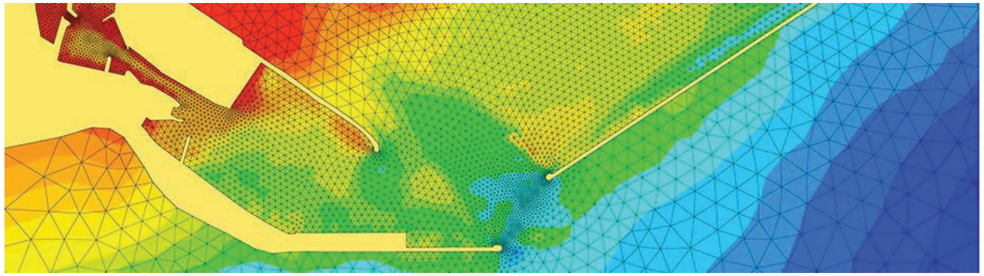
General Introduction of hydrodynamic: Presentation of Telemac, governing equations mathematical properties, numerical aspects



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Acknowledgments

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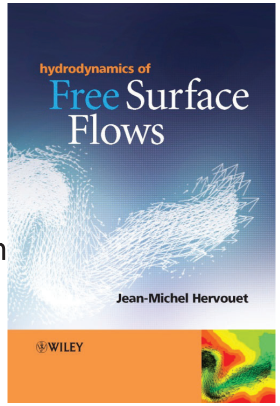
- …

Sources of information

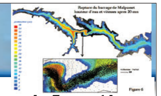
- On the Website: www.opentelemac.org

- **User manual**
- Reference manual
- Forum and Frequently Asked Questions
- Guide to programming in the Telemac system
- Release notes for every new version
- At Wiley editors (published in 2007)



- "Hydrodynamics of free surface flows", by Jean-Michel Hervouet

What is TELEMAC?



- TELEMAC system is a set of FE&FV programs designed for the open channel flows which uses a string of common processes.
- It contains two and three dimension modules for the study of currents, sedimentation, waves and water quality, …etc..
- Forming the core of this system, **TELEMAC-2D**, the first module of this package, is a program for the solution of the two dimensional Saint-Venant equations.
- The water depth and the velocity averaged on the vertical are the main variables, but the transport of a passive tracer as well as turbulence can be taken into consideration.
- Telemac-3D for solving the three-dimensional Navier-Stokes equations with or without the hydrostatic pressure assumption.
- TELEMAC-2D can be used for numerous studies in fluvial, coastal, sediment transport, salinity, contamination, flood, GW

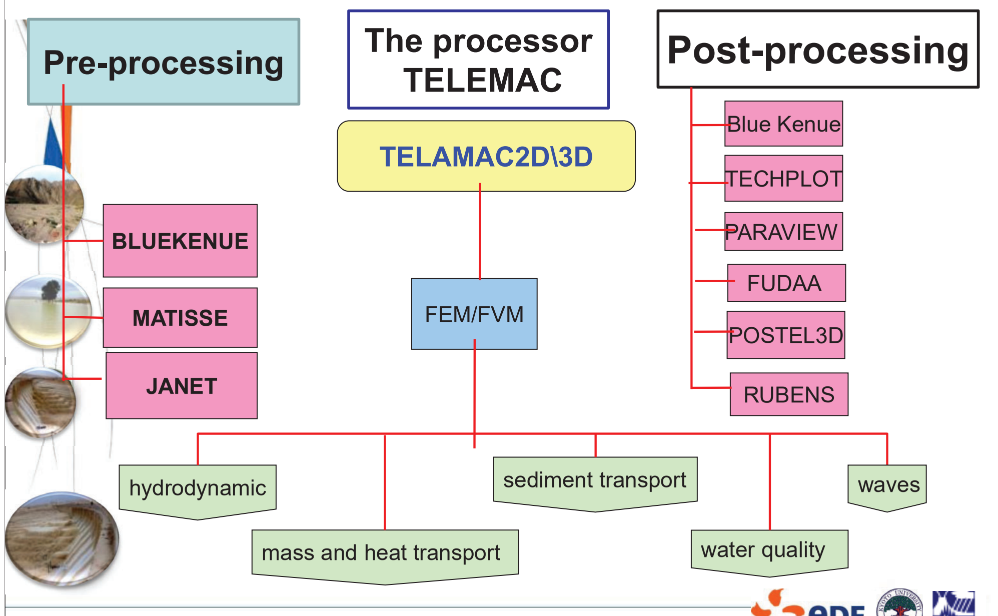
What is TELEMAC?

- TELEMAC is an integrated open-source group of solvers suitable for modelling free surface water developed since **1987**
- TELEMAC is built up according to the wishes of the users by successive addition of new functions (**toppings selection**)
- Based on unstructured grids
- Parallelism with domain decomposition
- World distributed (first commercial with 200 licenses, now freeware and open source)
- As this could lead to an increasing complexity, a constant effort to upgrade and simplify the program are continuously done by developer EDF in France and is now under the directorship of a consortium of organizations including EDF, HR Wallingford, Sogreah-Artelia, BAW and CETMEF.
- Software developments are carried out by staff from these organizations and many universities and other organizations.

The Processor, TELEMAC

	1D	2D	3D
HYDRODYNAMICS	MASCARET	TELEMAC-2D	TELEMAC-3D
MORPHODYNAMICS & Sediment transport	COURLIS	GAIA SISYPHE -2D NESTOR/ DREDGESIM	TELEMAC-3D GAIA SEDI-3D
WATER QUALITY	TRACER	WAQTEL or DELWAQ	With DELWAQ
GROUND WATER		ESTEL-2D	ESTEL-3D
WAVES		ARTEMIS TOMAWAC	
Hydrology		CEQEAU	
Mass & heat transport			

Modeling system, pre- and post-processing tools



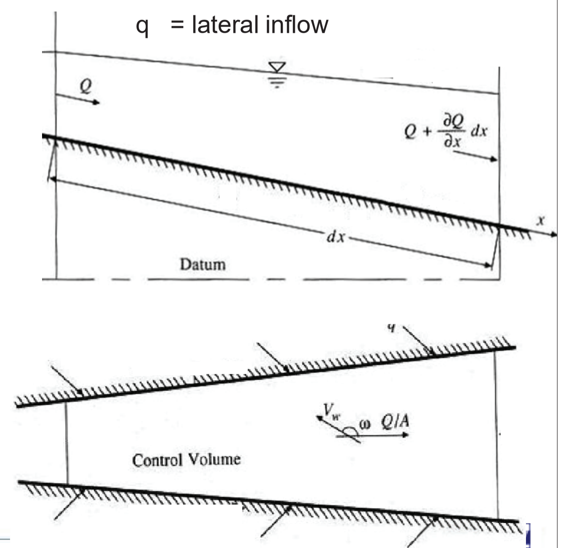
(Hervouet, 2007)

One-Dimensional Open Channel Flow

In the diagrams given,

Q = inflow to the control volume

q = lateral inflow



$\frac{\partial Q}{\partial x}$ = Rate of change of flow with distance

$Q + \frac{\partial Q}{\partial x} dx$ = Outflow from the C.V.

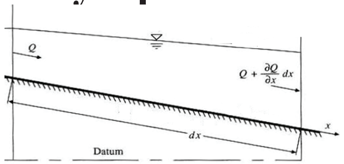
$\frac{\partial(\rho A dx)}{\partial t}$ = Change in mass

Three Conservation Laws

- Conservation of Mass (Continuity eq.)
- Conservation of Momentum (Momentum equation)
- Conservation of Energy (Energy equation)

Conservation of Mass (Continuity equation

Q = AV = volume water discharge [L^3/T]
ρQ = Mass water discharge = ρAV [M/T]



∂/∂t(Mass in control volume) = Net mass inflow rate (q=0)

$$\frac{\partial(\rho A)}{\partial t}\Delta x = \rho AV\big|_x - \rho AV\big|_{x+\Delta x} = -\rho\frac{\partial(AV)}{\partial x}\Delta x$$

$$i.e\ \frac{\partial(\rho A)}{\partial t}\Delta x + \rho\frac{\partial(AV)}{\partial x}\Delta x = 0 \qquad \Rightarrow \rho\Delta x\left(\frac{\partial A}{\partial t}+\frac{\partial AV}{\partial x}\right)=0;$$

Here Q = AV is the discharge through the cross section

$$\boxed{\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial X}=0}$$

Conservation of Momentum (Momentum equation)

In mechanics, as per **Newton's 2nd Law:**

Net force = time rate of change of momentum

$$\underbrace{\sum F_s}_{\text{Sum of forces in the s direction}} = \Delta(\overbrace{m}^{\text{mass}}\overbrace{v_s}^{\text{Velocity in the s direction}})$$

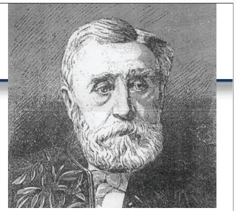
Change in momentum in the s direction

$$\sum F = \frac{d}{dt}\iiint_{c.v.} V\rho d\forall + \iint_{c.s.} V\rho V.dA$$

Sum of forces on the C.V.
Momentum stored within the C.V
Momentum flow across the C. S.

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial y}{\partial x}-g(S_o-S_f)=0$$

Governing Equations



Jean Claude Saint-Venant
1797-1886

- St.Venant equations are derived from Navier-Stokes Equations for shallow water flow conditions.

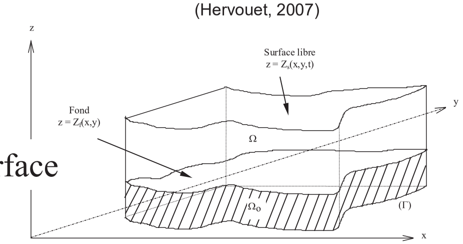
Assumptions of Shallow Water Equations

1- Hydrostatic pressure: p = ρg(Z_s-z)

2- No vertical acceleration (hence no wind waves)

3- No flow through bottom and free surface

(Hervouet, 2007)



Principle

Average of Navier-Stokes equations between bottom and free surface

$$u=\frac{1}{h}\int_{Z_f}^{Z_s}U\,dz \qquad v=\frac{1}{h}\int_{Z_f}^{Z_s}V\,dz$$

Horizontal velocity averaged on the vertical

Navier-Stokes equations for an incompressible fluid, in cartesian coordinates

Continuity

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial z}=0$$

« Momentum »

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+W\frac{\partial U}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\Delta U+F_x$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+W\frac{\partial V}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\Delta V+F_y$$

$$\frac{\partial W}{\partial t}+U\frac{\partial W}{\partial x}+V\frac{\partial W}{\partial y}+W\frac{\partial W}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+g+\nu\Delta W+F_z$$

(Hervouet, 2007)

Equations for 2D simulations

Conservation of mass

$$\frac{\partial h}{\partial t} + \vec{u} grad\ h + h\ div \vec{u} = Sce$$

Conservation of momentum

$$\frac{\partial u}{\partial t} + \vec{u}\ grad\ u = -g\frac{\partial Zs}{\partial x} + F_x + \frac{1}{h}div(h\nu_e grad\ u)$$

$$\frac{\partial \upsilon}{\partial t} + \vec{u}\ grad\ \upsilon = -g\frac{\partial Zs}{\partial x} + F_y + \frac{1}{h}div(h\nu_e grad\ \upsilon)$$

Advection

Gradient of hydrostatic pressure (propagation)

Source terms, friction

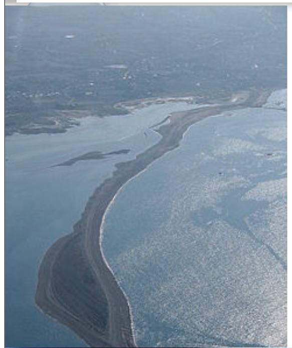
Diffusion Turbulence Dispersion

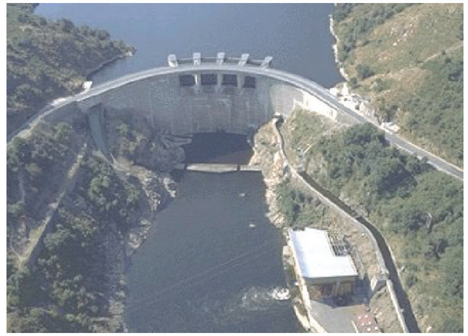
Transport equation

$$\frac{\partial T}{\partial t} + \vec{u}\ grad\, T - \frac{1}{h}div\,(\nu_t\ grad\ T) = \frac{(T_{sce} - T)Sce}{h}$$

(Hervouet, 2007)

Hydrodynamics/ Hydrology modeling

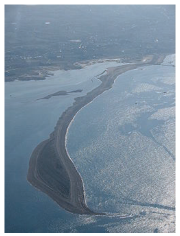




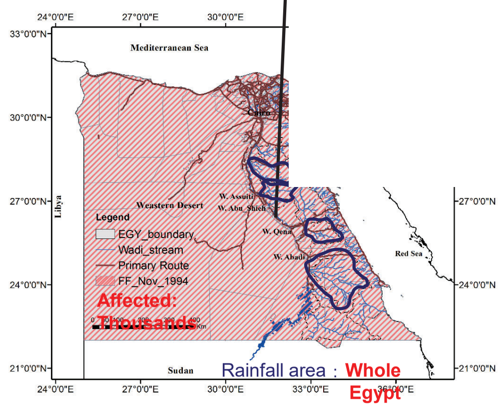
Hydrodynamics TELEMAC-2D

What is it ?

- Shallow water equations (Saint-Venant)
- Meshes of triangles
- FV and FE kernels
- Dry zones
- Turbulence models
- Tracers (temperature, pollutants, etc.)
- Oil Spill, algae
- Weirs
- Culverts
- Bridges
- Sources and sinks
- Open boundary conditions

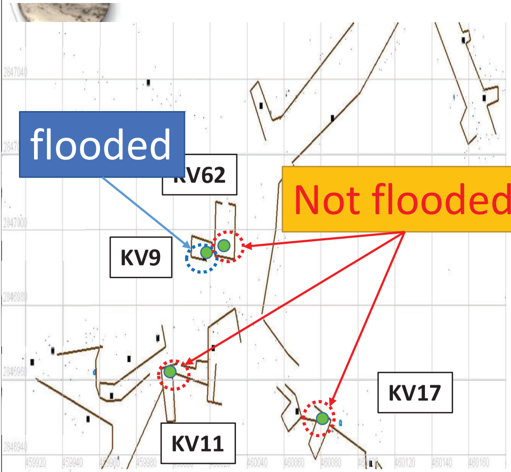


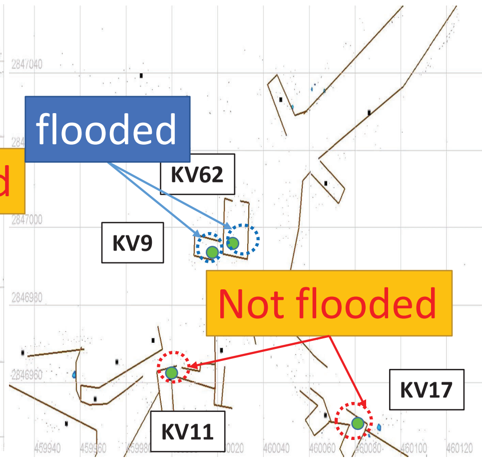
Risk assessment of flash floods in the Valley of the Kings, Egypt



Risk assessment of flash floods in the Valley of the Kings, Egypt

The simulations in the of 1994 flood, rainfall of 50-year return period and 100 return period were implemented



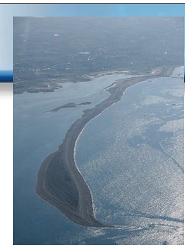


KV62 and KV9 were flooded with the rainfall of 100-year return period

Hydrodynamics TELEMAC-3D

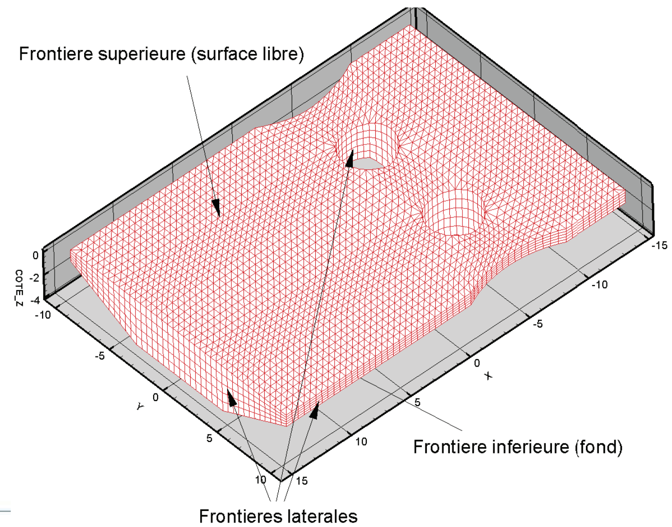
Telemac-3D

- Navier-Stokes equations
- Finite elements, finite volumes
- Meshes of prisms (superimposed 2D meshes)
- Hydrostatic and Non hydrostatic versions
- Dynamic free surface
- Dry zones,
- Turbulence models
- Active and passive tracers
- Conservative advection schemes
- Sediment transport
- MPI-based parallelism



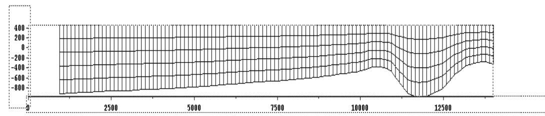
Hydrodynamics TELEMAC-3D

- 2D model (Saint-Venant) $\xrightarrow{\text{Easy + ~free}}$ 3D (Navier-Stokes)
- 2D mesh extruded in the vertical direction

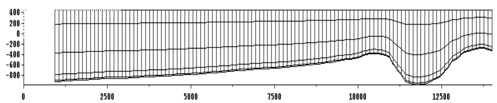


Hydrodynamics TELEMAC-3D

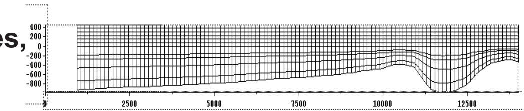
- Different ways for mesh extrusion (keyword: MESH TRANSFRMATION)
- = 1 : σ, equi-distant planes



- = 2 : σ, user-defined repartition of planes (routine `CONDIM.f`)



- = 3 : σ, with some fixed planes, (routine `CONDIM.f`



TELEMAC-3D: Marine and river pollution

Main objectives

- Heat transfer in oceans and rivers
- Pollutant advection and diffusion for water quality
- Automatic Oil spill pollution simulation
- Behaviour of algae and micro-organisms
- etc.

Offshore and near-shore wave modelling

Main objectives

- Wave forecasting for coastal design
- Extreme wave prediction for navigation and people safety
- Conception of offshore platforms and wind turbines.

III-Sediment transport and morphodynamics

Main objectives

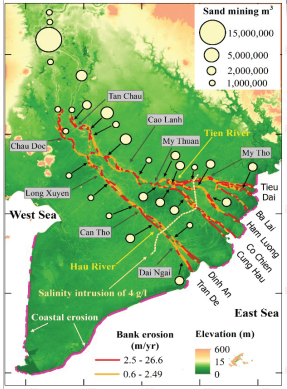
- Sand transport in oceans, coastal erosion, shoreline behaviour
- Turbidity in rivers and estuaries for water quality studies
- High mud transport rates during floods
- Morphodynamics of rivers, river meandering
- etc.

Telemac-2D/3D and Sisyphe coupled

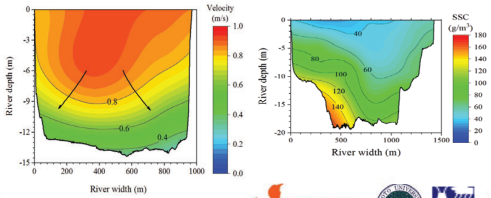
Sediment Transport Models

The dunes attained quasi-equilibrium features after about 2.5 hours of computational time

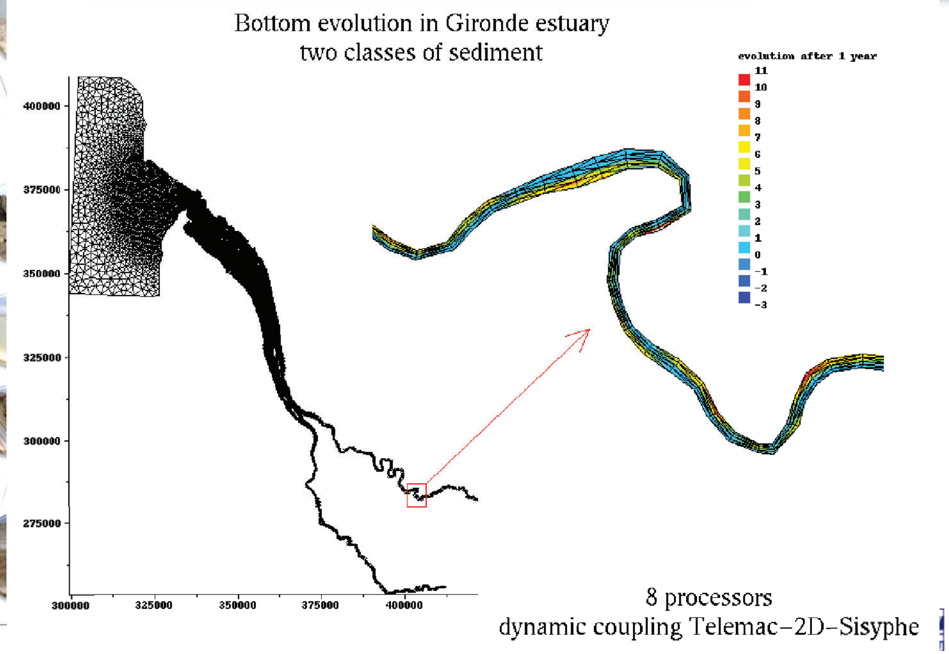
Morphodynamics in Mekong Delta



Source: PhD of Dr. Doan Van Binh



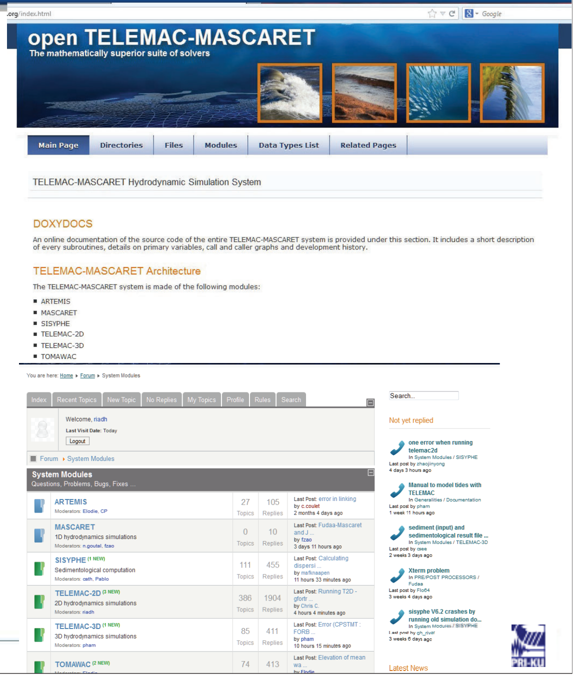
Telemac-2D/3D and Sisyphe coupled



Website and documentation

www.opentelemac.org

http://svn.opentelemac.org/svn/opentelemac/tags/



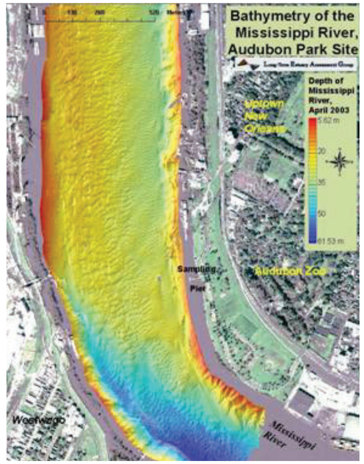
Documents

- User manual
- Reference manual
- Validation manual
- Principle manual

Sediment transport morphodynamics

FELIX M. EXNER AND THE ORIGINS OF MORPHODYNAMICS

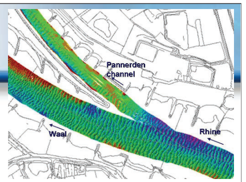
- Felix Maria **Exner** was an Austrian researcher who was active in the early part of the 20th Century.
- His main area of interest was meteorology. At some point he became interested in the formation of dunes in rivers (Exner, 1920, 1925; see also Leliavsky, 1966).
- In the course of his research on the subject, **he derived and employed one version of the various statements of conservation of bed sediment that are now referred to as "Exner equations."**
- In addition, he made an important early contribution to 1D nonlinear wave dynamics.



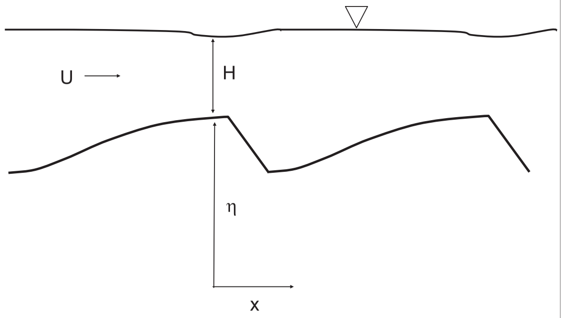
s in the Mississippi River, New Orleans, USA
Image from LUMCON web page:
http://weather.lumcon.edu/weatherdata/audubon/map.html

Source: Gary Parker November, 2004

EXNER'S QUESTION: *WHY ARE DUNES ASYMMETRIC?*



The parameters:
x = streamwise distance [L]
t = time [T]
η= bed elevation [L]
q_t = volume total sediment transport rate per unit stream width [L^2/T]
λ_p = bed porosity [1]
g = acceleration of gravity [L/T^2]
H = flow depth [L]
U = depth-averaged flow velocity [L/T]
C_f = bed friction coefficient [1]



The notation in brackets denotes dimensions: M denotes mass, L denotes length and T denotes time. The bed friction coefficient is defined such that $\tau_b = \rho C_f U^2$, where τ_b denotes bed shear stress [$M/L/T^2$] and ρ denotes water density [M/L^3].

Source: Gary Parker November, 2004

THE EQUATIONS

St. Venant shallow water equations:

$$\boxed{\begin{aligned}&\frac{\partial H}{\partial t}+\frac{\partial UH}{\partial x}=0\\&\frac{\partial UH}{\partial t}+\frac{\partial U^2H}{\partial x}=-\frac{1}{2}gH\frac{\partial H}{\partial x}-gH\frac{\partial \eta}{\partial x}-C_fU^2\end{aligned}}$$

These are statements of conservation of water mass and momentum in a 1D river (constant width).

Exner's equation of conservation of bed sediment:

$$(1-p)\left(\frac{\partial z_b}{\partial t}\right)_k+\frac{\partial(q_{bk}\cos\alpha_k)}{\partial x}+\frac{\partial(q_{bk}\sin\alpha_k)}{\partial y}=0$$

Where,
p = porosity of bed material
α_k = angle between the bedload direction and the x-axis
$\left(\frac{\partial z_b}{\partial t}\right)_k$ = rate of change in bed elevation corresponding to the k[th] fraction size.

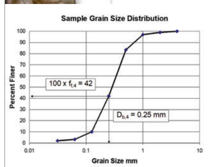
Source: Gary Parker November, 2004

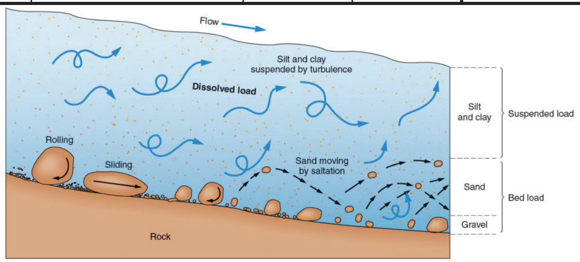
Sketch of sediment transport in water

Type	D (mm)	ψ	ϕ	Notes
Clay	< 0.002	< -9	> 9	Usually cohesive
Silt	0.002 ~ 0.0625	-9 ~ -4	4 ~ 9	Cohesive ~ non-cohesive
Sand	0.0625 ~ 2	-4 ~ 1	-1 ~ 4	Non-cohesive
Gravel	2 ~ 64	1 ~ 6	-6 ~ -1	"
Cobbles	64 ~ 256	6 ~ 8	-8 ~ -6	"
Boulders	> 256	> 8	< -8	"

Grain size standard by (a) AGU, (b) USCS.

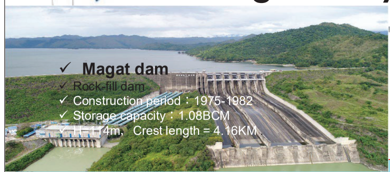
non-cohesive
cohesive

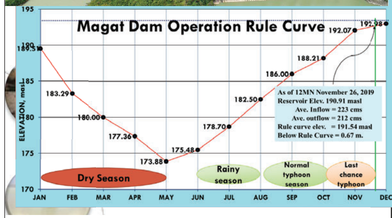


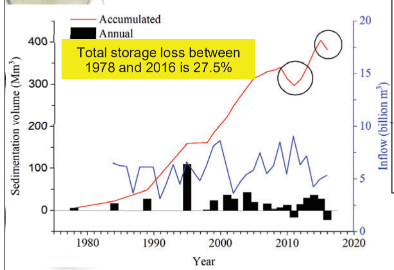


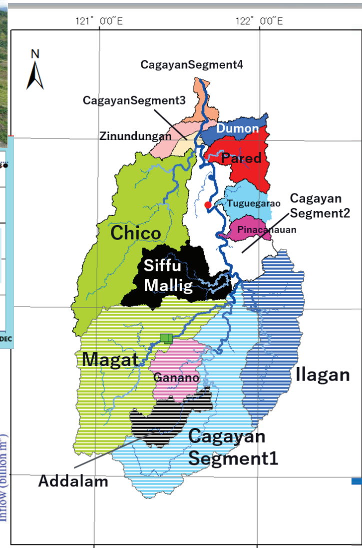
(http://worldrivers.net/2020/03/31/sediment-transport/)

The target study area during the Training Course

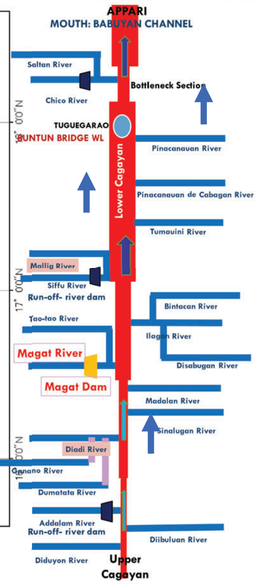






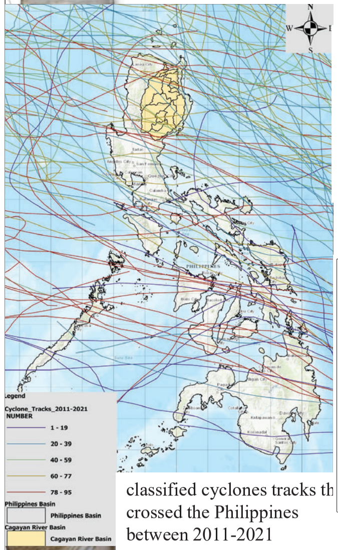


Cagayan River and 15 subbasins

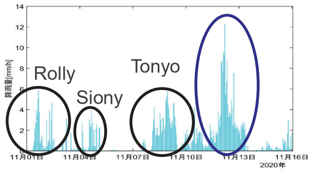


SCHEMATIC DIAGRAM OF CAGAYAN RIVER & ITS TRIBUTARIES

Successive Typhoons and Flooding in CRB



classified cyclones tracks th crossed the Philippines between 2011-2021



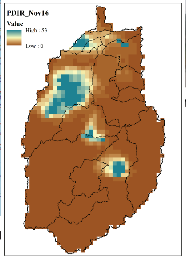
There are **7** typhoons from Oct to Nov in 2020

ULYSSES

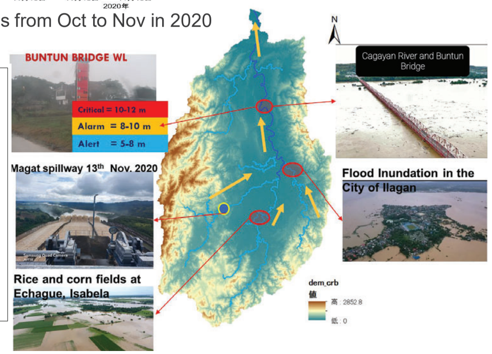
✓ 73 death and 85 injured

➢ *Annual flood damage cost : 400,000 USD/year*

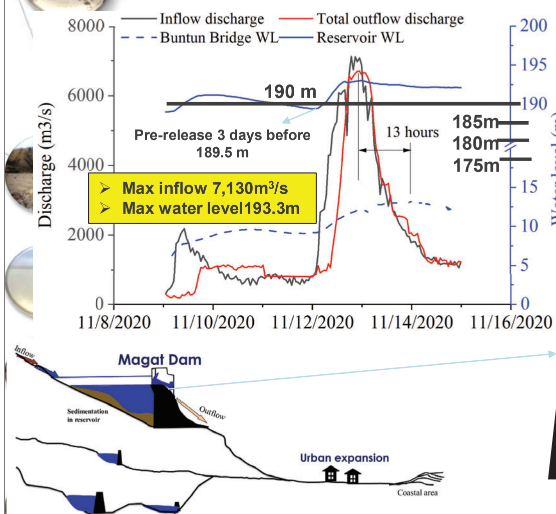
➢ *The number of casualty: 59 persons/year*

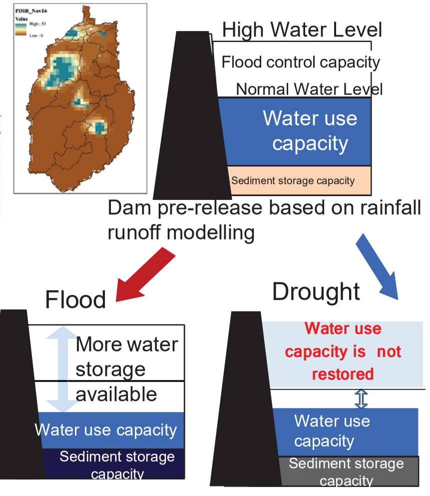


Spatial total rainfall

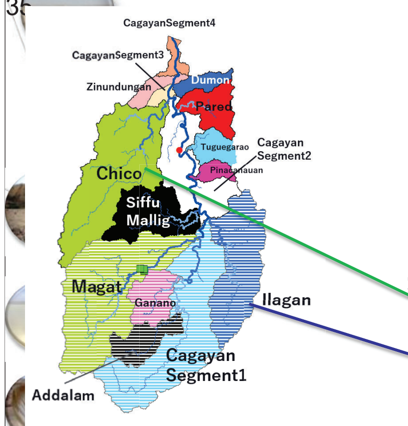


Inflow, outflow, and reservoir and downstream elevation in typhoons Ulysses 2020





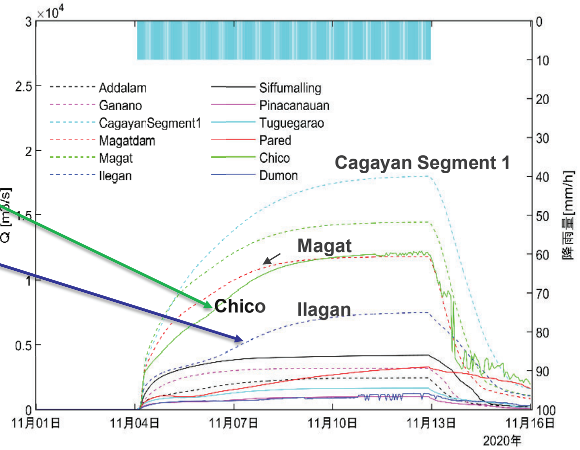
Results of the hydrological responses and the contribution of each tributary under synthetic rainfall



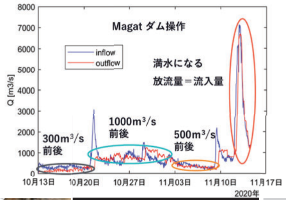
➢ **Cagayan Segment-1 36.6%**

➢ **Magat 29.8%**

➢ **Ilagan 14.6%**



Simulation Scenarios with dams: Optimized operation and additional dams



Magat dam's operation

Constant discharge 100m³/s, 300m³/s 500m³/s, 1000m³/s

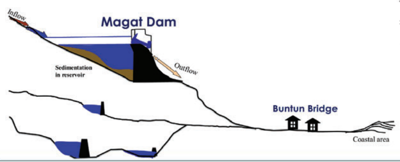
constant rate released
Flood control start discharge (300m³/s, 500m³/s, 1000m³/s) + Discharge rate (α=0.3, 0.5, 0.7, 0.9)

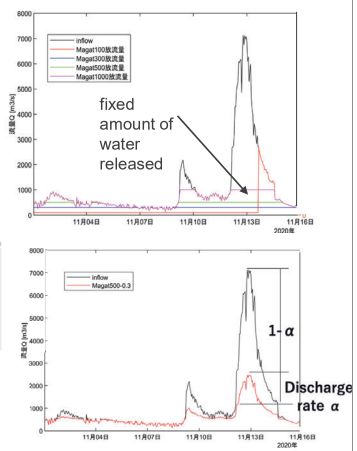
With additional proposed dams in other sub-basins

Cagayan Segment-1
Ilagan1
Ilagan2

Cagayan Segment1

Ilagan



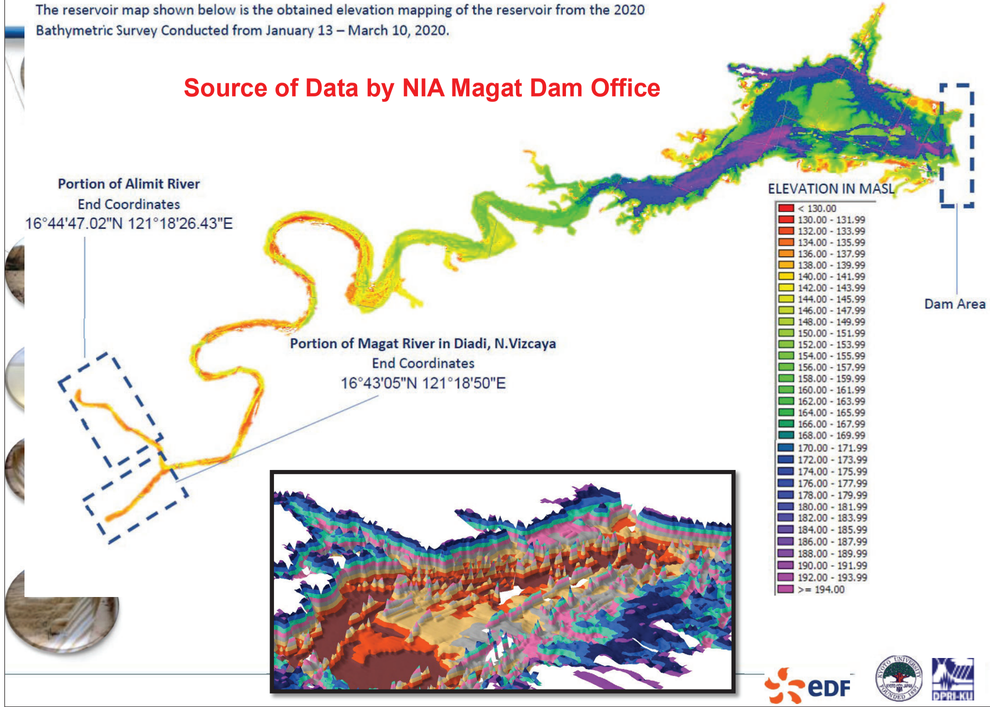


Sedimentation of Magat Dam Reservoir

- Bathymetric surveys showed that more than 30% the reservoir trapping efficiency
- Annual average sedimentation rate in the reservoir of 20 MCM/yr (5.5 times)
- The rate of siltation in the live storage is 16.3 MCM/yr and 3.7m MCM/yr in the dead storage
- It is expected that the power generation will stop most probably within 6 years without partial flushing implementation.
- Maybe also the irrigation service area will be affected or reduced by 393 ha/yr

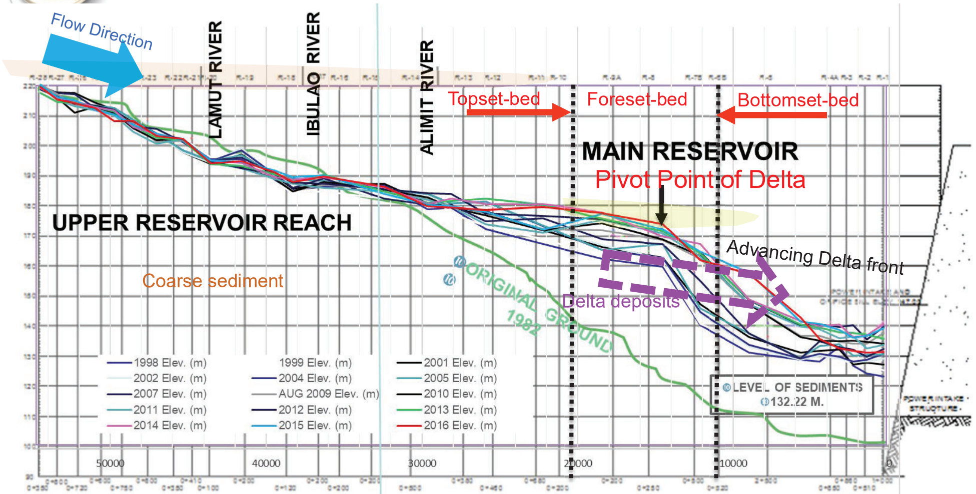
The reservoir map shown below is the obtained elevation mapping of the reservoir from the 2020 Bathymetric Survey Conducted from January 13 – March 10, 2020.

Source of Data by NIA Magat Dam Office

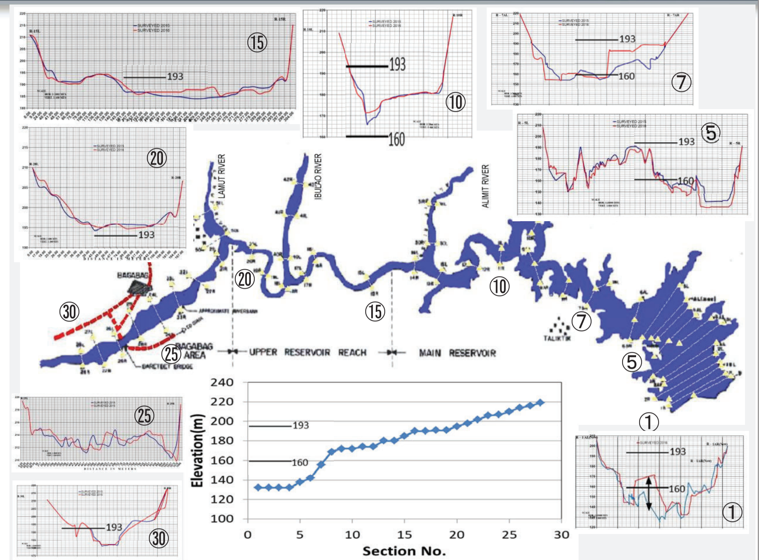


Longitudinal Profile of Sediment Deposition along Magat Reservoir

Source of Data by NIA Magat Dam Office

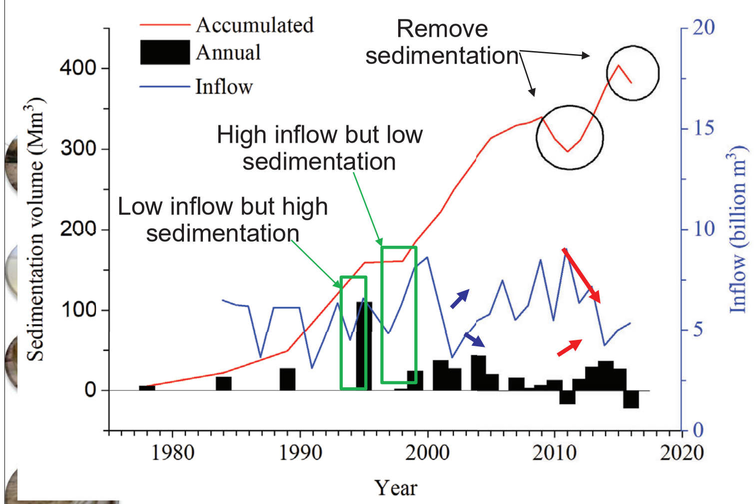


Bathymetric Surveys in Magat reservoir



Source of Data by NIA Magat Dam Office

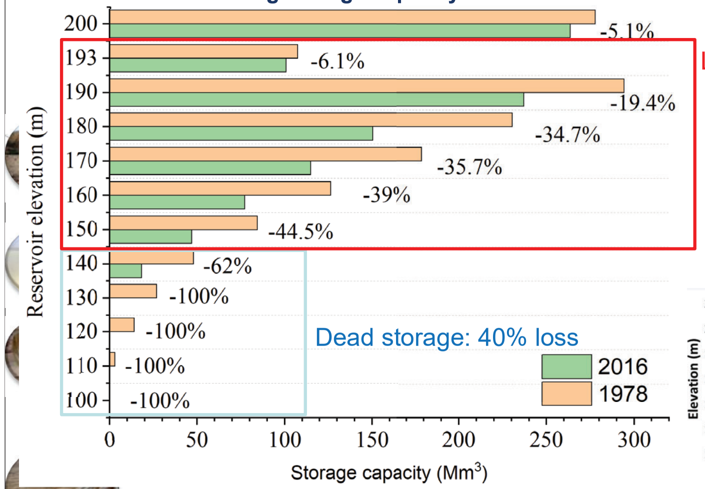
Annual and accumulated sedimentation in Magat dam



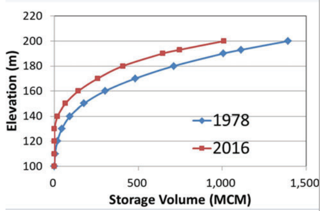
Sedimentation = **40%** live and dead reservoir capacity

Source of Data by NIA Magat Dam Office

Losing storage capacity due to sedimentation in Magat dam

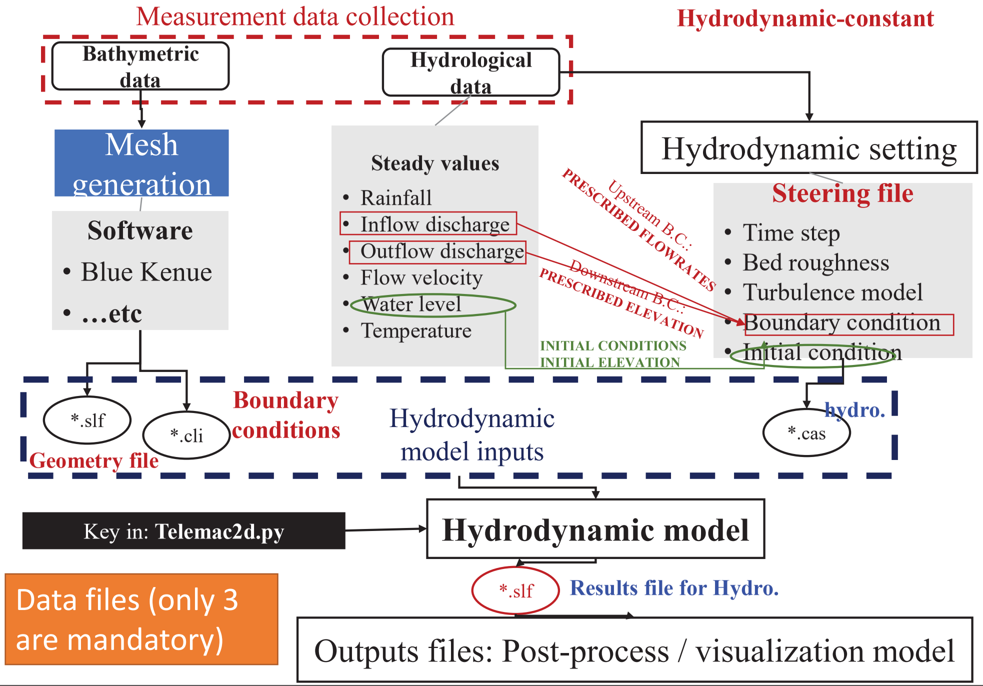


Total storage loss between 1978 and 2016 is 27.5%



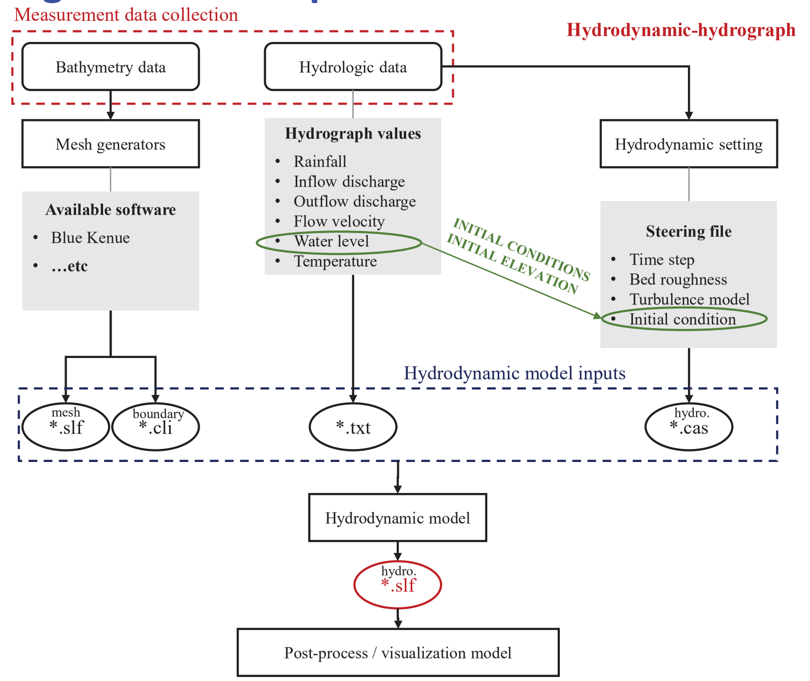
Source of Data by NIA Magat Dam Office

Steering Telemac-2D: parameters and data files

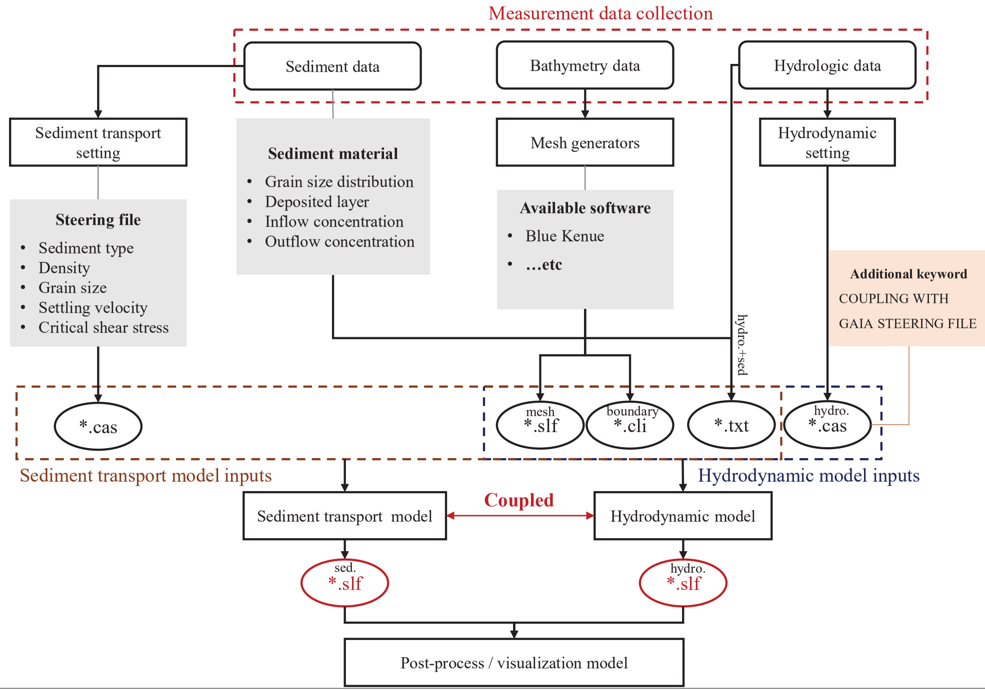


Data files (only 3 are mandatory)

Steering Telemac-2D: parameters and data files



Steering Telemac-2D: parameters and data files

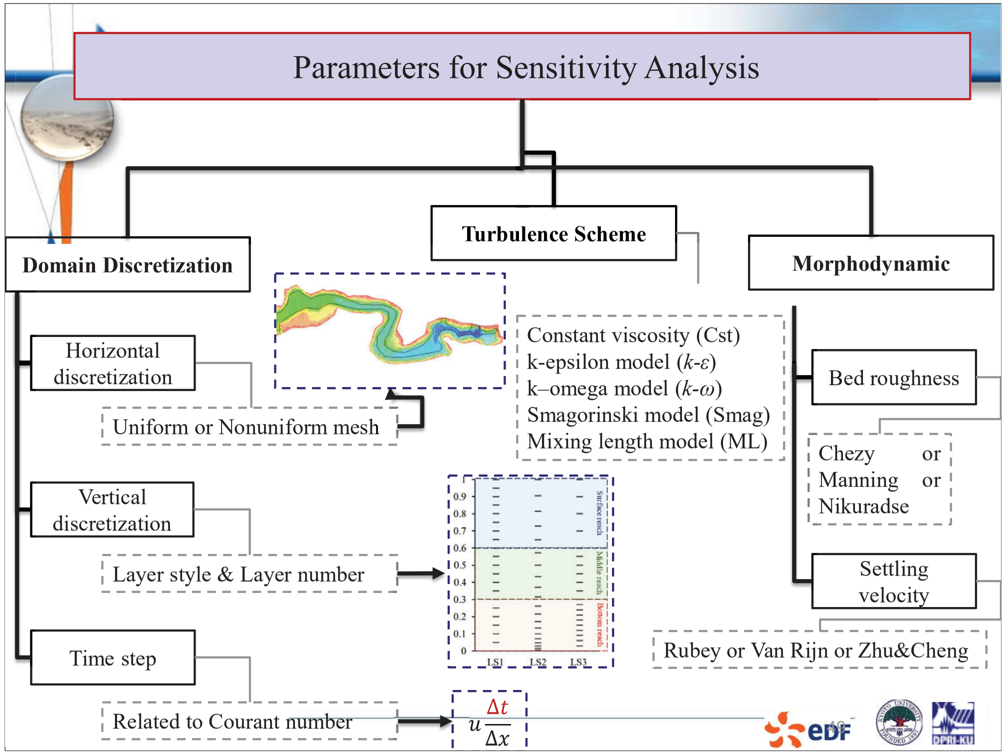


Physical phenomena taken into account

- Propagation of long waves with non linear effects,
- Bottom friction,
- Coriolis force,
- Wind and atmospheric pressure,
- Turbulence,
- Fluvial and supercritical flows,
- Horizontal gradients of salinity,
- Cartesian coordinates or spherical coordinates for large domains,
- Dry zones, floodplains, wetting and drying,
- Tracers (salinity, pollutants, temperature) subject to currents, diffusion, with sources and sinks,
- Floating bodies, lagrangian drift,
- Singularities: weirs, culverts, bridges
- Drag forces due to vertical structures,
- Porosity,
- Oil spill
- Algae transport
- Wave forcing (coupling or chaining with Tomawac, chaining with Artemis),
- Coupling with sediment transport (Sisyphe)
- Coupling with sediment transport (Gaia)
- Advanced water quality (files created for Delwaq)

Physical parameters: Turbulence

- Keyword: *TURBULENCE MODEL*
- 1 : Constant viscosity
- 2 : Elder law
- 3 : K-Epsilon
- 4 : Smagorinski
- VELOCITY DIFFUSIVITY
- COEFFICIENT FOR DIFFUSION OF TRACERS
- - if constant viscosity (1) it must take turbulence and dispersion into account
- - in other cases must be molecular viscosity
- For Elder: *NON-DIMENSIONAL DISPERSION COEFFICIENTS* (longitudinal/transversal, generally 6 and 0.6)
- For K-Epsilon: see user manual. Requires expertise (boundary conditions). Two extra variables k and epsilon. Think of velocity gradients computed with your mesh size.



Data files (only 3 are mandatory)

- The STEERING FILE (mandatory), which contains a number of parameters chosen in a dictionary,
- The GEOMETRY FILE (mandatory), which contains the mesh and (optional) the topography and friction,
- The BOUNDARY CONDITIONS FILE (mandatory), with a description of (simple) boundary conditions,
- The FORTRAN FILE, which contains subroutines or functions dedicated to a specific case (Telemac user subroutines, or others),
- The LIQUID BOUNDARIES FILE, if prescribed values at boundaries vary time,
- The PREVIOUS COMPUTATION FILE, to restart a computation,
- The REFERENCE FILE, which contains results to be compared with,
- The FRICTION DATA FILE, for complex friction cases (zones, friction laws),
- The STAGE-DISCHARGE CURVES FILE, to prescribe a relation between discharge and free surface at boundaries,
- The SOURCES FILE, with informations on sources when they vary in time,
- 3 files for tidal boundary conditions (when a regional model is available)
- And the dictionary, which in principle must not be modified, it is the reference for keywords and default values.

Output files

- The RESULTS FILE, for graphical displays,
- The output listing, which reports on the computation and is monitored with keywords: LISTING PRINTOUT PERIOD, DEBUGGER
- The SECTIONS OUTPUT FILE giving fluxes through sections.
- And: BINARY RESULTS FILE, FORMATTED RESULTS FILE

Choice of variables in the results file

- U="velocity along x axis (m/s)"
- V="velocity along y axis (m/s)"
- C="wave celerity (m/s)"
- H="water depth (m)"
- S="free surface elevation (m)"
- B="bottom elevation (m)"
- F="Froude number "
- Q="scalar flowrate of fluid (m2/s)"
- T1="tracer 1 etc. "
- K="turbulent kinetic energy in k-epsilon model (J/kg)"
- E="dissipation of turbulent energy (W/kg)"
- D="turbulent viscosity of k-epsilon model (m2/s)"
- I="flowrate along x axis (m2/s)"
- J="flowrate along y axis (m2/s)"
- M="scalar velocity (m/s)"

X="wind along x axis (m/s)"
Y="wind along y axis (m/s)"
P="air pressure (Pa)"
W="friction coefficient"
A="drift along x (m)"
G="drift along y (m)"
L="Courant number "
N="supplementary variable N "
O="supplementary variable O "
R="supplementary variable R "
Z="supplementary variable Z "
MAXZ="maximum elevation"
TMXZ="time of maximum elevation "
MAXV="maximum velocity"
TMXV="time of maximum velocity"
US="friction velocity ""

For tracers, T* or T** possible

Boundary conditions

- Many possibilities (thus many possibilities of errors…)
- Files: boundary conditions file
- Keywords: many…
- Functions:
- Keywords have priority over boundary conditions file
- Call of Functions are triggered by the presence of keywords in the steering file and can modify their values
- The goal: giving LIHBOR, LIUBOR, LIVBOR, LITBOR, HBOR, UBOR, VBOR, TBOR
- (types of boundary conditions and prescribed values)

Initial conditions

- Case of a first run:

Keyword for the depth INITIAL *CONDITIONS*
- *ZERO ELEVATION,*
- *CONSTANT ELEVATION combined with INITIAL ELEVATION,*
- *ZERO DEPTH,*
- *CONSTANT DEPTH + INITIAL DEPTH*
- *PARTICULAR* , *initial* depth to be programmed in CONDIN

Think of dry zones on liquid boundaries or weirs (possible but problem well posed ?).
Free surface and velocity can be initialised by FUDAA-PREPRO and Blue Kenue
No keyword for the velocity: it is set to zero in CONDIN but may be initialised

- Computation continued (restart):

COMPUTATION CONTINUED = YES
PREVIOUS COMPUTATION FILE
PREVIOUS COMPUTATION FILE FORMAT
INITIAL TIME SET TO ZERO (YES/NO)

Boundary conditions

File created by the mesh generator, STBTEL or FUDAA-PREPRO
One line per boundary point

```
4 5 5 0.000000 0.000000 0.000000 0.000000 5 0.000000 0.000000 0.000000 14   1
2 2 2 0.000000 0.000000 0.000000 0.000000 2 0.000000 0.000000 0.000000 10   2
2 2 2 0.000000 0.000000 0.000000 0.000000 2 0.000000 0.000000 0.000000 124  3
```

Depth (LIHBOR) — Velocity (LIUBOR and LIVBOR) — Tracer(s) (LITBOR) — Global number of point — Boundary number of point. May be modified to any value, saved as boundary_colour in Fortran

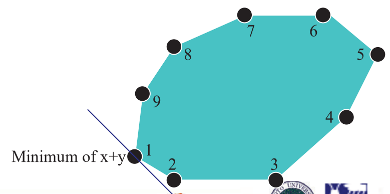
Types of boundary conditions:

- 2 = wall with free slip
- 4 = free boundary
- 6 = prescribed velocity (for U and V)

0 = wall with no slip condition
5 = prescribed value (discharge if U and V)

Practical combinations:

- Wall with free slip : 2 2 2 … 2
- Wall with no slip condition : 2 0 0 … 2
- Prescribed discharge, free depth : 4 5 5 … 5
- Prescribed depth, free velocity : 5 4 4 … 4
- Prescribed velocity, free depth : 4 6 6 … 5
- Prescribed velocity and depth : 5 6 6 … 5



Boundary conditions

Prescribed values of boundary conditions, wall friction, flux law for tracers
Taken into account if boundary type = 5 or 6

Here only taken as profile (a discharge is asked)

UBOR VBOR TBOR

```
4 5 5 0.000000 0.500000 0.000000 0.000000 5 6.000000 0.000000 0.000000 14  1
4 5 5 0.000000 1.000000 0.000000 0.000000 5 0.000000 0.000000 0.000000 14  1
4 5 5 0.000000 1.000000 0.000000 0.000000 5 0.000000 0.000000 0.000000 14  1
4 5 5 0.000000 0.500000 0.000000 0.000000 5 0.000000 0.000000 0.000000 14  1
2 2 2 0.000000 0.000000 0.000000 0.000000 2 0.000000 0.000000 0.000000 10  2
2 2 2 0.000000 0.000000 0.000000 0.000000 2 0.000000 0.000000 0.000000 15  2
5 6 6 3.000000 1.000000 0.000000 0.000000 2 0.000000 0.000000 0.000000 124 3
```

HBOR — UBOR VBOR Here really taken — AUBOR — ATBOR BTBOR

Friction coefficient of wall (depends on law chosen)

Boundary points numbering or boundary colours

Last line of boundary conditions file may be changed and will be retrieved in Fortran under the name BOUNDARY_COLOUR

May be used to define groups of points (useful in parallel)
Currently done in Telemac-2D, Telemac-3D and Sisyphe

2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	1	1
2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	9	2
2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	10	3
2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	11	4
2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	12	5
2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	13	6
2	2	2	0.000	0.000	0.000	0.0	2	0.000	0.000	0.000	14	7

Boundary conditions with keywords

- When constant in time and space, per liquid boundary
  - **PRESCRIBED ELEVATIONS : 10.;5.,... (one per liquid boundary)**
  - **PRESCRIBED FLOWRATES : 50.;0.;...**
  - **PRESCRIBED VELOCITIES : 2.;1.;... (normal velocity)**
- **When these keywords are present, they take over values in the BOUNDARY CONDITIONS FILE**

Boundary conditions with functions and files

- When the conditions are variable in time:
  - **Programming functions SL (free surface), Q (discharge), VIT (velocity)**
  - **Programming subroutine BORD**
  - **LIQUID BOUNDARIES FILE**

```
#
# Example with two liquid boundaries
#
T       Q(1)    SL(2)
s       m3/s    m
0.      0.      135.0
25.     15.     135.2
100.    20.     136.
500.    20.     136.
```

Boundary conditions: stage-discharge curves

Keyword STAGE-DISCHARGE CURVES : 0;1;2 (one per liquid boundary)
Tells if a stage-discharge curve must be used

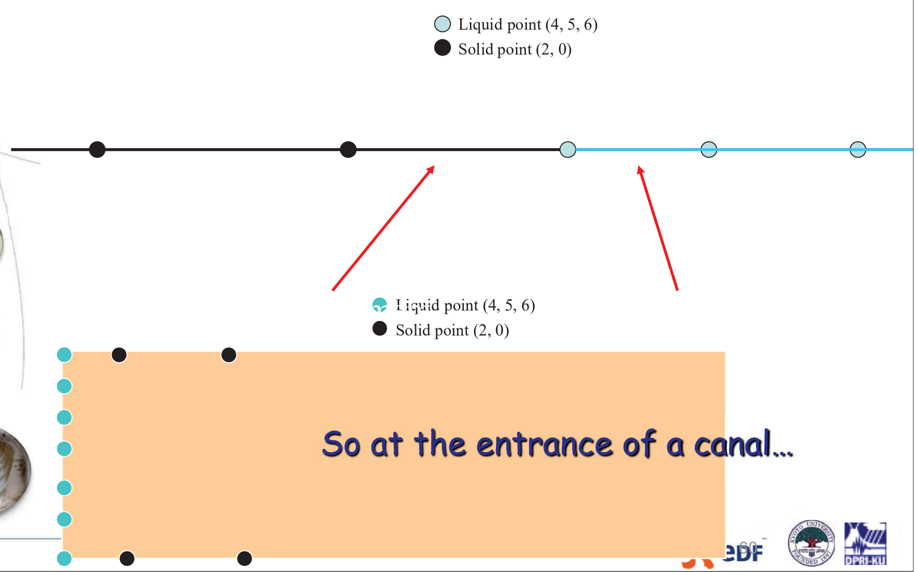
- **0: no**
- **1: level as a function of discharge**
- **2: discharge as a function of level (not yet implemented)**

STAGE-DISCHARGE CURVES FILE:

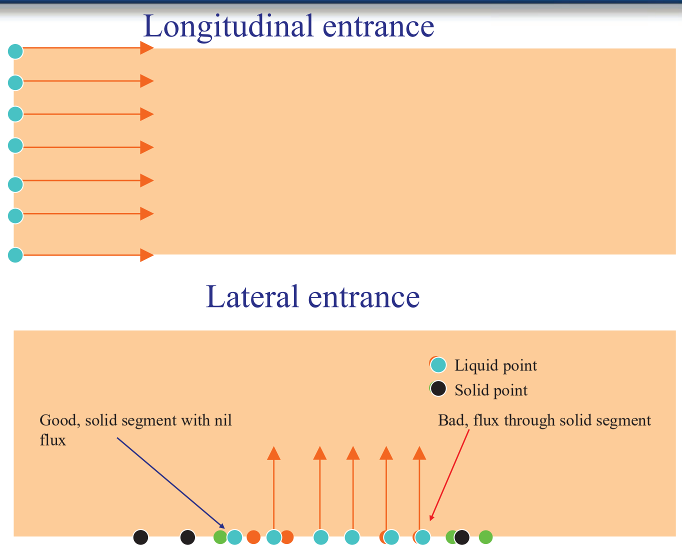
```
#
# STAGE-DISCHARGE CURVE BOUNDARY 1
#
Q(1)   Z(1)
m3/s    m
61.    0.
62.    0.1
63.    0.2
#
# STAGE-DISCHARGE CURVE BOUNDARY 2
#
Z(2)   Q(2)
m      m3/s
10.    1.
20.    2.
30.    3.
40.    4.
```

Caution will first step if discharge = 0 (preferably start with a constant elevation and do a restart)

Boundary conditions are given per boundary points
but what about boundary segments?
Solid points are between two solid segments



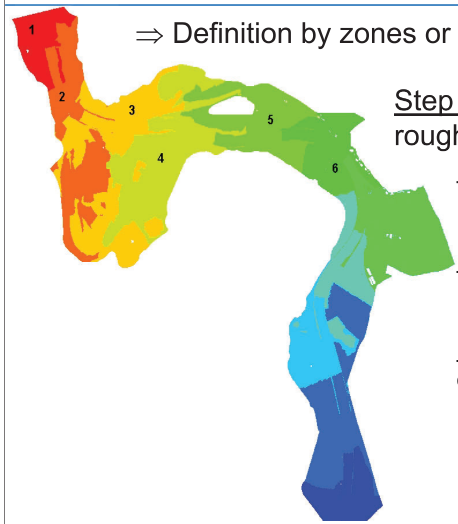
Longitudinal entrance / Lateral entrance



Use key-word VELOCITY PROFILE, option 3 and boundary conditions file

Several zones with different coefficients and friction laws

⇒ Definition by zones or categories



Step 1 : define the parameters of the roughness zones

Bottom parameter
- Law of friction
- Roughness parameter

Boundary conditions
- Law of friction
- Roughness parameter

Non submerged-vegetation (optional, correction of friction coefficient with velocity)
- Diameter of roughness element
- Spacing of roughness element

*Zone	Bottom		Boundary condition		Non-submerged vegetation	
*no	Law	Value	Law	Value	Diam	Spac
1	NIKU	0.20	LOGW	0.08	0.004	0.11
from 2 to 5	NIKU	0.24	LOGW	0.003	0.001	0.08
6	NIKU	0.26	LOGW	0.08	0.004	0.11

Numerical parameters: equations

- Equations solved: *EQUATIONS*
- SAINT-VENANT EF
- SAINT-VENANT VF
- …

- Type of discretisation : *DISCRETIZATIONS IN SPACE*
- 3 values : velocity, depth, tracers

- Example: *DISCRETIZATIONS IN SPACE* : 12;11;11 (default: 11;11;11)

- 11 : linear triangle
- 12 : quasi-bubble triangle
- 13 : quadratic triangle

- In practice : 11;11 or 12;11 (13;11 very expensive and only with primitive equations)

- Other solution to suppress wiggles:

- COMPATIBILITY OF FREE SURFACE GRADIENT: 0.9 (should be between 1 and 0)

General recommendations before using a numerical model

NEVER USE IT AS A BLACK BOX !

- Understand the physical background and governing equations
- Keep in mind the limitations and assumptions leading to the equations
- Have a basic understanding of numerical methods
- First try the model on simple test cases
- Test the influence of grid size and time step
- Test the influence of input data (both physical and numerical)

GARBAGE IN ! GARBAGE OUT !

Thank you all for listening