
Image: Andrew Watson lonelyplanet.com

How mathematical modelling can be useful to better define performance and restoration options for gullies

Griffith UNIVERSITY
Queensland, Australia

Australian Rivers Institute

Melanie Roberts *– Queensland Water Modelling Network Senior Research Fellow*

QWMN Forum 2020
26 – 27 February 2020

@MelanieEmmajade @GriffithARI @qldwmn

Australian Rivers Institute

Griffith UNIVERSITY

Gullies

- Responsible for 40 - 50% of sediment reaching the GBR
- Contribute to both sediment and nutrient levels in lagoon
- Form as a result of disturbed land
  - runoff driven
- Opportunity for targetted intervention

Gully rehabilitation


Queensland Government


Greening Australia

Direct

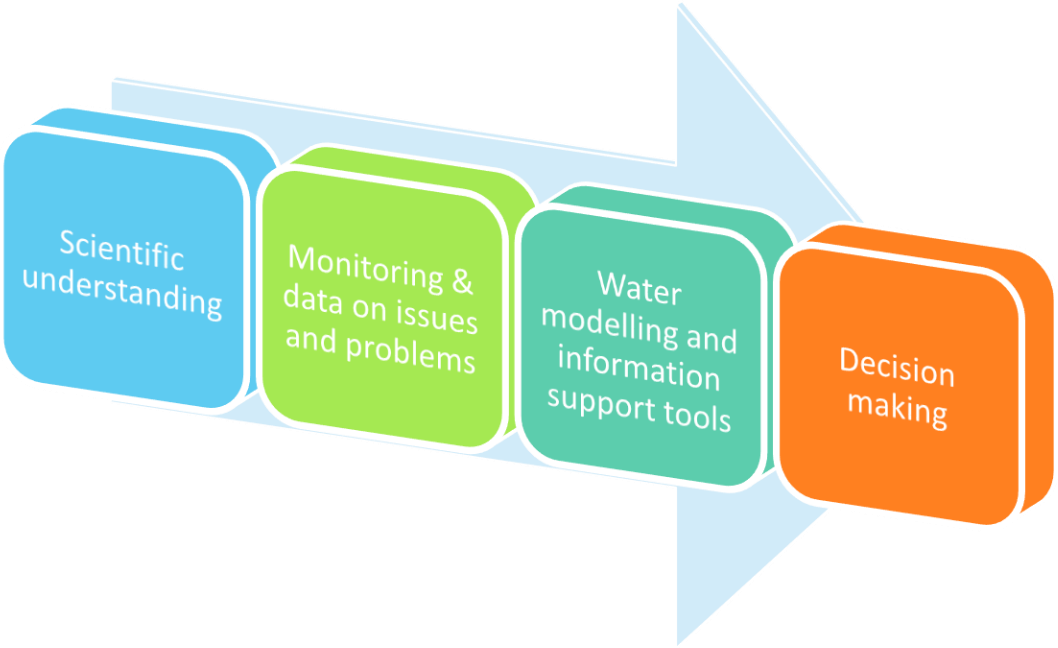
- porous check dams
- revegetation
- rock capping
- compact & fill
- water diversion

Indirect

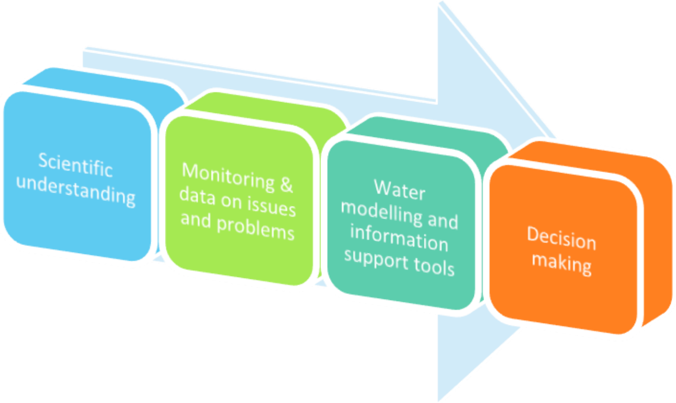
- reduce stocking rates
- intensive stocking rotation
- stock exclusion
- sediment traps


futurebeef

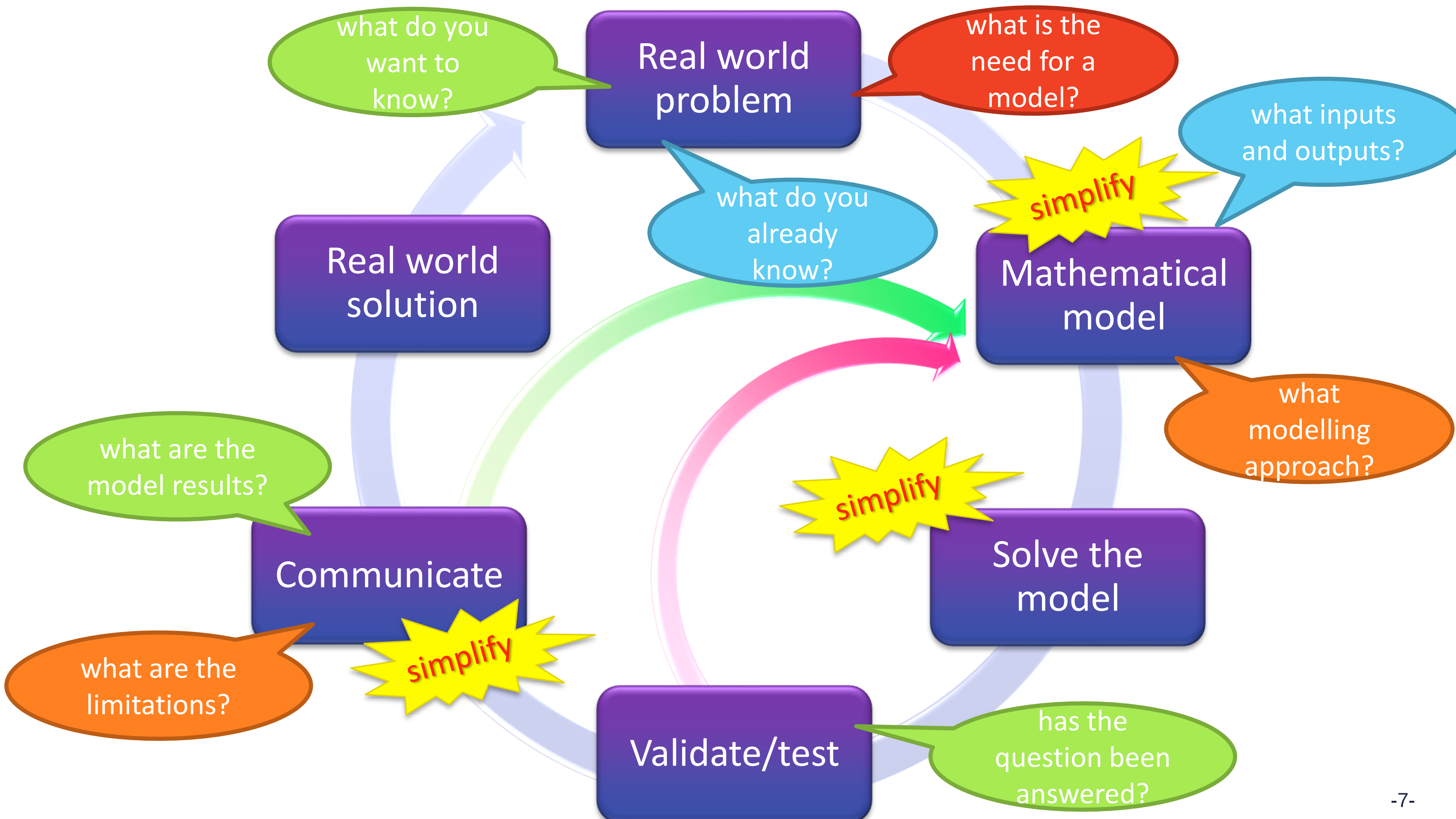
The pipeline



Why model gullies?



- Support quantification of impacts
- Identify areas to rehabilitate
- Compare options for rehabilitation
- Understand effectiveness of action
- Understand processes in a connected landscape
- Support trading or credit systems
- Inform monitoring programs


Real world problem
what do you want to know?
what is the need for a model?
what do you already know?
Mathematical model
simplify
what inputs and outputs?
what modelling approach?
Solve the model
simplify
Validate/test
has the question been answered?
Communicate
simplify
what are the model results?
what are the limitations?
Real world solution

MERGE

- 1D process based model to inform interventions at the local scale
- Conservation of mass – sediment exiting the gully
- Entrainment and deposition
  - growth depositional layer
- Analytical steady-state solutions

$$\overbrace{W\frac{\partial(Cd)}{\partial t}}^{\text{change in sediment}} + \underbrace{\frac{\partial(CQ)}{\partial x}}_{\text{advection}} = \overbrace{\eta}^{\text{entrainment}} - \underbrace{\delta}_{\text{deposition}}$$

How MERGE can inform decisions

- Sediment exiting gully under different scenarios
- Test interventions – ground cover, porous check dams
- Simple analytical expressions feed into optimisation schemes
- Couple with nutrient behaviour – value of wetlands, impact of dams
- Criteria for gully growth

Next steps

- Validation
- Parameterisation
  - soil erosivity
  - interventions
- Sediment-nutrient interactions
  - aggregate distributions

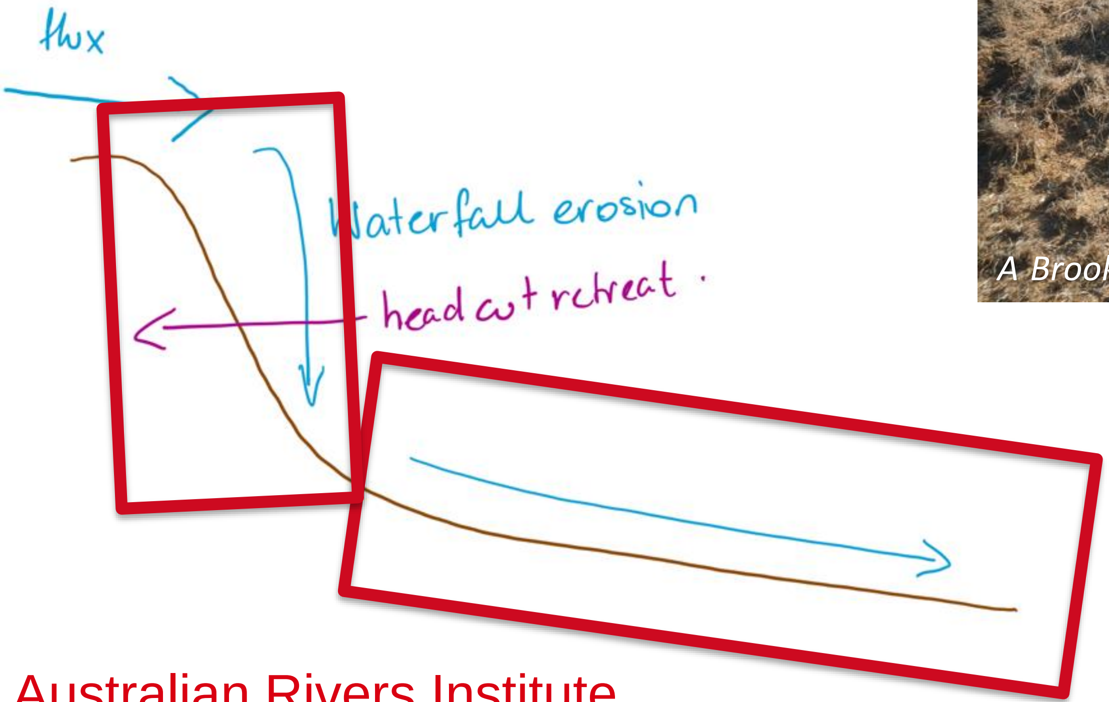
Documentation

Modelling considerations

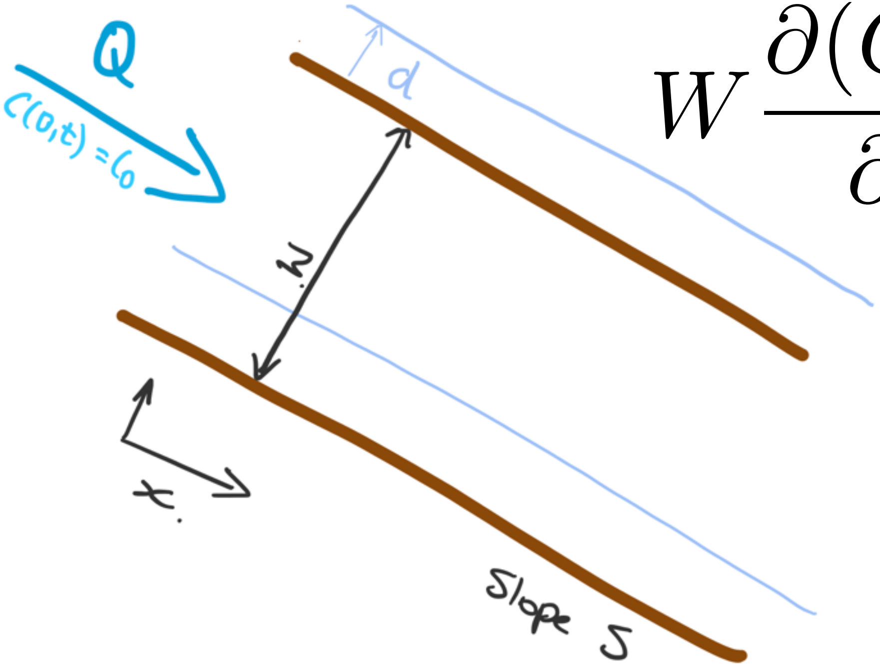
- What does the model represent?
  - processes?
  - temporal and special scale?
- What does the model output?
- What inputs does it require?
- What is the model intended for?

Image: Andrew Watson lonelyplanet.com

Idealised linear gully



Conservation of mass – 1D approximation



$$W\frac{\partial (Cd)}{\partial t}+\frac{\partial (CQ)}{\partial x}=\eta-\delta$$

C - sediment concentration

Q - flux

W - gully width

d - depth

η - rate of entrainment

δ - rate of deposition

$\boxed{\text{Solutions shown with } C_0 = 0}$

Deposition

Settling velocity – Stokes Law

$$w_s = \frac{2(\sigma - \rho)}{9\mu} R^2 g$$

Deposition rate

$$\delta = bWCw_s$$

w_s - settling velocity
R - sediment radius
W - width gully
b - sediment conc. ratio

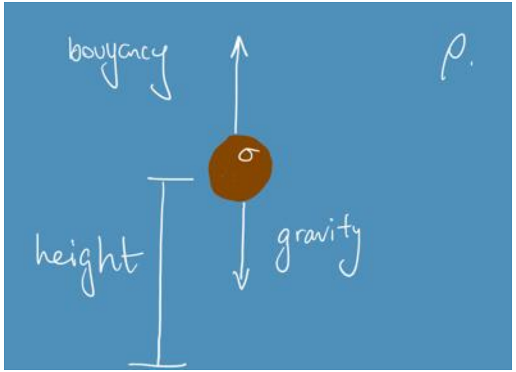
σ - density sediment
μ - dynamic viscosity
δ - rate deposition

ρ - density fluid
g - gravity
C - sediment concentration

Power to entrain sediment

$$\frac{\Delta PE}{\Delta t} = mgh$$

$$\eta \left[J + F + \underbrace{\left(\frac{\sigma - \rho}{\sigma} \right) gh}_{\beta} \right]$$



Immersive weight: $\frac{\sigma - \rho}{\sigma} g$

J - erosivity

F - static friction

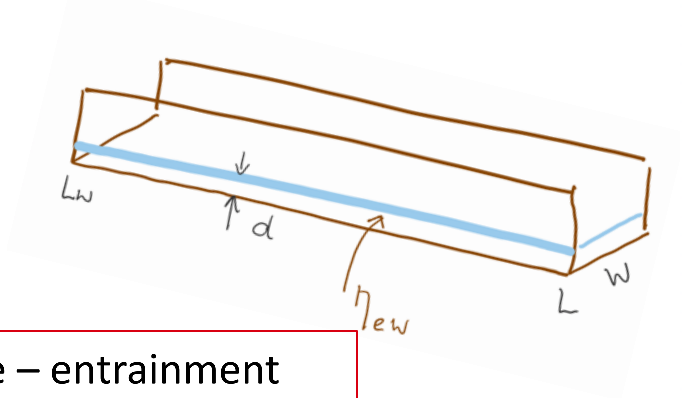
σ - density sediment

ρ - density fluid

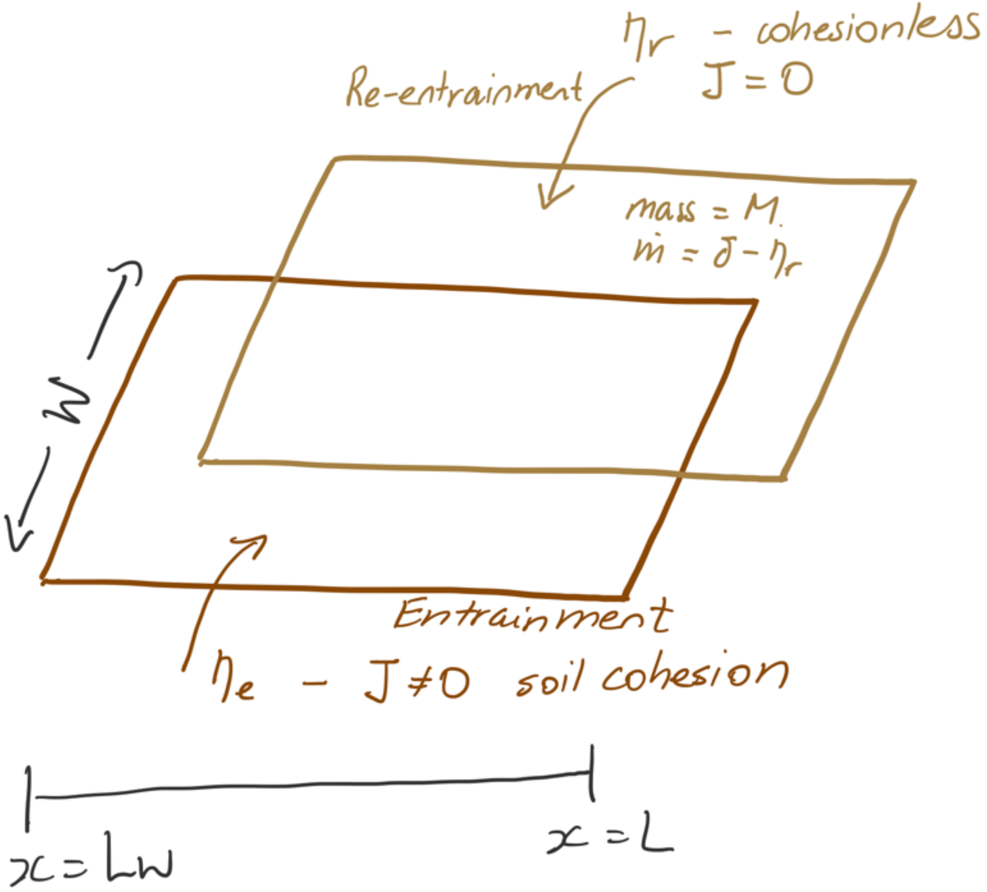
h - entrainment height

η - rate of entrainment

Entrainment and Re-entrainment

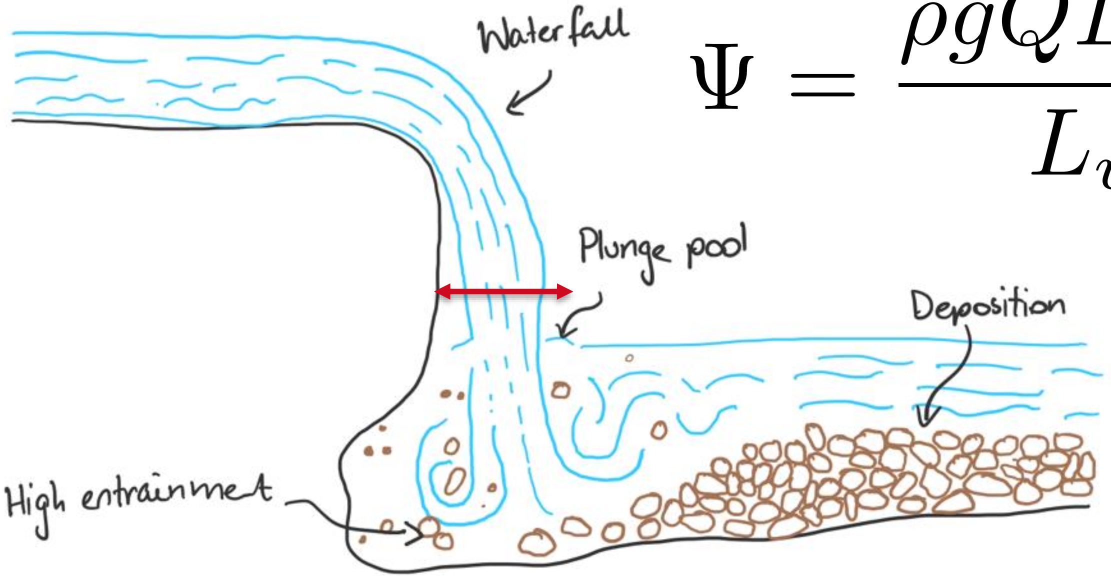


e – entrainment
h – head
w – wall
f – floor
r – re-entrainment



Waterfall power available

$$\frac{\Delta PE}{\Delta t} = mgh$$



$$\Psi = \frac{\rho g Q D(x)}{L_w}$$

Ψ - waterfall power

ρ - density fluid

g - gravity

Q - flux

D - gully depth

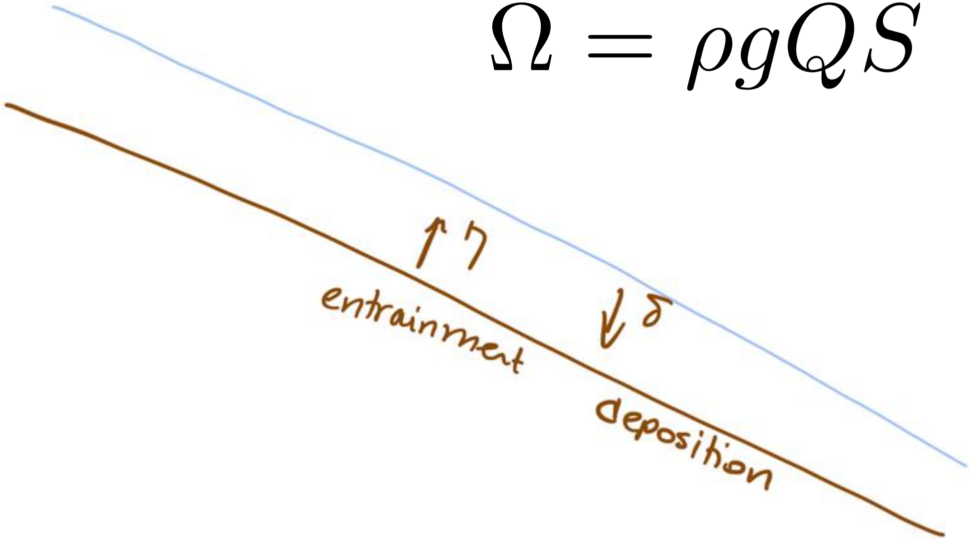
L_w - length waterfall region

S - slope

Stream power available

$$\frac{\Delta PE}{\Delta t} = mgh$$

$$\Omega = \rho g Q S$$



ρ - density fluid

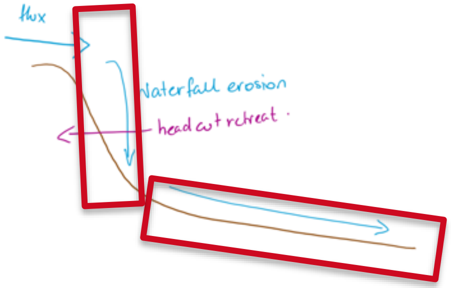
g - gravity

Q/W - flux per unit width

d - flow depth

Ω - stream power

S - slope



Rates of entrainment - head and wal

$$\eta_{eh} = \left[\frac{\boxed{k}(\Omega + \Psi)}{J + F + \beta} - \delta \frac{F + \beta}{J + F + \beta}\right] \boxed{\left(\frac{C* - C}{C*}\right)}$$

$$\eta_{ew} = \frac{2d}{W + 2d} \frac{k\Omega}{J + F + \beta} \frac{C* - C}{C*}$$

$$\eta_r = \min\left(\frac{W}{W + 2d} \frac{k\Omega}{F + \beta} \frac{C* - C}{C*}, \mathcal{M}\right)$$

$$\eta_{ef} = \begin{cases} 0 & \eta_r \leq \mathcal{M} \\ \dfrac{W}{W + 2d} \dfrac{k\Omega}{J + F + \beta} \dfrac{C* - C}{C*} - \eta_r \dfrac{F + \beta}{J + F + \beta} & \eta_r > \mathcal{M}. \end{cases}$$