How to deal with mixing zones for priority pollutant discharges?

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Water quality in Europe (UNEP, 2004; BMU, 2005):

- More money is spent on wastewater treatment than on flood protection, drinking water supply, and dredging
- Most East European countries with less economic power will not be able to reach the new EU standards
- still half of all european water bodies do not reach water quality aims of new Water framework directive (WFD)
- priority substance pollution mainly from point source discharges
- whom causes which pollution? / how to control?

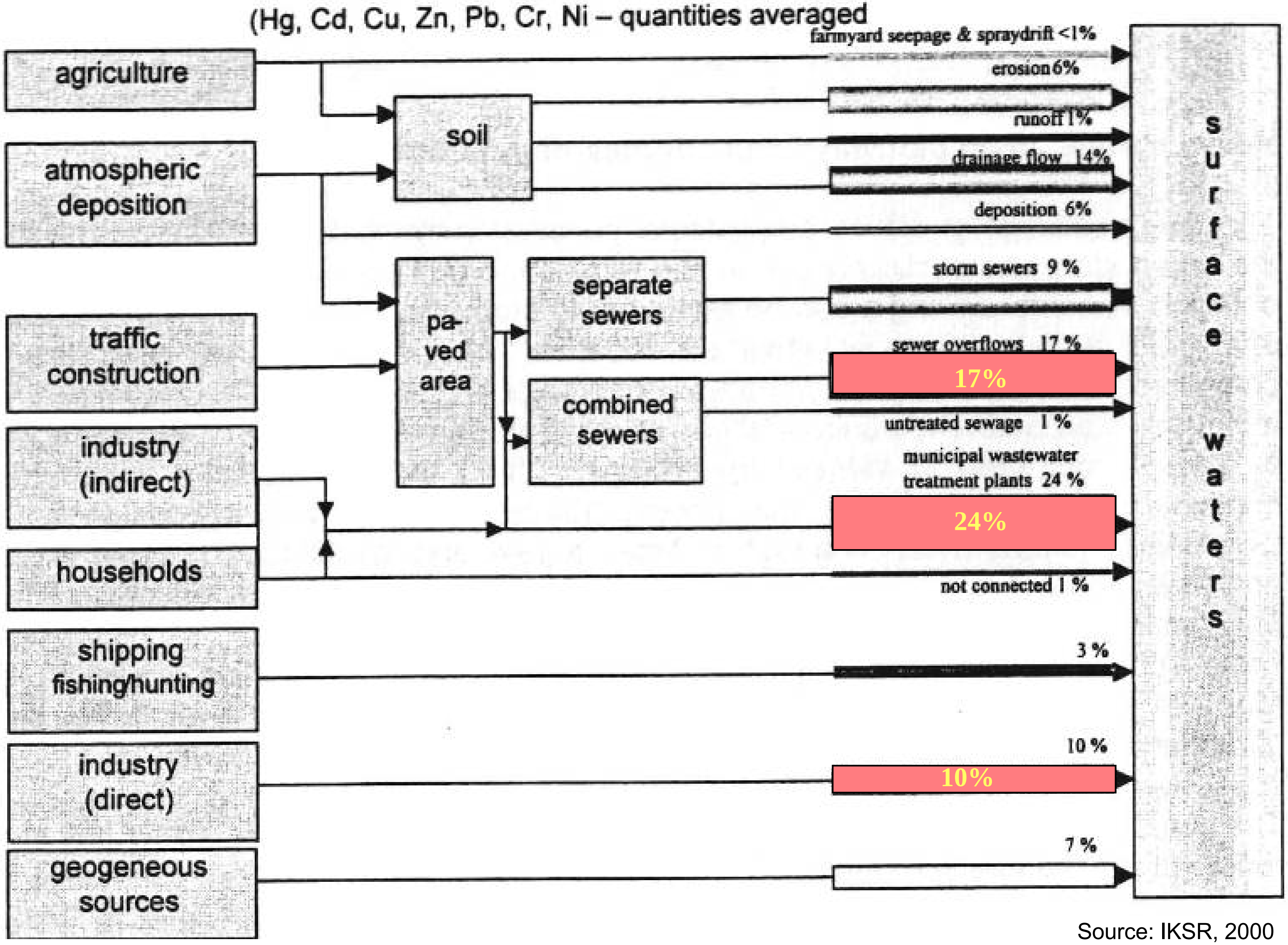
Abb. 5: Ergebnisse der Bestandsaufnahme für den guten Zustand der größeren Oberflächengewässer in Deutschland

Stand: Januar 2005
Weitere Informationen: Siehe Text und Anhang

Quelle: Daten aggregiert aus den Angaben der Länder
Kartengrundlage UBA, BKG

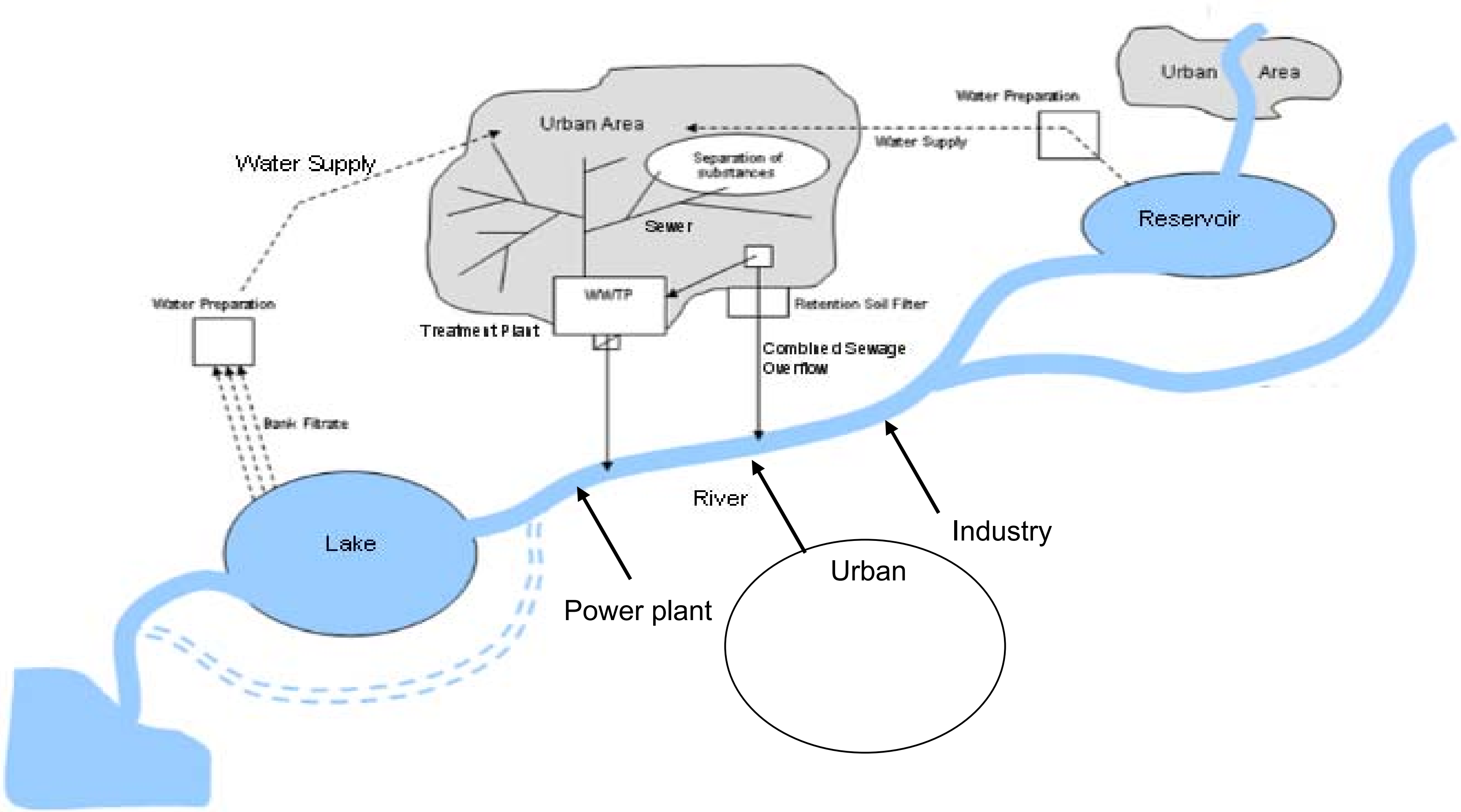
Illustration: point-source contributions

Heavy metals in the Rhine watershed

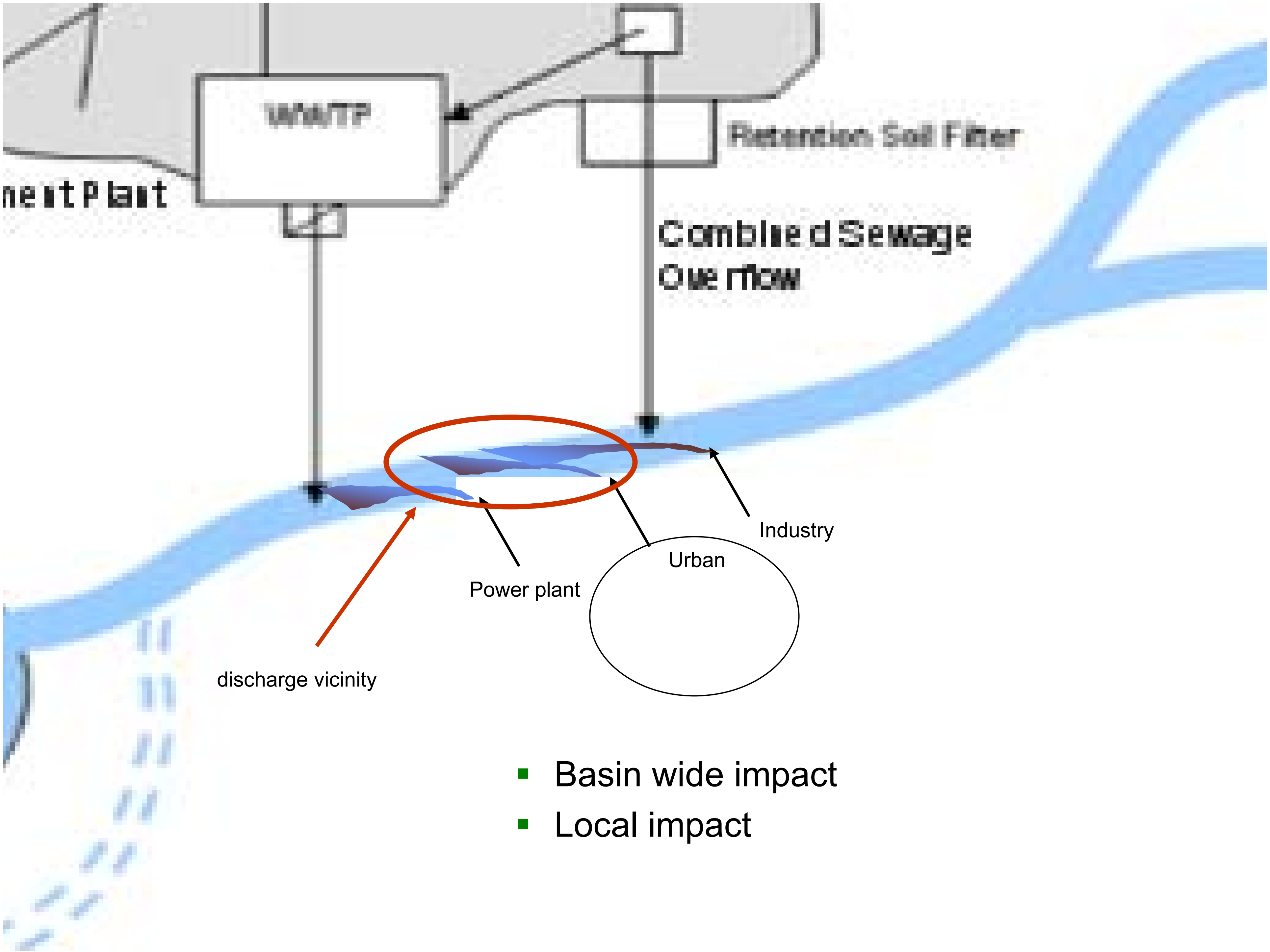


Source: IKSR, 2000

Aquatic Ecosystem - River Basin Management



- Basin wide impact
- Local impact
- optimal management needs to consider both



discharge vicinity

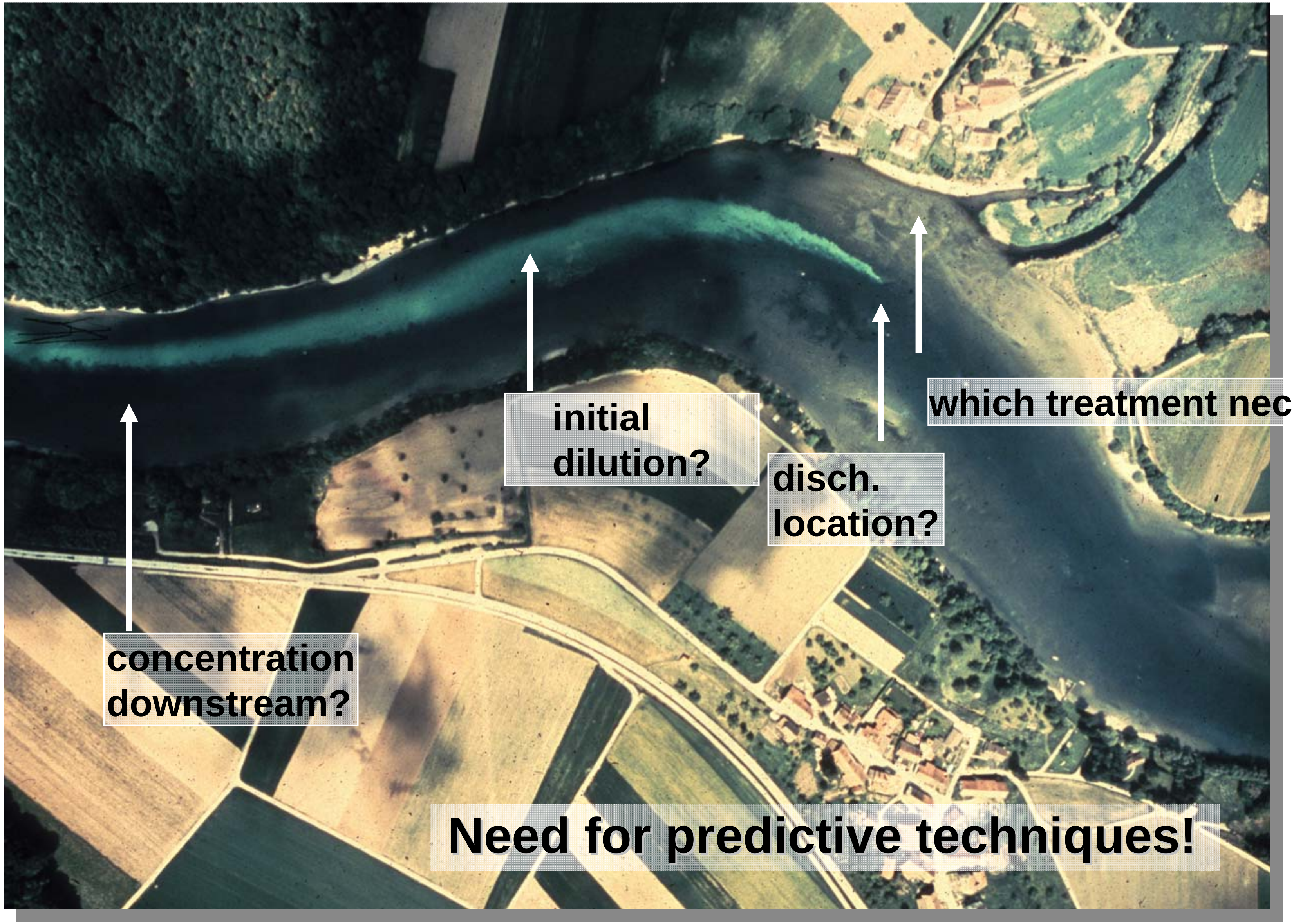
Power plant

Urban

Industry

- Basin wide impact
- Local impact

Point source discharges:



initial dilution?

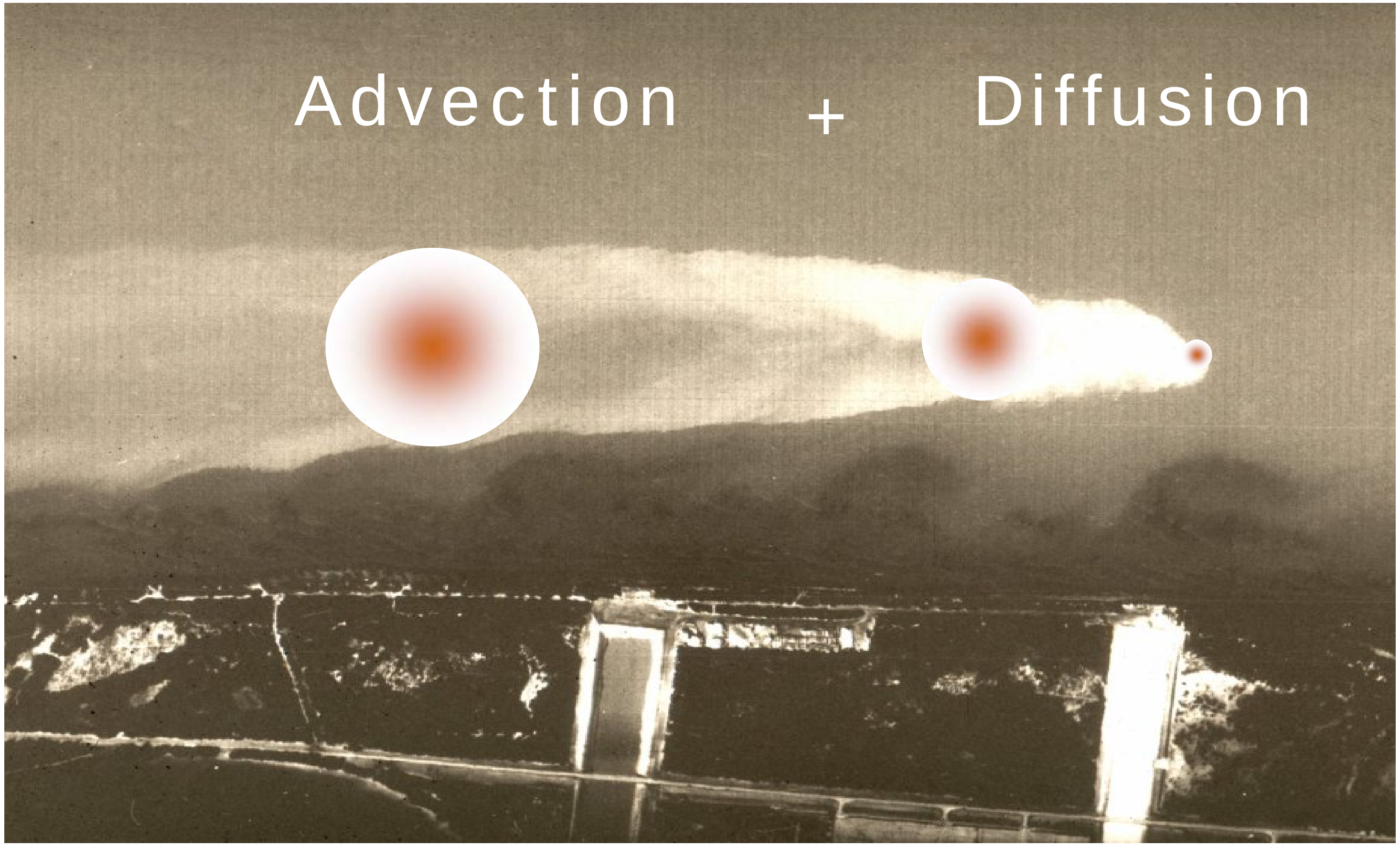
disch. location?

which treatment necessa

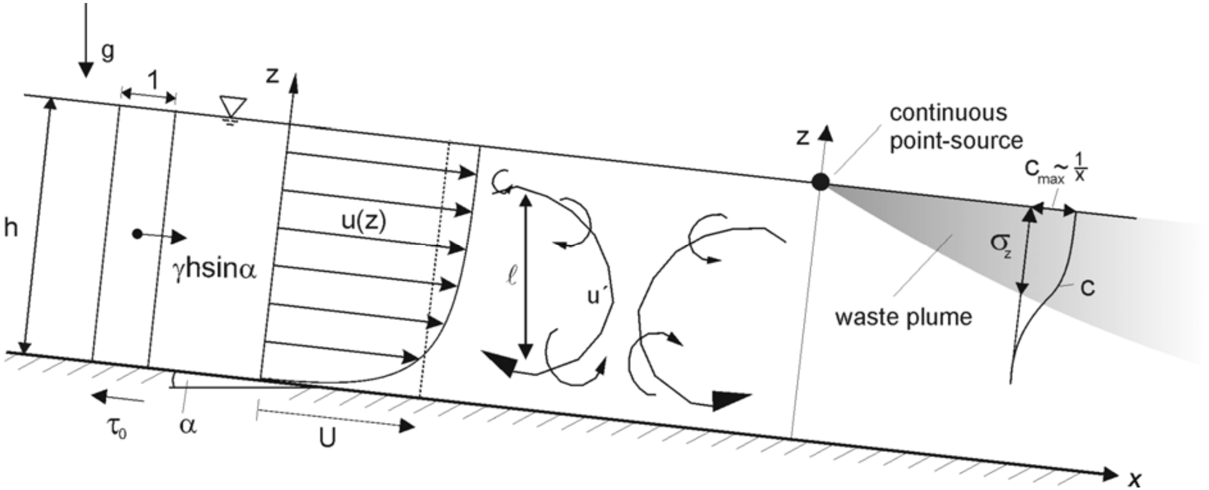
concentration downstream?

Need for predictive techniques!

Mixing processes: Advection and Diffusion



Vertical mixing (Advection + Diffusion)



- vertical Diffusivity: $E_z = \alpha_z u_* h$ $\alpha_z = 0{,}07$ +/- 50%
- vertical distribution: $\sigma_z = \sqrt{2E_z t} = \sqrt{2E_z \frac{x}{U}}$ **$t = \frac{x}{U}$ = „flowtime“ (Advection)**
- Vertical passive mixing (method-of-images)

Mixing if $\sigma_z \approx h$, then $x = x_{MV}$

$$x_{MV} \approx \frac{h^2U}{2E} = \frac{h^2U}{2(0{,}07u_*h)} \approx 70h$$

→ independent of velocity

→ morphology dominates!

0,10U

<u>Ex. 1:</u> Rhein near Karlsruhe

B = 250m, h = 3m, U = 3m/s

x_{MV} = 70x3 = 210m ~fast!

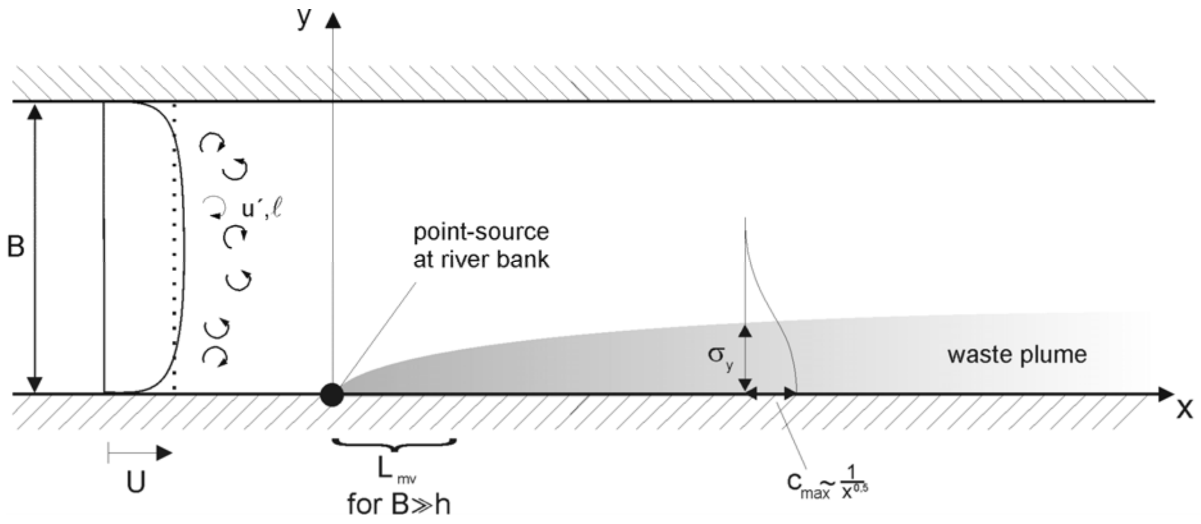
<u>Ex. 2:</u> Small river in Schwarzwald (Murg)

B = 5m, h = 0,5m

x_{MV} = 70x0,5 = 35m ~fast!

vertical mixing is fast process!

Lateral mixing (Advection + Diffusion)



- Horizontal Diffusivity: $E_y = \alpha_y u_* h$ $\alpha_z = 0{,}5$ +/- 50%
  moderate heterogeneities
- Horizontal distribution: $\sigma_y = \sqrt{2E_y \frac{x}{U}}$
- Horizontal mixing (river bank)

Lateral mixing if $\sigma_y \approx B$, $x = x_{ML}$

→ independent of velocity

→ morphology dominates!

$$x_{ML} \approx \frac{B^2U}{2E} = \frac{B^2U}{2(0{,}5u_*h)} \approx 10\frac{B^2}{h}$$

0,10U

<u>Ex. 1:</u> Rhein near Karlsruhe

$x_{ML} \approx 10x250^2/3$

$= 208.000m \approx 200km$ slow!

Ex. 2: small river in Schwarzwald (Murg)

$x_{ML} \approx 10x5^2/0{,}5$

$= 500m = 0{,}5km$

lateral mixing is slow process!

Example for complete mixing

Passive point source at water surface and river border

Example	B/h	Mixing lenghts	
		Vertical L_{mv}	Horizontal L_{mh}
A) Big river **B = 250 m, h = 3 m**	**≈ 80**	**210 m**	**208 000 m**
B) Small river **B = 5 m, h = 0,5 m**	**10**	**35 m**	**500 m**

↑ ≈ fast

↑ very slow!

- Discharge dynamics: “Active source”
- Heterogeneities: river curvature, constructions (bridges, sluices, power plants)
- Position: Middle of river cross section
- most effectiv: Diffuser

Example for mixing: field observations

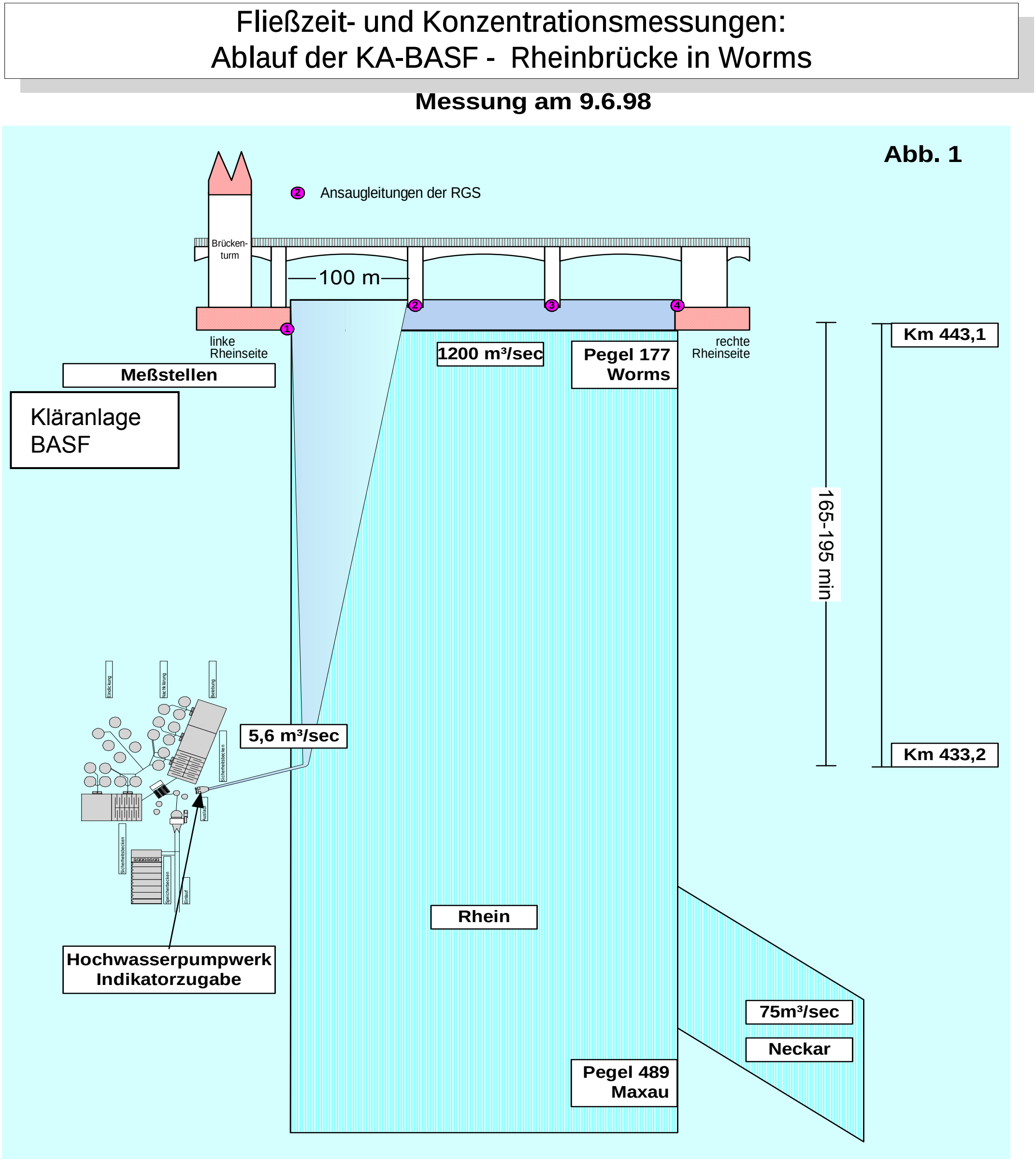
Example: plume monitoring

- **Rhein River**
- densly populated watershed (ca. 50 mio. inhabitants) and numerous large industrial facilities
- → municipal and industrial discharges and cooling water

- Natural habitat and cultural ressources, protected zones, drinking water supply, recreation
- → water quality of major importance

Landesamt für Wasserwirtschaft Rheinland-Pfalz, Fließgewässer-Informationssystem 1998

Example: plume monitoring



BASF WWTP:
km 433,2

Monitoring station:
10 km downstream
(km 443,1)

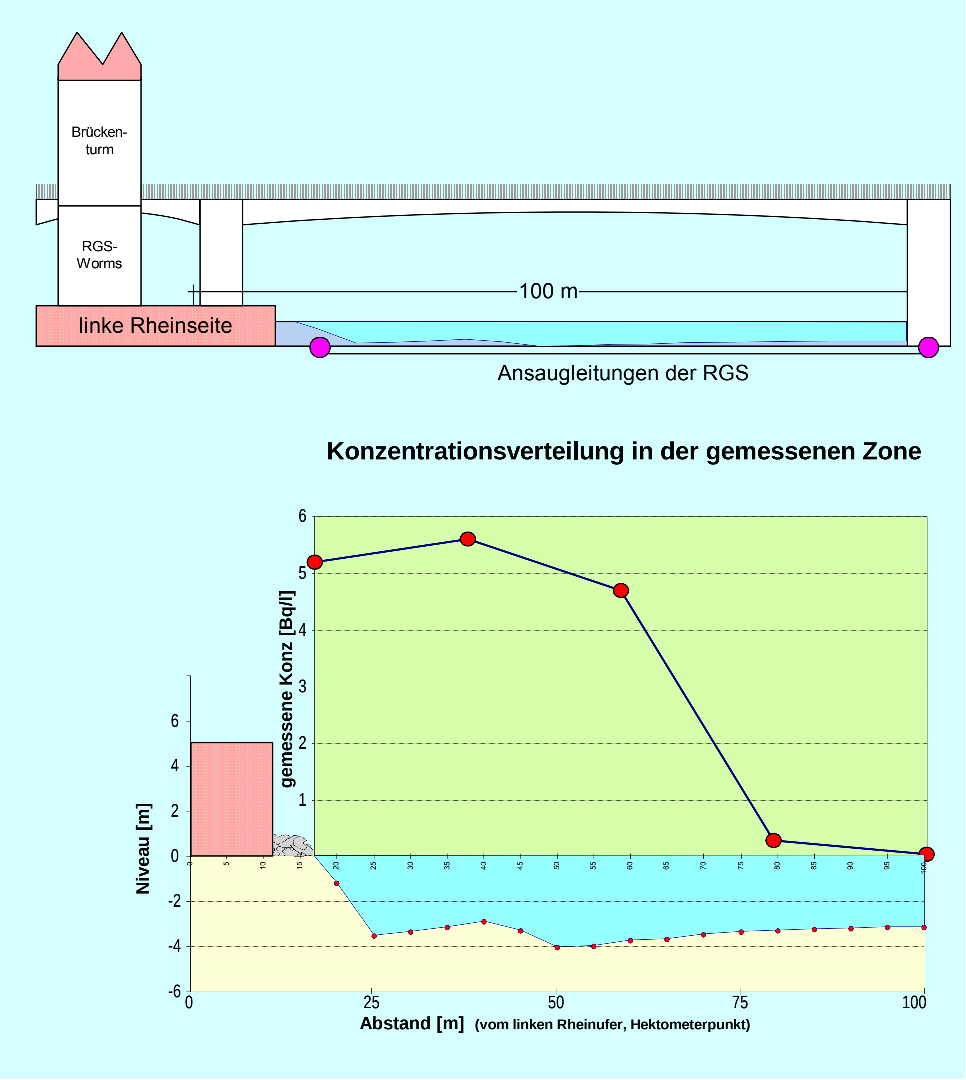
Estimated complete
lateral mixing:
60 km downstream
(km 490 (Mainz)) or more

Fahnenbildung durch
BASF-Kläranlagen-Ablauf
(Abbildung: BASF AG)

Example: plume monitoring

Fließzeit- und Konzentrationsmessungen vom Ablauf der KA-BASF bis zur Rheinbrücke in Worms

Messung am 9.6.98



River width: ca. 300 m

Plume width
10 km downstream WWTP:
ca. 50 m

Plume from
BASF-WWTP discharge
(Source: BASF AG)
Measurements: BASF in cooperation with
Rheingütestation Worms

EC-Water Framework Directive (WFD)

Goal:

- integrated (catchment or regional) water quality protection for all European waters
- Monitoring until 2005
- Management plans until 2009
- Realization of management plans until 2012
- good quality status by year 2015
  - biological parameters (such as flora and fauna)
    - hydromorphological characteristics (such as flow and substrate conditions)
    - physico-chemical quality components (such as temperature, oxygen or nutrient conditions)
  - specific pollutants (such as metals or synthetic organic compounds).

Approach

New strategies for point source reduction (municipal, industrial):

- „Combined approach“:
  - Emission limit values (ELV)
  - Environmental quality standards (EQS)
- Pollutant releases must meet both requirements
  - new practice for EU countries
  - compromise solution, but significant improvement

ELV - EQS

ELV (effluent standard)

- \+ direct source reduction: mass flux or concentration limit
- \+ easy to monitor (end-of-pipe sampling)
- \- no consideration of WQ response of water body (assimilative capacity)
- \- no ecosystems responsibility for discharger

EQS (ambient standard)

- \+ consider WQ response due to discharge
- \+ makes discharger aware of WQ response
- \- difficult to monitor
- \- needs predictive models

Consequences for Combined Approach

ELV and EQS – values:

- EU directives
- National directives

- e.g. Chemical pollutants:

Pollutant	Emission limit value ELV	Environmental quality standard EQS	$\frac{\mathrm{ELV}}{\mathrm{EQS}}$
Cadmium	**0,5 mg/l (83/513/EEC)**	**1 μg/l (76/464/EEC)**	**500**
Trichlorethane	**0,1 mg/l (AbwV, 2000)**	**10 μg/l (76/464/EEC)**	**10**

↑ acute effects

↑ chronic effects

↑ dilution requirement 5 to 1000

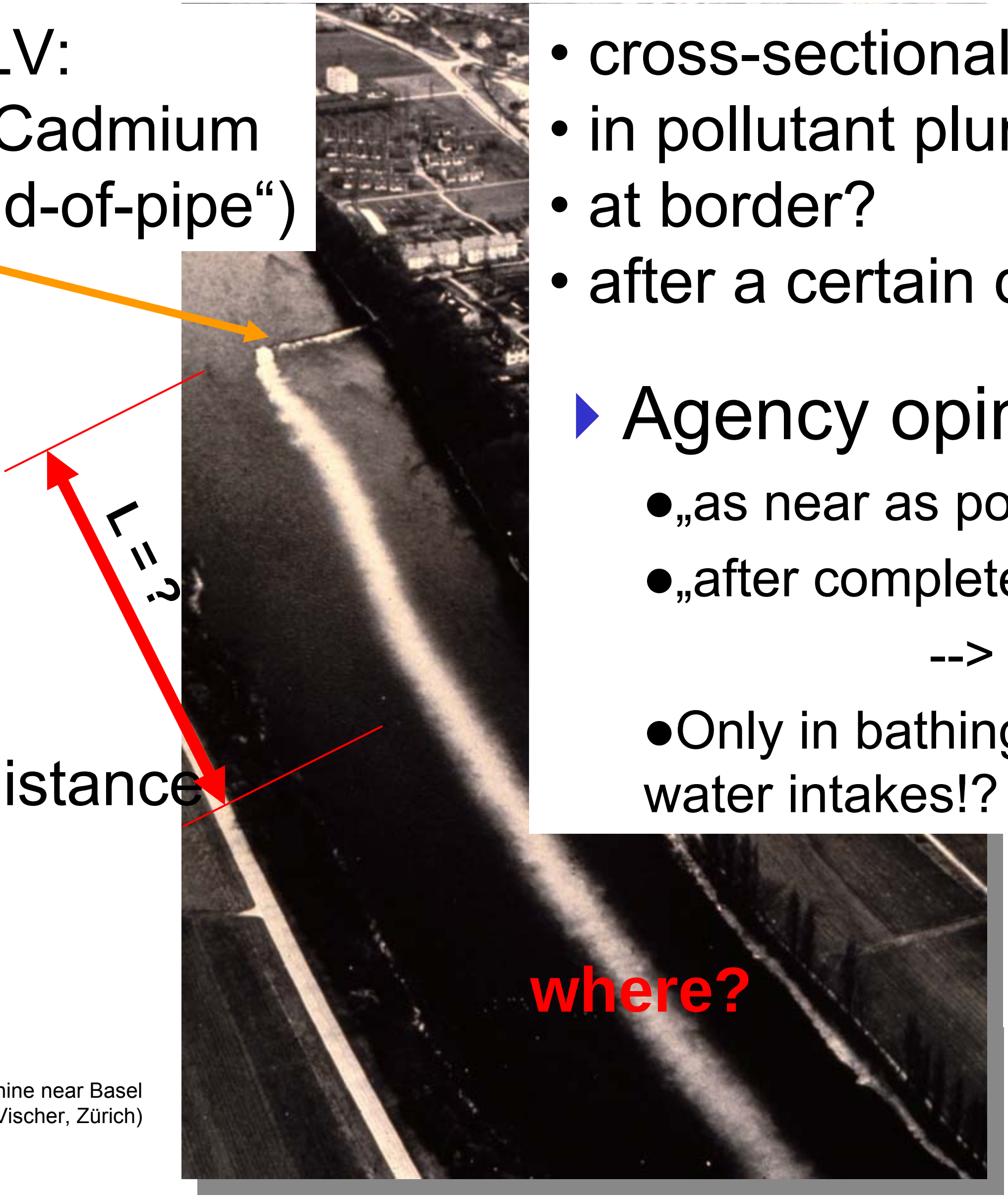
Consequences for Combined Approach

ELV:
0,5 mg/l Cadmium
(WFD: „end-of-pipe“)

- cross-sectional average?
- in pollutant plume?
- at border?
- after a certain distance?

▸ Agency opinions:

- „as near as possible“ !?
- „after completet mixing“!?
  --> sacrification?
- Only in bathing waters or at drinking water intakes!?



e.g.: Distance

Aerial photograph of Rhine near Basel
(ca. 1960, courtesy D. Vischer, Zürich)

EQS:
1µg/l Cadmium
(WFD: ?)

Consequences for Combined Approach

2001: WFD critizised, recommended amendment:

- Accept and explicitly state “mixing zone” concept (Jirka, et al, 2003)

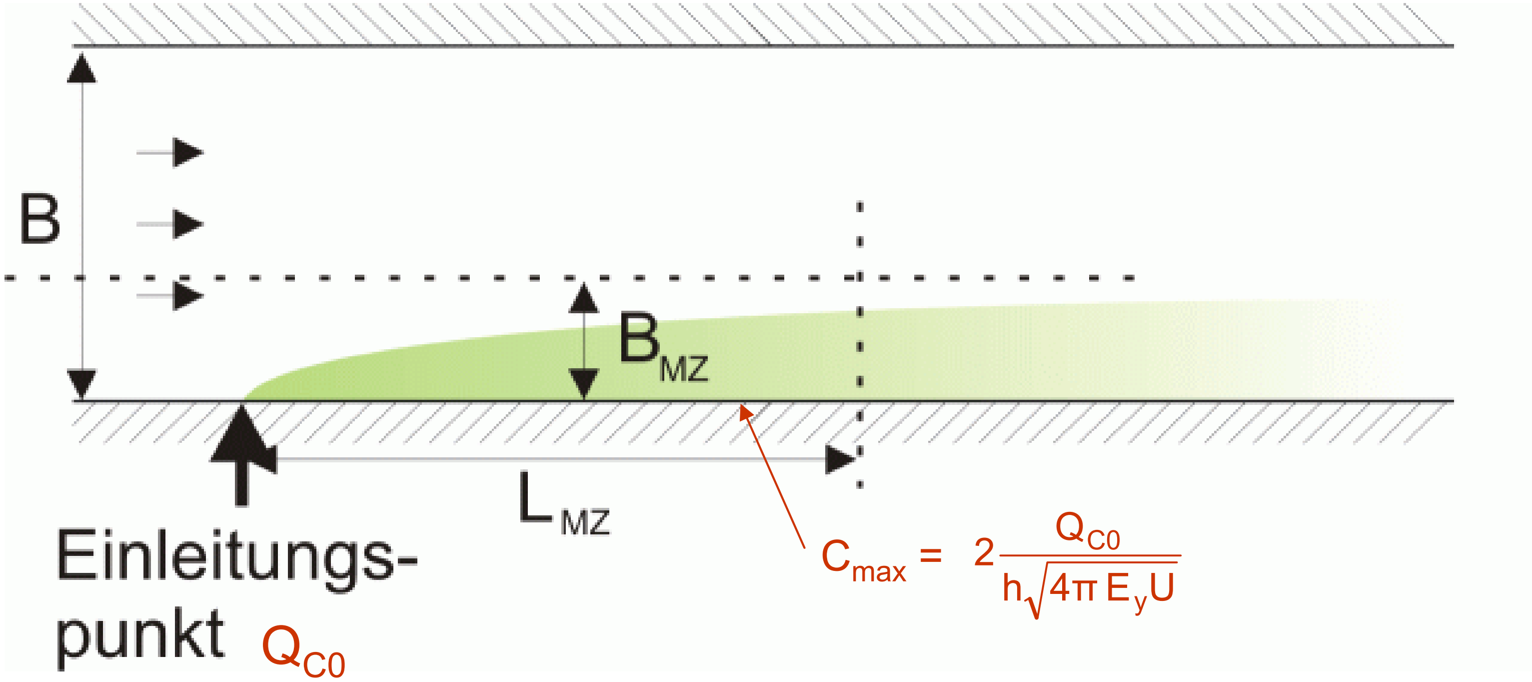
2008: Amendment of WFD (2008/105/EC):

- Article 4, (1): *"Member States may designate mixing zones adjacent to points of discharge. Concentrations of one or more substances listed in Part A of Annex I may exceed the relevant EQS within such mixing zones if they do not affect the compliance of the rest of the body of surface water with those standards"*

Now: Implementation until 2010!

- include approaches and methodologies in river basin management plants to apply and control such zones
  - Define water bodies, where mixing zones need to be defined
  - Define mixing zone:
    - regarding receiving water body qualities
    - regarding discharged effluent
    - restricted to proximity of discharge
  - Develop mixing zone regulation and technical guidelines:
    - how to monitor, predict and assess?
    - mitigation measures in case of non-compliance

Example for mixing zone concept



$$C_{max} = 2\frac{Q_{C0}}{h\sqrt{4\pi E_y U}}$$

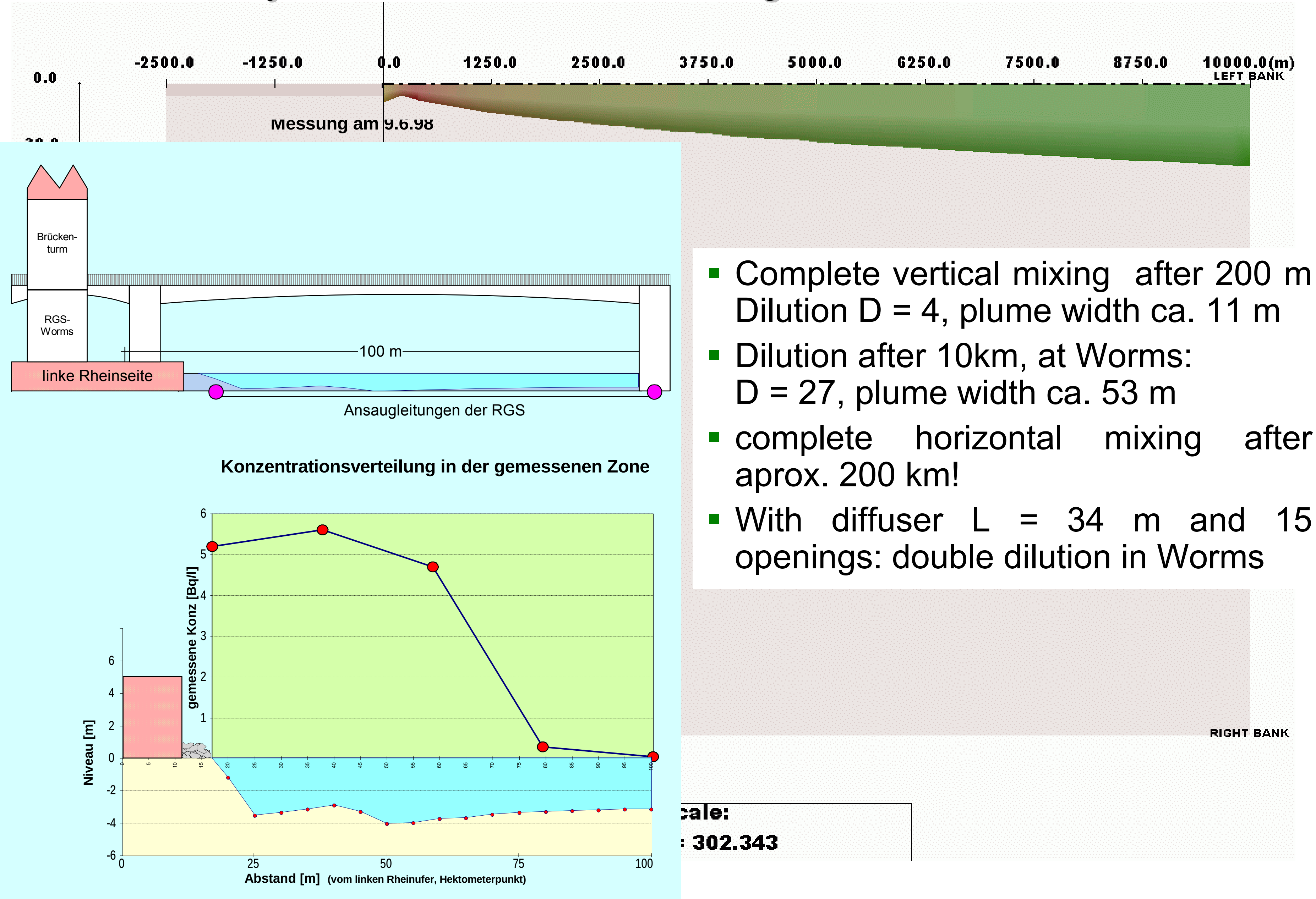
- width limitation e.g. B_{MZ} = (0,2 to 0,5)B
- length limitation e.g. L_{MZ} = (1 to 5)B
- combinations

Consequences for Combined Approach

Increased application of modelling techniques supporting measurements and for new discharge permits

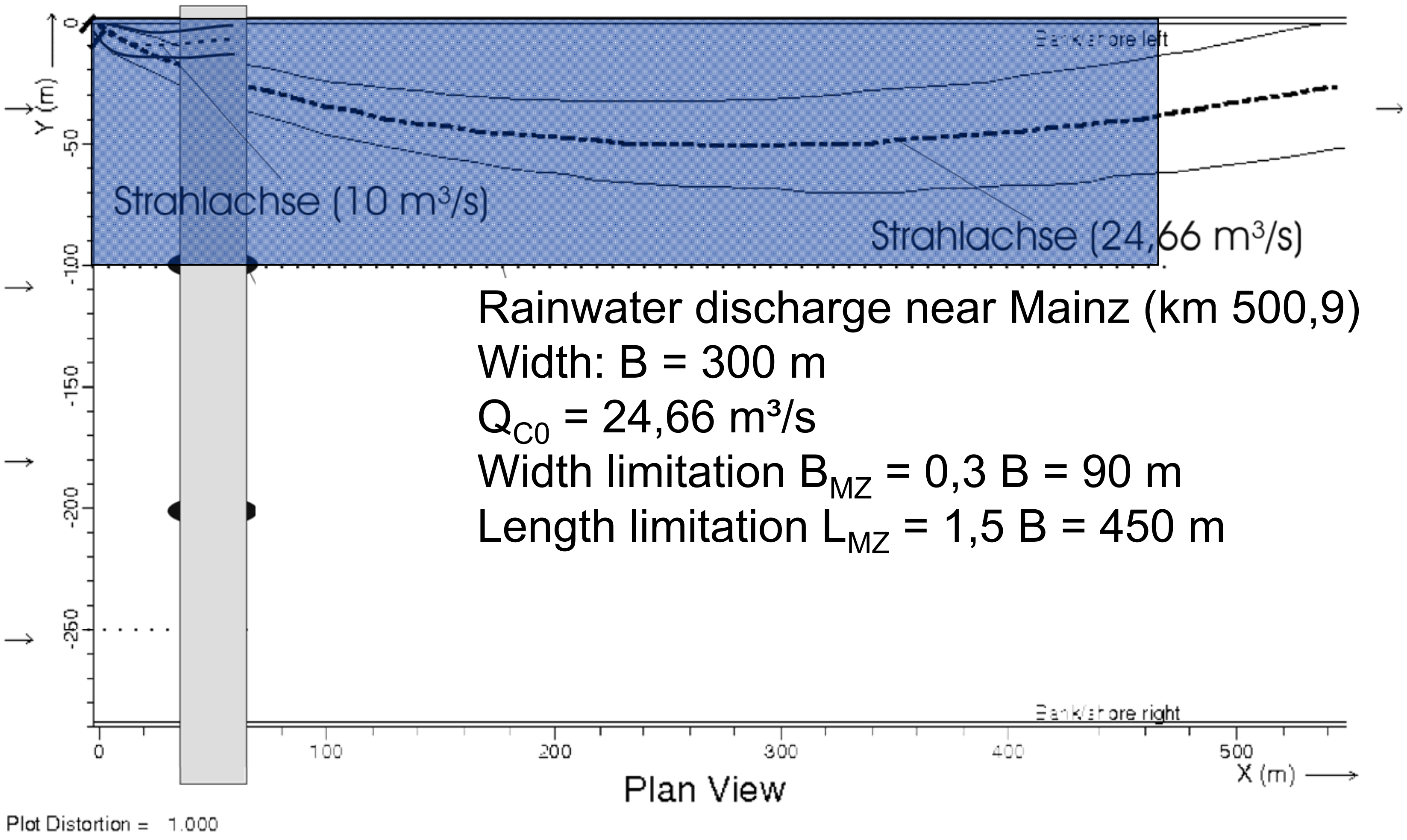
1) **Mixing zone models**:
    - discharge control → reduce concentrations
    - high spatial detail (i.e. 3D)
    - steady flow conditions
    - simple mass kinetics
    - clear limits of applicability (e.g. to single source only)
    - expert systems preferable, e.g. CORMIX (www.cormix.de / www.cormix.info)
2) **Full system models: General WQ models**
    - river wq control → reduce loads
    - basin wide assessment, long distances, low spatial detail (i.e. 1D)
    - unsteady conditions, larger temporal scales
    - complex pollutant kinetics (modeling water quality parameters)
    - multiple sources
        - e.g. AVG (ATV-DVWK)
        - BWK Merkblatt 3 (BWK)
        - QUAL-2 (USEPA)
        - RWQM1 (IWA)

Case study: industrial discharge into Rhein



- Complete vertical mixing after 200 m Dilution D = 4, plume width ca. 11 m
- Dilution after 10km, at Worms: D = 27, plume width ca. 53 m
- complete horizontal mixing after aprox. 200 km!
- With diffuser L = 34 m and 15 openings: double dilution in Worms

Case study Mainz (Rhein): CORMIX calcluations



Rainwater discharge near Mainz (km 500,9)

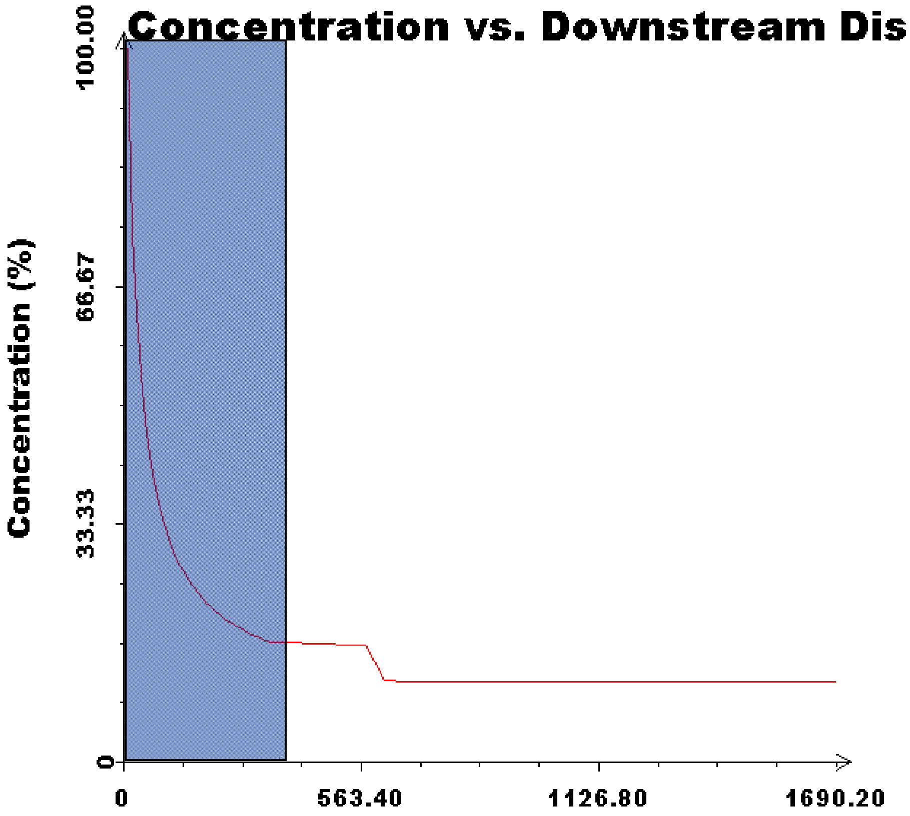
Width: B = 300 m

Q_{C0} = 24,66 m³/s

Width limitation B_{MZ} = 0,3 B = 90 m

Length limitation L_{MZ} = 1,5 B = 450 m

Case study Mainz (Rhein): CORMIX calcluations



$$C_{max} = 2\frac{Q_{C0}}{h\sqrt{4\pi\,E_y U x}}$$

CORMIX calculation
= ca. 15% of Q_{co} after 450

simple equation model
= ca. 4 % of Q_{C0} after 450m

Further problems

- hydrological / climatic extreme conditions (dry periods)
- Mining disposal in Germany: Weser receives ca. 100 kg Chlorid/s
- Combined sewer overflows (untreated drainage to river)
- Cooling water discharges during dry periods: shut down power plant or special permission?
- Mixing processes are more complicated for lakes/reservoirs/coastal waters

Conclusions

- Point sources are major pressure for surface waters regarding chemical pollutants (i.e. priority substances)
- Mixing processes are slow and need long distances
- Immission oriented regulations need mixing zone definition
- Need for predictive technologies (modeling) in water quality management
- Clear decision making process necessary for design and control
- Advantages:
    - better understanding of receiving water response
    - better allocation of investments regarding water quality impact
    - improved designs for discharge installations (choice of discharge location, use of special discharge devices)

Ressources

- CORMIX: **www.CORMIX.info**
- Research at University Karlsruhe: **www.IFH.uni-karlsruhe.de**
- International Committee: IAHR / IWA Committee on Marine Outfall Systems: **http://outfalls.ifh.uni-karlsruhe.de**
- **International Conference:** Marine Waste Water Discharges and Coastal Environment: **www.mwwd.org**
- **Publications:**
    - **Jirka, G.H., T. Bleninger, R. Burrows & T. Larsen, 2004, "Management of point source discharges into rivers: where do environmental quality standards in the new EC-water framework directive apply?" Journal of River Basin Management, Vol. 2, Issue 1, 2004, www.jrbm.net**
    - **Bleninger T., Hauschild I., Jirka G. H., Leonhard D., Schlenkhoff., 2004, "Immissionsorientierte Bewertung von Einleitungen in Gewässer: Mischzonen oder Opferstrecken, wo gelten die Gütekriterien?“, KA - Abwasser, Abfall, 51.Jahrgang, Nr.3, March 2004; Wasserwirtschaft, 94.Jahrgang, Nr.4, April 2004**
    - **Jirka G. H., Bleninger T., Burrows R., and Larsen T., 2004, “Environmental Quality Standards in the EC-Water Framework Directive: Consequences for Water Pollution Control for Point Sources”, European Water Management Online (EWMO), 26/01/04**

Thanks for your attention