Fluid Mechanics and the Effectiveness of Water Covers

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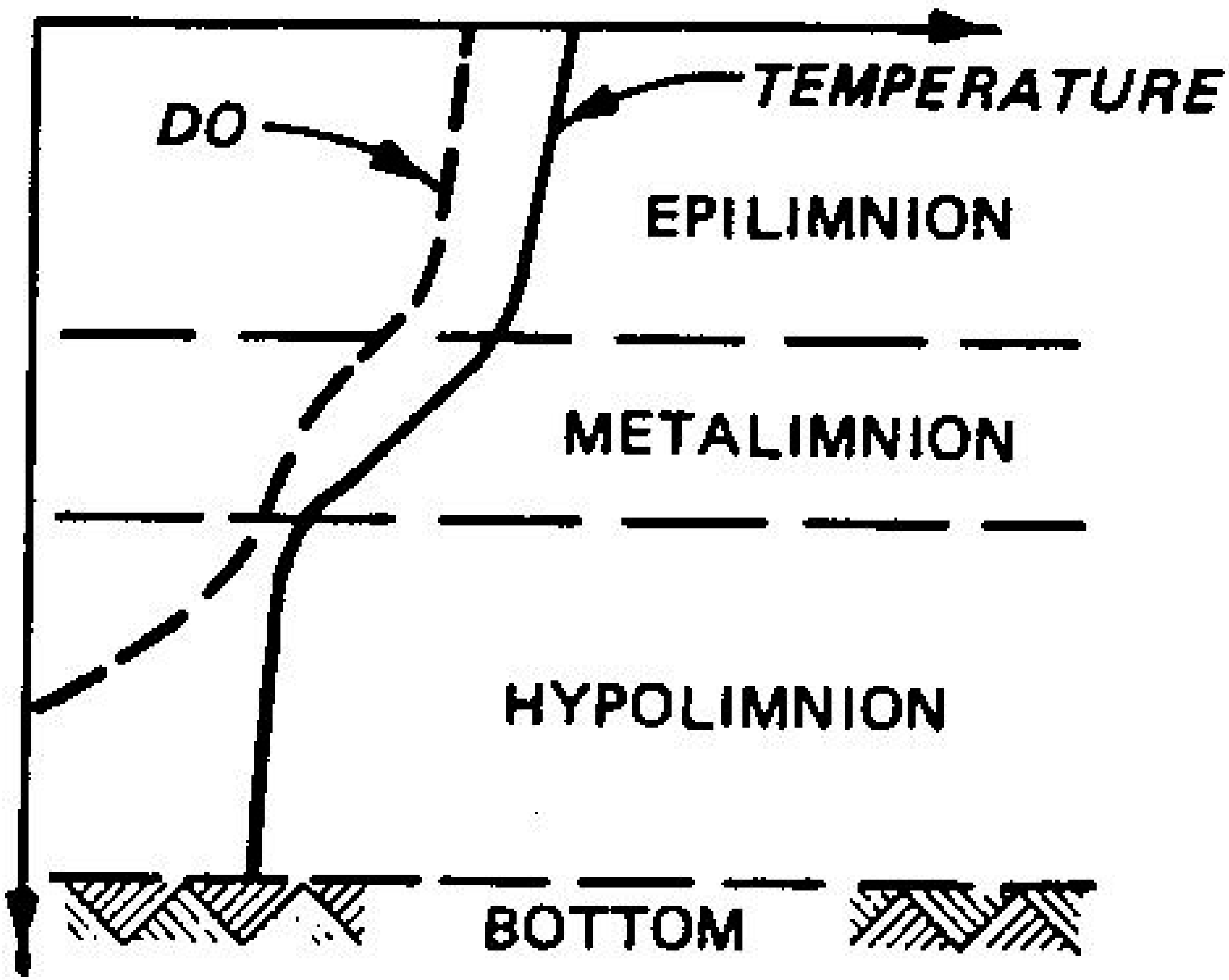
Outline

- Benefits of Water Covers
- Lake Stratification
- Tailings Resuspension in Shallow Covers
- Concentration Prediction
- Deep Covers
- Monitoring and Testing
- Conclusions

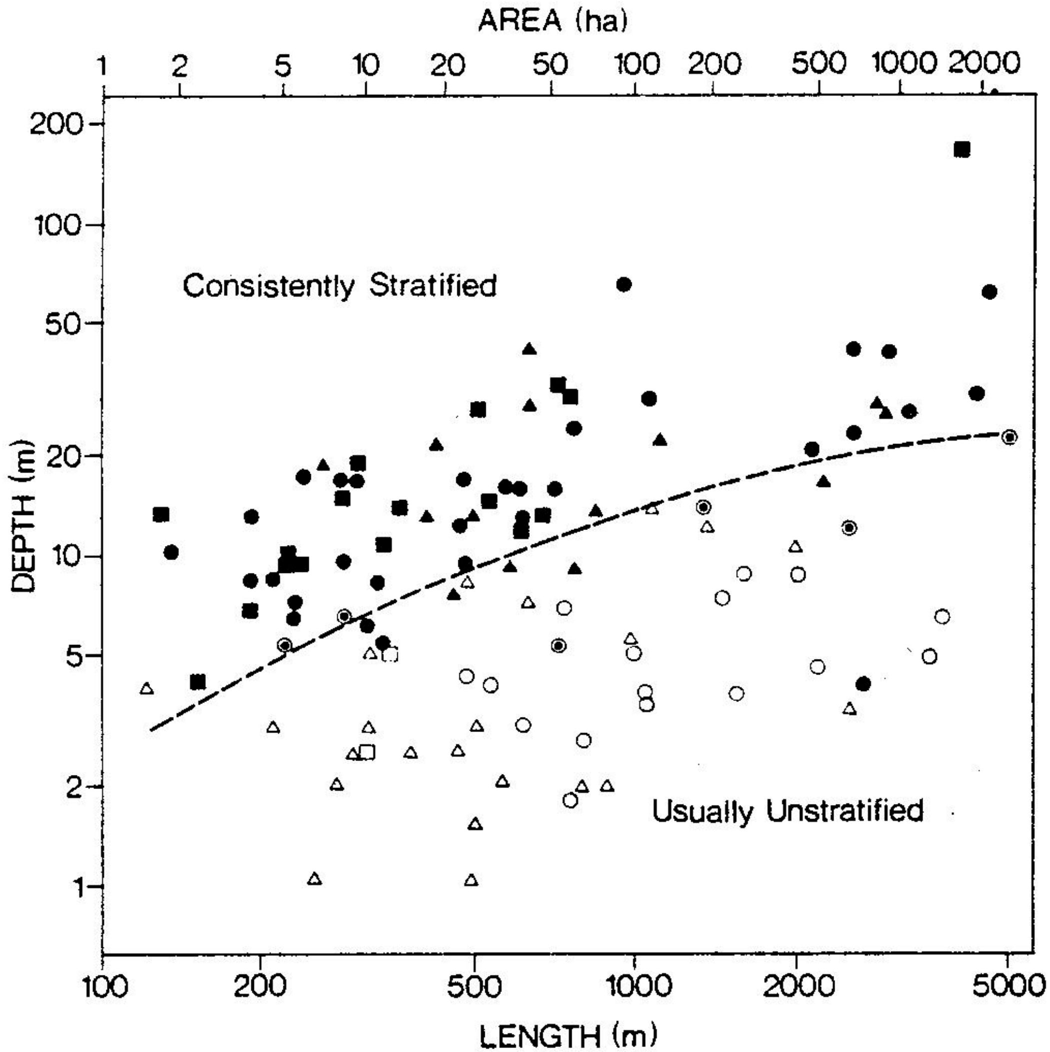
Benefits of Water Covers

- Reduced oxygen concentrations
  - Air ≈ 290 mg/L
  - Water:14.6 mg/L at 0 ^{O}C
    11.3 mg/L at 10 ^{O}C
- Very Low Replenishment Rates?
  - Not true in shallow covers

Typical Stratification



Stratification
Gorham and Boyce (1989)



General Rule

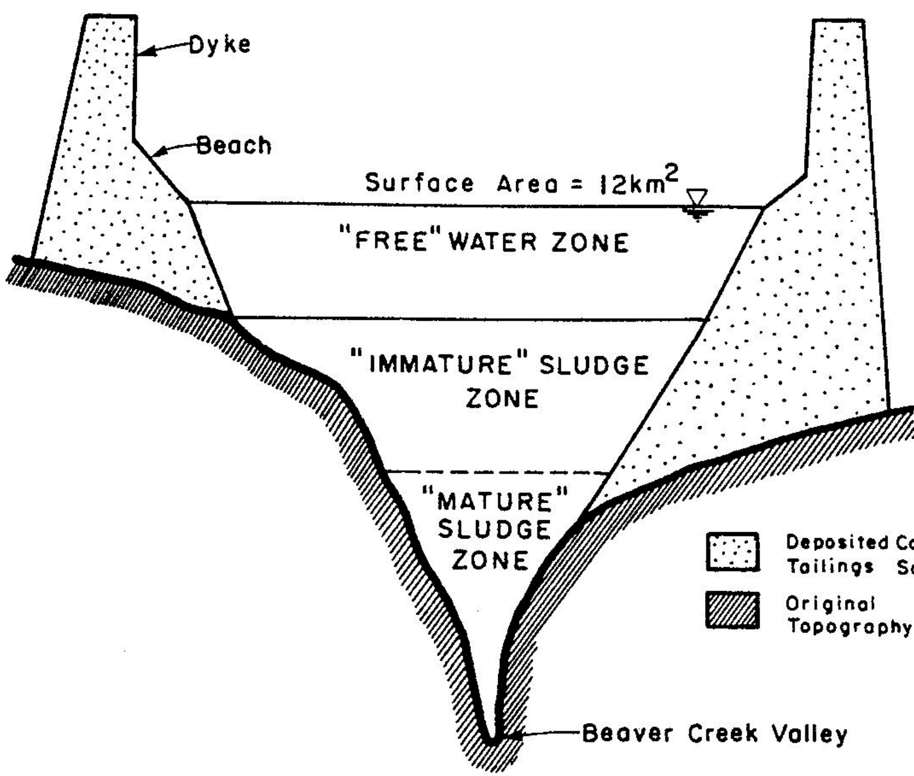
- Most natural lakes stratify
  - Deep cover
    - Often low DO at depth
- Most artificial water bodies don't
  - Shallow cover
    - DO close to saturation
    - Replenishment rates high
    - Forget about molecular diffusion in cover

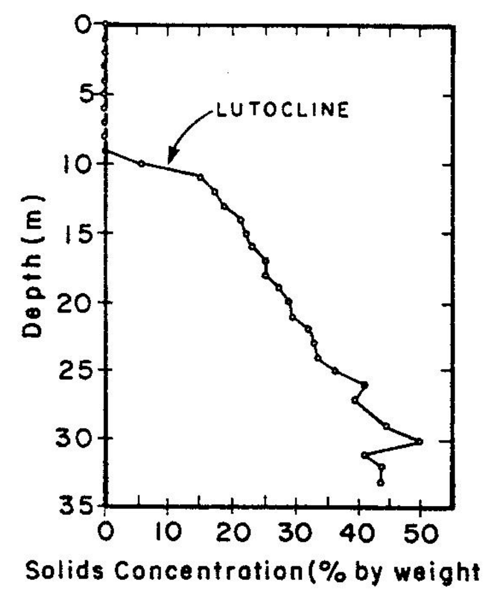
Tailings Resuspension in Shallow Covers

- Wind-wave action
- Currents
- Internal waves
- Resonant Interactions
- Upwelling
- Langmuir cells
- Wave breaking
- Penetrative convection

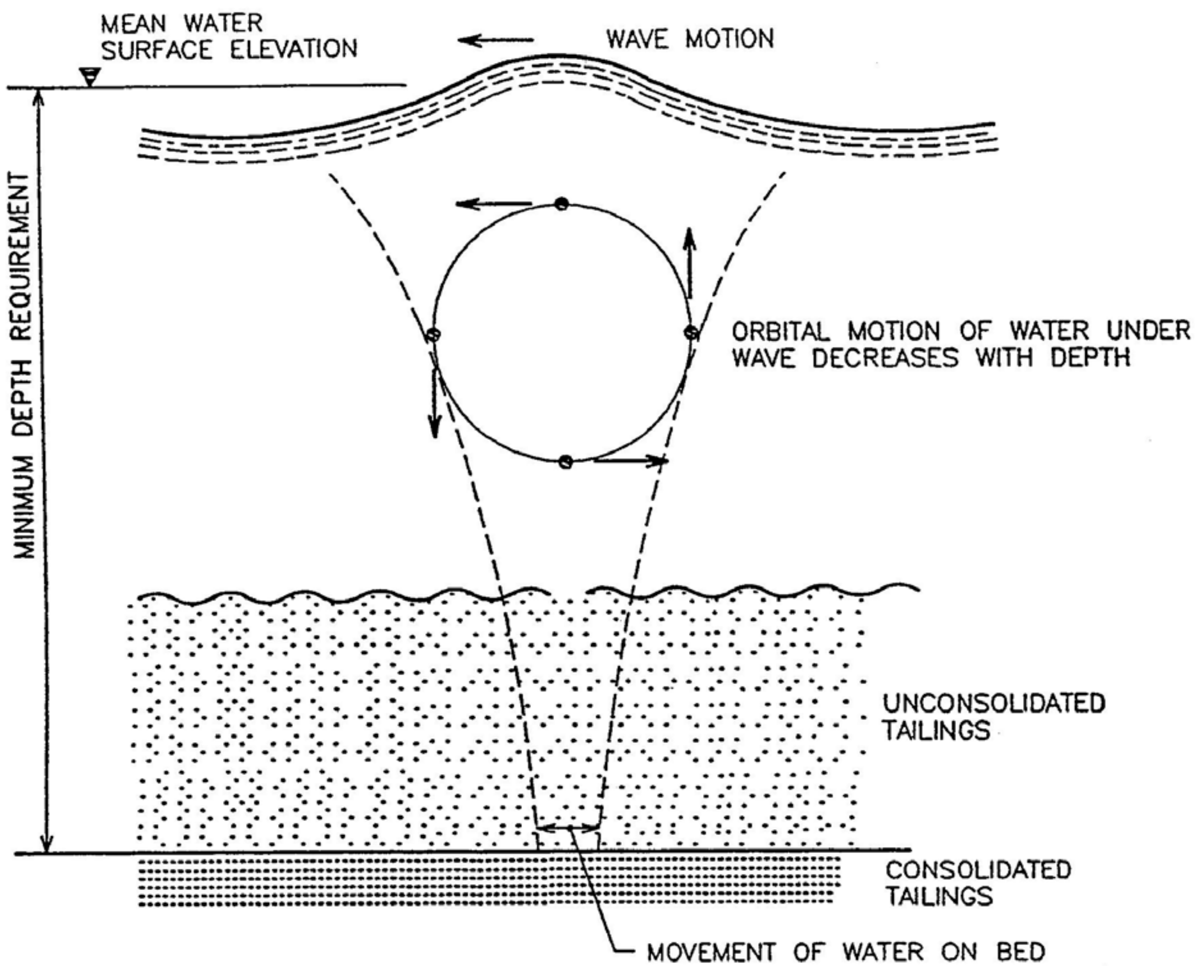
Design Depth Based on Wind Wave Action

- Syncrude case





Orbital Motions



Design Depth

$$d = 0.00187\left(\frac{U^2F^2}{g}\right)^{1/3}\ln\left[0.037\frac{R\left(gFU^4\right)^{1/6}}{U_t}\right]$$

- U = Wind Speed
- F = Fetch
- R = Wave Height Ratio
- U_t = Threshold velocity
- Assumes linear, deep water, wave theory

Results

- Next four slides show design depth vs:
  - Wind velocity
  - Fetch
  - Threshold velocity
  - Wave height ratio

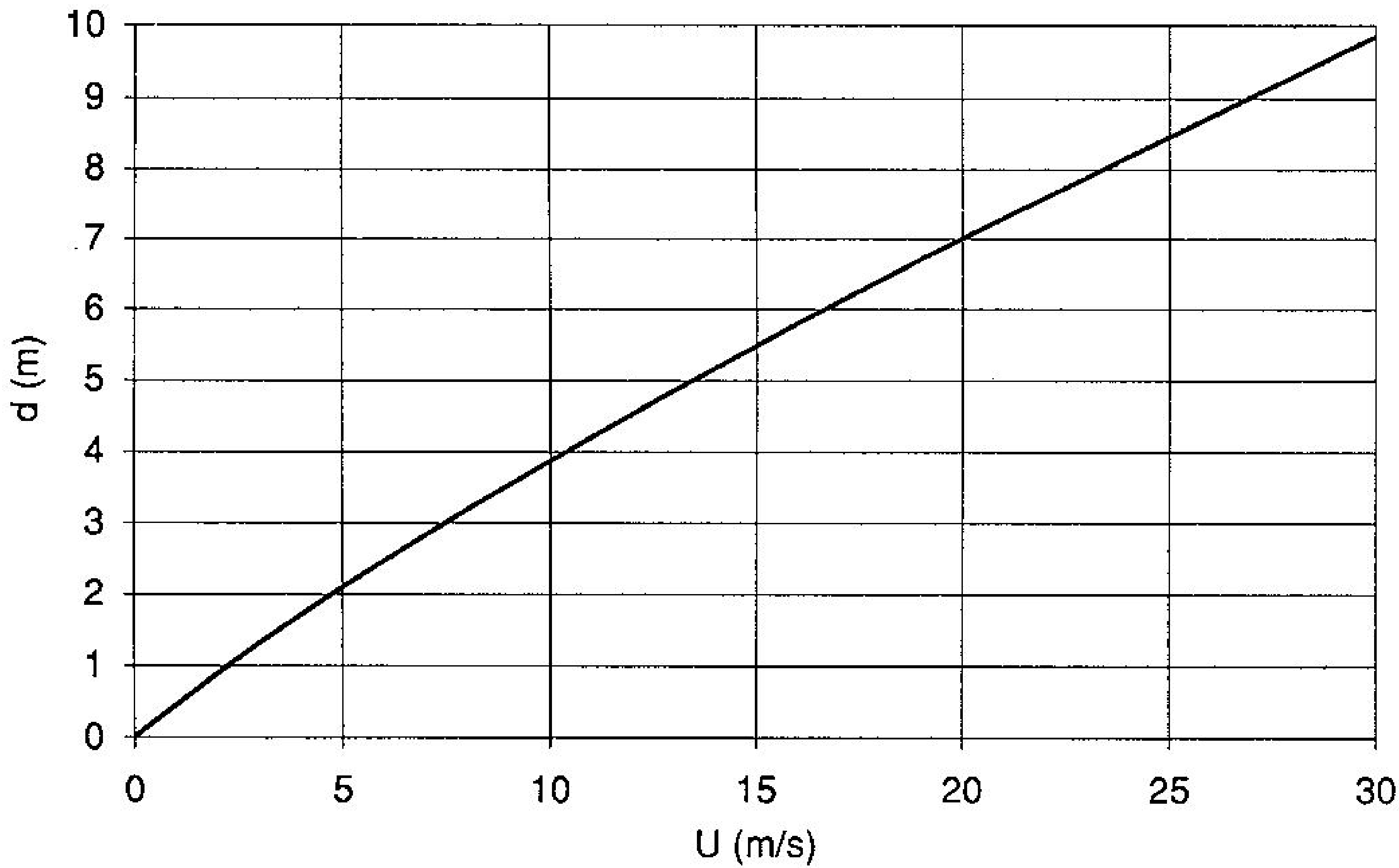


FIG. 2. Minimum depth as a function of wind velocity ($F = 5$ km, $R = 1$, and $U_t = 0.04$ m/s).

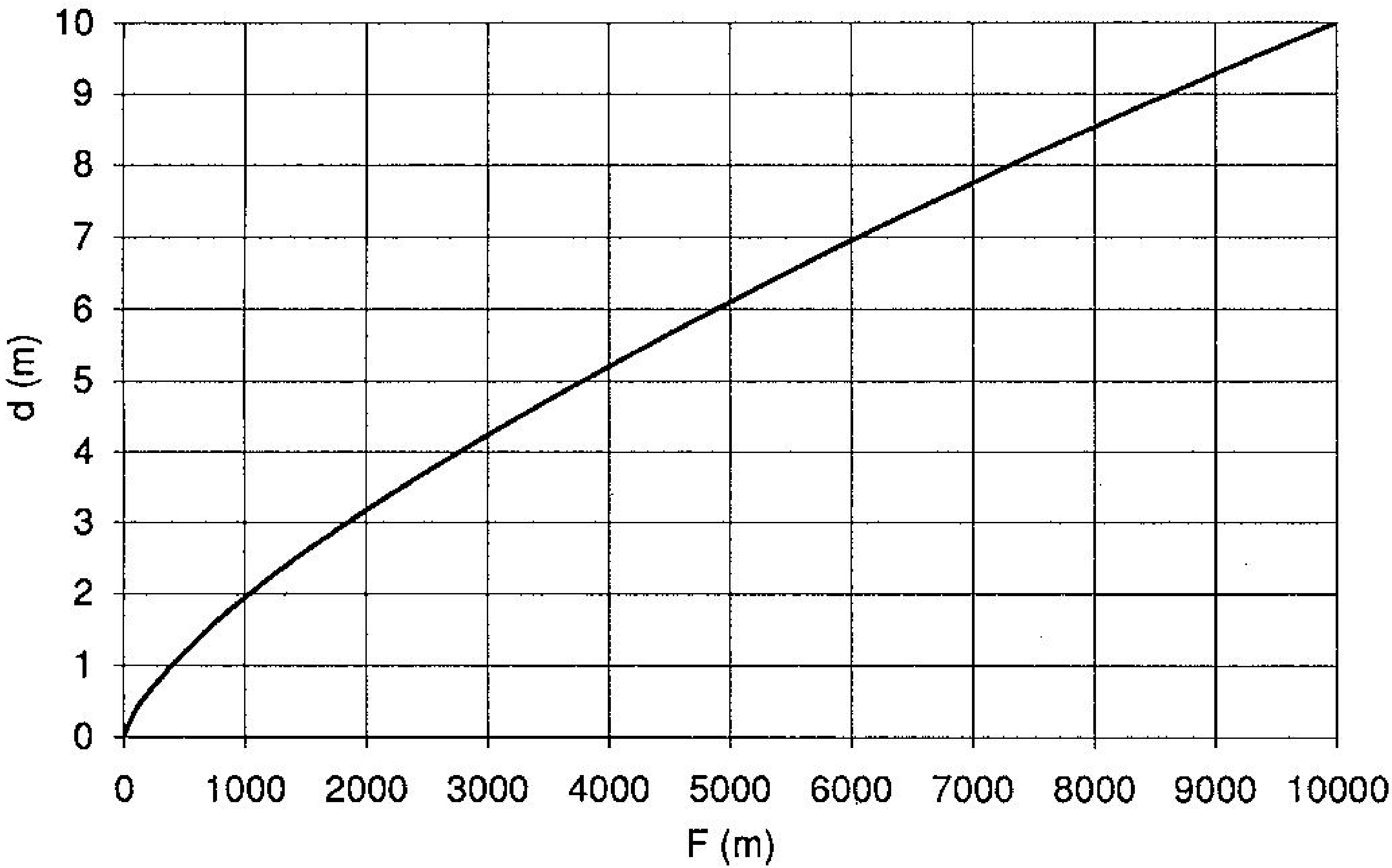


FIG. 3. Minimum depth as a function of fetch ($U = 17$ m/s, $R = 1$, and $U_t = 0.04$ m/s).

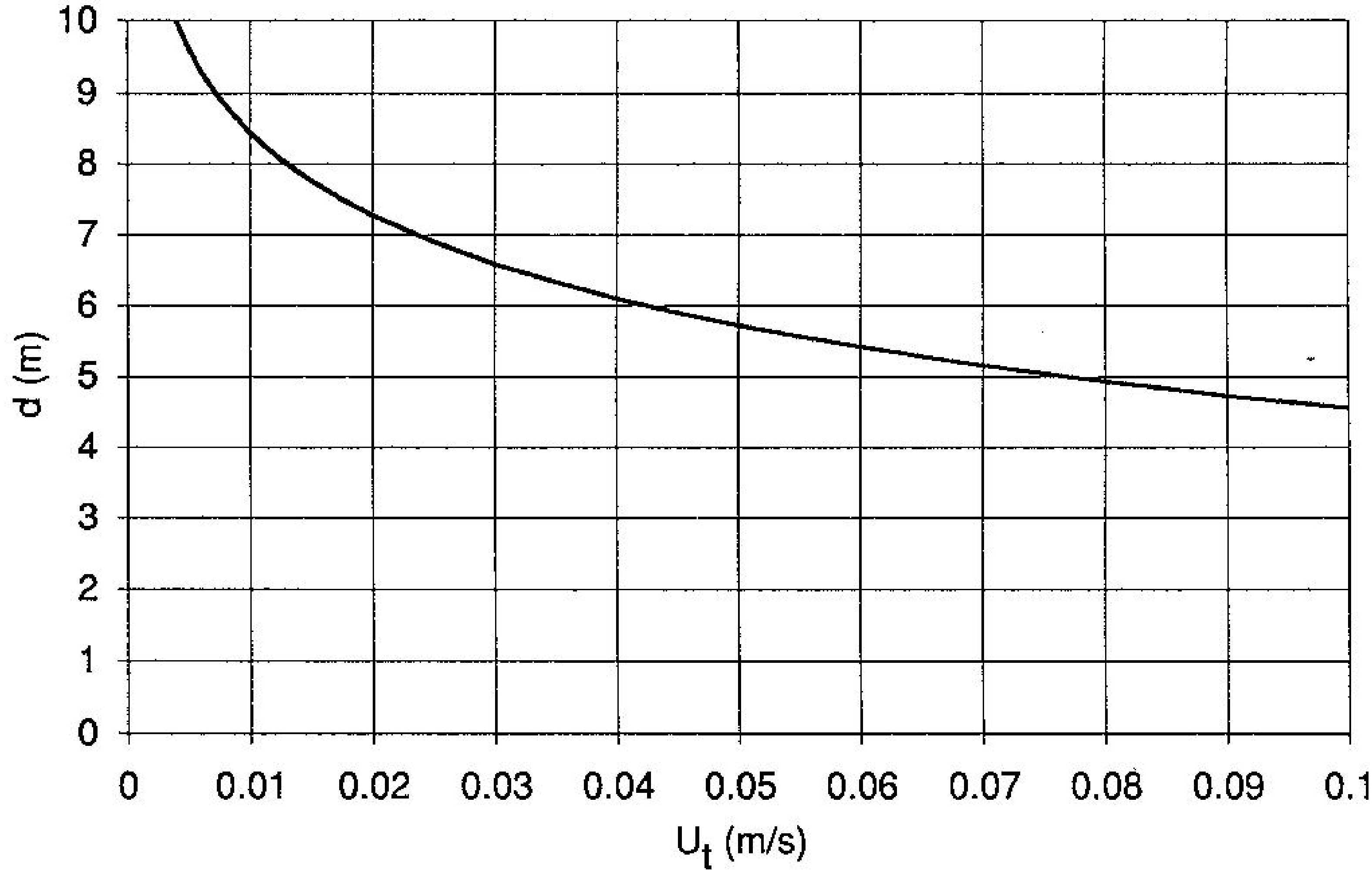


FIG. 4. Minimum depth as a function of threshold velocity (U = 17 m/s, F = 5 km, and R = 1).

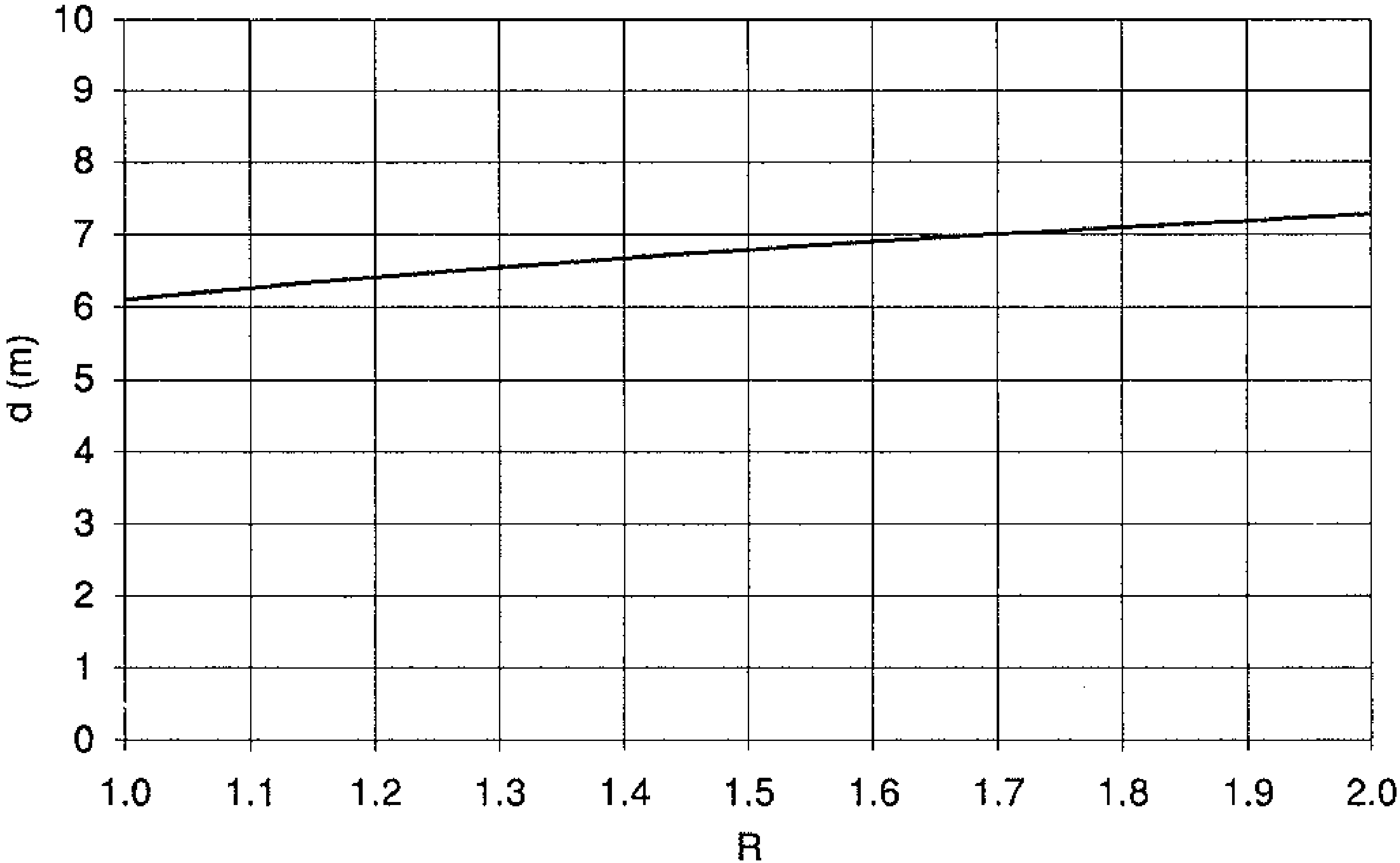
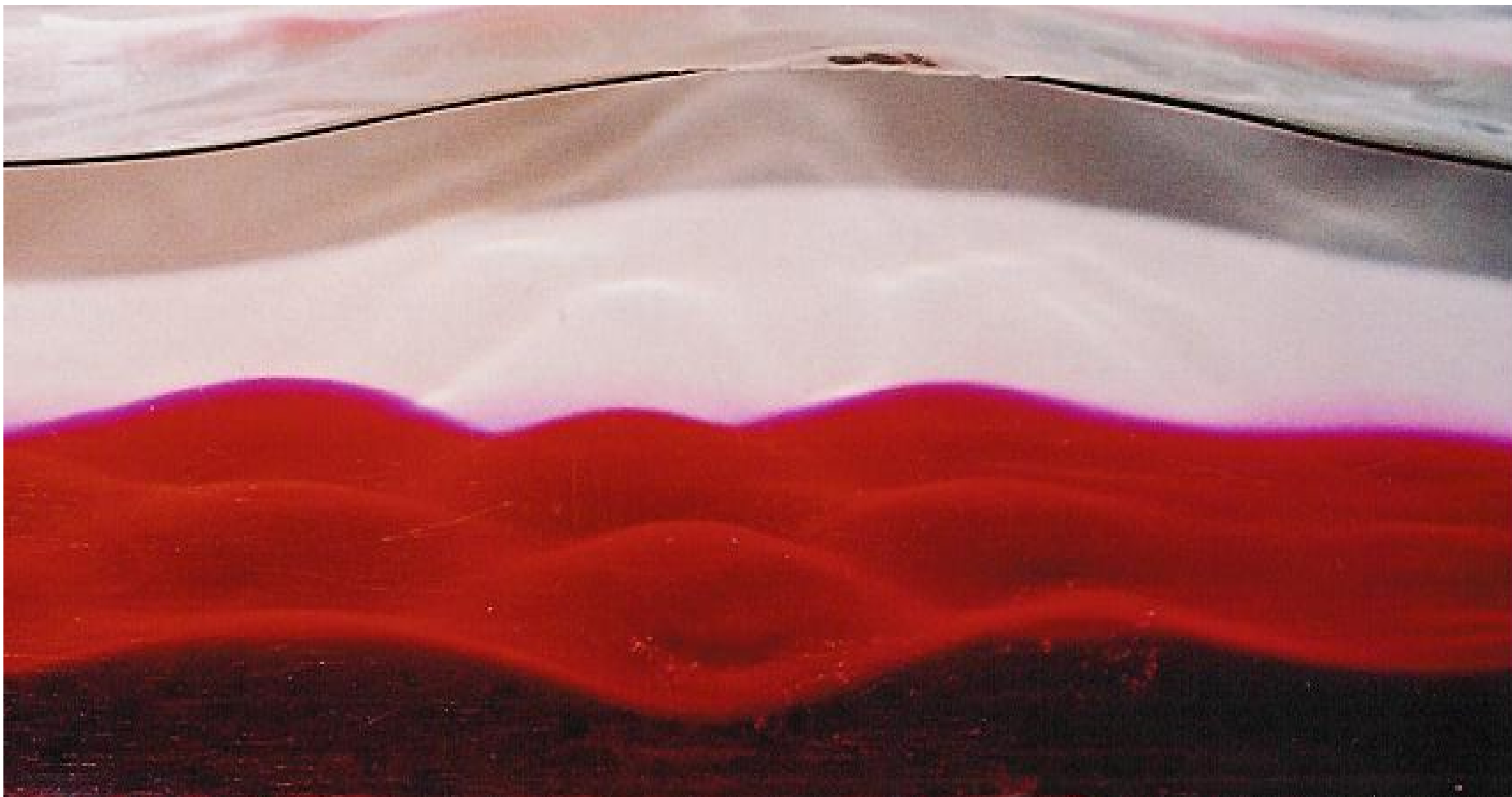


FIG. 5. Minimum depth as a function of wave height ratio (U = 17 m/s, F = 5 km, and U_t = 0.04 m/s).

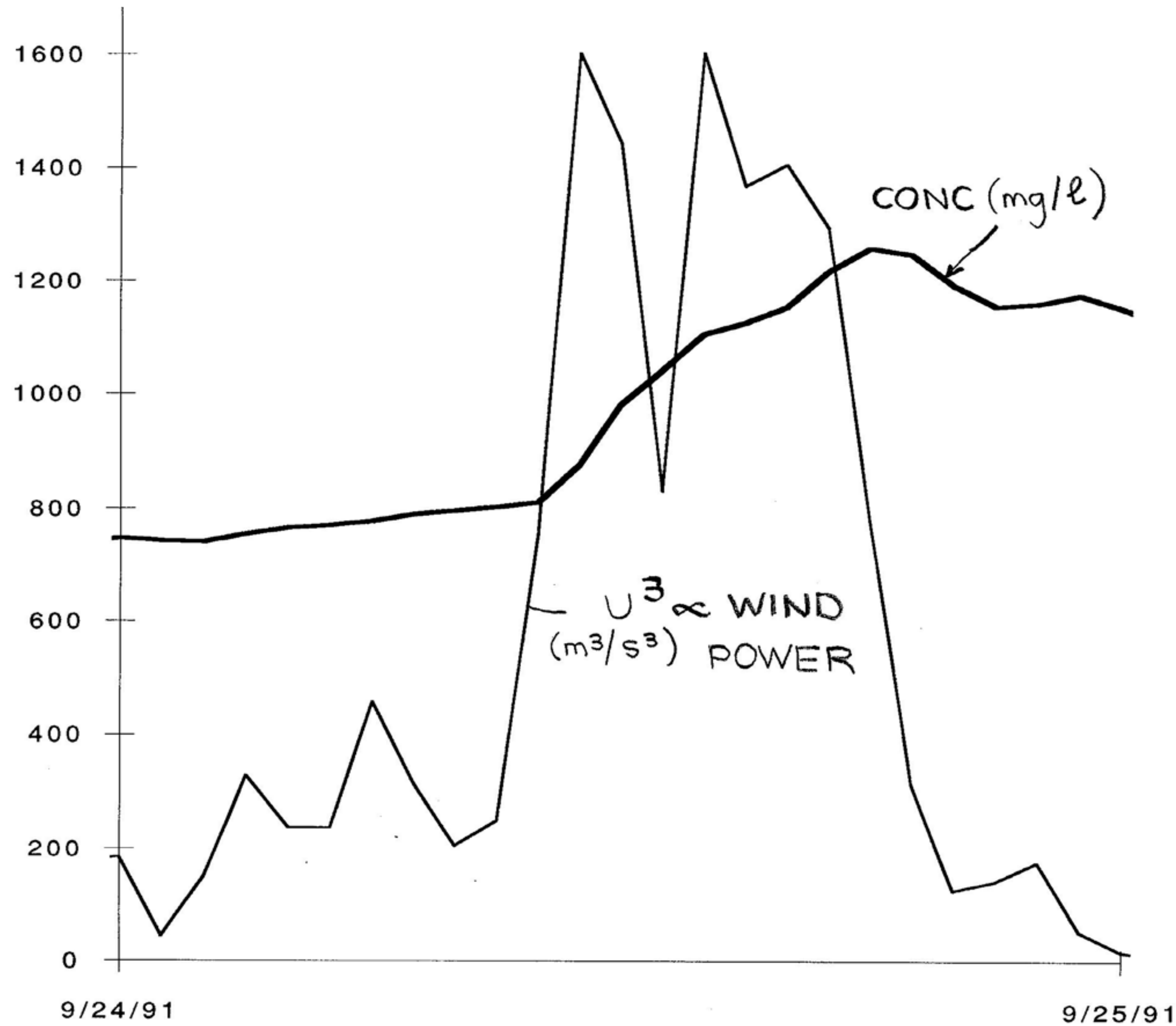
Other Mechanisms
Resonant Interactions



Concentration Prediction

- When resuspension occurs
  - Need to predict how much
  - Need to account for particle settling
  - Need model incorporating:
    - Wind stirring
    - Penetrative convection
    - Settling
    - Comparison with field data

Field Data



1600
1400
1200
1000
800
600
400
200
0
CONC (mg/ℓ)
$U^3 \propto$ WIND POWER
(m³/s³)
9/24/91
9/25/91

Deep Covers

- Added complications in lakes that stratify
  - Model annual cycle
  - Mechanisms more subtle

Monitoring

- Optical backscatter - Syncrude

Conclusions

- No end to how complicated the problem might be
- Some Basic results though
  - For shallow covers the following are in decreasing order of importance:
    - Wind Speed
    - Fetch
    - Factor of safety
    - Threshold velocity
- Molecular diffusion irrelevant in shallow covers
  - May be relevant in pore waters