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Federal Waterways Engineering
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Tracing gravel in the German Upper Rhine using radio acoustic transmitters

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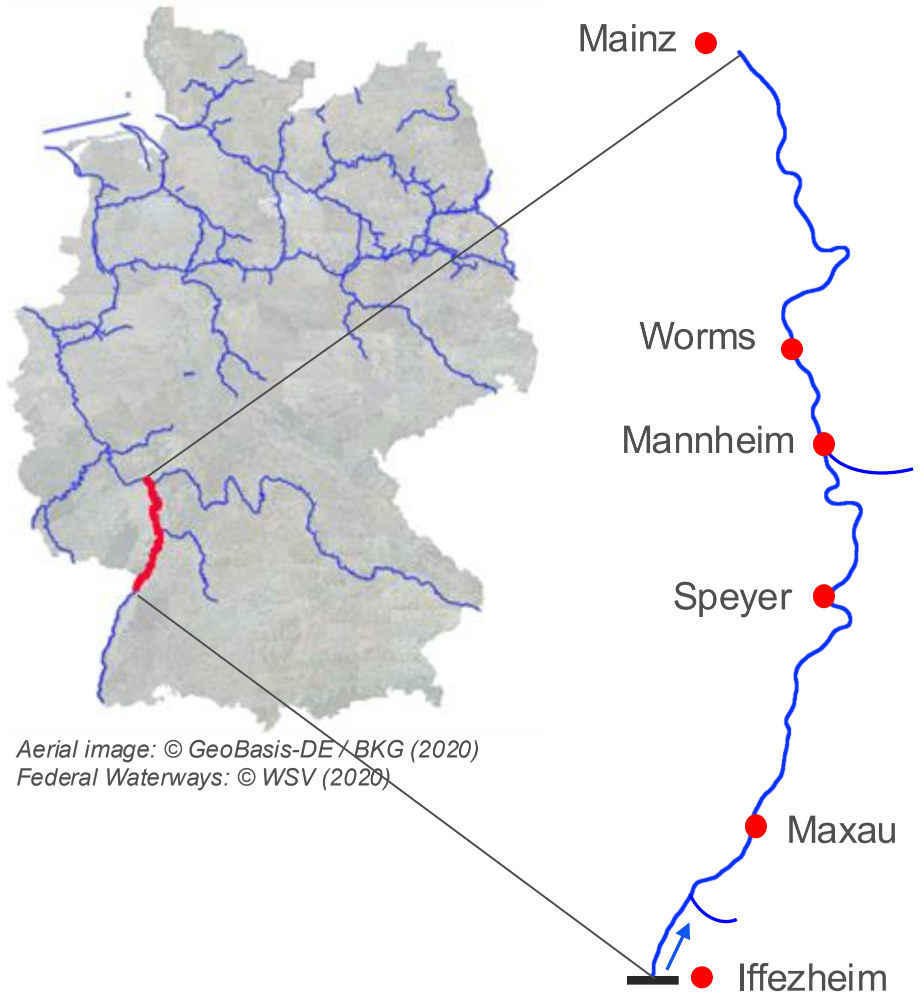
Background and motivation

- Free-flowing German Upper Rhine downstream of Iffezheim barrage



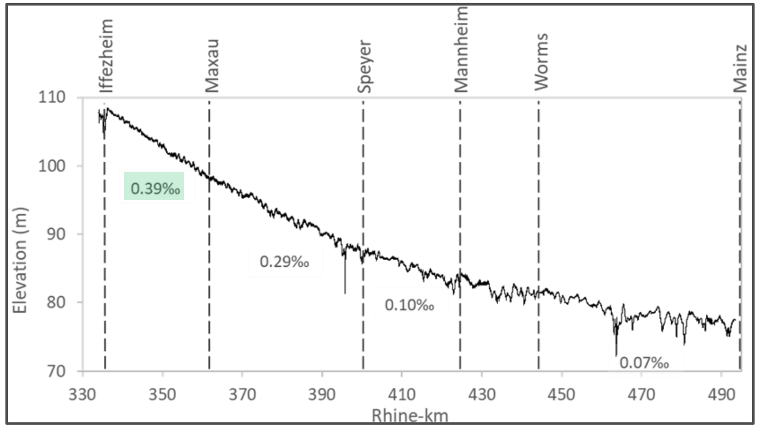
Aerial image: © GeoBasis-DE / BKG (2020)
Federal Waterways: © WSV (2020)

Background and motivation

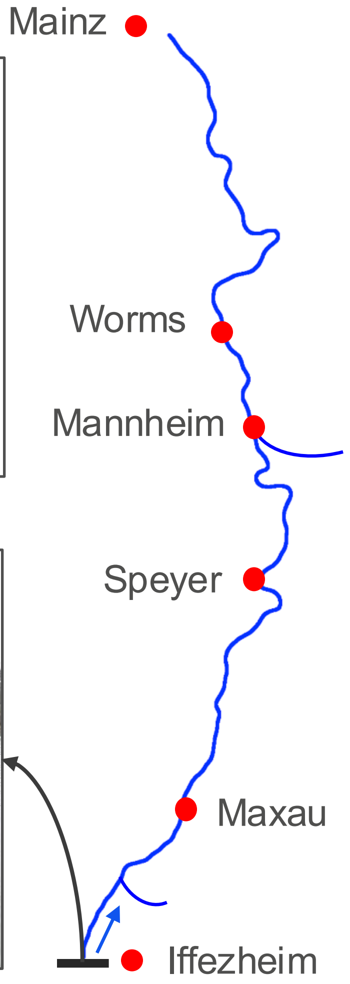
- Free-flowing German Upper Rhine downstream of Iffezheim barrage
- Gradient: ~0.4‰
- Bed load nourishment since 1978 (~180,000 m^3/yr)
  - Grain sizes: 2 – 63 mm
- Challenges:
  - Significant bed erosion after flood events
  - Localised dredging required downstream due to aggradation
- Focus of investigations:
  - Bed load dynamics downstream of Iffezheim barrage
    - Incipient motion
    - Transport velocities, distances and pathways

→ Efficiency monitoring of bed load nourishment

→ Input parameters for bed load transport models




Bed load nourishment: © WSV



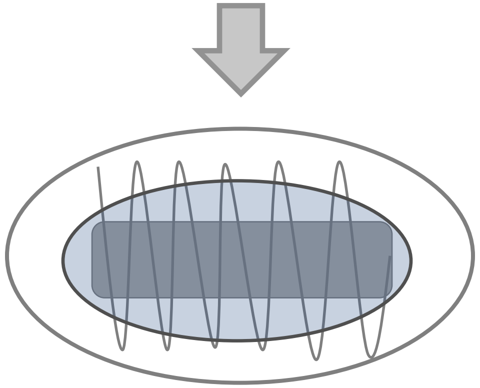
Tracer production

- The transmitters:
  - Active transmitters used in fish monitoring (~4.5 x 1.0 cm and larger)
  - Individual ID's
  - Lifespan up to several years

- The tracer stones:
  - Artificial stones made from epoxy-based mass and lead balls
  - Antenna embedded inside the stone

→ Tracing of individual particles

→ Identification of relevant sediment transport parameters



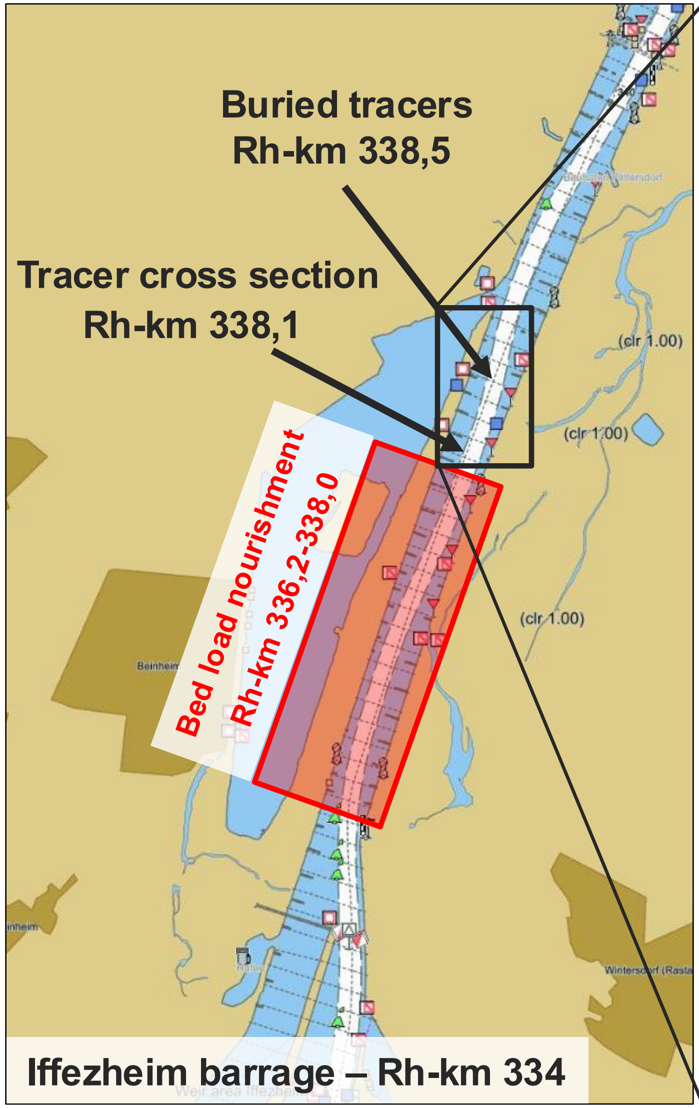
Study area

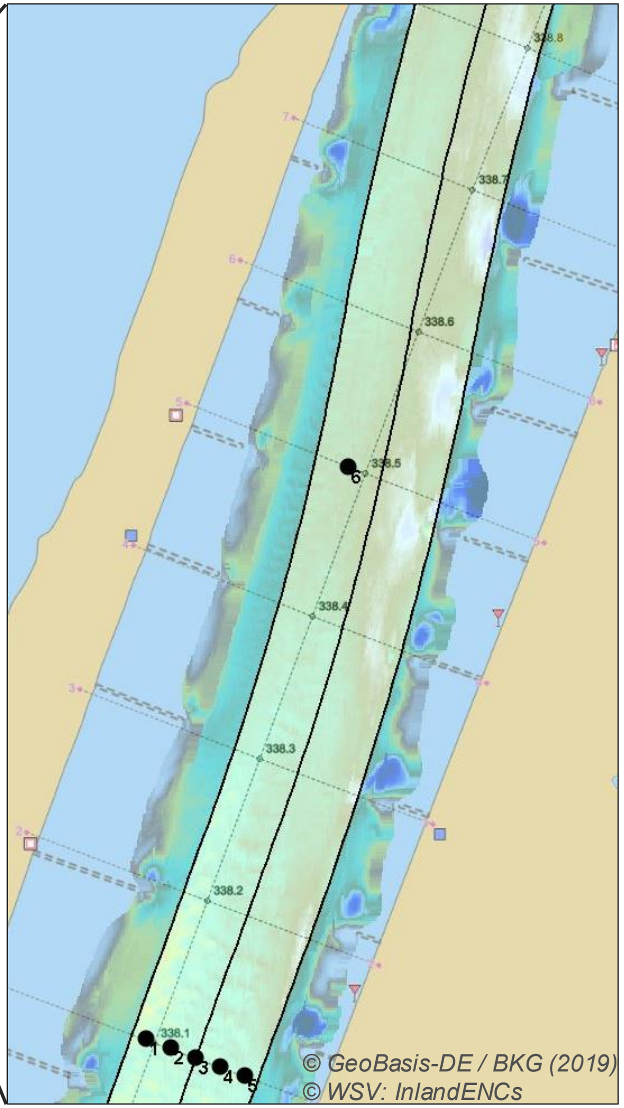
Surface:

- 2 x d_{50} (24 mm)
- 10 x d_m (27,5 mm)
- 8 x d_{90} (49,7 mm)
- 2 x d_{99} (67,3 mm)

Buried:

- 4 x d_{90}
- Depths:
  - 20, 30, 40, 55 cm





The big moment!

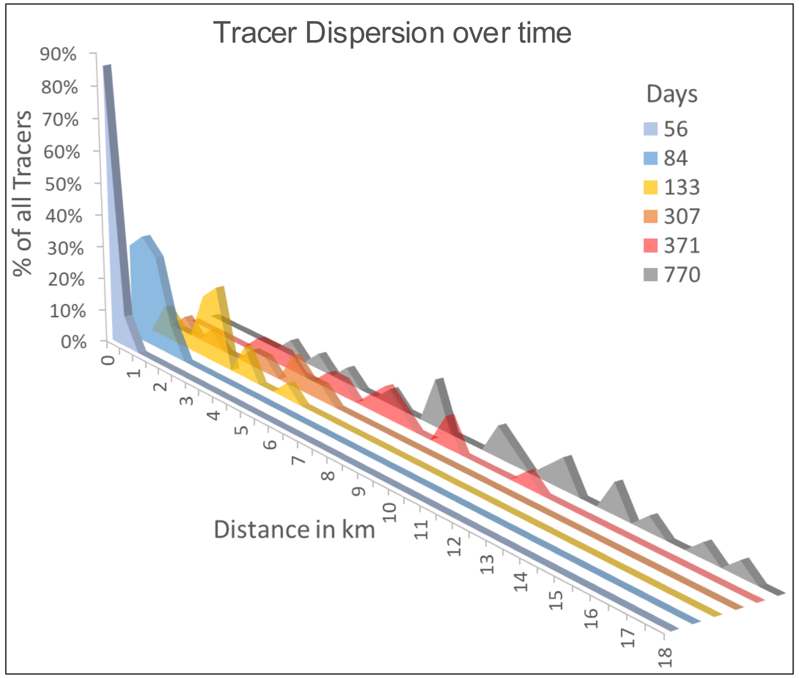
Detection method

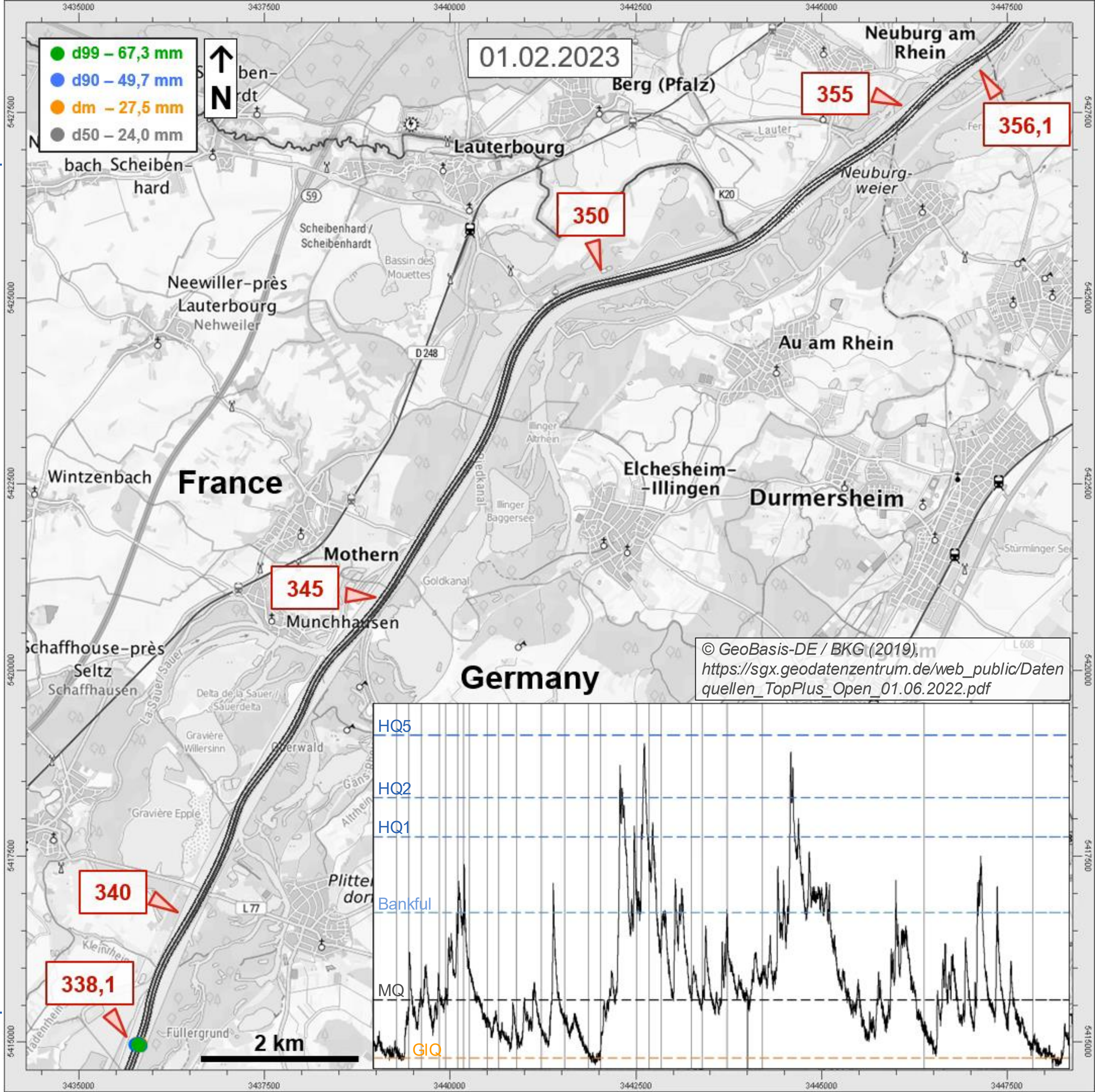
www.lotek.com

- 1st year: roughly fortnightly measurements
- From 2nd year: discharge dependent

Results – Tracer movement

1) Water-level dependent detection success
2) Discharge-dependent incipient motion
3) Discharge dependent and grain-size specific transport velocities
4) Grain-size dependent transport distance



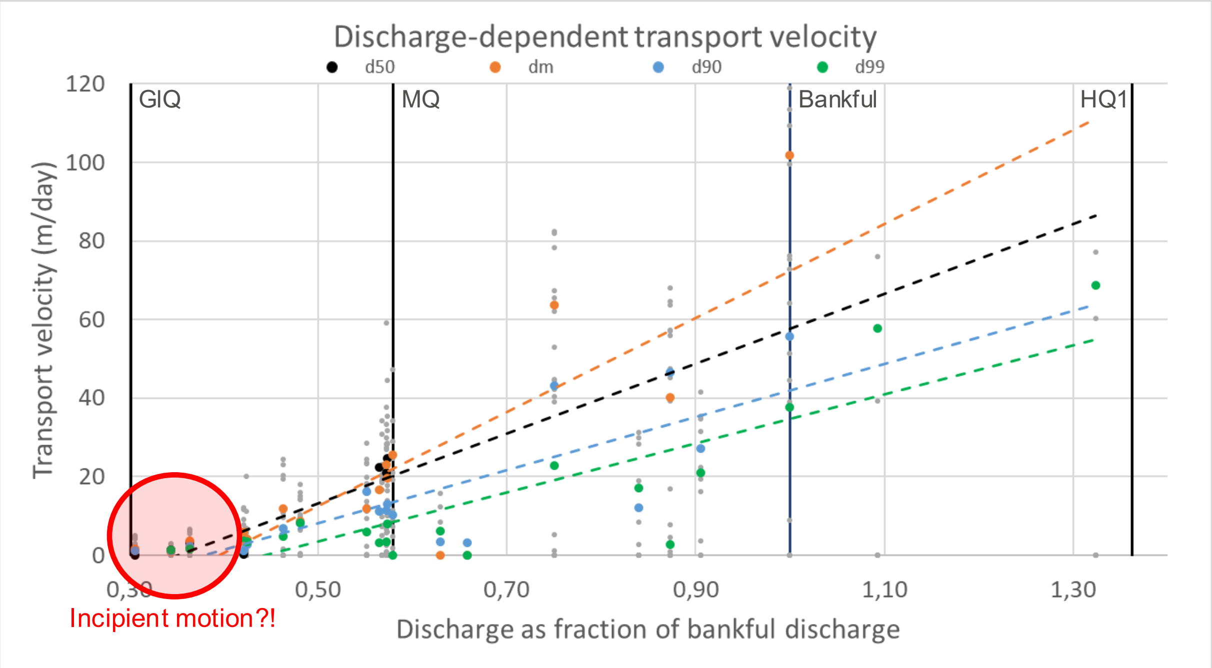


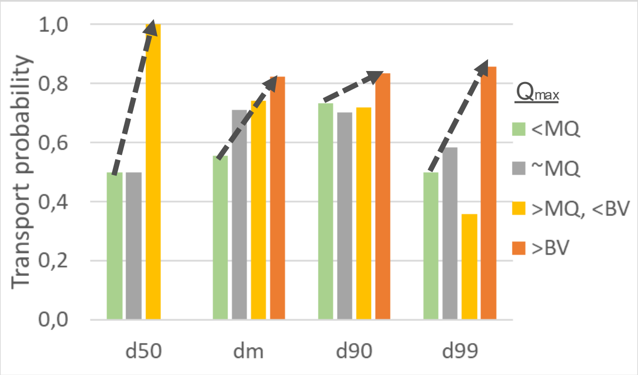
Results – Detection rates

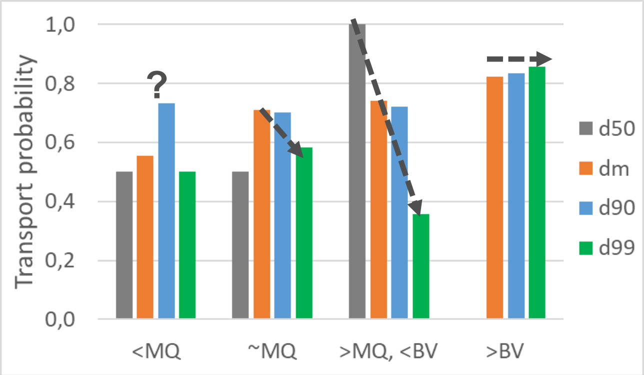
- Water-level dependent
- Tracer-size dependent
  - d_{99} – 100% (always detected)
  - d_{90} – 86% (difficult detection >6 m depth)
  - d_m – 60% (difficult detection >5 m depth)
  - d_{50} – 46% (lost since 10/2023)

  → Average detection rate ~75%
- Increasing dispersion, potential deep burial and potentially exceeded life-span reduce detection success

Results – Transport velocities and incipient motion



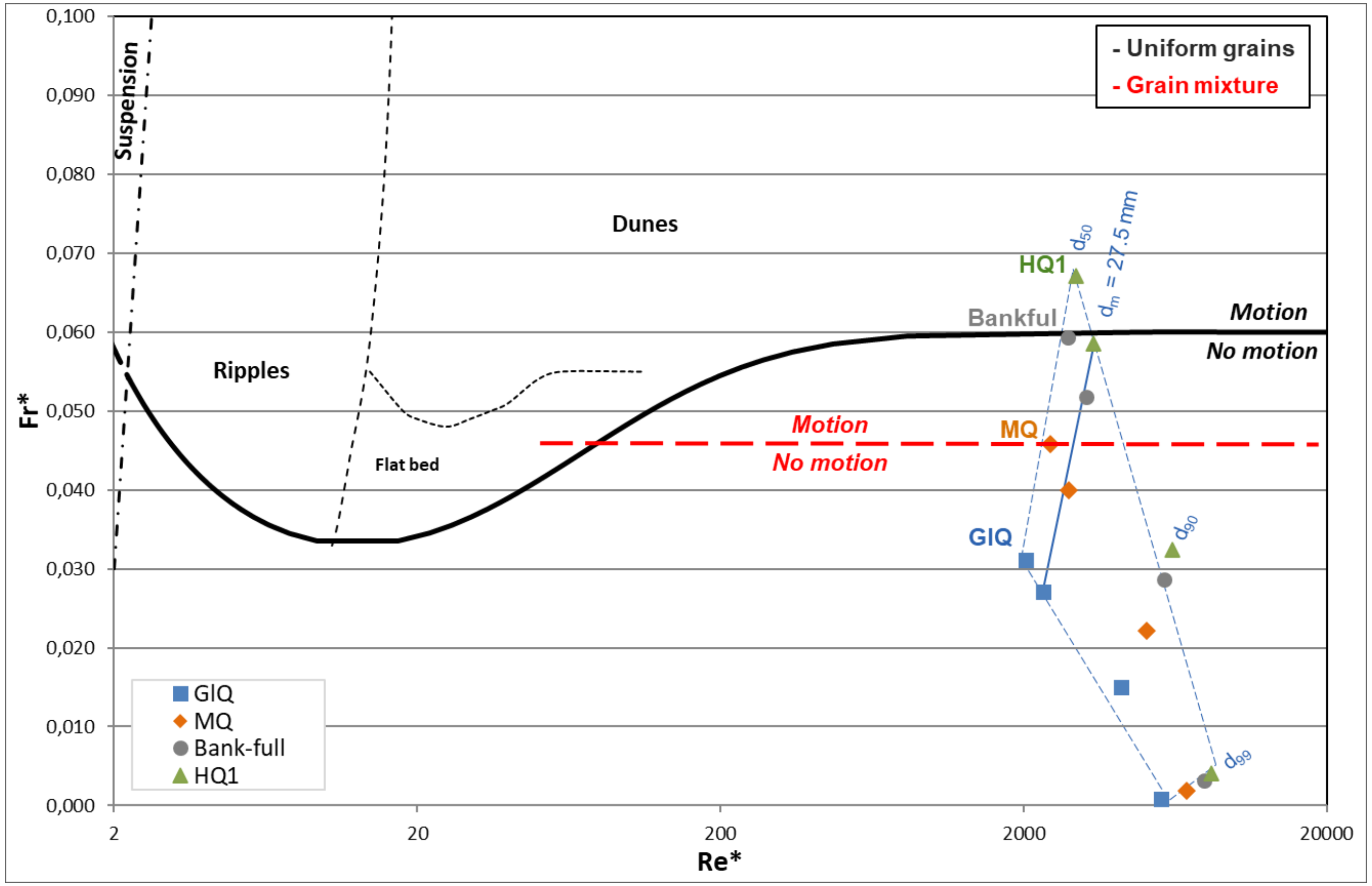


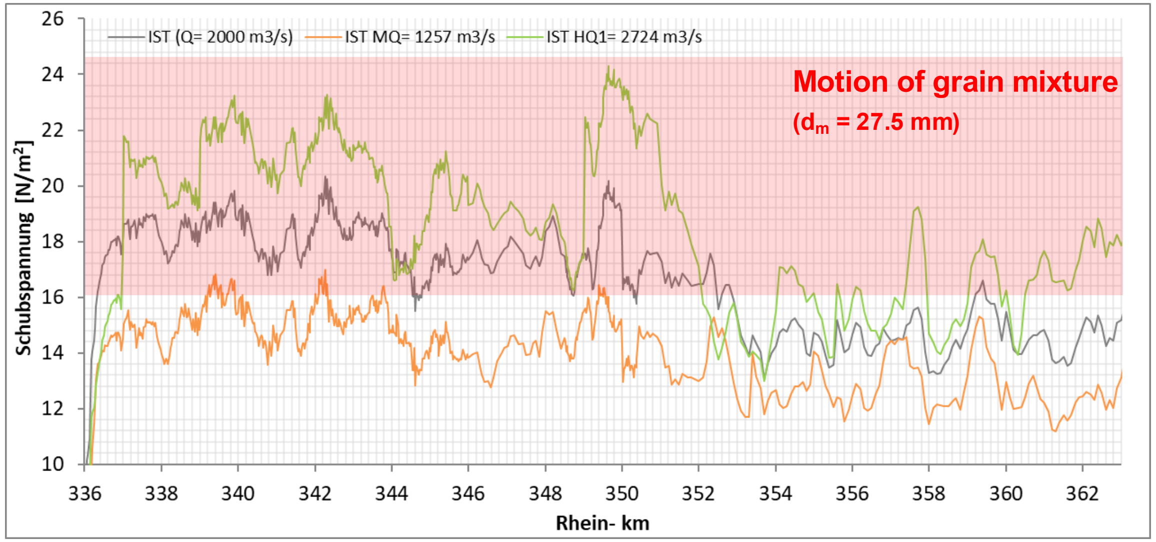


- Increasing transport probability with increasing maximum discharge!
- Decreasing transport probability with increasing grain size?
  - Inconsistent trends

- Transport velocities are dependent on discharge and tracer size
- Incipient motion occurs between GlQ and half-MQ

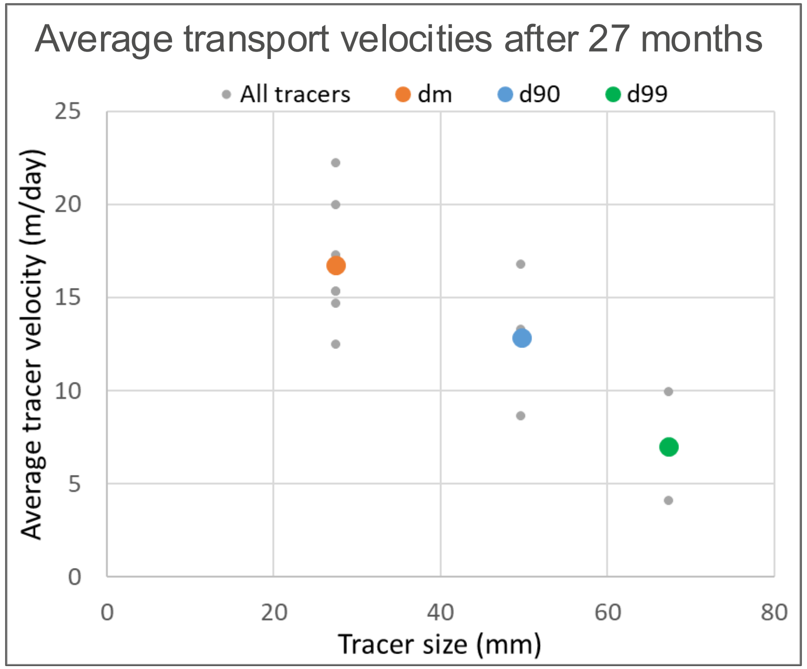
Results – Transport velocities and incipient motion



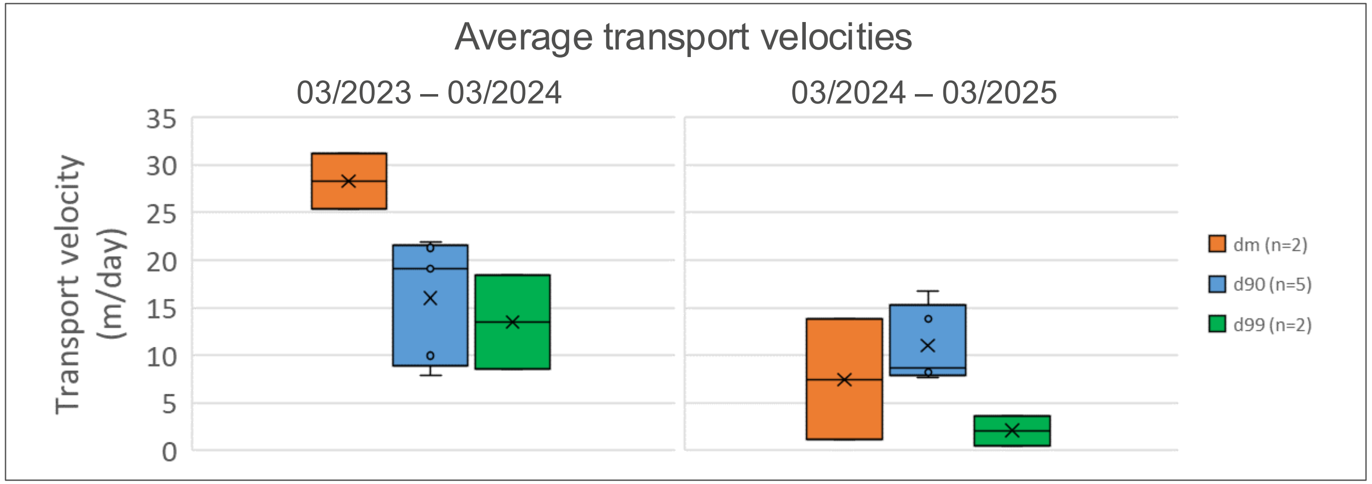


- Theoretical incipient motion above MQ

Results – Average transport velocities

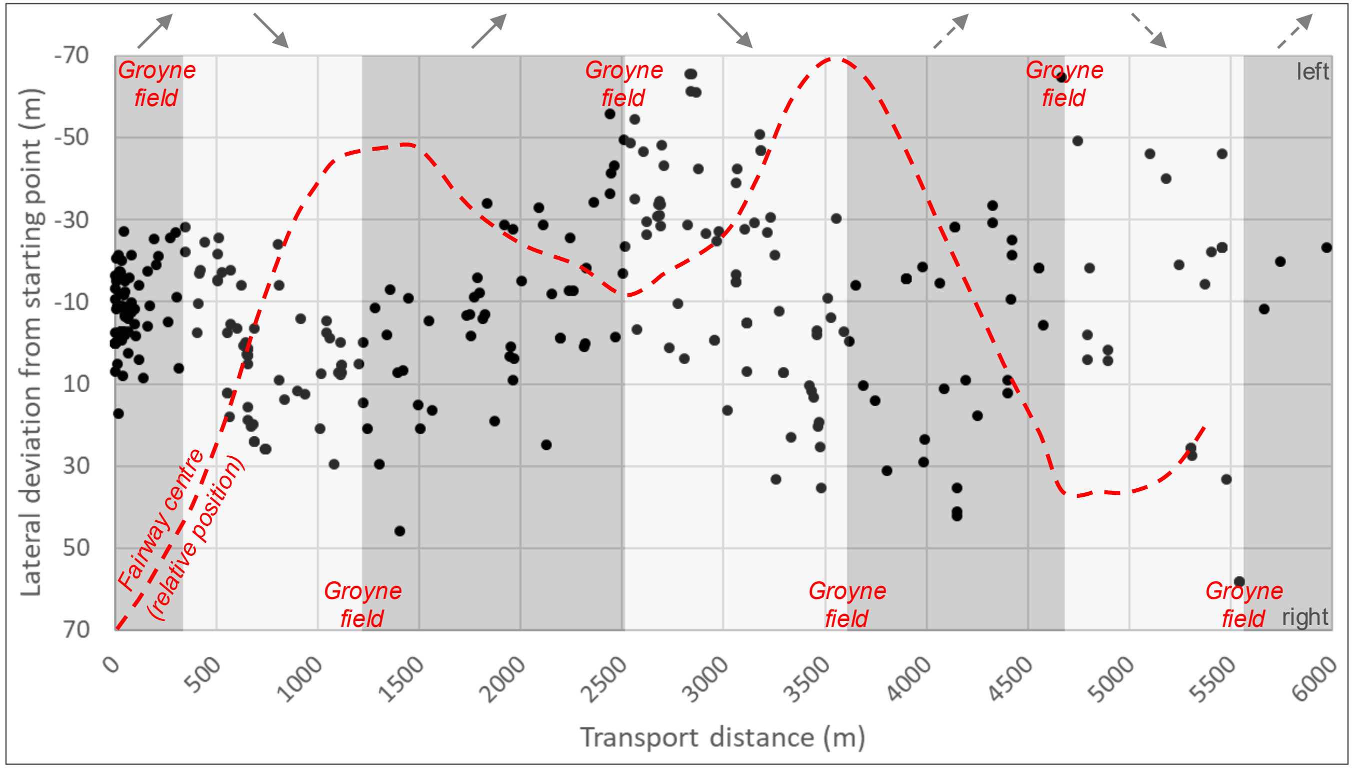


- Grain-size dependent transport rates
  - Mean: 7 – 17 m/day
  - Max: 10 – 22 m/day

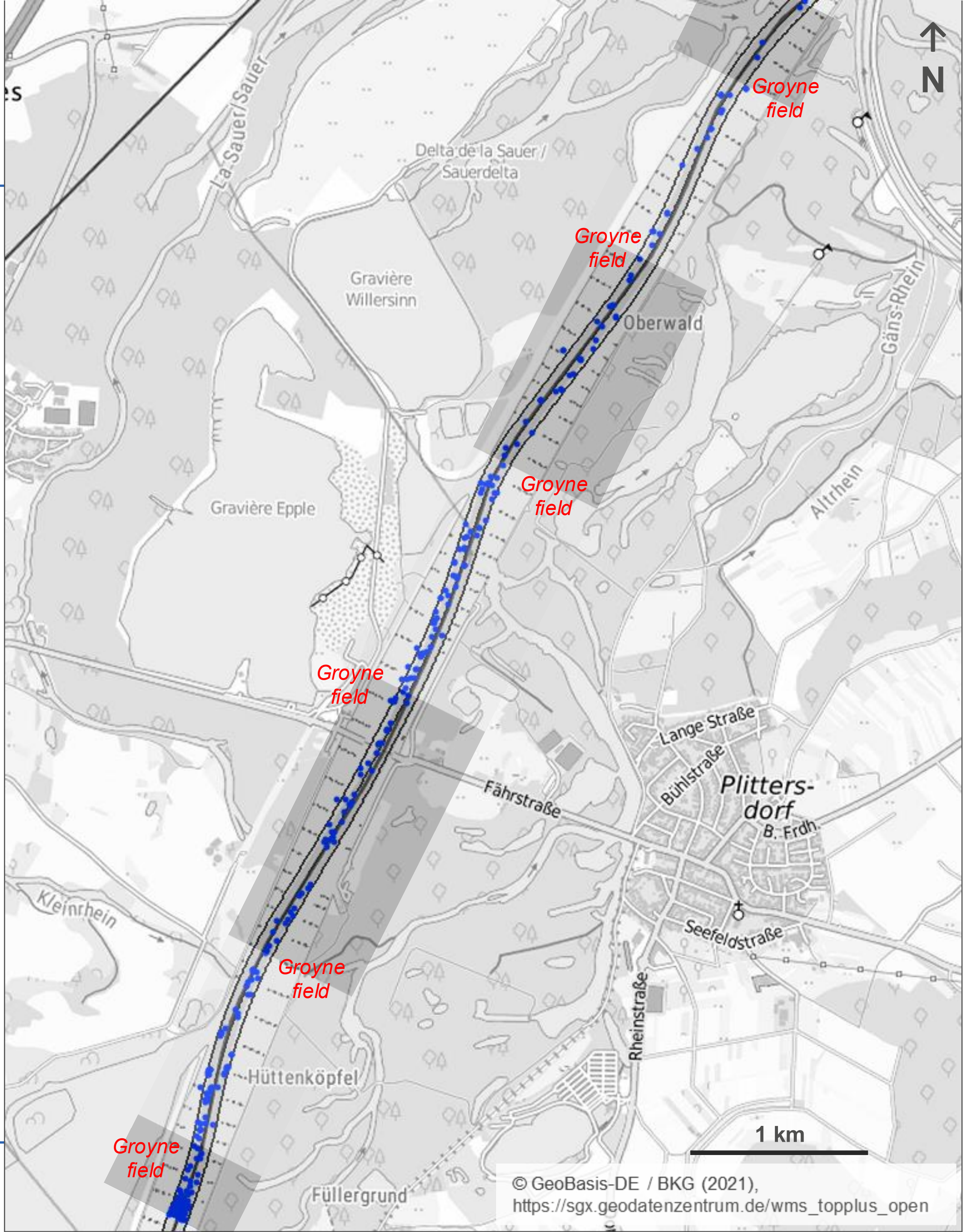


- Tracers slow down over time!
- Possible reasons:
  1) Downstream-decreasing transport capacity
     – Longitudinal slope of the river bed decreases slightly
  2) Potential partial burial → slower transport rates than at the bed surface
  3) Slightly higher and longer peak discharges (> HQ1) during the first year

Results – Tracer pathways



- Alternating tracer movement towards point bars

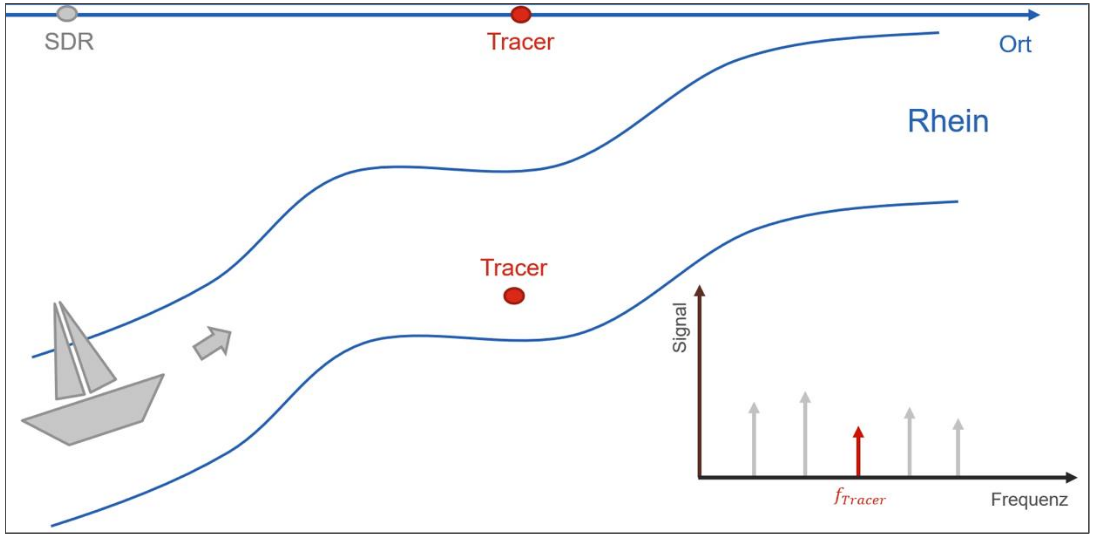


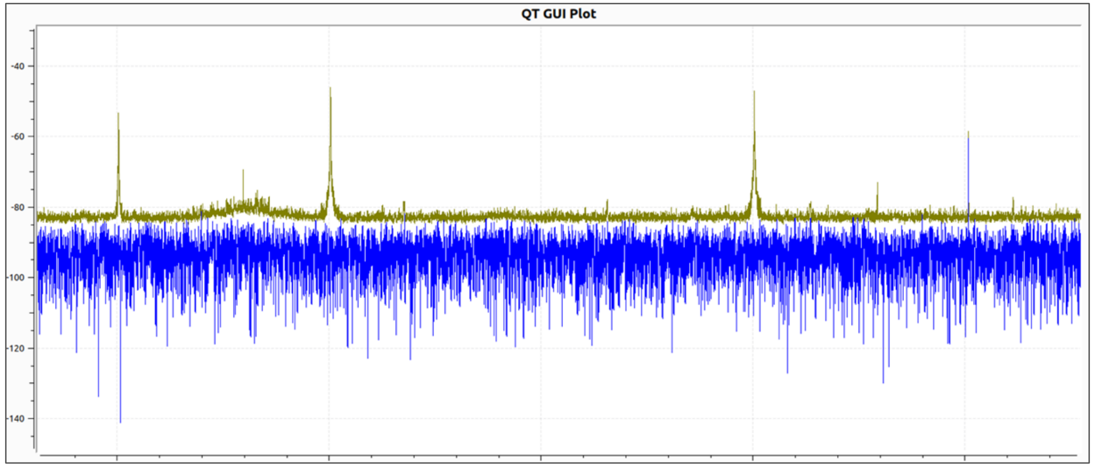
Automation

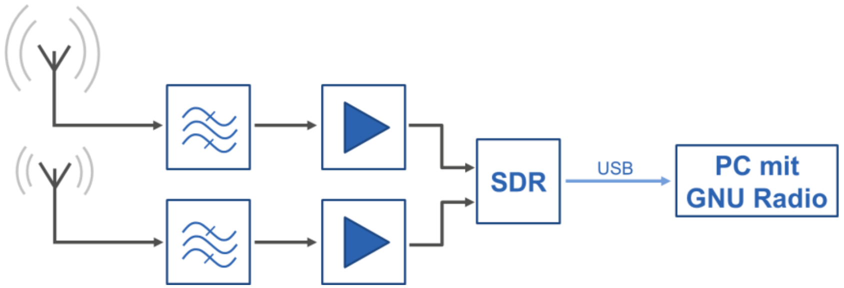
- Tracer detection using a software defined radio
  - Primarily based on signal strength of different tracer frequencies
  - Two antennas covering both sides of the fairway
  - Installation on ships regularly operating on the river stretch

→ Reduces search efforts

→ Increases relevance of results (due to use of up to 200 tracers)







Conclusions

- Radiotelemetric tracers provide novel insights into bed load dynamics at the German Upper Rhine regarding:

  1. Incipient motion → somewhat above GlQ
  2. Grain-size specific and discharge-dependent transport probabilities and transport velocities
  3. Dispersal mechanisms
  4. Transport pathways within the fairway → alternating between point bars

- The method is limited by:

  1. Water levels → > 5 m only very coarse gravel can be reliably detected
  2. Number of tracers → Manual detection: ≤ 30 tracers

     → Automated detection: up to ~200 tracers


Iffezheim barrage: © BAW

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