Refinement of the FOCUS Stream Scenario

Mark Russell

DuPont Crop Protection

Third European Modelling Workshop

Catania, Italy

February 17-19, 2004

Sequential steps for FOCUS surface water models

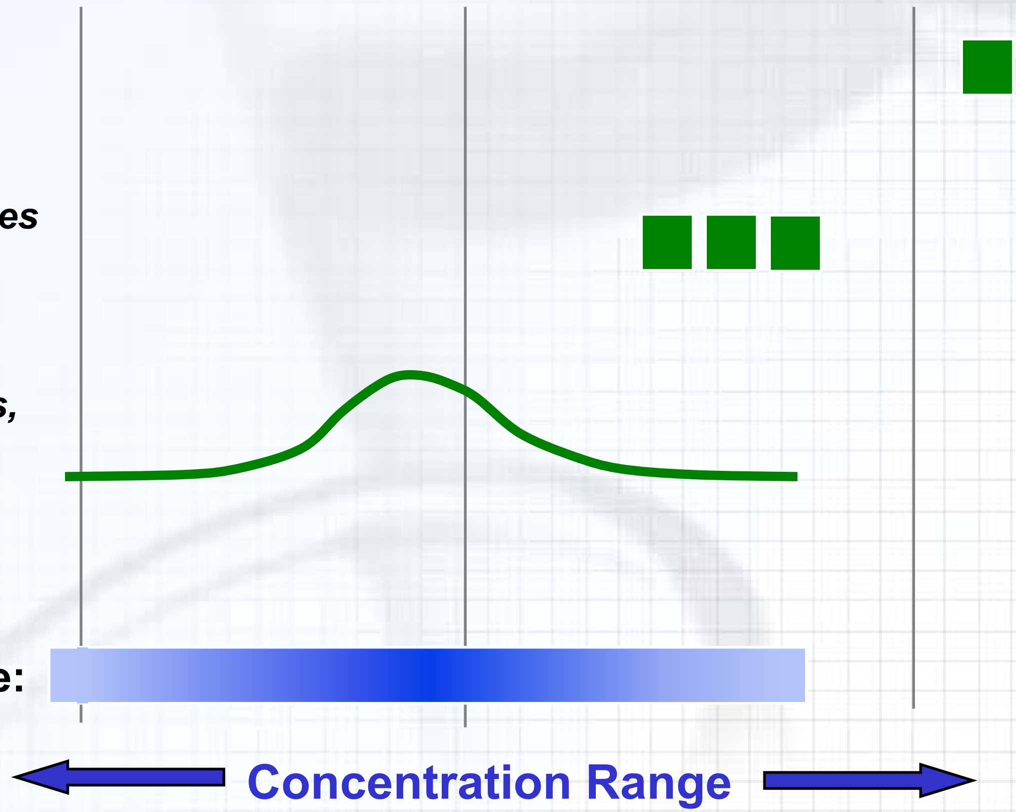
Type of Exposure Estimate

Step 1: *Initial estimates*
Step 2: *(screening model)*

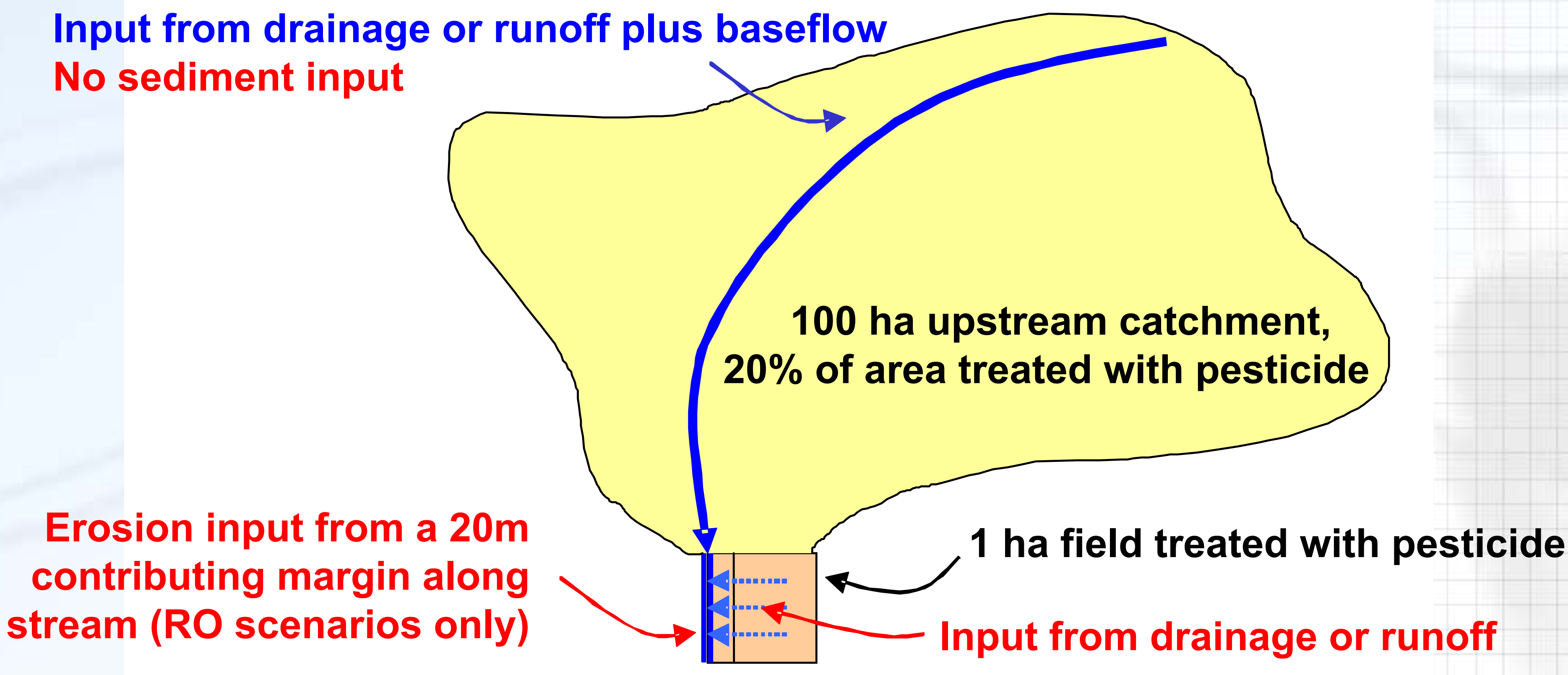
Step 3: *Deterministic estimates (mechanistic model)*

Step 4: *Refined estimates (scenario refinements, catchment model, probabilistic model)*

Actual Range of Exposure:



Current FOCUS Step 3 stream scenario



Assumptions in current stream scenario

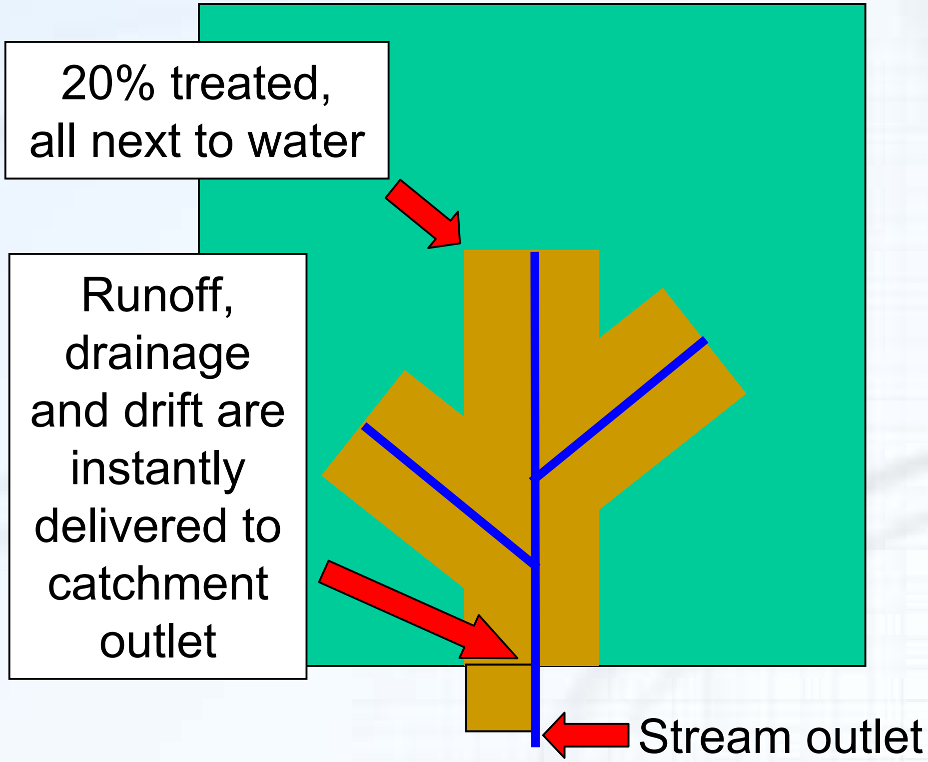
Parameter	*Assumption for Step 3*
Treated field	
size	1 ha
location	immediately adjacent to stream
buffer zone	none
Catchment	
size	100 ha
% cropped	100% (although not explicitly stated)
% treated	20%
location of treated fields	immediately adjacent to stream
delivery of RO, DR & drift	same timing as from treated field

Assumptions in current FOCUS stream scenario

Parameter	*Assumption for Step 3*
Stream	
width	1 m
length	100 m (control section)
depth	dynamic with minimum depth of 0.3 m
ratio of field:water body	100:1 (area:area)
extent of baseflow	based on MAM7 and excess precip, minimal due to small size of catchment
extent of subsurface flow	drainage: included in drainflow runoff: proportional to infiltration

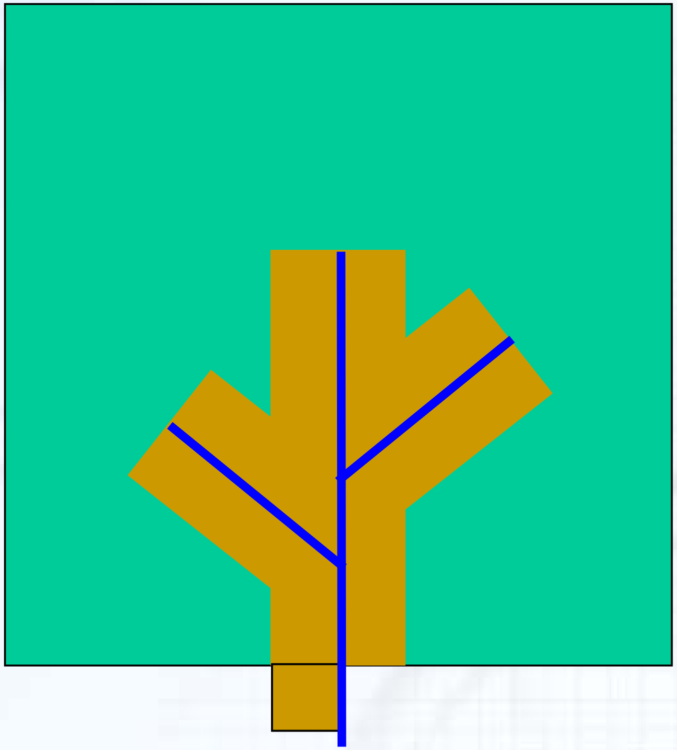
Current Step 3 stream scenario

Current Step 3 scenario
1 km² catchment (100 ha)



Estimation of concentration due to runoff

Current Step 3 scenario
1 km² catchment (100 ha)



From 1 ha treated field

Let M = daily mass of chem lost via runoff and erosion

V = daily volume of runoff from 1 ha field

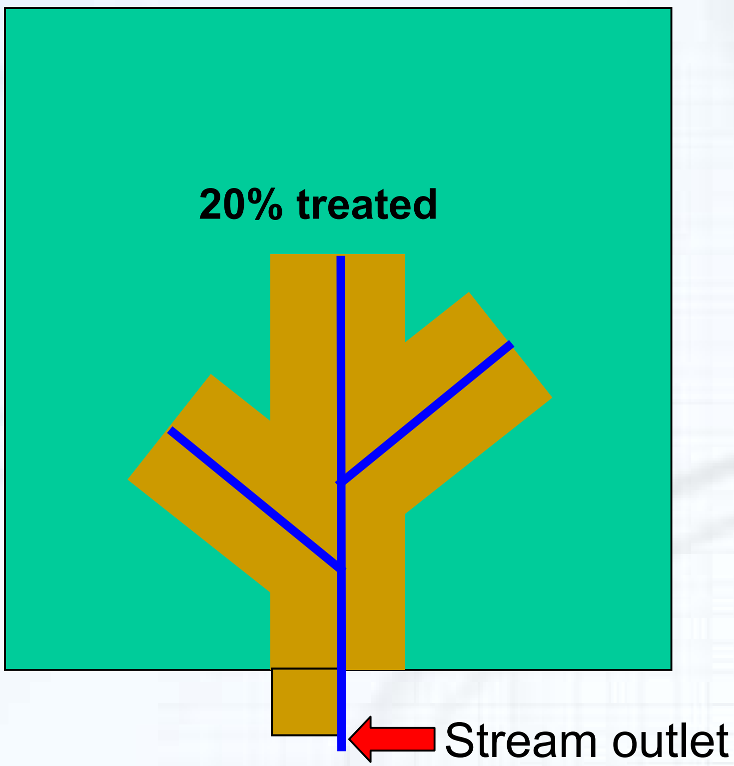
Mean daily edge-of-field concentration from 1 ha field

$$Cf = \frac{M}{V}$$

For Step 3, there is no mitigation due to buffer zones

Estimation of concentration due to runoff

Current Step 3 scenario
1 km^2 catchment (100 ha)



From the catchment

Let 20M = daily mass lost in catchment

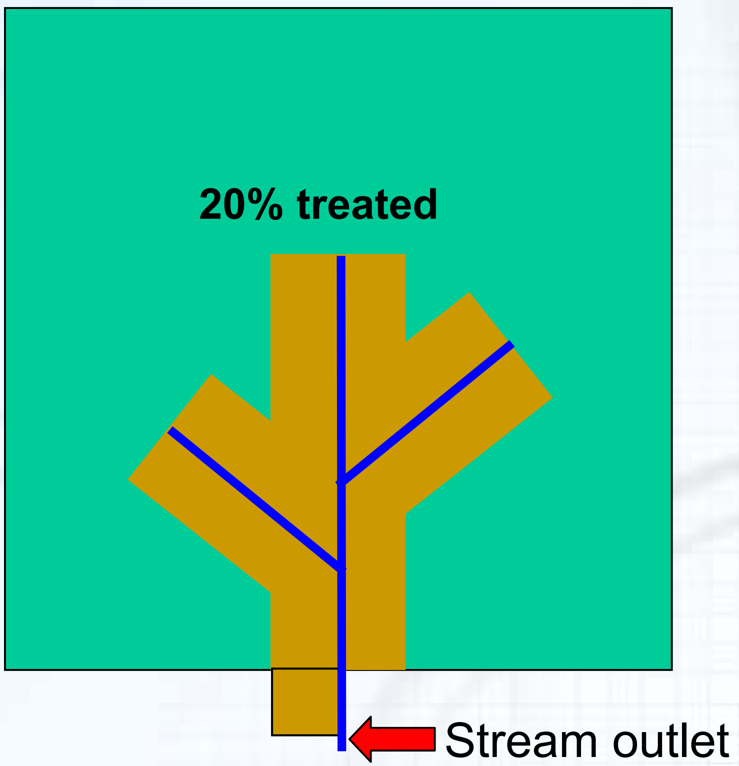
100V = daily volume from catchment

An estimate of the peak concentration at the stream outlet is then

$$Co = \frac{(M + 20M)}{(V + 100V + BF)}$$

Estimation of concentration due to runoff

Current Step 3 scenario
1 km² catchment (100 ha)



If baseflow is << V, then

$$Co = \frac{(M + 20M)}{(V + 100V + BF)}$$

becomes

$$Co = \frac{21M}{101V} = 0.21\ Cf = \frac{Cf}{4.8}$$

Net concentration reduction of 4.8X from peak edge-of-field concentration

Reality check: modeling versus monitoring

- ***Comparison of modeling and monitoring in USA***
  - PRZM/EXAMS modeling of edge-of-field runoff and drift entering a drinking water reservoir
  - USGS/EPA monitoring of 12 water supply reservoirs
- ***Results***
  - modeling systematically overestimated measured exposure by 10-10,000 fold (most typical: 100-1000 fold)
- ***Primary reasons***
  - landscape factors not considered in PRZM/EXAMS
  - use intensity factors exaggerated in catchment modeling
  - EPA's method of parameterization (worst-case)

Reference: SETAC 2000 poster: "A Comparison of USEPA's Tier 1 and 2 Index Reservoir Model Estimates to Drinking Water Reservoir Monitoring Results in Selected US Systems in 1999/2000"

Factors in stream scenario subject to refinement

- ***Field characteristics***
  - buffer width: consider mitigation due to edge-of-field buffer zone
- ***Catchment characteristics***
  - size: increased size could create a more permanent stream with increased baseflow
  - buffer width: spatially distribute treated fields with respect to stream, resulting in a distribution of buffer widths
  - hydrograph: evaluate timing of catchment runoff delivery with respect to runoff from downgradient treated field
- ***Stream characteristics***
  - change size of stream and slope of streambank to create more realistic stream profiles

Field and catchment: effect of buffer strips

Chemical	Buffer Strip		Reduction in runoff and erosion (%)	Reference
	Vegetation	Width (m)		
2,4-D	grass, wet	24	69	Asmussen et al (1977)
trifluralin	grass, wet	80	96	Rhode et al (1980)
atrazine	oats, wet	6	65 - 91	Hall et al (1983)
atrazine	grass, wet	4.6	28-35	Mickelson and Baker (1993)
atrazine	grass, wet	9.1	51-59	Mickelson and Baker (1993)
atrazine	grass, wet	12.2	26-50	Misra et al (1996)
metolachlor	grass, wet	12.2	27-47	Misra et al (1996)
cyanazine	grass, wet	12.2	26 - 47	Misra et al (1996)
dicamba	grass, wet	4.9	0 - 27	Cole et al (1997)
2,4-D	grass, wet	4.9	0 - 35	Cole et al (1997)
mecoprop	grass, wet	4.9	0 - 33	Cole et al (1997)
chlorpyrifos	grass, wet	4.9	80 - 100	Cole et al (1997)
atrazine	grass, wet	20	13 - 100	Arora et al (1996)
metolachlor	grass, wet	20	22 - 100	Arora et al (1996)
cyanazine	grass, wet	20	15 - 100	Arora et al (1996)

Reduction is function of

- chemical properties (primarily Koc)
- width and composition of buffer
- intensity of the precip event
- field management practices

Field and catchment: effect of buffer strips

- ***Current German guidance on efficacy of buffer strips***

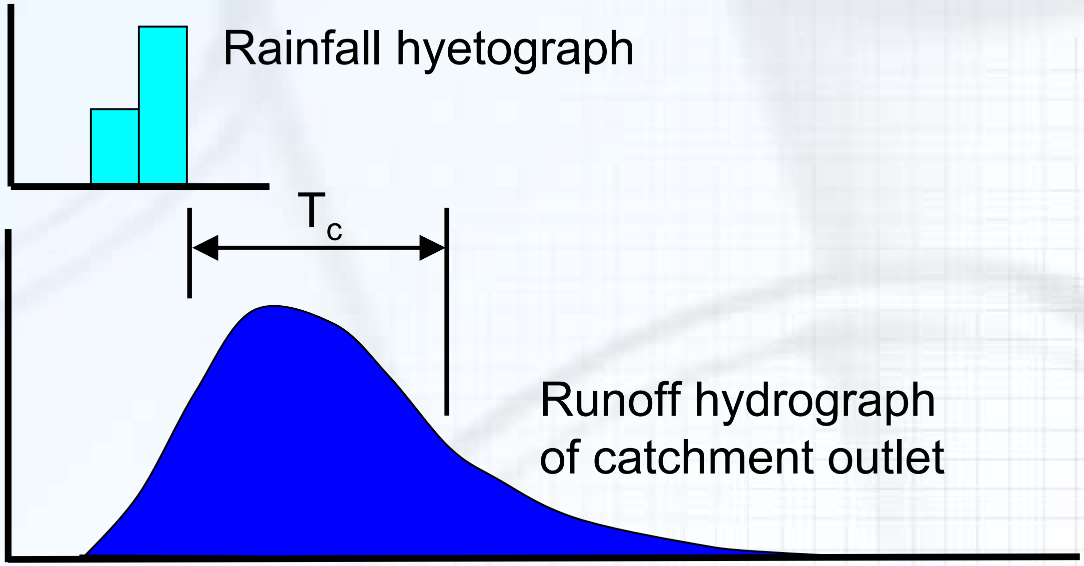
Buffer width (m)	Reduction in runoff and erosion
5	50%
10	90%
20	95%

on fields with slopes > 2%

Catchment response: timing of runoff delivery

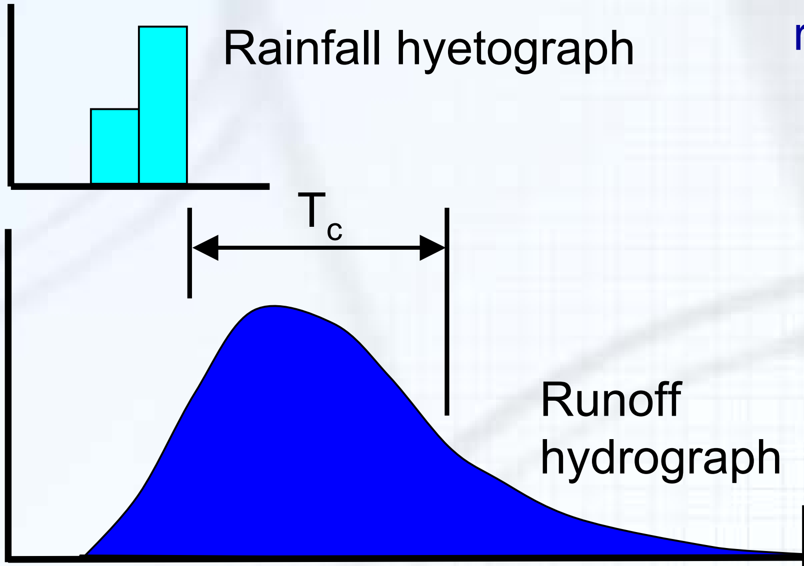
- ***Analysis based on time of concentration, T_c***

  T_c = elapsed time between end of rainfall and point of inflection on direct runoff hydrograph



Catchment response: timing of runoff delivery

- T_c = elapsed time between end of rainfall and point of inflection on direct runoff hydrograph



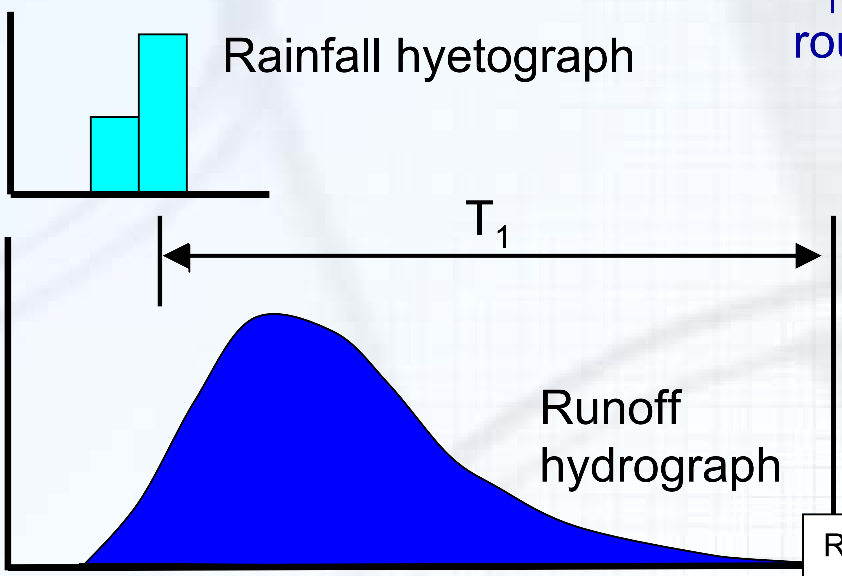
T_c is a function of area, slope, surface roughness and rainfall intensity

Catchment area (km^2)	T_c (hr)
1	4-5
10	7-10
100	15-19

Reference: Singh, V.P., Hydrologic Systems, Volume 1: Rainfall-Runoff Modeling, Prentice Hall.

Catchment response: duration of runoff event

- T_1 = elapsed time between storm peak and end of overland flow



T_1 is a function of area, slope, surface roughness and rainfall intensity

Catchment area (km^2)	T_1 (hr)
1	20
10	31
100	43

Reference: Singh, V.P., Hydrologic Systems, Volume 1: Rainfall-Runoff Modeling, Prentice Hall.

Catchment response: conclusions

- ***Time scale for 1-10 km2 catchments***

  - typically one day or less, depending on analysis

- ***Practical considerations***

  - MACRO can generate hourly drainage values
  - SWASH expects hourly input values for drainage and runoff

However:

  - current met data is in daily increments
  - PRZM is a daily time step model; hourly runoff values are estimated by dividing daily runoff by estimated hours of rainfall, assuming an average rainfall intensity of 2 mm/hr

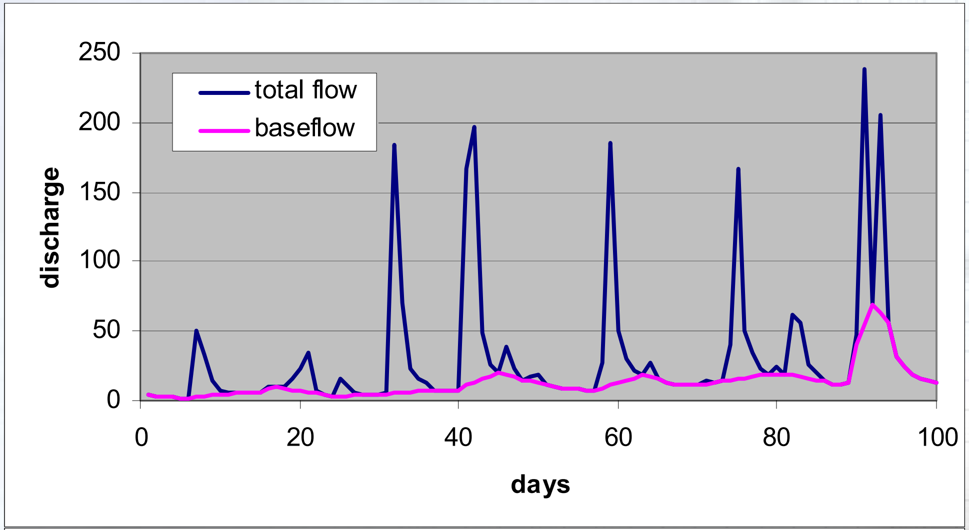
  - Refinement of catchment response requires finer resolution met data and a mechanistic catchment model

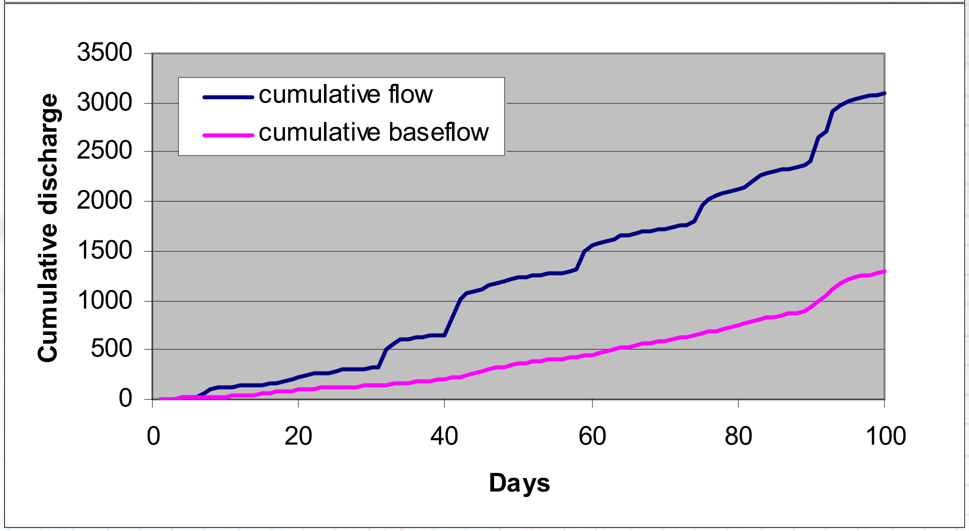
Catchment baseflow

Typical flow characteristics of 10-100 km² catchments

<u>short term</u> (storm event)
- 5-10% of discharge
- multi-day recession

<u>long term</u> (cumulative)
- 30-50% of discharge is BF
- relatively smooth curves





Reference:	"Estimated Baseflow Characteristics of Selected Washington Rivers and Streams", Water Supply Bulletin No. 60, October 1999.

Catchment baseflow

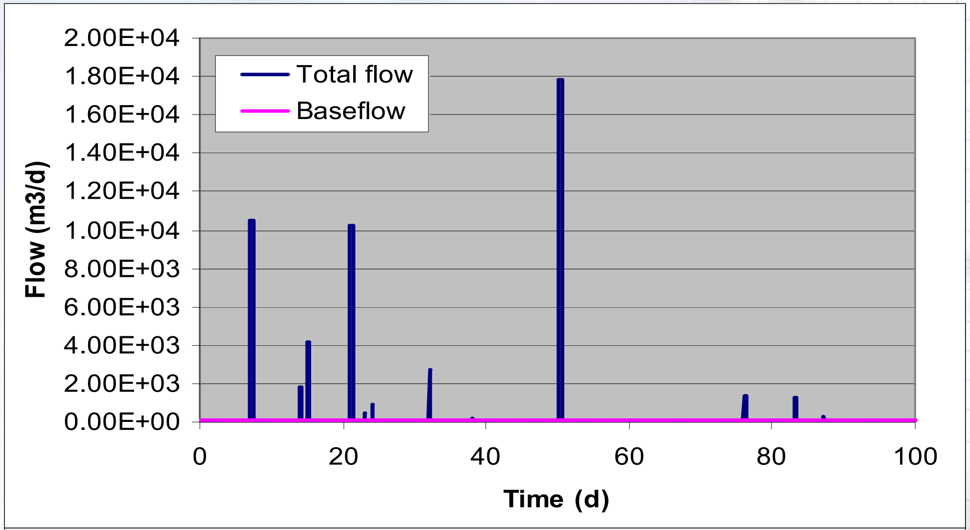
Response in FOCUS Step 3 stream scenario (1 km²)

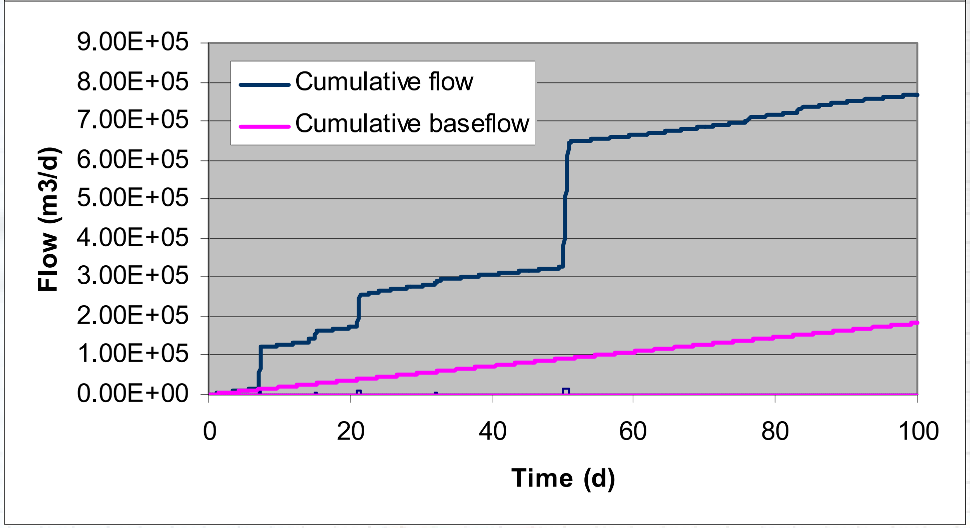
<u>short term</u> (storm event)

- 0.4 - 2.8% of discharge
- highly transient events
- immediate recession

<u>long term</u> (cumulative)

- 18% of discharge
- ~ continuous baseflow with abrupt storm events



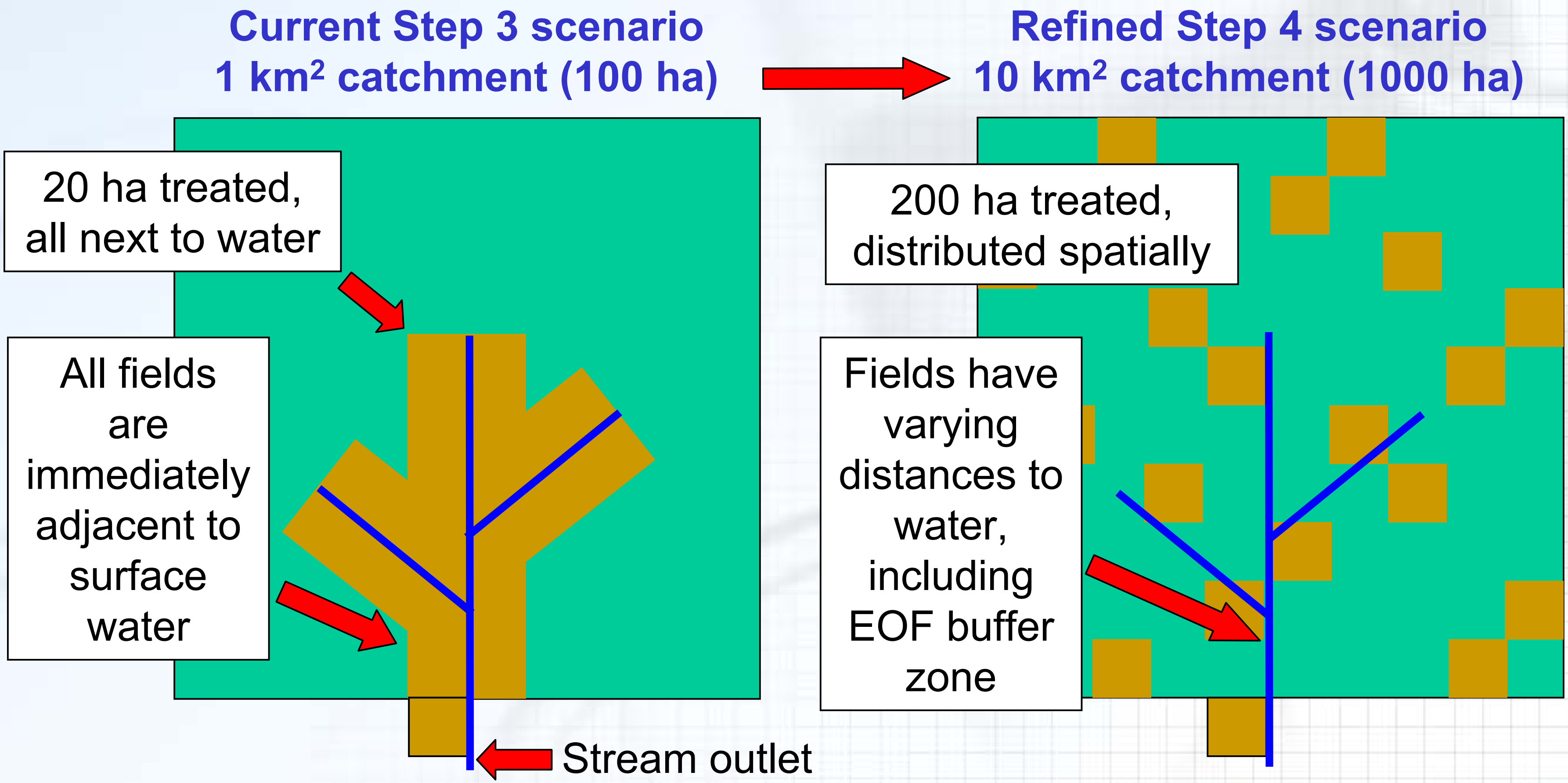


Reference:	FOCUS Surface Water Scenarios in the EU Evaluation Process Under 91/414/EEC, SANCO/4802/2001-Rev1

Proposed refinements for Step 4 stream scenario

- *Increase catchment size to ~10 km^2 to obtain a more sustainable stream*
- *Spatially distribute treated fields in catchment*
- *Consider mitigating effect of vegetated buffer zones between treated fields and streams to reduce*
  - *runoff and erosion*
  - *drainage (if discharge enters grassed waterways or vegetated ditches prior to stream)*
  - *drift*

Proposed Step 4 refinements to stream scenario

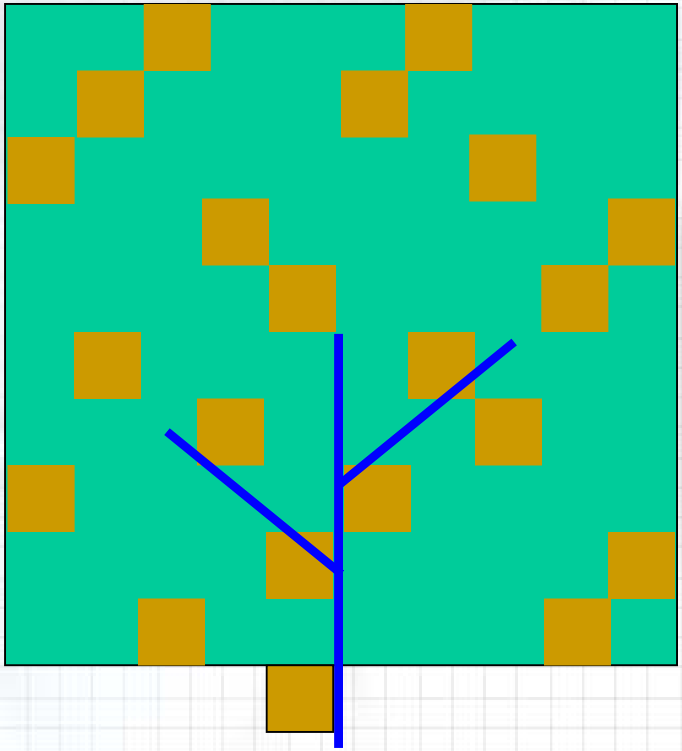


Effect of buffer zone on edge-of-field loading

Determine appropriate mitigation factors for runoff and erosion as a function of distance between field and stream:

Distance	Example Mitigation factor
2m	0.20
5m	0.50
10m	0.90
20m	0.95

Mitigation factors should be based on
- experimental measurements
- literature citations or
- accepted regulatory values



Example calculation for Step 4 stream scenario

- ***Additional input values (beyond Step 3)***

  Width of edge of field buffer: 5m

Example calculation for Step 4 stream scenario

- ***Additional input values (beyond Step 3)***

Width of edge of field buffer: 5m

Distribution of fields in catchment and mitigation factors:

10% with 5m buffers	→	30% reduction, $f_i = 0.7$
10% with 10m buffers	→	50% reduction, $f_i = 0.5$
10% with 20m buffers	→	80% reduction, $f_i = 0.2$
70% with > 20m buffers	→	90% reduction, $f_i = 0.1$

Example calculation for Step 4 stream scenario

- ***Additional input values (beyond Step 3)***

Width of edge of field buffer: 5m

Distribution of fields in catchment and mitigation factors:

10% with 5m buffers	→	30% reduction, $f_i = 0.7$
10% with 10m buffers	→	50% reduction, $f_i = 0.5$
10% with 20m buffers	→	80% reduction, $f_i = 0.2$
70% with > 20m buffers	→	90% reduction, $f_i = 0.1$

- ***Resulting catchment mitigation factor***

$f = \Sigma\, area_i * (f_i)$

$f = (1*0.7) + (20*0.7) + (20*0.5) + (20*0.2) + (140*0.1)$

$f = 42.7$

Example calculation for Step 4 stream scenario

- ***Resulting loading (approximate)***

$$Co = \frac{42.7\ M}{1001\ V} = 0.043\ Cf = \frac{Cf}{23}$$

- ***Summary of reduction from edge-of-field to water***

Step 3 = 4.8X
Step 4 = 23 X

Drift loadings in Step 4 stream scenario

- ***Drift loading as a function of distance***

  appln to maize at 5 m = 0.52%
  10 m = 0.28%
  15 m = 0.18%
  20 m = 0.14%

- ***Determine average drift using same area weighting***

  Cdf = area fraction * drift percent
  Cdf = (0.1*0.52%) + (0.1*0.28%) + (0.1*0.18%) + (0.7*0.14%)
  Cdf = 0.20% average drift loading over catchment stream
  Assume wind only blows from one direction → divide by 2

- ***Overall drift loading (field plus catchment)***

  Cdf = 0.52% + 0.20%/2 = 0.62% = 1.19 * drift from 1 ha field

Drift loadings in Step 4 stream scenario

- ***Similar drift loadings result for other crops:***

  arable crops = 1.19 * drift from 1 ha field
  vines / late = 1.12 * drift from 1 ha field
  pome / late = 1.13 * drift from 1 ha field

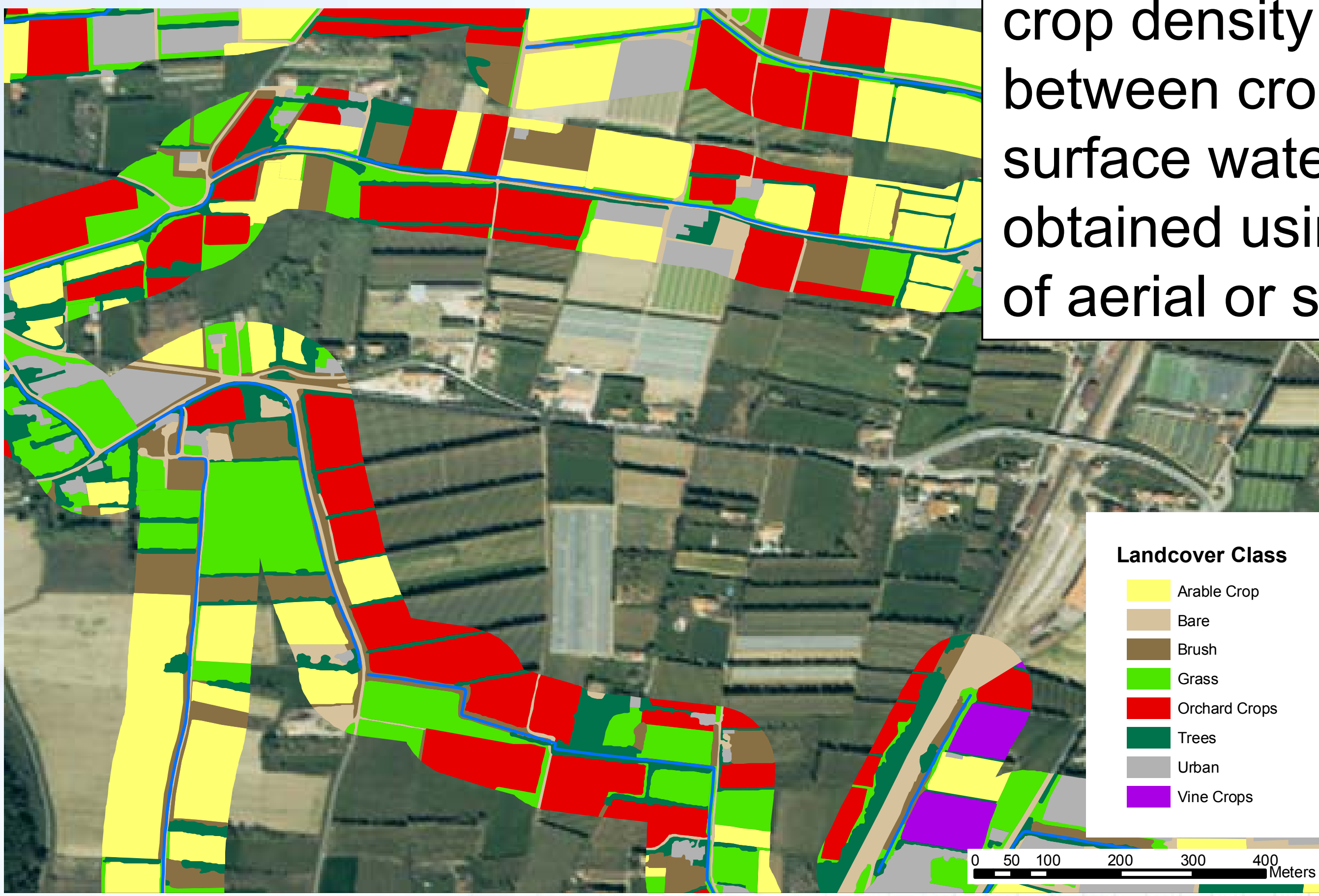
- ***Conclusion for drift***

  If runoff dominates, continue to use the current Step 3 factor of 1.2 to represent overall drift loading of surface water

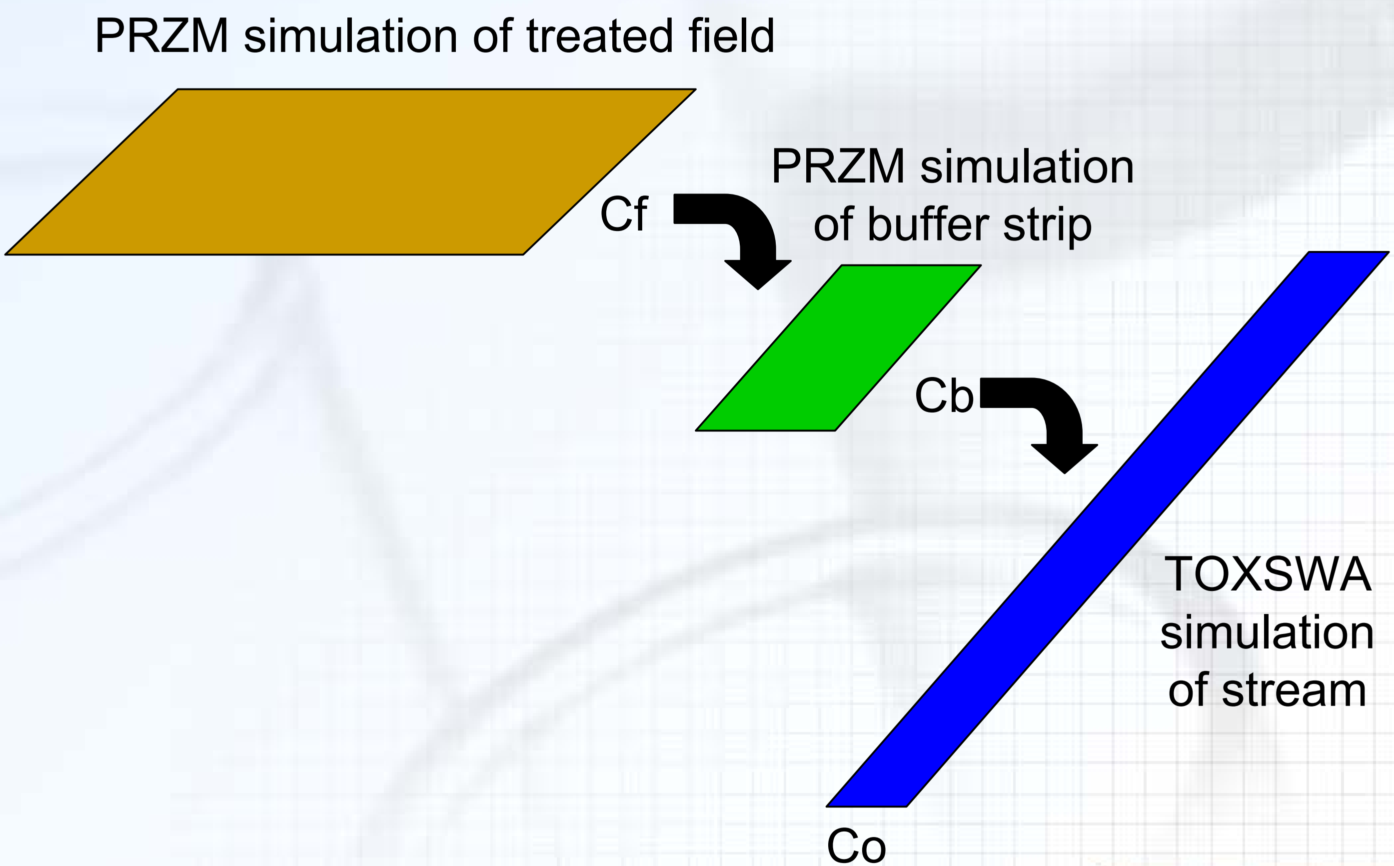
  If drift dominates, evaluate and use refined drift value for crop

Proximity analysis using GIS

Statistical evaluations of crop density and distances between crops and adjacent surface water can be obtained using GIS analyses of aerial or satellite imagery



Simulation of effect of buffer strips using PRZM



Example comparison of Step 3 and Step 4 stream scenarios

- ***For the limiting case where runoff and erosion dominate***

  Step 3: Cf = 10 ug/L
  Co = 2.1 ug/L (peak conc 4.8X lower than Cf)

  Step 4: Cf = 10 ug/L
  Cb = 7 ug/L (30% reduction for 5 m buffer)
  Co = 0.43 ug/L (peak conc 23X lower than Cf)

- ***For the limiting case where drift dominates***

  Step 3: Cf = 0 ug/L (negligible RO, ER, DR)
  Co = 1.5 ug/L (for example)

  Step 4: Cf = 0 ug/L (negligible RO, ER, DR)
  Co = 1.4 ug/L (if drift factor is 1.12 rather than 1.2)

Step 4 stream scenario: next steps

- ***Develop tables of mitigation factors as f(buffer width)***
  - PRZM to PRZM to TOXSWA runs
  - Literature data
  - Regulatory values
- ***Develop Step 4 stream routine for TOXSWA in SWASH***
  - calibrate TOXSWA for larger catchment
  - user will enter a series of field distances with appropriate mitigation factors
  - refined drift values are automatically determined
  - PRZM p2t file is automatically read and used with runoff mitigation factor and/or refined drift factor to calculate refined Step 4 stream concentration