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Morphological evolution of bifurcation in gravel-bed rivers with erodible banks

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Morphological characteristics of gravel-bed river bifurcations

Field and laboratory observations

Federici and Paola (WRR, 2003), Zolezzi et al. (Braided Rivers, 2003), Bertoldi and Tubino (RCEM, 2005), ...

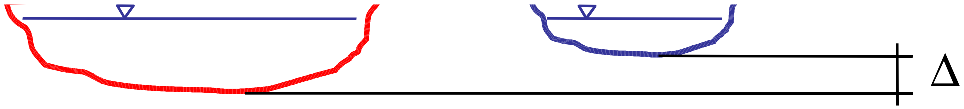
- river bifurcations are typically asymmetrical

one of the two branches is fed with a larger water and sediment discharge

channel widths and water depths are markedly different

- at low values of the Shields parameter bifurcations are highly unstable

- generation of an inlet step



just upstream of the bifurcation diverging streamlines induce sediment deposition

different bed elevations at the inlets of the two branches

- the inlet step induces intense transverse bed load

- migration of alternating bars along the upstream channel

strongly influences the partition of water and sediment discharges in the two branches

produces time fluctuations of the feeding of the two channels

Scope of the present work

Reproducing the main morphological features of gravel-bed river bifurcations through a one dimensional model

↓

Understanding the **basic processes** which govern the morphological evolution of bifurcations

Useful **engineering tool** for river network modeling

Previous 1D models of river bifurcations

- **Wang et al. (JHR, 1995; RCEM Meeting, 2001)**

  first approach to the problem

  empirical “nodal point relationship”

  equilibrium configurations and stability of a simple channel bifurcation

- **Bolla Pittaluga et al. (WRR, 2003)**

  alternative formulation of the nodal point conditions

  richer scenarios of equilibrium solutions of a simple bifurcation

  existence of asymmetrical solutions

  stability conditions depend on the Shields parameter

- **Hirose et al. (RCEM Meeting, 2001)**

  “local” approach to the stability problem

Common fundamental assumptions

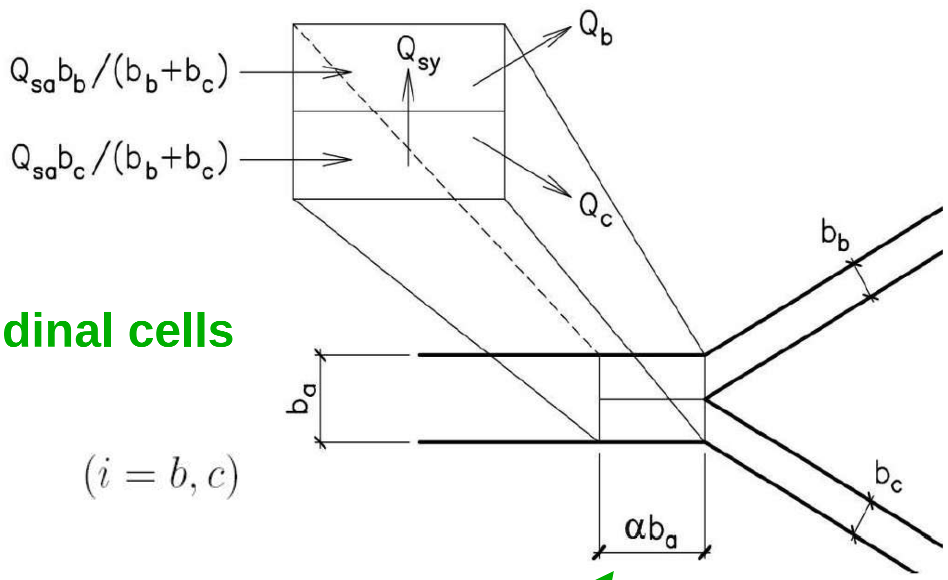
- Constant water discharge

- **Fixed channel widths**

The nodal point conditions proposed by Bolla Pittaluga et al. (2003)

Quasi 2D approach

scheme of the nodal point conditions



upstream distance from the bifurcation at which bed morphology is affected by the bifurcation

1-2 Exner equation applied to the two longitudinal cells

$$\frac{1}{2}(1-p)\left(1+\frac{b_a}{b_b+b_c}\right)\frac{d\eta_i}{dt}+\frac{q_i-q_a\left(\frac{b_a}{b_b+b_c}\right)}{\alpha b_a}\mp\frac{q_y}{b_i}=0 \qquad (i=b,c)$$

2 - 3 water level constancy

$$H_i = H_a \qquad (i=b,c)$$

5 water discharge conservation

$$Q_a = Q_b + Q_c$$

Width adjustments to flow conditions

Regime relationships for channel width → rational / empirical

most of existing regime formulas have been developed for single thread channels rather than single branches of a braided river

in case of gravel bed braided rivers we can hardly think of "regime conditions"

Regressions on field data from single branches in braided rivers (Ashmore, 2001)

$$b = 0.087\ \Omega^{0.599} d_s^{-0.445}$$

b channel width

d_s mean sediment diameter

$\Omega = \gamma S Q$ stream power

Important note

the use of the above formula implies a further relationship between the dimensionless parameters that govern the problem

constant width case

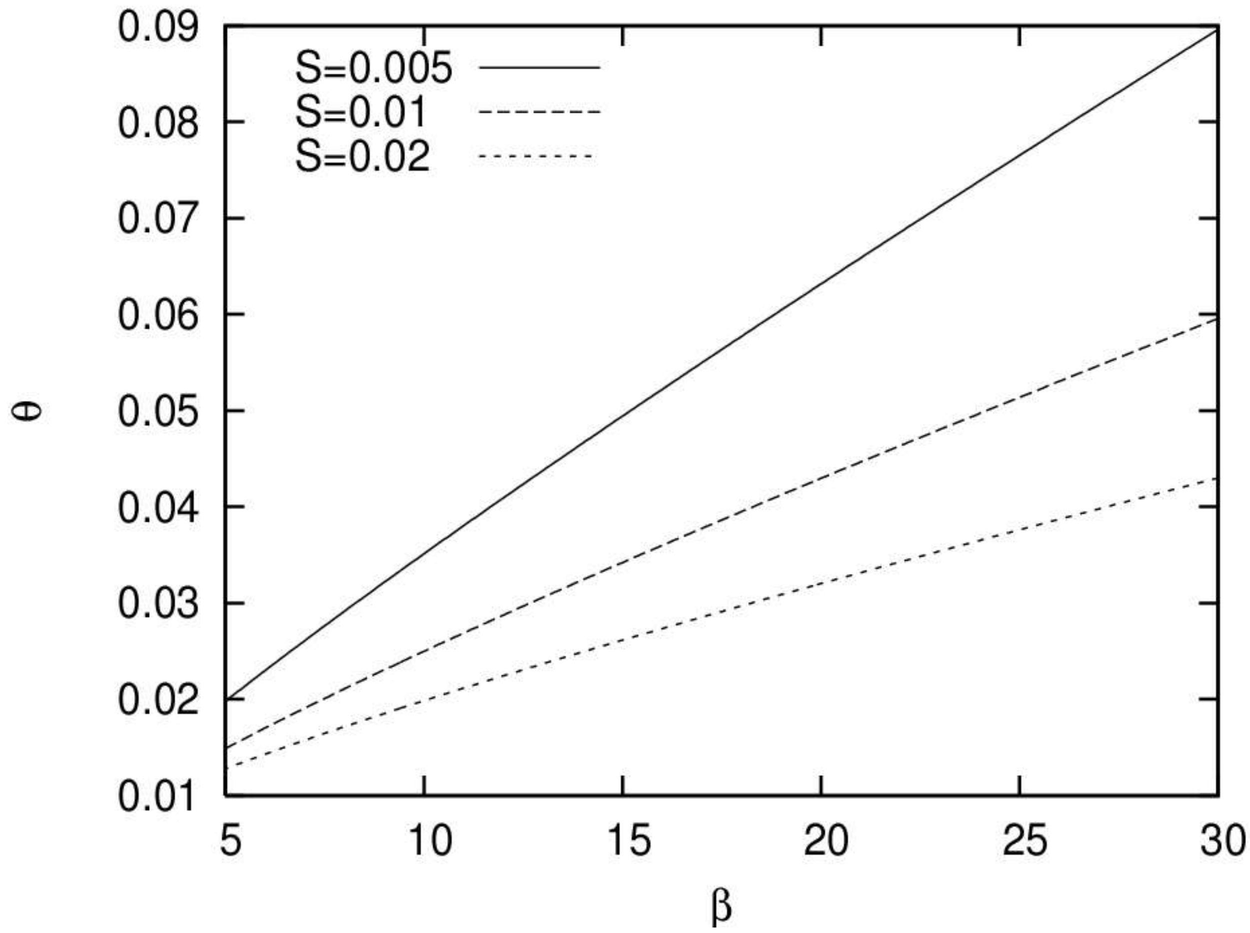
S channel slope
β channel aspect ratio
θ Shields stress

→ three parameters are required to completely define the flow in dimensionless form

variable width case

only 2 dimensionless parameters

Relationship between β and θ as predicted by the formula proposed by Ashmore (2001)

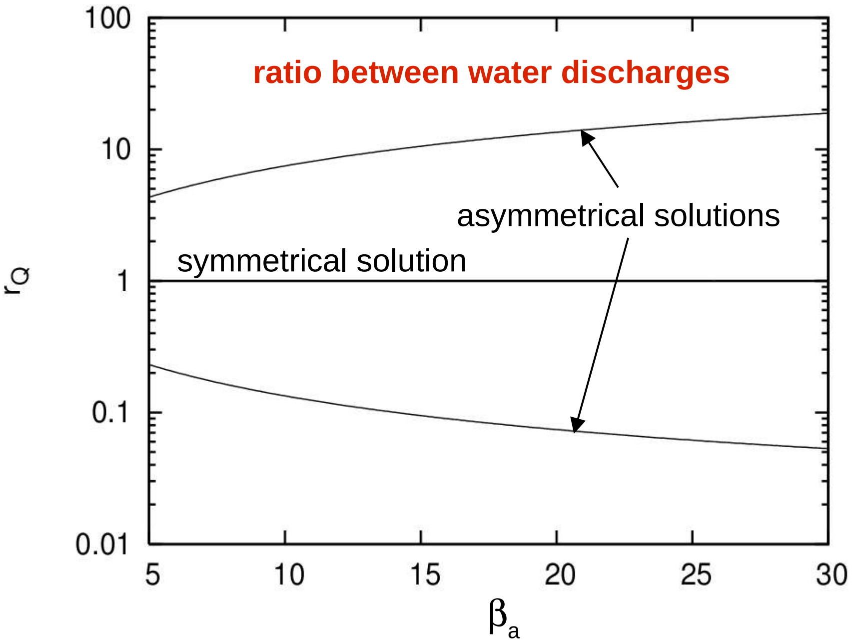


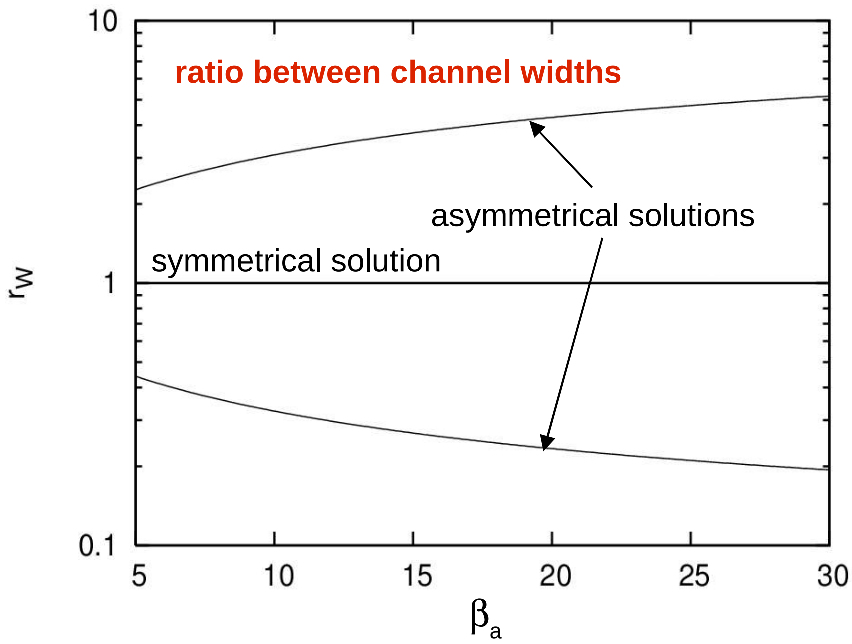
θ=Shields parameter, β=aspect ratio, S=channel slope

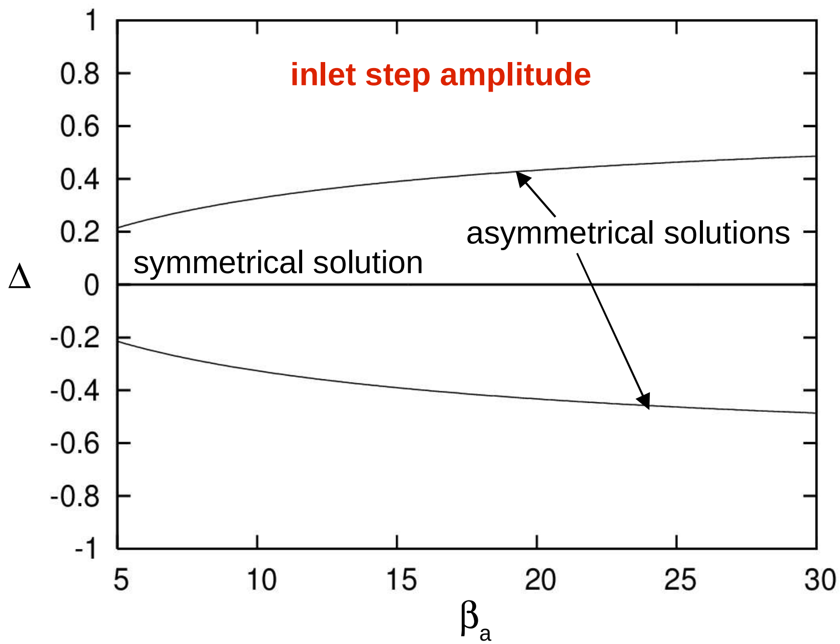
Note: the predicted values of the Shields parameter are very low

close to critical conditions for sediment motion

Equilibrium configurations of a bifurcation







for any value of the controlling parameters three equilibrium solutions exist

- **1 symmetrical solution**
- **2 asymmetrical and reciprocal solutions**

Stability of the equilibrium configurations

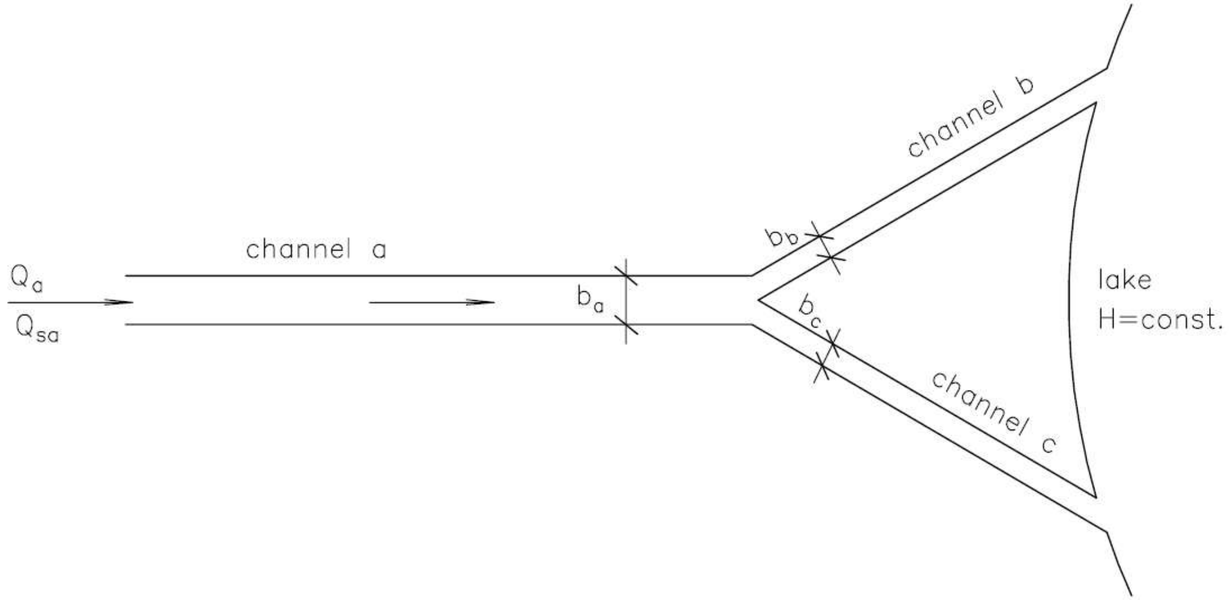
Approach followed by Wang et al. (1995) and Bolla Pittaluga et al. (2003)

stability of the whole network ("network approach")

the nodal point conditions are coupled with **two further Exner equations relative to the two downstream branches** under the assumption of uniform flow throughout the network

$$(1-p)\frac{d\eta_b}{dt} = \frac{q_b^{(i)} - q_b^{(o)}}{L_b}$$

$$(1-p)\frac{d\eta_c}{dt} = \frac{q_c^{(i)} - q_c^{(o)}}{L_c}$$



Bolla Pittaluga et al. found that when three solutions exist the symmetrical one is unstable and the other two are stable

Stability of the equilibrium configurations

Local approach

- only the nodal point conditions are employed to study the stability of the bifurcation

$$\frac{1}{2}(1-p)\left(1+\frac{b_a}{b_b+b_c}\right)\frac{\mathrm{d}\eta_i}{\mathrm{d}t}+\frac{q_i-q_a\left(\frac{b_a}{b_b+b_c}\right)}{\alpha b_a}\mp\frac{q_y}{b_i}=0 \qquad (i=b,c)$$

.....

- backwater effects are disregarded
- **correct time scale of the system evolution**

It can be shown that the present "local approach" is recovered from the "network approach" adopted by Bolla Pittaluga et al. in the limiting case of downstream channels with vanishing length

Results

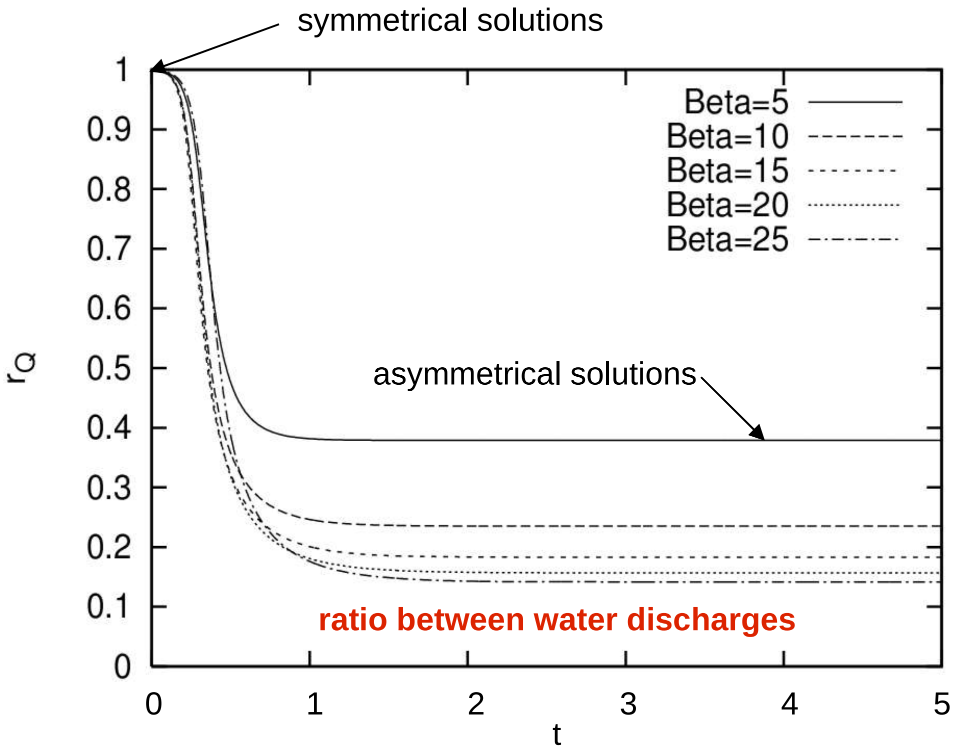
In agreement with the results by Bolla Pittaluga et al. we find that

the symmetrical solution is unstable

the asymmetrical solution are stable

Stability of the equilibrium configurations

Results



t dimensionless time scaled with the morphological time scale $T_m = (1-p)\frac{Db}{q_s}$

Summarizing: a first outcome of the model

in agreement with field and laboratory observations

the model predicts that in equilibrium conditions gravel-bed channels bifurcations are invariably asymmetrical

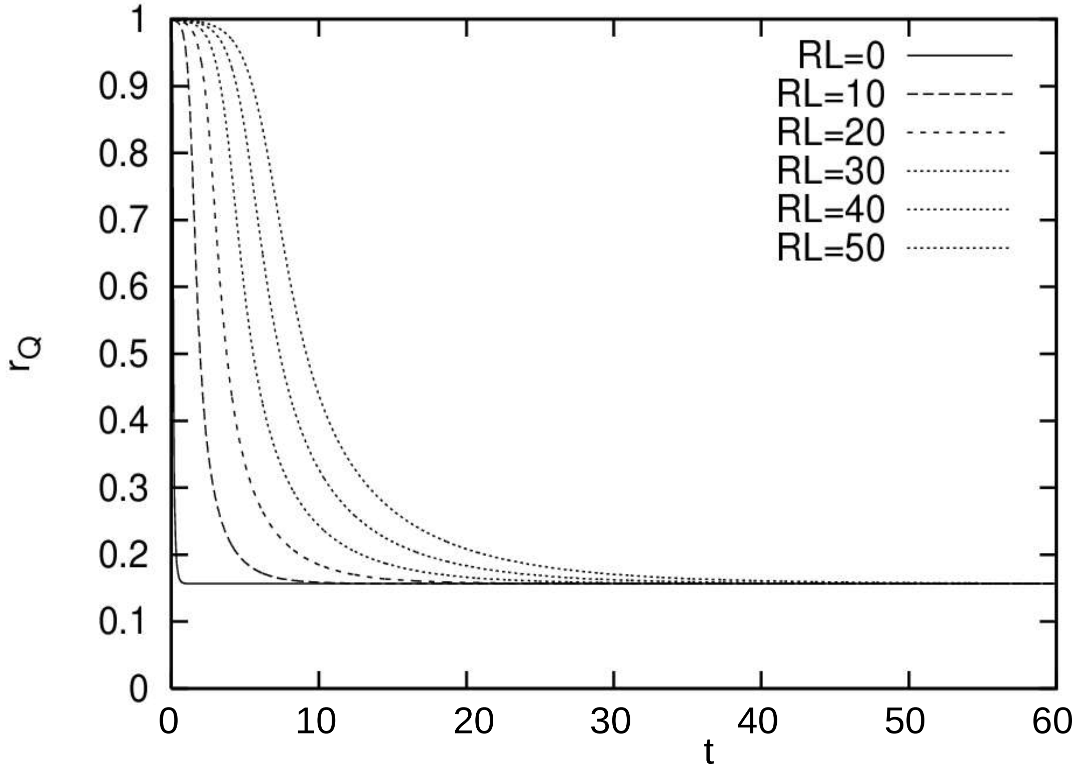
Stability of the equilibrium configurations

Network stability

the time scale of evolution of the system is relative to the whole network and therefore crucially depends on the length of the downstream branches

Local stability

the time scale of system evolution is set by the nodal point conditions



RL=ratio between downstream channel length and upstream channel width

time evolution of the ratio between water discharges for different values of the downstream channel lengths

Is a "regime relationship" suitable to describe the time evolution of a bifurcation?

According to the adopted relationship:

- increase of water discharge ⇒ channel widening
- decrease of water discharge ⇒ channel narrowing

field and laboratory observations suggest that the second process is by far less intense than the first one in the case of gravel-bed rivers

Does the mechanism of generation of a bifurcation play any role on its equilibrium configuration?

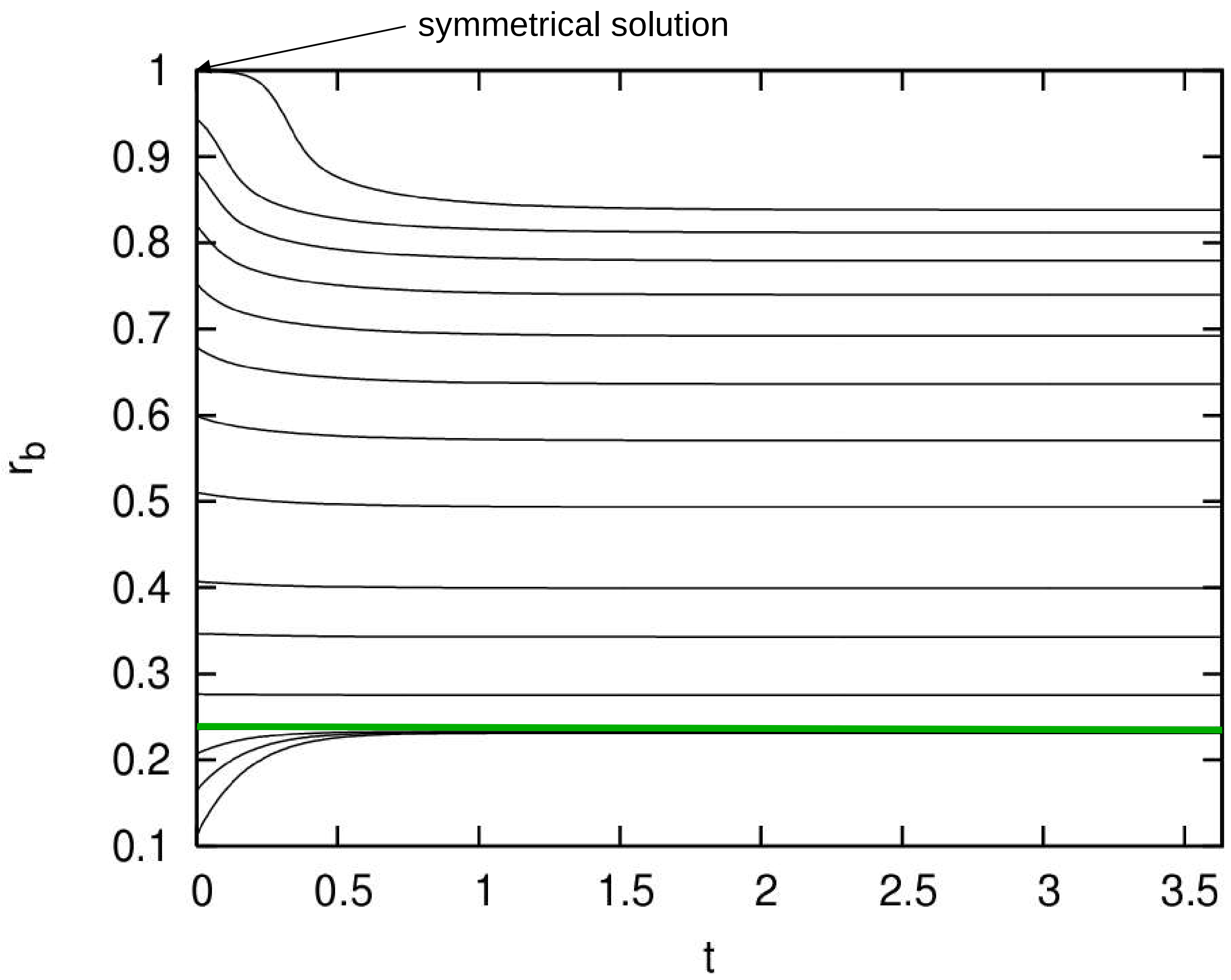
bifurcation generated from the deposition of a central bar

bifurcation generated through the incision of a new channel

in order reproduce the above effect we performed simulations allowing channel widening and inhibiting channel narrowing

Time evolution of the system for different initial conditions

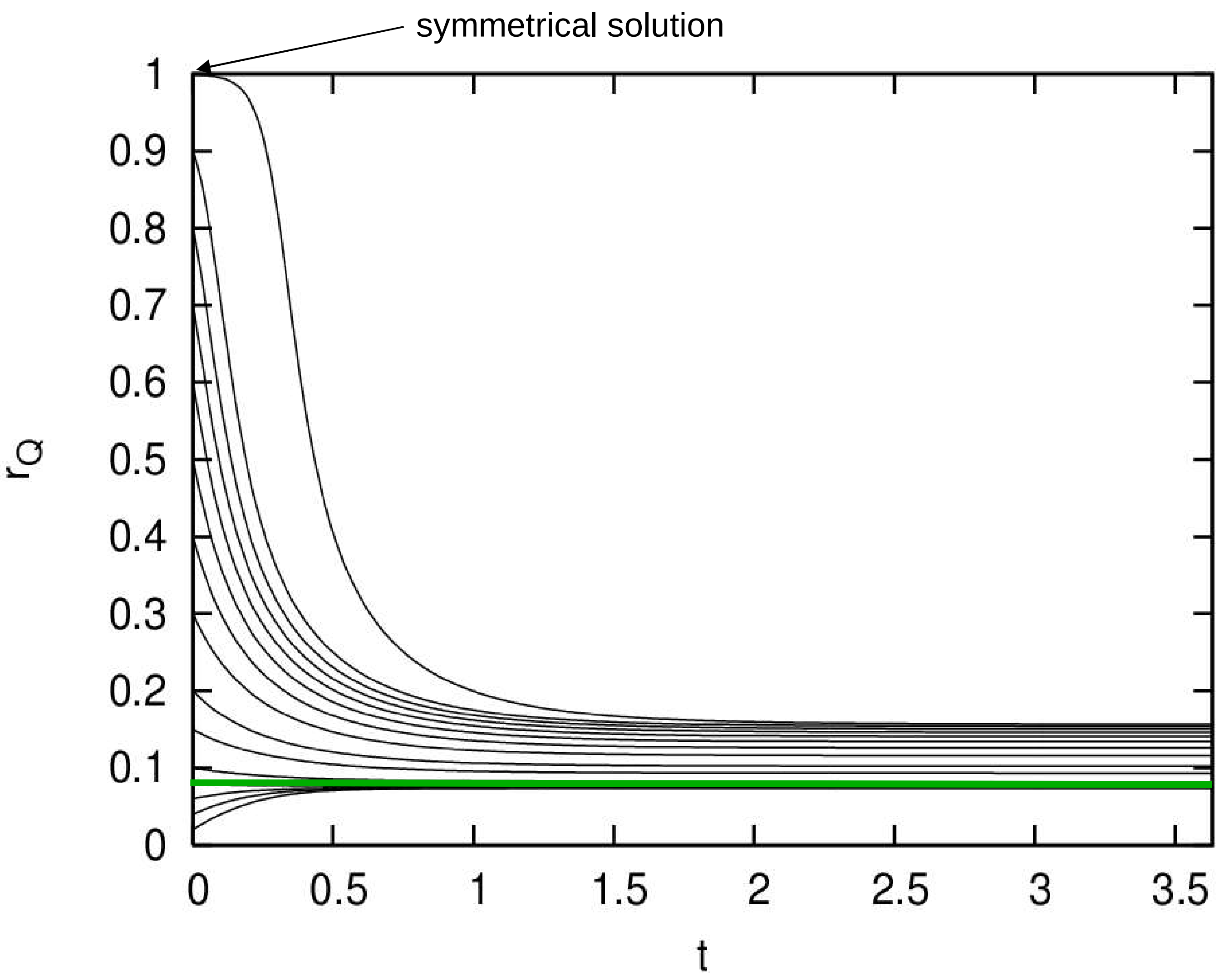
ratio r_b between channel widths versus time



the final solution reached by the bifurcation strongly depends on the initial conditions (mechanism of generation)

Time evolution of the system for different initial conditions

ratio r_q between water discharges



the final solution varies within a relatively narrow range

Conclusions

- if width is not kept fixed the model invariably predicts strongly asymmetrical stable configuration

- generation of an inlet step

- a “local” stability analysis has been adopted

correct time scale of the system evolution

this may be important to study the interaction between the evolution of the system and unsteady forcing effects such as

- width variations in time
- migration of alternate bars along the upstream channel

- the processes of channel widening and narrowing have been reproduced in a simple manner

the model shows that the mechanism of generation of a bifurcation affects the equilibrium configurations

- strong influence on the planimetric shape of the bifurcation
- weak influence on the ratio between water discharges