COMPLEX DYNAMIC PHENOMENA IN
ENVIRONMENTAL PLANNING AND MANAGEMENT
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1. ENVIROMENTAL MANAGEMENT AND NONLINEAR DYNAMICS
   An overwiew of the most typical problems one encounters in enviromental planning and management. Emphasis on relationships with nonlinear dynamics.Further reading: *Journal of Enviromental Management* (1996), 48, 357-373.

2. THE PROBLEM OF FLOATING PLANTS IN RESERVOIRS
   Description of the problem through a model of competition between floating and submerged plants. Analysis of the model: alternative stable states. Bifurcation analysis and derivation of possible control actions. Analysys of the history of Lake Kariba on the Zambesi river.
   Further raeading: *PNAS* (2003), 100, 4040-4045.

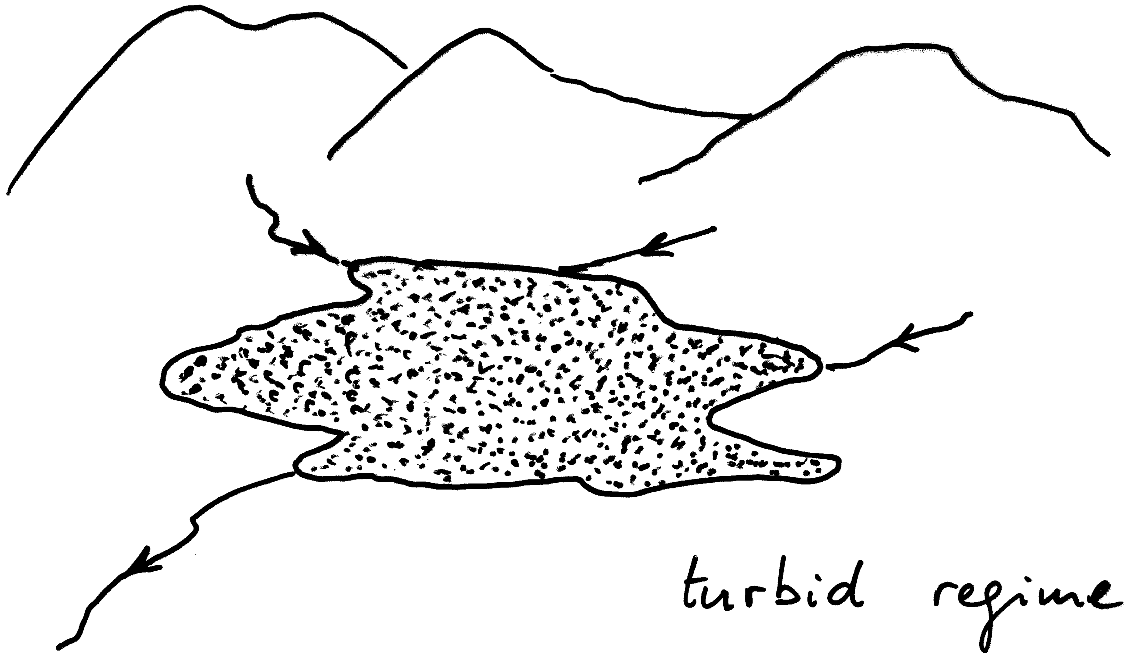
3. FOREST EXPLOITATION AND ACID RAIN: A DANGEROUS MIX
   Description of the problem through a series of minimal models. Existence of catastrophic bifurcations (forest collapse). Cusp bifurcation: negative synergistic effect of acid rain and exploitation.
   Further reading: *Vegetatio* (1987), 69, 213-222
   Appl. Math. Modelling (1989), 13, 674-681
   Theor. Pop. Biol. (1998), 54, 257-269.

4. THE RECLAMATION OF EUTROPHIC WATER BODIES
   Description of the problem in terms of minimal models involving algae, zooplankton and planktivorous fish. Analysis of the bifurcations of the model: the appearance and disappearance of clear-water regimes. Biological control.
   Further reading: *OIKOS* (1997), 80, 519-532.

5. TOURISM SUSTAINABILITY: AN OVERVIEW
   The three components of the problem: tourists, environment and facilities. Detection of possible scenarios. Profitable, compatible and sustainable policies. Adaptivity. The case of alternative classes of tourists and of diversified investments.
   Further reading: *Conservation Ecology* (2002), 6(1): 13 [online].
   Chaos and Complexity Letters (2004) first issue (in the press).

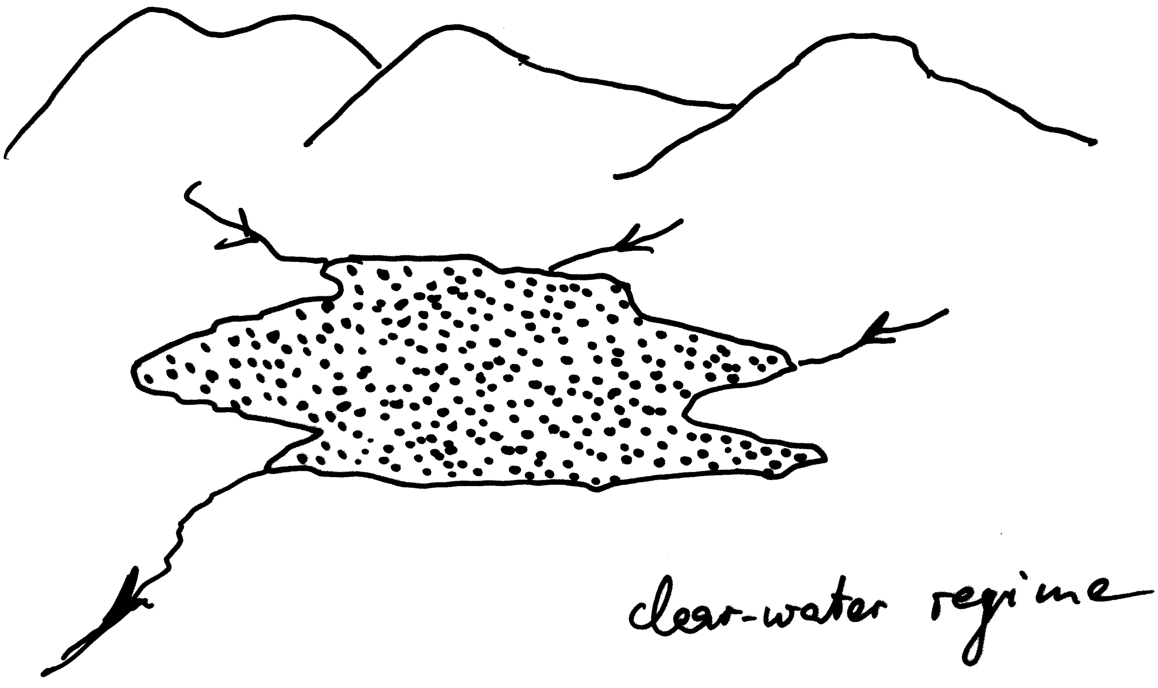
6. ENRICHMENT AND YIELD MAXIMIZATION
   Exploitation of renewable resources. Enrichment and mean yield maximization. Analysis of the case of tritrophic food chains. Optimality at the edge of chaos. Derivation of management rules.
   Further reading: *Am. Nat.* (1997) 150, 328-345
   Bull. Math. Biol. (1998) 60, 703-719
   Ecol. Lett. (1999) 2, 6-10
   J. Math. Biol. (2002) 45, 396-418.

RECLAMATION OF EUTROPHIC WATER BODIES

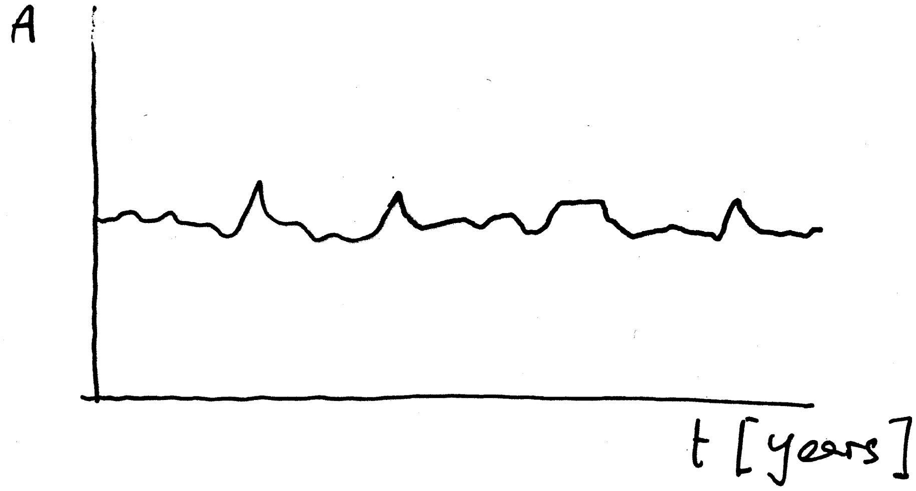


turbid regime

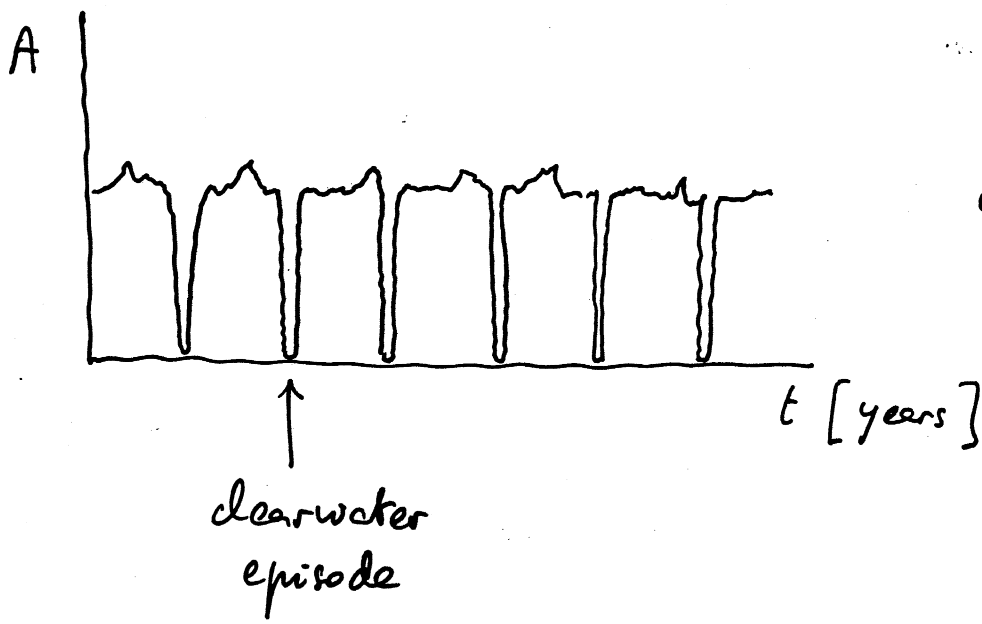
⇓ ?



clear-water regime



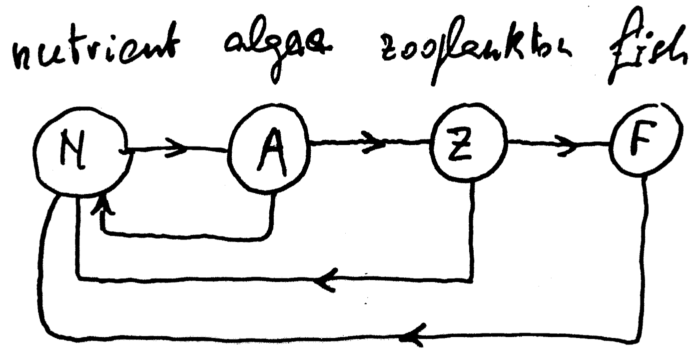
turbid regime
T



clearwater regime
CW

Lakes
- always turbid — T regime
- 1 c.w.e. / year — CW regime
- 2 c.w.e. / year — CW regime
- random — random regi

STRUCTURE OF THE MODEL



$$\dot{N} = f_N (N, A, Z, F)$$

$$\dot{A} = f_A (N, A, Z)$$

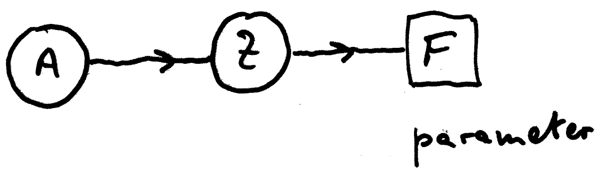
$$\dot{Z} = f_Z (A, Z, F)$$

$$\dot{F} = f_F (Z, F)$$

high nutrient concentration $\Rightarrow$ N does not count

different time scales $\Rightarrow$ F is exogenous

$$\Downarrow$$



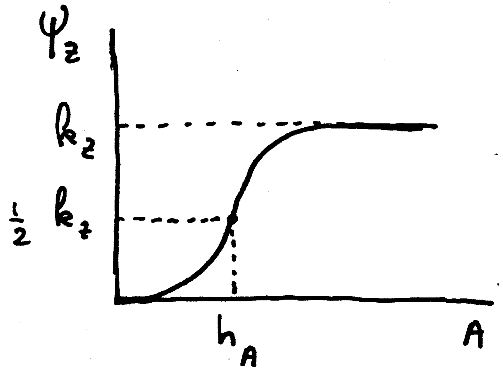
THE MODEL

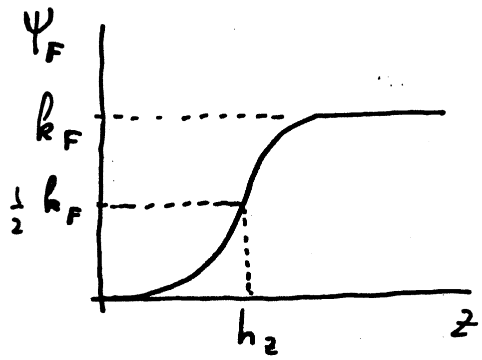
$$\dot{A} = r\,A\left(1 - \frac{A}{k}\right) - Z\,\psi_z(A)$$ algae

$$\dot{Z} = e\,Z\,\psi_z(A) - m\,Z - F\,\psi_F(Z)$$ zooplankton

planktivorous fish

$$A \to Z \to \boxed{F}$$





$$\psi_z(A) = k_z \frac{A^2}{A^2 + h_A^2} \qquad \psi_F(Z) = k_F \frac{Z^2}{Z^2 + h_z^2}$$

9 parameters $\quad r, k, e, m, \boxed{F}, k_z, h_A, k_F, h_z$

Seasons : parameters vary periodically

No seasons : parameters are constant

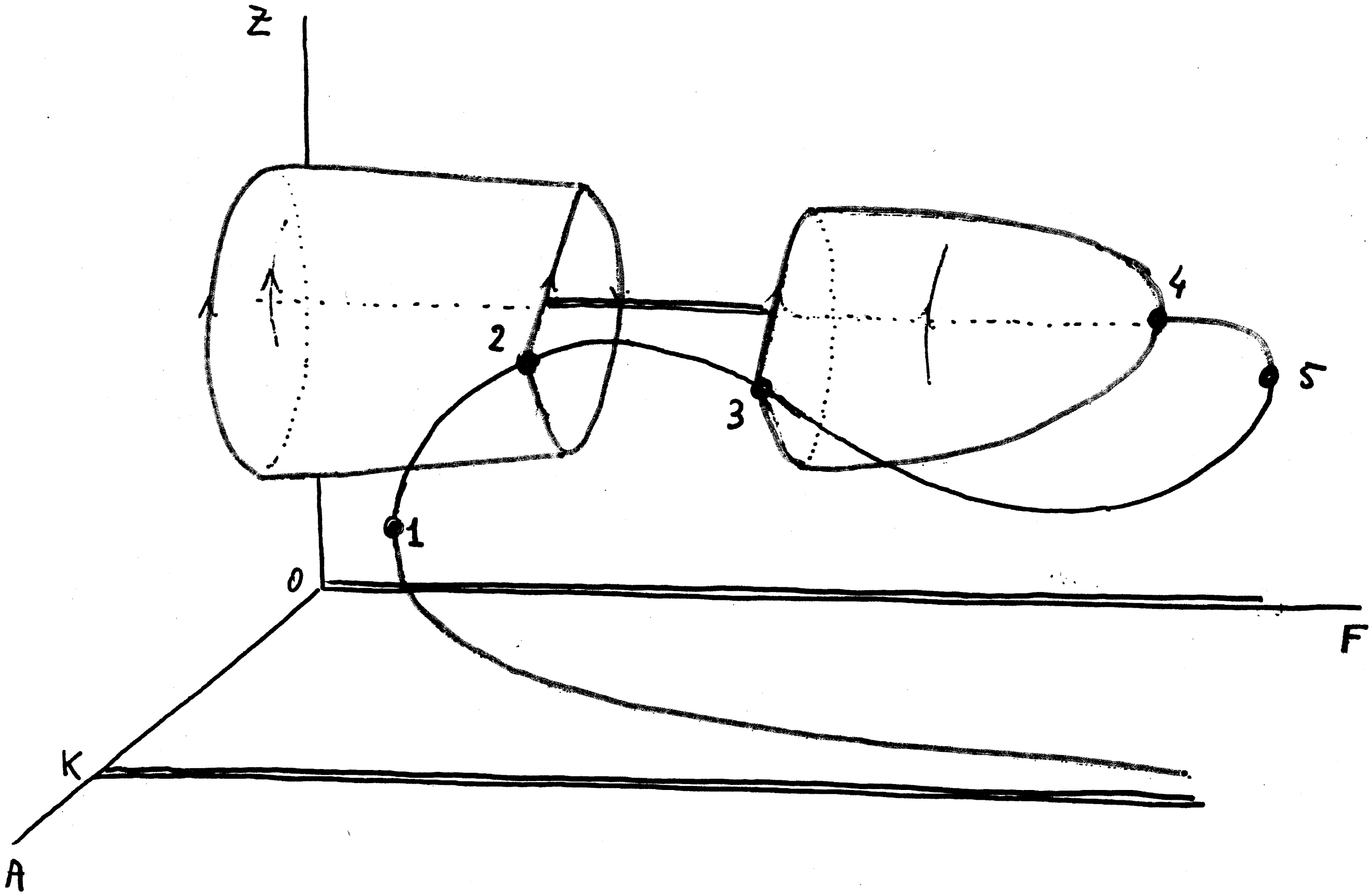
CONSTANT ENVIRONMENT (constant parameters)

<u>Problem</u> Fix all parameters <u>but F</u> and find all bifurcations w.r.t. F

- Interest of this analysis $\longrightarrow 0$ (only chemosta
- But analysis is needed for the seasonal versio(*)
- Why only F ? Because it works.

(*) See <u>Oikos</u> <u>80</u> 519-532 (1997) for the analysis of seasonal effects

CONTROL DIAGRAM



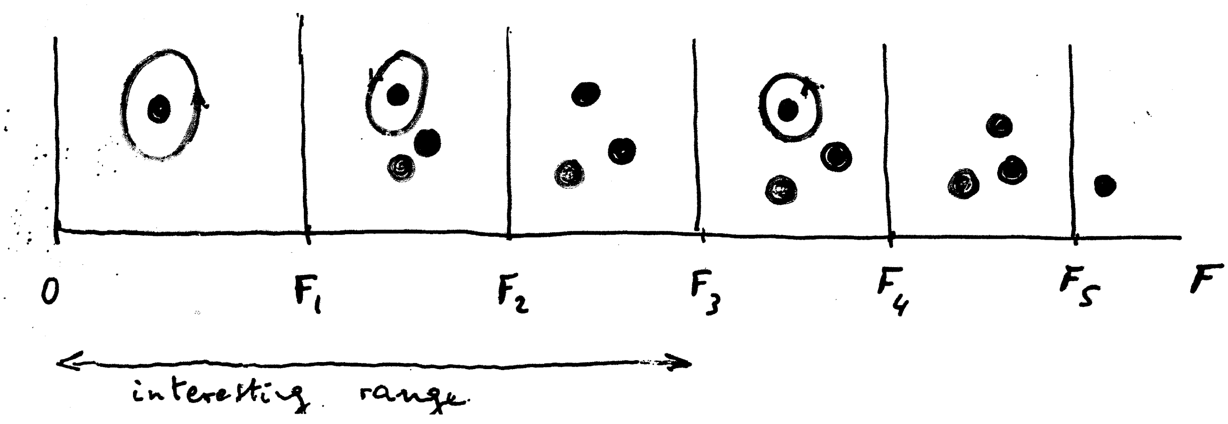
1 saddle-node (fold)

2 homoclinic } global bifurcations (?)

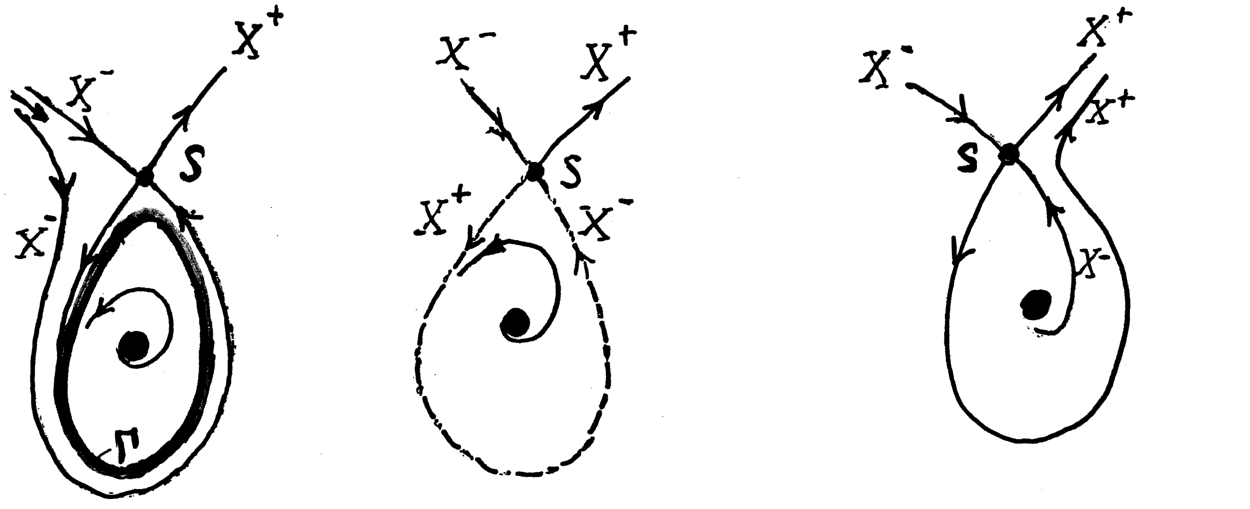
3 homoclinic

4 Hopf

5 saddle-node (fold)

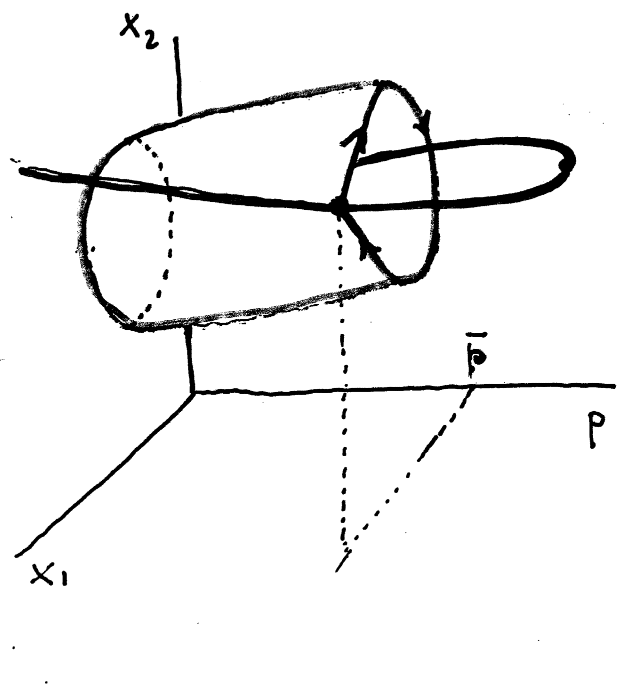


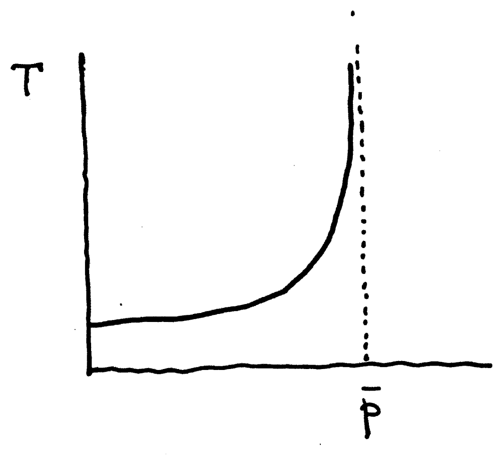
Homoclinic Bifurcation



$p < \bar{p}$ $\qquad$ $p = \bar{p}$ $\qquad$ $p > \bar{p}$

$$X^+ \cap X^- \neq \phi$$

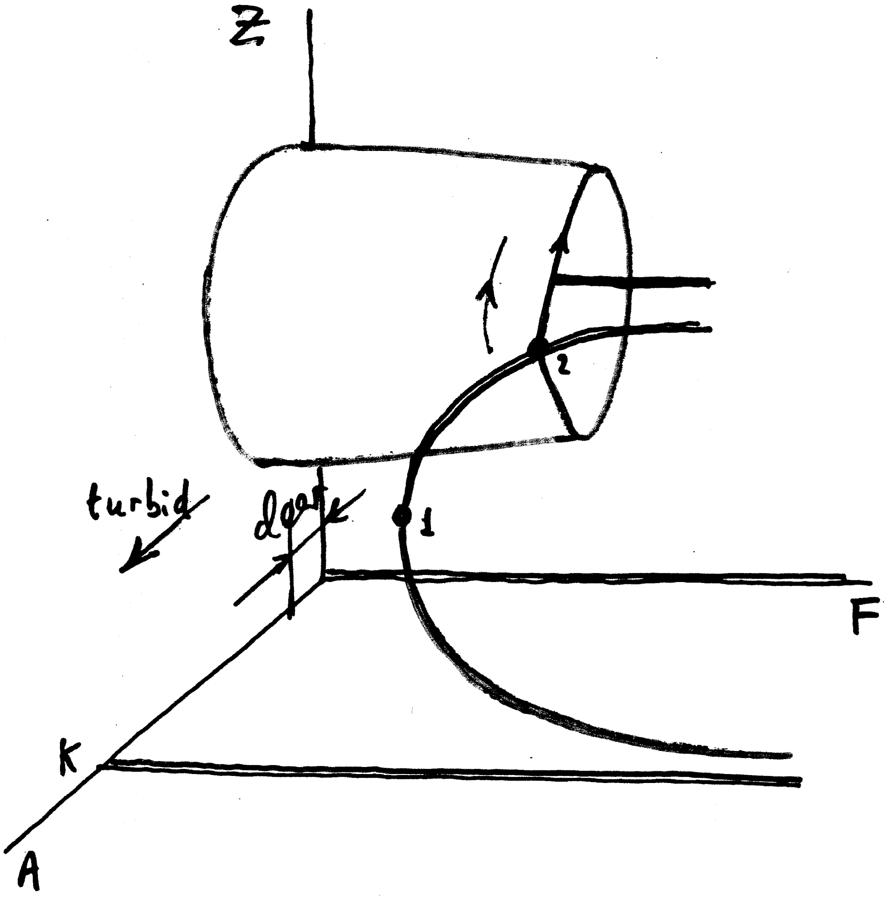


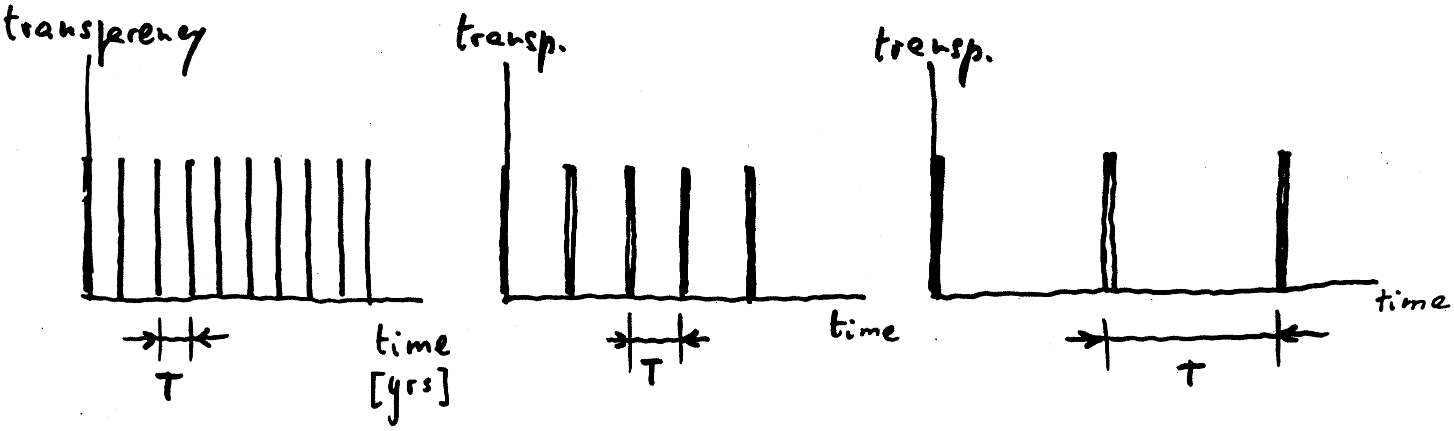


The period of the cycle tends to ∞ approaching the homoclin

FISH REGULATES CLEAR WATER EPISODES

↑ actually their frequency





$F \ll F_2$ $\qquad$ $F < F_2$ $\qquad$ $F = F_2 - \varepsilon$

CW episodes are always strong, but more and more rare if F is increased. If F is sufficiently high the lake is permanently turbid.

<u>Restoration</u> : release carnivorous fish $\Rightarrow F\downarrow$