

Manual for Package: open-channel-flow

Revision 11:12M

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1 @Backwater1D

1.1 Backwater1D

solve the gradually varied flow equation (backwater equation)
in one dimension

c.f. Chow, Bresse

1.2 backwater_approximation

approximation of the backwater curve by an exponential function
note: this is not necessarily a good approximation
in the case of tide, Q_t can be given

1.3 `backwater_curve_iterative`

analytic solution of the gradually varied flow equation
c.f. Bresse, Chow

1.4 `backwater_length`

backwater length

1.5 `dh_dx`

change of depth along channel for the backwater equation
beta : momentum coefficient
this is effectively an equation in h^3

1.6 `dh_dx_`

1.7 `dzs_dx`

change of surface elevation along channel

1.8 `gvf_x_chow`

analytical solution to the gradually varied flow equation (
backwater equation)
c.f. Chow, Bresse

1.9 `invert`

determine bed level from surface elevation
(inverse backwater equation)
this is ill conditioned, as the surface is smooth for subcritical
flow,

even if the bed is not smoth

C : chezy
W : width
Q : discharge
S : bed slope
y0 : surface elevation at outflow
lateral inflow

1.10 solve

solve the gradually varied flow equation (backwater equation)
C : chezy
W : width
Q : discharge
S : bed slope
y0 : surface elevation at outflow

1.11 solve_analytic

analytical solution to the gradually varied flow equation (bresse
method)
 $u_{-}^{(n-m)}/(1-u_{-}^{(n)})$

1.12 solve_matrix

2 @Compound_Cross_Section

2.1 Compound_Cross_Section

2.2 area

2.3 discharge

2.4 roughness

3 @Cross_Section

3.1 Cross_Section

3.2 average_across_section

3.3 compute_discharge

3.4 compute_sediment_transport

3.5 expand

3.6 fit_bed_level

3.7 flat

3.8 grain_size

3.9 init

3.10 invalidate

3.11 parse_arguments

3.12 wetted_cross_section

3.13 wetted_width

4 bifurcations-and-weirs/@Lateral_Diversion_Finite_Width

4.1 Jb

4.2 Lateral_Diversion_Finite_Width

4.3 dR

4.4 derive

4.5 evalk

4.6 lateral_outflow_finite_width1

4.7 load_functions

4.8 stagnation_point

```
fdx = isnan(x);
```

4.9 streamline

4.10 u_far

4.11 v_far

4.12 velocity

4.13 velocity_near_bed

5 bifurcations-and-weirs/@Lateral_Diversion_Finite_Width_Gradual

5.1 Jb

5.2 Lateral_Diversion_Finite_Width_Gradual

5.3 coefficients

5.4 condA

5.5 dR

5.6 derive

5.7 evalk

5.8 evalk_

5.9 lateral_outflow_finite_width1

5.10 load_functions

6 bifurcations-and-weirs/@Lateral_Diversion_Finite_Width_Gra

6.1 coefficients_old

7 bifurcations-and-weirs/@Lateral_Diversion_Finite_Width_Gra

7.1 stagnation_point

```
fdx = isnan(x);
```

7.2 streamline

7.3 streamline_radius_of_curvature

7.4 u_far

7.5 uv1

7.6 uv_side_branch

7.7 v_far

7.8 velocity

7.9 velocity_linear

7.10 velocity_near_bed

7.11 xp

8 bifurcations-and-weirs/@Lateral_Diversion_Wide_Channel

8.1 Lateral_Diversion_Wide_Channel

8.2 derive_lateral_outflow

derive potential flow solution to lateral outflow from an
infinitely
wide main channel

8.3 derive_lateral_outflow_finite_width

derive coefficients for lateral outflow in the case of potential
flow

8.4 load_functions

load analytical solutions for potential flow field at a lateral
diversion
with an infinitely wide main channel

8.5 stagnation_point

8.6 streamline_radius_of_curvature

9 bifurcations-and-weirs/@Lateral_Diversion_Wide_Channel_Map

9.1 Lateral_Diversion_Wide_Channel_Map

wrapper to store precomputed streamlines of potential flows

9.2 streamline

10 bifurcations-and-weirs/@Side_Weir

10.1 Side_Weir

side weir, analytical solution to (critical) lateral outflow

10.2 dzs_dx

side weir, along channel surface gradient

10.3 surface_elevation

along-channel surface elevation for (critical) lateral outflow over
a side-weir

11 bifurcations-and-weirs

11.1 Lateral_Diversion_Finite_Width_Map

12 bifurcations-and-weirs/bifurcation-empirical

12.1 bifurcation_potential_flow_dividing_streamline_radius

12.2 sediment_division_herrero

12.3 sediment_division_meijer_ksiazek_1

12.4 sediment_division_meijer_ksiazek_2

12.5 sediment_division_raudkivi

12.6 sediment_division_van_der_mark

12.7 sediment_division_wang

13 open-channel-flow

functions for open channel flow, sub modules:

- @Backwater1D
 - gradually varied flow in 1D (backwater)
- @Potential_Flow
 - depth averaged potential flow, numerical solution
- @Potential_Flow_Analytic
 - depth averaged potential flow, analytical solution
- rating-curve
 - empirical rating curves
- @Side_Weir
 - analytical solution to lateral outflow over a side weir
- @SWE
 - dynamical solution of the shallow water equation (saint-venant-equation)
 - in 1D
- @SWE_2d
 - dynamical solution of the shallow water equation (saint-venant-equation)
 - in 2D
- velocity-profile
 - vertical and transverse velocity profiles of the streamwise velocity

13.1 cdf_hydrograph

13.2 derive_discharge_step_response

13.3 discharge2stage

13.4 eddy_diffusivity

13.5 eddy_viscosity_depth_averaged

13.6 hfilter

13.7 hydraulic_radius

13.8 inv_hydrograph

14 kinematik-and-diffusion-wave

14.1 diffusion_wave

propagation of a diffusion wave (flood wave), c.f. ponce
advection
diffusion
where is the bed slope?
friction slope
eddy slope
chow 1988
$$\frac{d(A+A_0)}{dt} + \frac{dQ}{dx} = q$$
$$\frac{dQ}{dt} + \frac{d}{dx} \left(\frac{\beta Q^2}{A} + gA \left(\frac{dh}{dx} + S_f + S_e \right) - \beta q_i v_i + W_f B \right) = 0$$
$$A_0 \text{ ignored}$$
$$\text{inflow and wind shear ignored}$$

14.2 flood_wave_diffusion_coefficient

14.3 linear_wave

linear wave routing (linearised kinematic wave)

15 meander-bend/@Equilibrium_Bend

15.1 Equilibrium_Bend

Transverse profile of the bed level and bed material grain size in an equilibrium (infinitely long) meander bend

15.2 Q_s

15.3 bed_profile

predict transverse bed profile of an equilibrium meander bend

15.4 bed_profile_uniform

transverse profile of the bed level of an equilibrium meander bend with uniform grain size

15.5 calibrate

calibrate bend geometry to given profile

15.6 dD_{dr}

15.7 dh_{dr}

across channel derivative of flow depth for a meandering river

15.8 $dh_{dr_uniform}$

transverse gradient of the bed level of an equilibrium meander bend for the case of uniform bed material

15.9 grain_size_profile

transverse (across channel) profile of the bed material grain size
in a river meander

16 meander-bend

16.1 Kinoshita

% Public properties
% Public get properties
% Private properties
% Constructor
% Setters and getters
% generic methods

16.2 bend_transverse_velocity

transverse profile of the streamwise velocity in a meander bend

16.3 bend_velocity_near_bed

near-bed-velocity in a meander bend

16.4 kinoshita_

16.5 meander_bend_idealized

16.6 meander_centreline

16.7 random_meander

generate a pseudo random meander

16.8 secondary_velocity_profile_ikeda

16.9 test_rozovskii

16.10 transverse_slope_rozovskii

17 potential-flow/@Potential_Flow

17.1 Potential_Flow

numerical potential flow solver by various methods
analytic (series)
or FDM on non-orthogonal curvilinear grids
or FEM by unstructured meshes

17.2 contour

contour plot of the potential flow solution

17.3 infer_bed_level

note: this is pretty much a broken function for the inference of
stationary
morphology

Missing:

- rolling down of transverse slope to balance secondary flow in bends

- quasi time steippong

at stationary state:

- changes of discharge along the streamlines of discharge are
balanced
by a change in depth, to keep the velocity and sediment transport
constant along the streamline

$$dz_b/dt = dq_s/dx + dq_s/dn = 0 \quad (i)$$

TODO this only true for infinite bends, as sediment can also move
to the side

$$dq_s/ds = d/s(q/h) = 1/h \, dq/ds - q/h^2 \, dh/ds = 0$$

TODO this is only true in an ifinite bend (ikedada)

$$dq_s/dn = 0$$

streamlines along discharge or velocity -> does not matter eq (i)
is direction independent

17.4 infer_bed_level2

infer the bed level

17.5 infer_bed_level3

17.6 infer_bed_level_loop

the bed level does not completely converge but starts to oscillate,
this is presumably due to the non-compact kernel implementation of
the laplacian oerator

17.7 objective_bed_level

objective function for determining the bed level

17.8 plot

surface plot

17.9 quiver

17.10 sediment_transport

compute the sediment transport

17.11 solve_potential

solve for the potential

17.12 streamline

compute a streamline

17.13 surface_elevation

compute surface elevation according to Bernoulli's law
note : this is likely very different from the true surface
elevation,
as streamline curvature causes a transverse pressure gradient

17.14 test_case

17.15 velocity_near_bed

determine the velocity near the bed

17.16 vertical_velocity

determine the vertical velocity by continuity

18 potential-flow/@Potential_Flow_Analytic

18.1 Potential_Flow_Analytic

analytical solutions to various depth-averaged potential flow problems

18.2 streamline

numerically follow path along streamline by integrating the velocity

19 potential-flow/@Potential_Flow_SM

19.1 Potential_Flow_SM

numerical solver for flow on a curvilinear grid (not necessarily orthogonal)
by means of the Finite Difference Method

19.2 assemble_discretization_matrix_rectilinear

assemble the discretisation matrix

19.3 assemble_potential_matrix

assemble the discretisation matrix for potential flow

19.4 boundary_condition_side_outflow

apply boundary conditions for side outflow
 $p\phi + (1-p)d/db \phi = rhs$
y : along channel coordinate
TODO, make this return the bc-struct

19.5 boundary_condition_side_outflow_1

```
apply boundary conditions
p*phi + (1-p)*d/db phi = rhs

TODO, make this return the bc-struct
```

19.6 cut_boundary

```
cut the boundary from the domain
wa : width of inlet to side channel
wb : width of side channel
```

19.7 cut_rectangle

```
cut a rectangle from the domain
TODO, this requires also an adaptation of the derivative matrices
-> step over to semi-unstructured mesh
```

20 potential-flow/@Potential_Flow_UM

20.1 Potential_Flow_UM

```
numerical solver for flow on an unstructured mesh (triangulation)
by means of the Finite Element Method
```

20.2 assemble_potential_matrix

21 potential-flow

21.1 poisson_flow_rate

22 rating-curve

22.1 ChezyRatingCurve

rating curve, Chezy formalism

22.2 DynamicKeuleganRC

Dynamic Rating Curve, Keulegan roughness formulation
(dynamic = correction for hysteresis loop)

22.3 DynamicManningRC

Dynamic Rating Curve, Manning roughness formulation
(dynamic = correction for hysteresis loop)

22.4 DynamicPowerRC

Dynamic Power Law Rating curve
(dynamic = correction for hysteresis loop)

22.5 KeuleganRatingCurve

22.6 ManningRatingCurve

22.7 PolyRatingCurve

22.8 PowerRatingCurve

stationary rating curve, power law

22.9 PowerRatingCurveOffset

stationary rating curve, stage-discharge follows power law

22.10 RatingCurve

Fri Feb 13 10:02:52 CET 2015
rating curve superclass

22.11 csarea

predict cross sectional area from transverse bed level profile
and surface elevation

22.12 csdischarge

compute discharge

22.13 csperimeter

compute wetted perimeter

22.14 csradius

compute hydraulic radius of the cross section

22.15 cswidth

determine cross section width

22.16 test_PowerRatingCurve

22.17 wfunc

determine channel width

23 open-channel-flow

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 - empirical rating curves
- @Side_Weir
 - analytical solution to lateral outflow over a side weir
- @SWE
 - dynamical solution of the shallow water equation (saint-venant-equation)
 - in 1D
- @SWE_2d
 - dynamical solution of the shallow water equation (saint-venant-equation)
 - in 2D
- velocity-profile
 - vertical and transverse velocity profiles of the streamwise velocity

23.1 residual_swe

24 shallow-water/@SWE

24.1 SWE

Class to solve the (cross sectionally averaged) shallow water equation
(st venant equation)

24.2 `bc_incoming_non_reflecting`

set non-reflecting boundary condition for the 1D SWE

24.3 `bc_inflow`

inflow boundary condition

24.4 `bc_inflow_low_pass`

set low frequency Dirichlet, high frequency pass boundary condition

24.5 `bc_inflow_non_reflecting`

set non-reflecting boundary condition

24.6 `bc_level`

set surface level as Dirichlet boundary condition

24.7 `bc_level_sommerfeld`

set surface level as boundary condition by sommerfeld method

24.8 `bc_nonreflecting`

set non-reflecting boundary condition
extrapolate 0-order

24.9 `bc_reflecting`

set reflecting boundary condition
extrapolate 0-order and invert v

24.10 dot

time derivative
(only for matlab internal ode-solver)
TODO this is not swe specific
continuity
$$dA/dt + dQ/dx = I$$

momentum
$$dQ/dt + d/dx(Qu + 1/2 gh^2) = gA(S_f - S_b)$$

$$S_b = dz_b/dx$$

$$S_f = \tau_x/\rho_w = C_f u|u|$$

24.11 dt_cfl

determine time step required by cfl

24.12 energy

determine total energy as sump of potential and kinetic energy
this is preserved for fricitionless flows

24.13 flux

st venant's shallow water equation fluw

24.14 flux_lin

linearised st-venant equation

24.15 fluxmateig

eigenvalues und vectors of the swe

24.16 jacobian

Jacobian of the SWE

$$\frac{dq}{dt} + J \frac{dq}{dx} = \text{sourceterm}$$

note: $\frac{d}{dx}(A*q) = J \frac{dq}{dx}$

24.17 lindot

linearised SWE

width variation not included, goes into rhs force term

$$\begin{bmatrix} 0, & 1 \\ -u^2+gH, & 2u \end{bmatrix} \begin{bmatrix} A \\ [Q]_{dx} \end{bmatrix} = \begin{bmatrix} Q \\ [Q^2/A+1/2gA^2/w]_{dx} - 1/2gA^2/w^2 dw/dx \end{bmatrix}$$

force term

24.18 roe_average

roe average for the SWE

24.19 solve_analytic

linearised analytic solution of the swe

24.20 solve_stationary

stationary solution to the SWE

24.21 source_bed_level

source term of the SWE caused by a change of the bed level

Note: this term causes splitting and averaging methods to fail to give accurate predictions of the smooth surface at steps of the bed

24.22 source_friction

friction source term of the SWE

24.23 source_width

source term (reaction term) for channels with variable width

24.24 swe_geometry

predefined functions to set up channel geometry

24.25 swe_ic

predefined functions of channel geometries

25 shallow-water/@SWE_2d

25.1 SWE_2d

Dynamic solution of the shallow water equation (depth average, 2D)

25.2 apply_boundary_condition_stationary

apply boundary condition for stationary flow

25.3 assemble_stationary

TODO, g should be replaced by gx,gy,gz, see chaudhri
assemble discretisation matrix for stationary flow

25.4 solve_stationary

solve SWE for stationary flow ($dU/dt = dQ/dt = 0$)

26 shallow-water

26.1 sw_reflection

reflection coefficients of shallow water waves at a sudden change
of the
cross section (sudden change of admittance)
c.f. lighthill, ippen-harleman

26.2 sw_reflection_stepwise

time passes and phase shifts
transmission and reflection coefficient depend on direction !
iterative (recursive) reflection and transmission

27 open-channel-flow

functions for open channel flow, sub modules:

@Backwater1D
 gradually varied flow in 1D (backwater)
@Potential_Flow
 depth averaged potential flow, numerical solution
@Potential_Flow_Analytic
 depth averaged potential flow, analytical solution
rating-curve
 empirical rating curves
@Side_Weir
 analytical solution to lateral outflow over a side weir
@SWE
 dynamical solution of the shallow water equation (saint-
 venant-equation)
 in 1D
@SWE_2d
 dynamical solution of the shallow water equation (saint-
 venant-equation)
 in 2D
velocity-profile
 vertical and transverse velocity profiles of the streamwise
 velocity

27.1 stage2discharge

28 test/test_Backwater1D

28.1 test_bw1d_solve_matrix

29 test

29.1 test_inverse_backwater_curve

29.2 test_normal_flow

29.3 test_nse_nz

30 open-channel-flow

functions for open channel flow, sub modules:

```
@Backwater1D
    gradually varied flow in 1D (backwater)
@Potential_Flow
    depth averaged potential flow, numerical solution
@Potential_Flow_Analytic
    depth averaged potential flow, analytical solution
rating-curve
    empirical rating curves
@Side_Weir
    analytical solution to lateral outflow over a side weir
@SWE
    dynamical solution of the shallow water equation (saint-
        venant-equation)
    in 1D
@SWE_2d
    dynamical solution of the shallow water equation (saint-
        venant-equation)
    in 2D
velocity-profile
    vertical and transverse velocity profiles of the streamwise
        velocity
```

30.1 test_hydrograph

31 turbulence

31.1 boundary_layer_height

31.2 kolmogorov_length

31.3 kolmogorov_time

31.4 kolmogorov_velocity

32 uniform-stationary-flow

32.1 chezy2drag

32.2 chezy2f

32.3 chezy2manning

convert chezy to manning

32.4 chezy2z0

32.5 critical_flow_depth

critical flow depth in uniform stationary flow

32.6 discharge_step_response

$Q(:) = 0;$

32.7 drag2chezy

convert drag coefficient to chezy coefficient
 $g \frac{dz_s}{dx} + c_d w \frac{u^2}{h} = 0$ (swe formalism)
 $- S + \frac{1}{C^2} \frac{U^2}{H} = 0$ (chezy formalism)

32.8 f2chezy

32.9 ks2z0

32.10 manning2chezy

manning to chezy conversion

32.11 manning2drag

32.12 manning2kc

32.13 manning2z0

32.14 normal_flow_depth

normal flow depth for uniform stationary flow
function H = normal_flow_depth(Q,W,C,S)

32.15 normal_flow_discharge

normal flow discharge for uniform stationary flow

32.16 normal_flow_roughness

roughness coefficient from uniform stationary flow

32.17 normal_flow_slope

energy slope (surface slope) for uniform stationary flow
normal flow slope in uniform stationary flow

32.18 normal_flow_velocity

normal flow velocity in uniform stationary flow

32.19 normal_flow_width

normal flow width for uniform stationary flow

32.20 normal_shear_velocity

32.21 shear_velocity

32.22 z02chezy

32.23 z02ks

33 velocity-profile/@Log_profile

33.1 Log_profile

logarithmic profile of the streamwise velocity

33.2 df_dh

sensitivity of profile with respect to depth

33.3 df_dh_

sensitivity of profile with respect to depth

33.4 df_dln_z0

sensitivity of velocity profile with respect to roughness length

33.5 df_dln_z0_

sensitivity of profile with respect to roughness length

33.6 profile

vertical profile of the streamwise velocity

33.7 profile_

scale of velocity at instrument depth to depth average velocity
roughness length and associated standard error can change in time,
i.e. may be passed as vectors

```
zs      : [1xn] water surface level
zb      : [1x1] bottom level
za      : [1xn] or [1x1]
           level of velocity measurement,
           i.e. level of HADCP beam bin centre, coincides with
           instrument level,
           if the HADCP is horizontally aligned
           only needs to be passed as vector if instrument is
           redeployed or
           becomes misaligned
ln_z0   : [1xn] or [1x1]
           natural logarithm of the roughness length
s       : [1xn] or [1x1]
           standard error of ln_z0
function [fz_mu fz_s fz_sp fz_bias fz_eps] = log_profile(zs,zb,za,
ln_z0,s,sp,e)
```

33.8 profile_bias

33.9 regmtx

regression matrix

33.10 ubar

depth averaged velocity

34 velocity-profile/@Log_profile_with_bend_correction

34.1 Log_profile_with_bend_correction

vertical velocity profile corrected for bend flow

34.2 df_dc

sensitivity of the velocity profile with respect to the bend
correction
parameter c

34.3 df_dc_

34.4 du_dz

34.5 fit

fit the vertical velocity profile

34.6 profile_

vertical velocity profile

34.7 regmtx

regression matrix

34.8 u

streamwise velocity

34.9 u_

streamwise velocity

35 velocity-profile/@Log_profile_with_cubic_wake

35.1 Log_profile_with_cubic_wake

log profile with cubic wake

35.2 df_dc

sensitivity of profile with respect to wave parameter

35.3 df_dc_

sensitivity of profile with respect to wake parameter

35.4 profile_

vertical velocity profile

35.5 regmtx

regression matrix

36 velocity-profile/@Log_profile_with_dip

36.1 Log_profile_with_dip

Logarithmic profile with dip

36.2 fit

fit the vertical velocity profile

37 velocity-profile/@Log_profile_with_linear_bend_correction

37.1 Log_profile_with_linear_bend_correction

log profile with linear bend correction

37.2 df_dc

sensitivity of profile with respect to wake parameter

37.3 df_dc_

sensitivity of velocity profile with respect to wave parameter

37.4 du_dz

velocity shear along vertical

37.5 profile_

velocity profile

37.6 regmtx

regression matrix

38 velocity-profile/@Log_profile_with_wake

38.1 Log_profile_with_wake

logarithmic velocity profile with wake correction
c.f. coles

38.2 df_dc

sensitivity of profile with respect to wake parameter

38.3 df_dc_

sensitivity of velocity profile with respect to wake parameter

38.4 du_dz

velocity shear

38.5 profile_

predict velocity profile

38.6 regmtx

log law with wake

$$u = u_s/k \ln(z) - u_s/k \ln(z_0) + u_s/k (2/H^2 z - 3/H^3 z^2)$$

39 velocity-profile/@VP

39.1 VP

velocity profile

39.2 process_joint

39.3 process_transverse_profile

process the transverse velocity profile

39.4 process_vertical_profile

predict vertical profile error distribution parameter for HADCP
error estimate

39.5 profile_prediction_error

input :
U : [nbin x nens]
- values for each bin (or across section) and ensemble (or
reference measurement)
this are estimates estimates of the discharge or the cross
sectional averaged
velocity from the raw values
- the profile should be limited to the effective profiling
range,
abobj 75-100m for a 600kHz ADCP

dn : distance between HADCP bins
width : cross section width

objput:
sd_n : expected standard deviation for increasing profiling
range

function [s_rel s_err s_dat rho res m2 u_pred fdx] =
velocity_variation(U)
hadcp_prediction_error
TODO take scales and unscaled velocity to do combine with harmmean
estimate

note: previus versions:
residual was computed with respect to the predicted local
velocity
mse was not upscaled to cs, as profile was expected to cover
entire cs
finite width of cs was not considered

parametric estimate from moments, objliers should be filtered
beforehand

Note that the median absolute deviation is not a good estimate,
because it may excludes rare events like reverse flow of floods
thus, the only acceptable more robust estimate would be mean
absolute deviation

40 velocity-profile/@Vertical_profile

40.1 Vertical_profile

vertical profile of the streamwise velocity, superclass

40.2 fit

fit vertical velocity profile parameter

function obj = fit(obj,U,S,h,binmask)

40.3 u

predict velocity along the vertical based on profile

41 velocity-profile

41.1 fit_displacement_profile

fit the log profile to the vertical profile of the streamwise velocity

41.2 lateral_division_method

transverse (across channel) profile of the streamwise velocity
in a straight channel
numerical solution
the eps seems incorrect, use better stationary_1d_swe

$$\rho g h S - \beta q^2 f / (8 h^2) + d/dy(\epsilon_{s,t} dq/dy) = 0$$
$$\rho g h S - \beta q^2 g / (C^2 h^2) + d/dy(\epsilon_{s,t} dq/dy) = 0$$

41.3 test_law_of_the_wall_fit

41.4 transverse_profile_parameter

41.5 transverse_velocity_profile

transverse profile of the streamwise velocity
c.f. shiono knight

41.6 transverse_velocity_profile_olesen

transverse profile of the streamwise velocity in a meander bend

41.7 transverse_velocity_profile_rozovskii

transversal velocity distribution in a bend
Rososkii,
as in the book central differences along the radius and euler
forward in space
are used, note that since the advent of the computer more advanced
schemes
could be used (see build in solvers)
cfl condition is not explicitly checked
Rosovsky assumes a constant water level, e.g. does not consider
superelevation

$I_{\theta} = -1/r \, dz/d_{\theta}$ (p. 22)
 $d_{\theta} = 1/R \, ds|_R$
 $\Rightarrow I_{\theta} = -R/r \, dz/ds = -R/r \, I_0$
It : (1.32) drop of level per unit angle, identical across section

41.8 transverse_velocity_profile_shiono_knight

transverse profile of the streamwise velocity, determined
analytically
by the method of shiono and knight
shape of velocity profile only dependent on λ , f , H , not slope

41.9 transverse_velocity_profile_tidal_channel

41.10 transverse_velocity_profile_with_slope

stationary 1D shallow water equation across a river section
 $0 = -g h S_0 - \tau_b/\rho + d/dn (\nu h du/dn)$
 $0 = -g h S_0 + g u^2/C^2 + d/dn (\nu h du/dn)$
includes tranverse gradient term

note that shiono/knight 1991 provide an `_analytic_` solution,
which takes the form of an exponentially decaying side wall effect

41.11 vertical_profile_of_velocity_vriend

vertical profile of the streamwise velocity, method of de vriend

41.12 vertical_velocity_profile

vertical profile of the streamwise velocity in non-uniform flow

41.13 z2s_rational

42 wrapper

42.1 discharge2stage

wrapper function

42.2 stage2discharge