0.104	0.247
512	42194	0.127	0.068	0.071	0.169
1024	141453	0.085	0.043	0.039	0.092

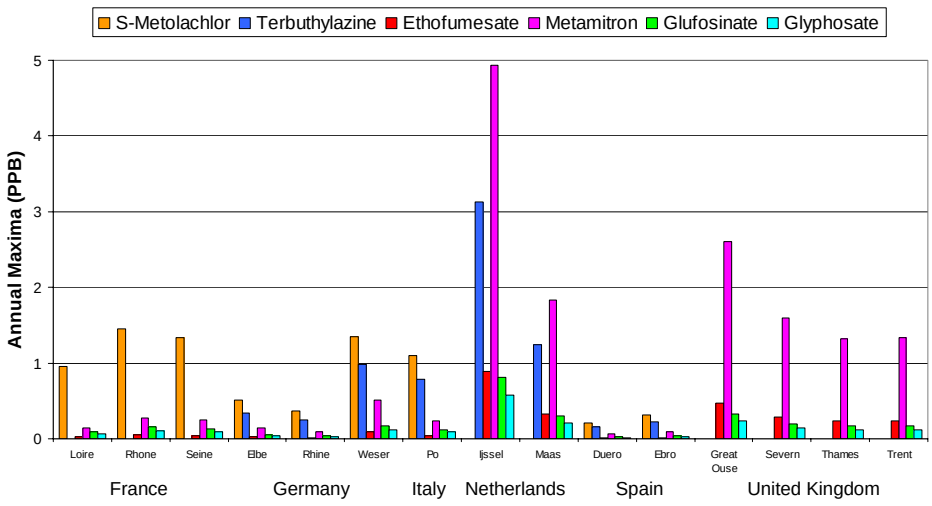
Sugar Beet Herbicide Results



Maize Herbicide Results



Maize and Sugar Beet Predictions Combined



Summary of Results, Future Plans

- New landscape model appears to give valid peak concentration estimates for European rivers
- Specific application to these two HT-crops:
  - Significant reductions in total pesticide concentrations in these major rivers would be associated with the adoption of the HT maize and sugar beet
- We intend to submit this work for publication in the peer-reviewed scientific literature