El modelo Iber
Capacidades

Modelo de flujo bidimensional en ríos y estuarios

www.iberaula.es

GOBIERNO DE ESPAÑA MINISTERIO DE FOMENTO MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO

CEDEX CENTRO DE ESTUDIOS Y EXPERIMENTACIÓN DE OBRAS PÚBLICAS

Grupo de Ingeniería del Agua y del Medio Ambiente

flumen Dinàmica fluvial i enginyeria hidrològica

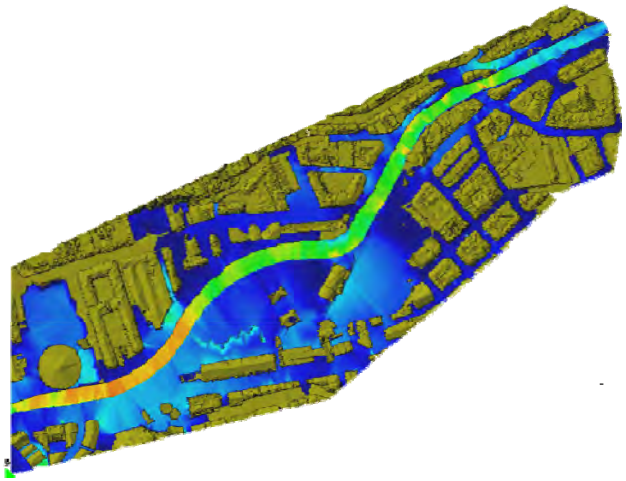
CIMNE

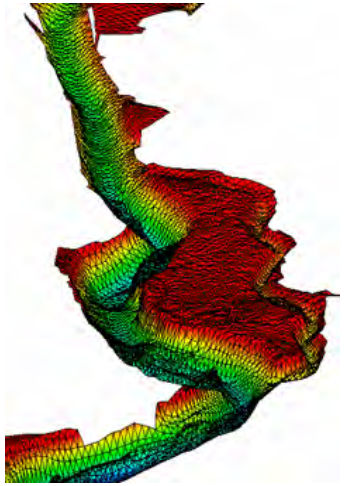
1. Introducción
2. Hidrodinámica
3. Turbulencia
4. Interfaz gráfica
5. Transporte de sedimentos
6. Desarrollos futuros

El modelo Iber
Introducción

Turbillon — **CARPA**

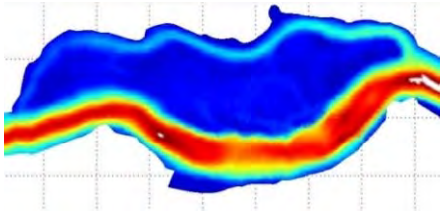
GiD





Introducción

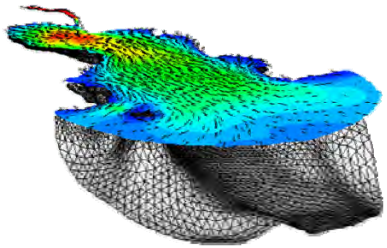
Módulos de cálculo



HIDRODINÁMICA

Velocidad

Calado



TRANSPORTE DE SEDIMENTOS

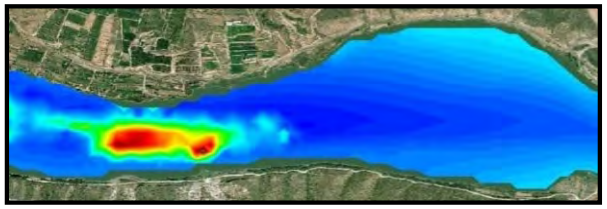
Carga en suspensión

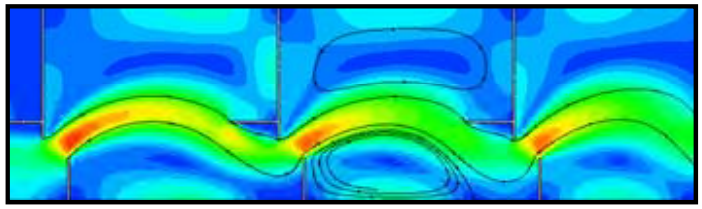
Carga de fondo

TURBULENCIA

Viscosidad turbulenta

Energía turbulenta y disipación





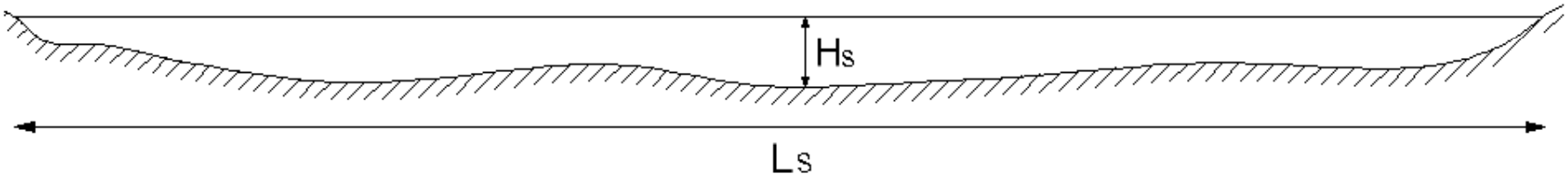
Ecuaciones de aguas someras 2D

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=0$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x^2}{h}+g\frac{h^2}{2}\right)+\frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right)=-gh\frac{\partial z_b}{\partial x}-\frac{\tau_{b,x}}{\rho}+\frac{\partial}{\partial x}\left(\nu_t\ h\frac{\partial U_x}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_t\ h\frac{\partial U_x}{\partial y}\right)$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q_y^2}{h}+g\frac{h^2}{2}\right)=-gh\frac{\partial z_b}{\partial y}-\frac{\tau_{b,y}}{\rho}+\frac{\partial}{\partial x}\left(\nu_t\ h\frac{\partial U_y}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_t\ h\frac{\partial U_y}{\partial y}\right)$$

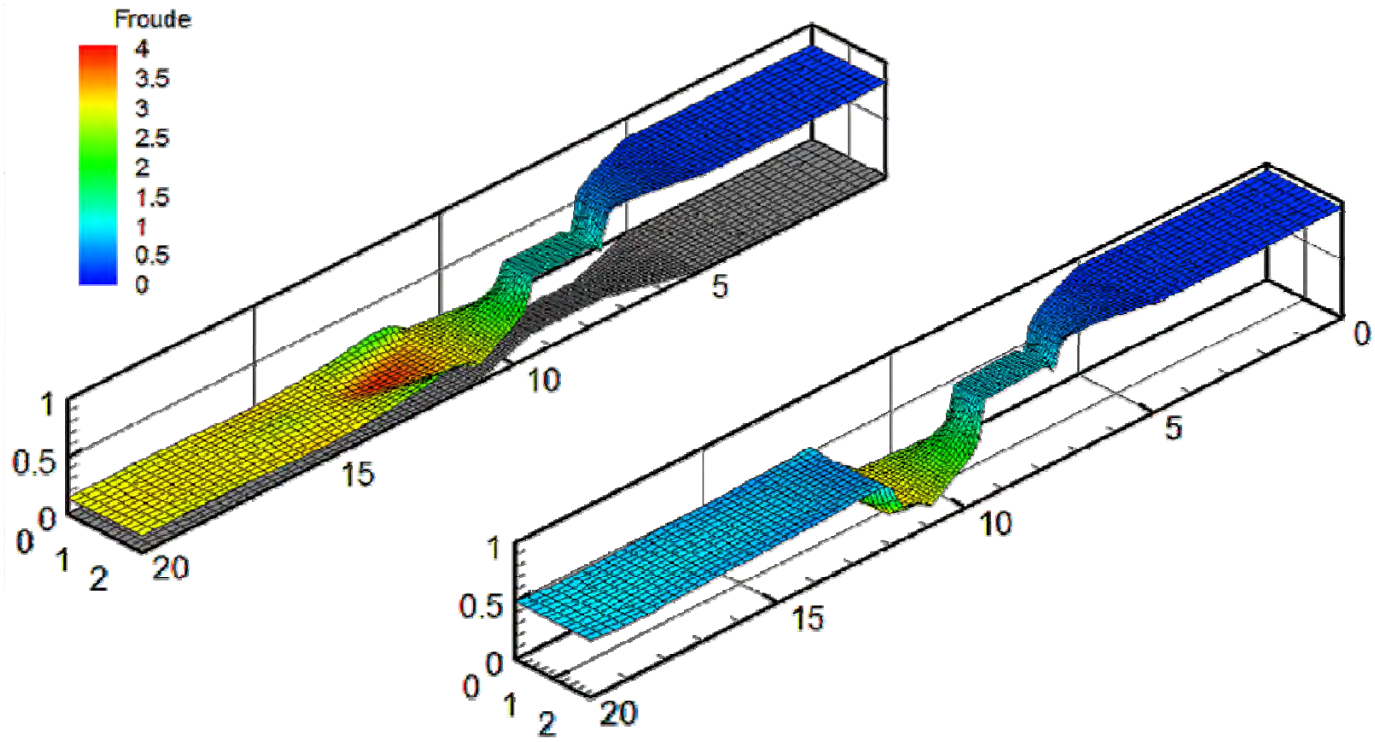
- Distribución de **presión hidrostática**
- Velocidad **uniforme en profundidad → h, U_x, U_y**



Hidrodinámica

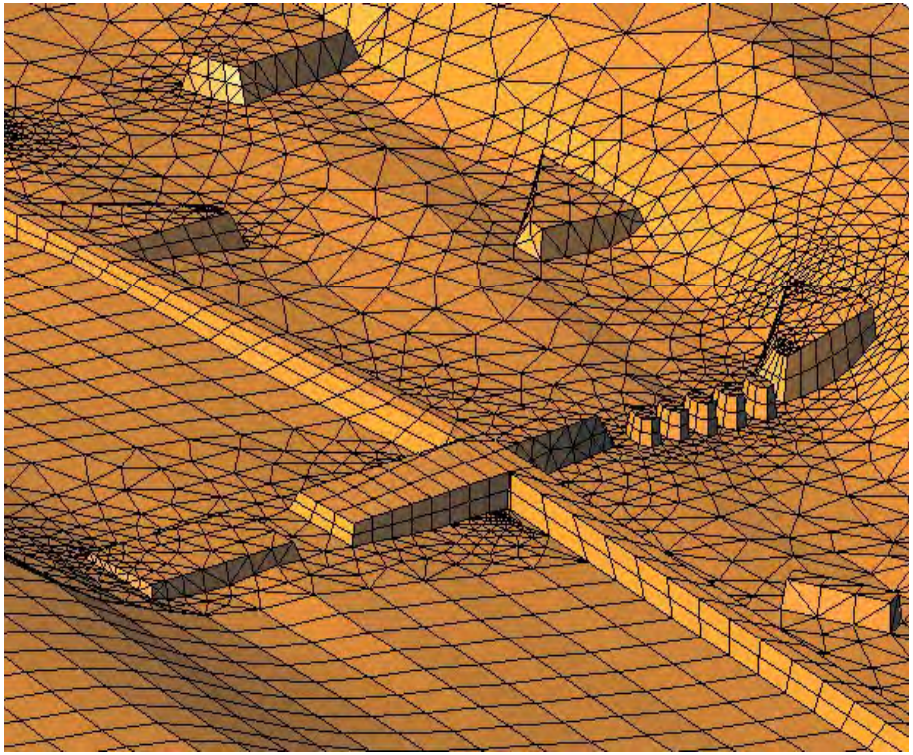
Esquemas en volúmenes finitos descentrados de alta resolución tipo Roe

- Robustos
- Cambios de régimen
- Frentes de onda
- Sin problemas de convergencia
- Explícitos



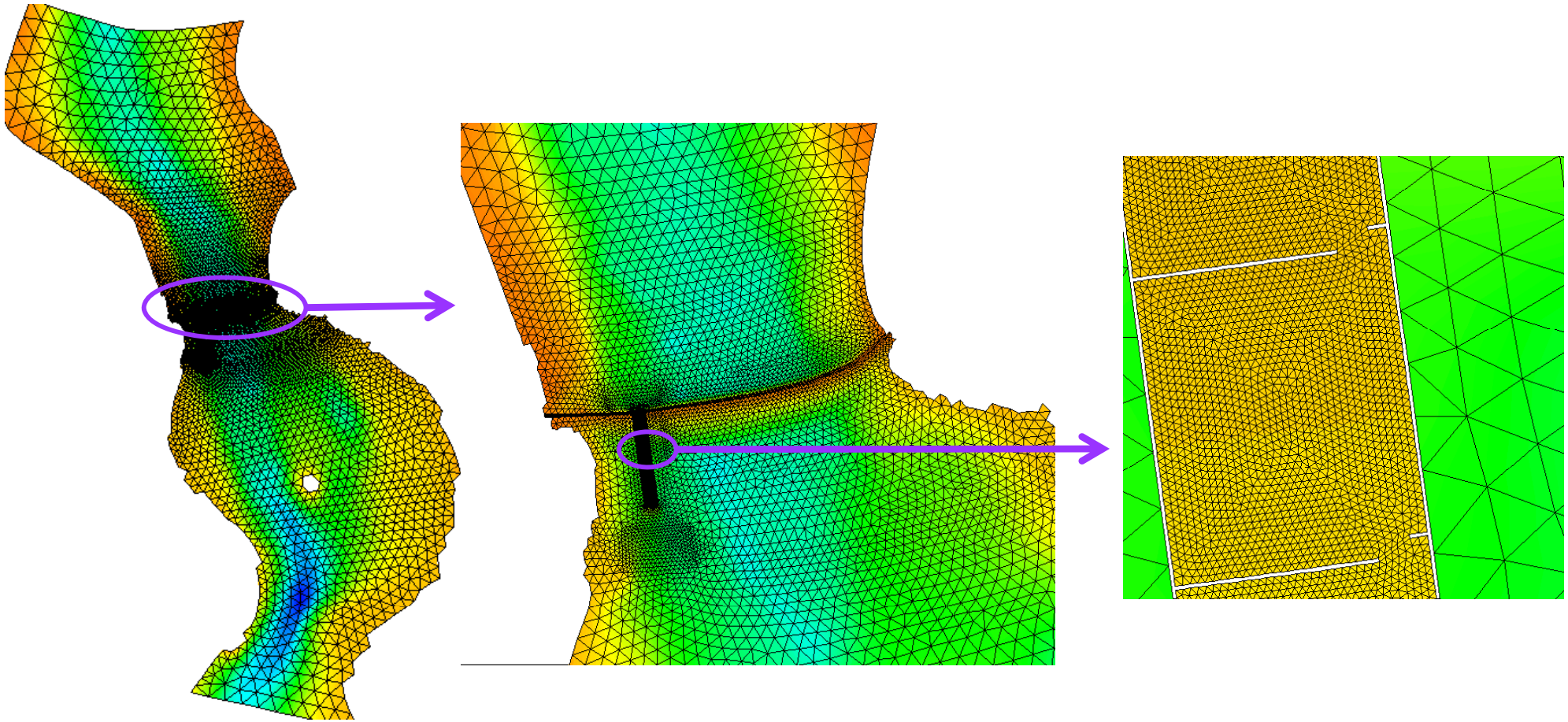
El modelo Iber
Hidrodinámica

Mallas no-estructuradas formadas por elementos de 3 o 4 lados



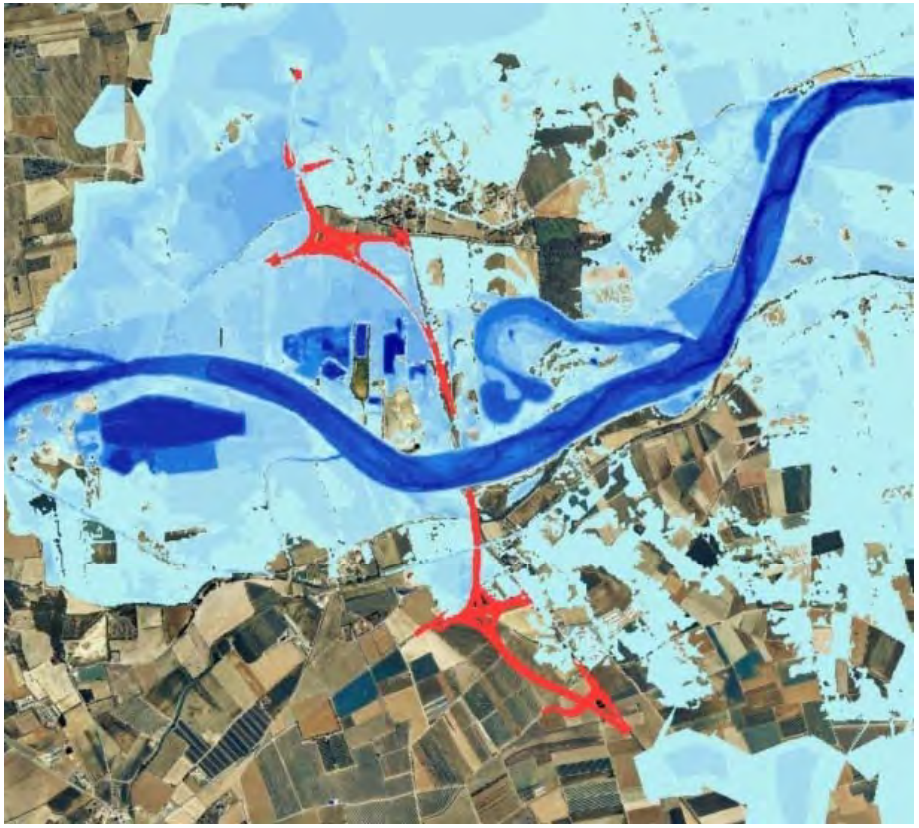
Hidrodinámica

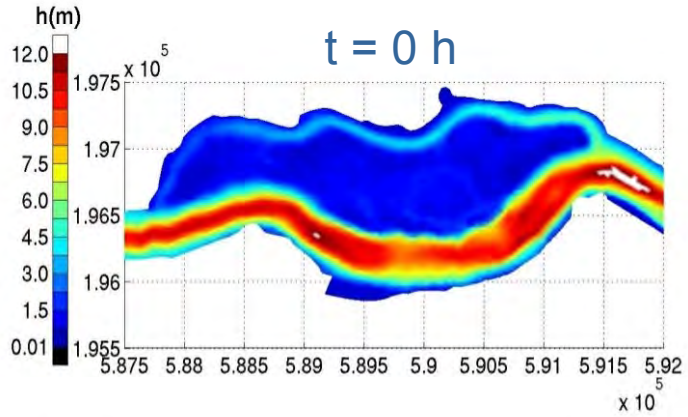
Mallas no-estructuradas formadas por elementos de 3 o 4 lados

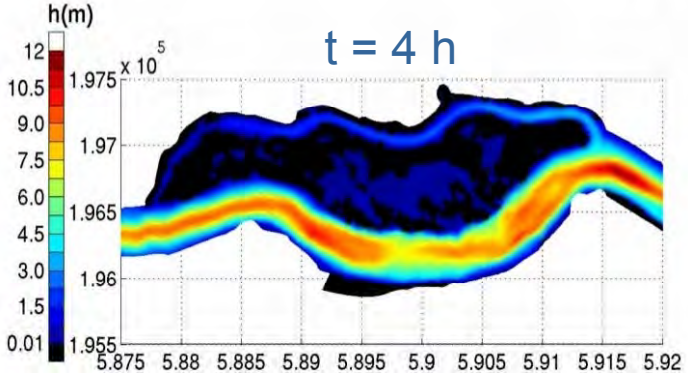


Frentes seco-mojado

Estable, conservativo, no difusivo



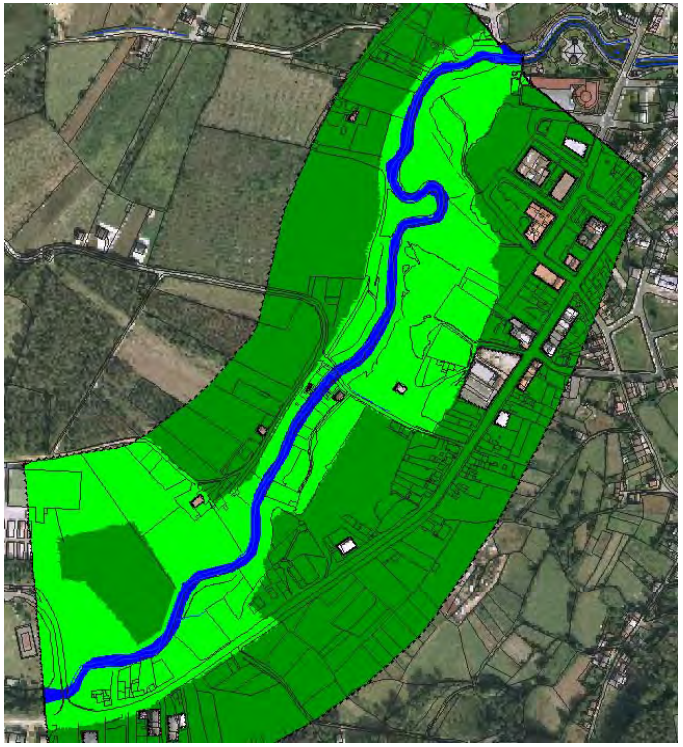


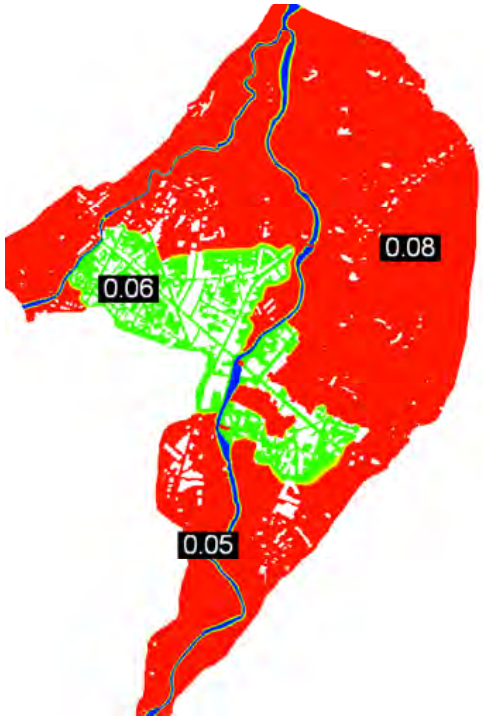


Fricción de fondo

Fórmula de Manning

$$\tau_{b,x} = \rho\, g\, h\, \frac{n^2 |U| U_x}{h^{4/3}} \qquad \tau_{b,y} = \rho\, g\, h\, \frac{n^2 |U| U_y}{h^{4/3}}$$



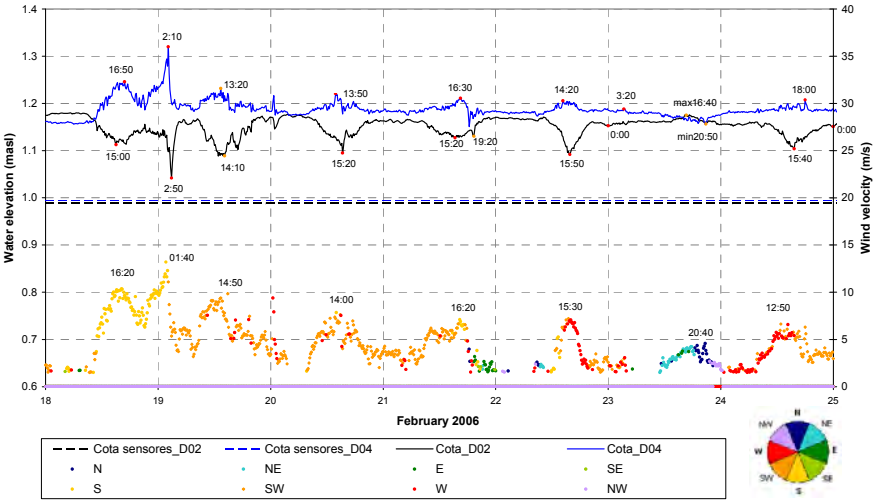


Rozamiento superficial por viento

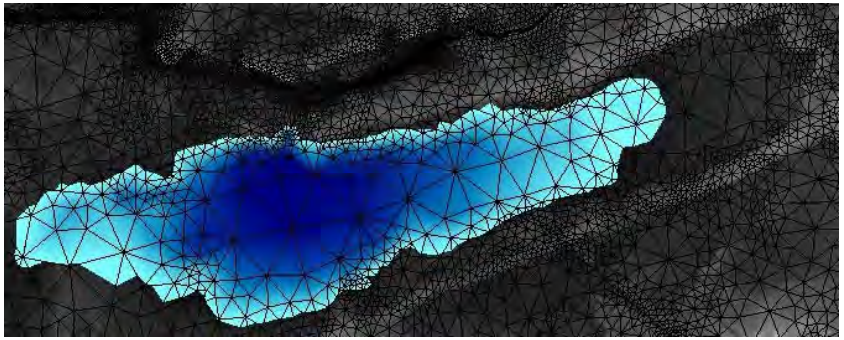
Van Dorn (1953)

$$\frac{\tau_s}{\rho} = \frac{\rho_a}{\rho} C_{10} \; V_{10}^{\;2}$$

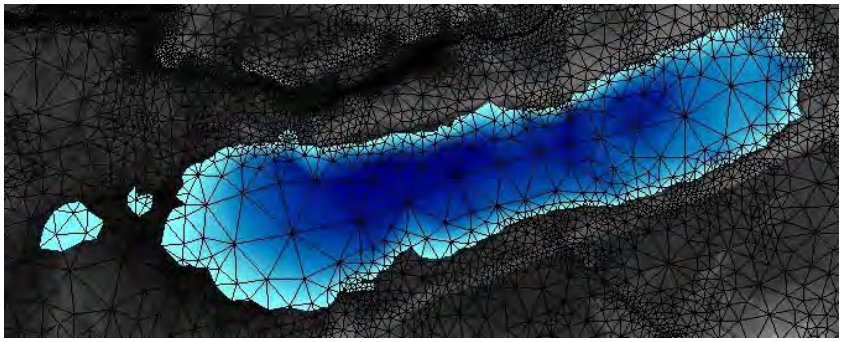
$$\frac{\tau_s}{\rho} \approx 3 \cdot 10^{-6} \; V_{10}^{\;2}$$



V=0 m/s

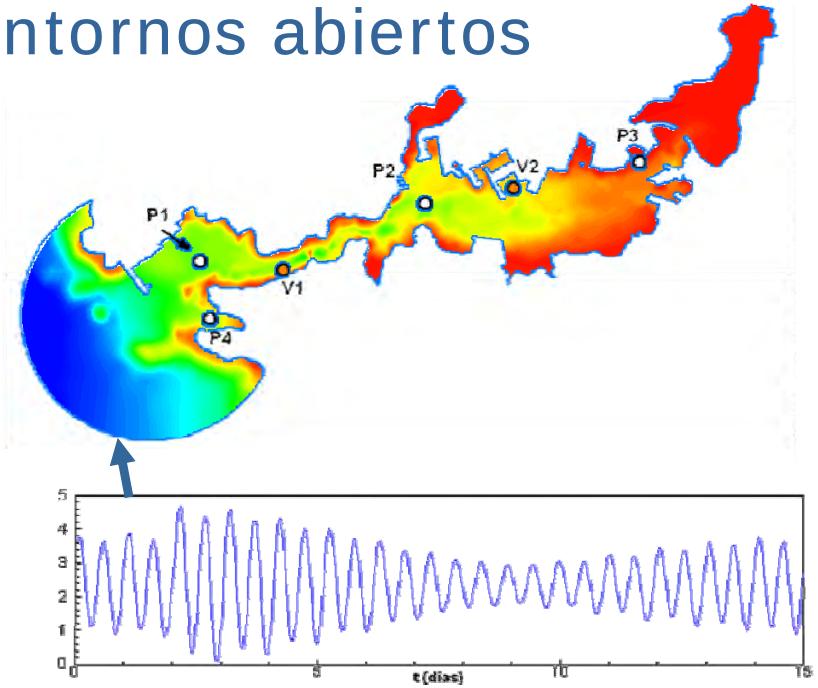


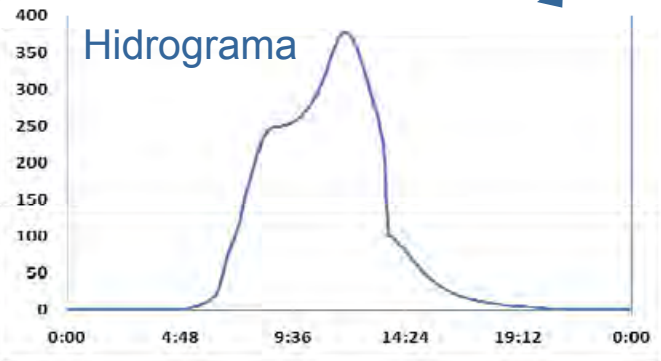
V=3 m/s

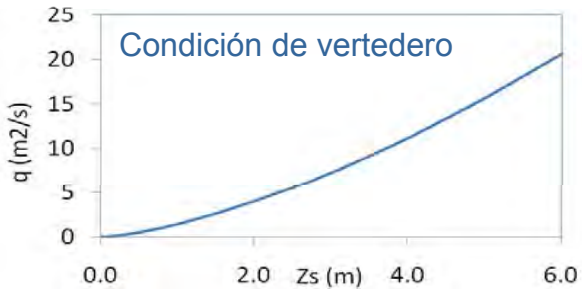


Condiciones de contorno en contornos abiertos

- **Calado constante o variable en tiempo**
  - → Marea
- **Condición de vertedero**
  - → Sección de control
  - → curva de gasto
- **Caudal constante o hidrograma**
  - → Entrada en ríos, canales
  - → Avenidas en ríos



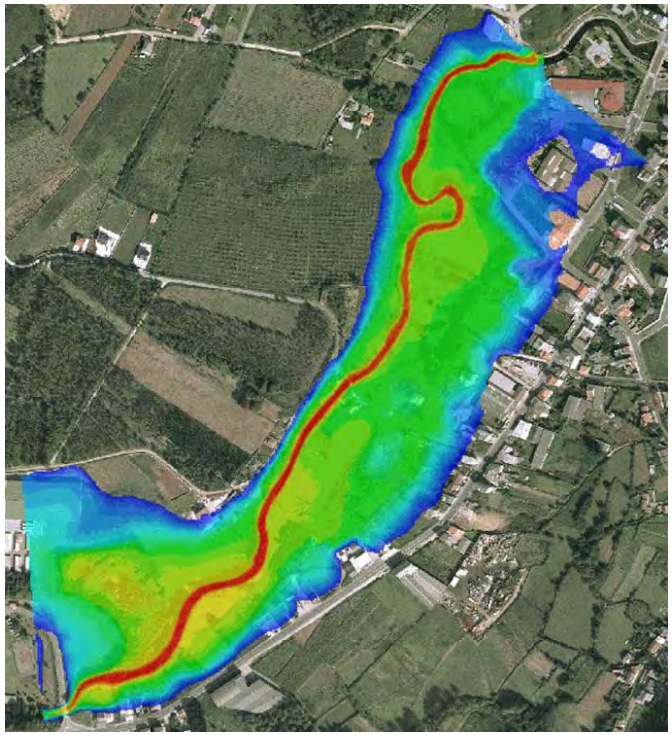




Condiciones de contorno en contornos de pared

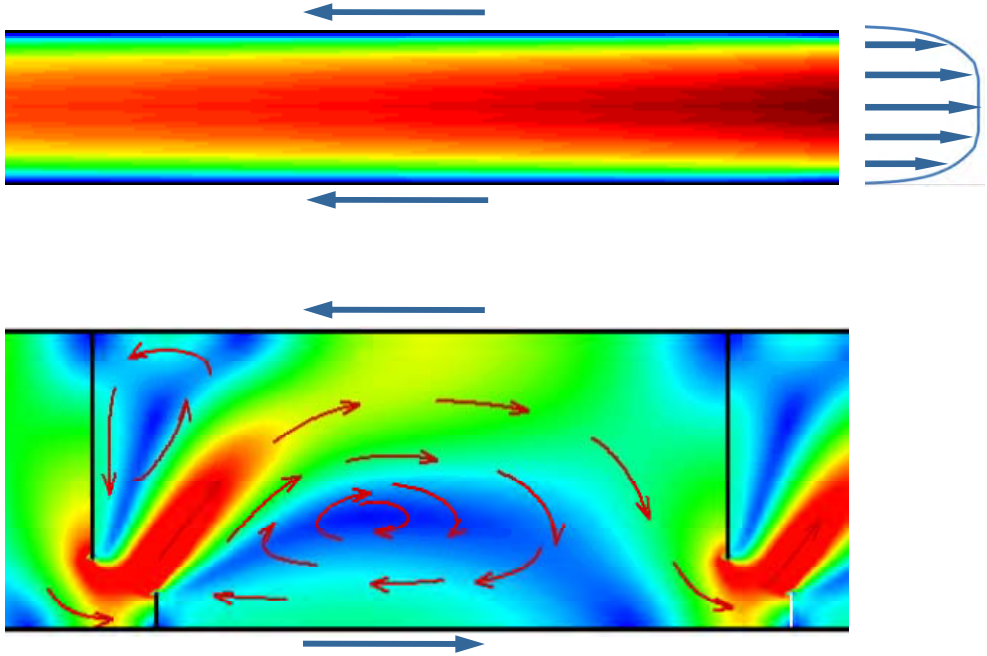
Sin rozamiento

Ríos, zonas costeras



Rozamiento

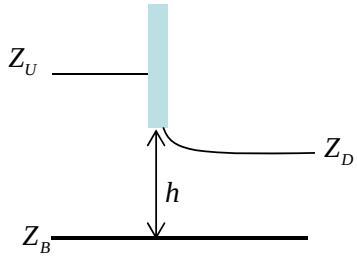
Canales, estructuras hidráulicas



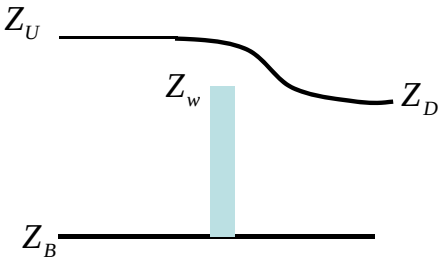
Hidrodinámica

Condiciones de contorno internas

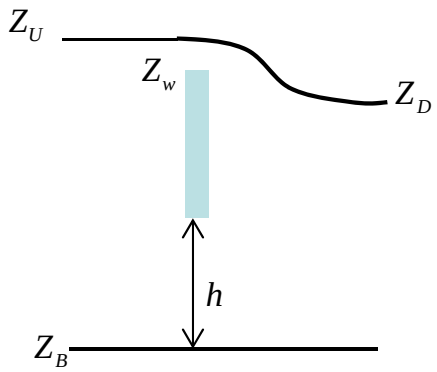
- Flujo bajo compuerta



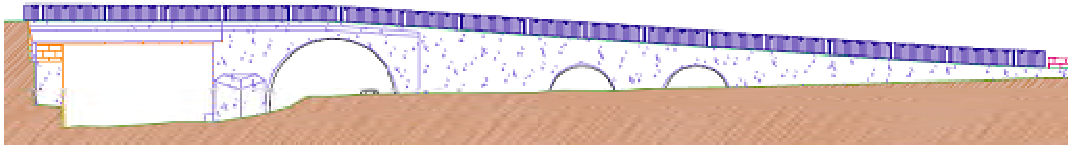
- Flujo sobre vertedero en lámina libre



- Combinación de compuerta y vertedero



- Pérdida localizada



$$\Delta H = \lambda \frac{V^2}{2g}$$

Herramientas de soporte para determinación vía intenso desagüe

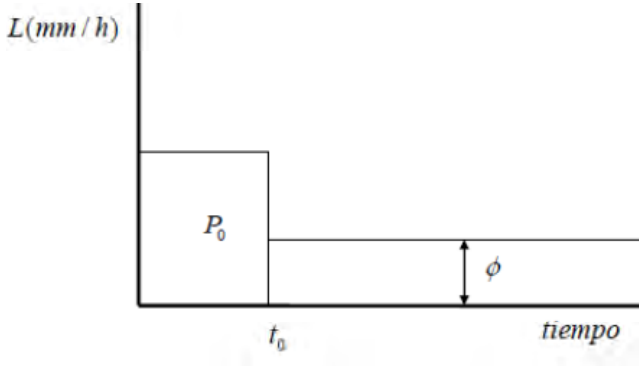
- Línea y distancia
- Polígono

Infiltración y precipitación

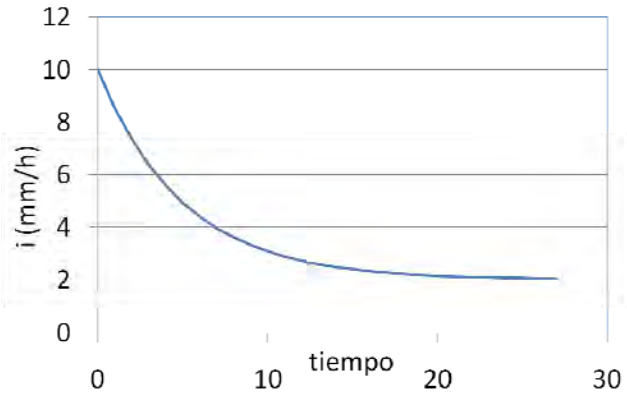
$$\frac{\partial h}{\partial t} + \frac{\partial hU_x}{\partial x} + \frac{\partial hU_y}{\partial y} = -i + R$$

Infiltración lluvia

Lineal



Horton

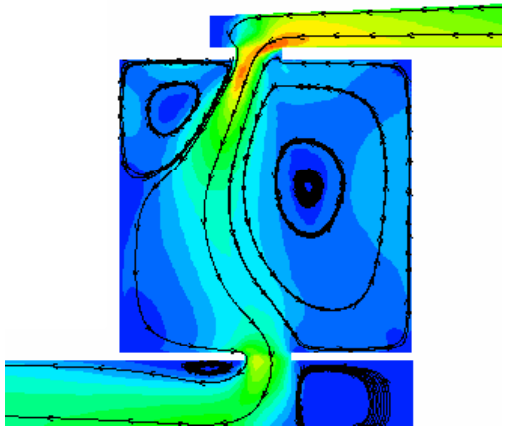


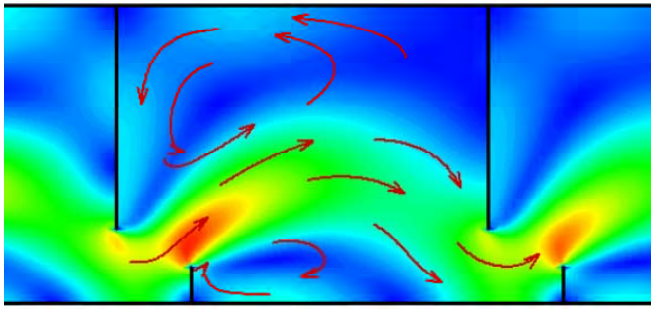
Green-Ampt

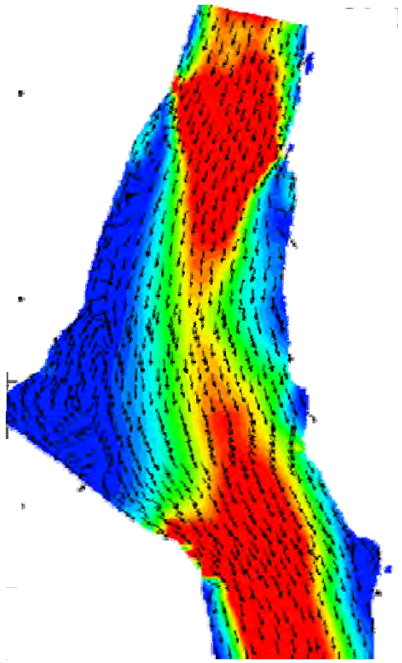
- Permeabilidad saturada
- Succión en la zona no-saturada
- Porosidad efectiva (drenable)
- Saturación efectiva inicial
- Pérdida inicial

Turbulencia

Flujos turbulentos







$$\frac{\partial hU_i}{\partial t} + \frac{\partial hU_iU_j}{\partial x_j} = -gh\frac{\partial z_b}{\partial x_i} - gh\frac{\partial h}{\partial x_i} - \tau_b + \boxed{\frac{\partial}{\partial x_j}\left(\nu_t\, h\frac{\partial U_i}{\partial x_j}\right)}$$

viscosidad turbulenta

Modelos de turbulencia promediados en profundidad

Turbulencia

Viscosidad turbulenta constante

$$\nu_t = \text{constante}$$

Modelo parabólico

$$\nu_t = 0.07\, u_f\, h$$

- Fricción de fondo

Modelo de longitud de mezcla

$$\nu_s = l_s^2 \sqrt{2 S_{ij} S_{ij} + \left(2.34 \frac{u_f}{\kappa h} \right)^2}$$

- Fricción de fondo
- Cortante horizontal

Modelo k-ε

$$\frac{Dk}{Dt} = \frac{\partial}{\partial x_j} \left(\left(\nu + \frac{\nu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right) + 2\nu_t S_{ij} S_{ij} + c_k \frac{u_f^3}{h} - \varepsilon$$

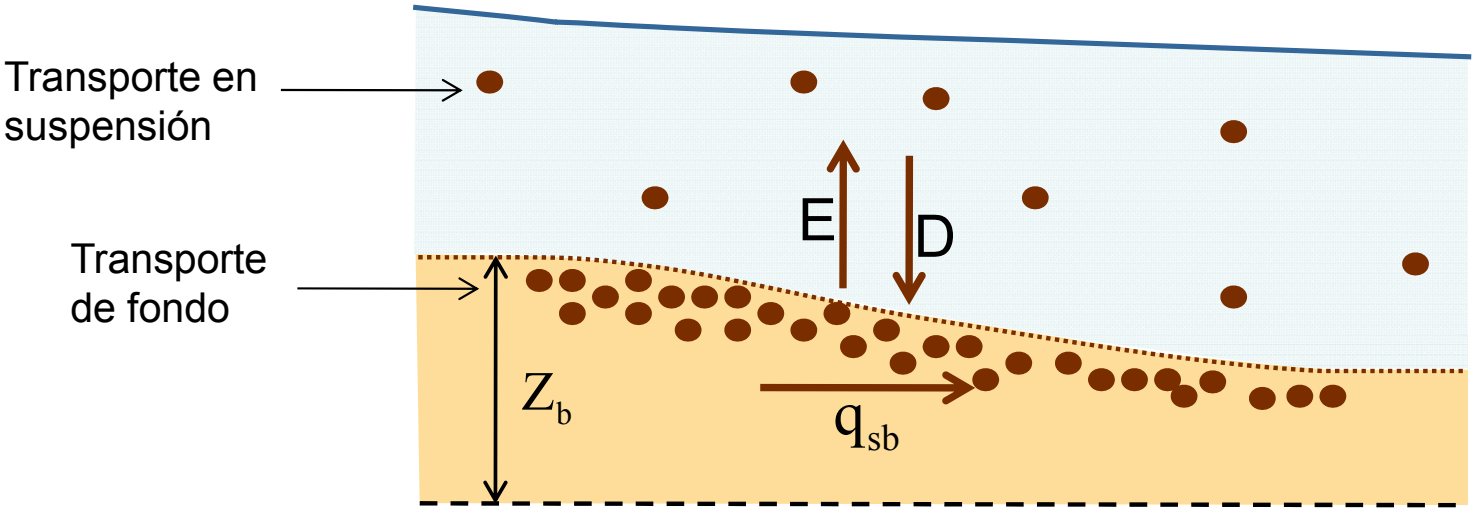
$$\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_j} \left(\left(\nu + \frac{\nu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right) + c_{1\varepsilon} \frac{\varepsilon}{k} 2\nu_t S_{ij} S_{ij} + c_\varepsilon \frac{u_f^4}{h^2} - c_{2\varepsilon} \frac{\varepsilon^2}{k}$$

- Fricción de fondo
- Cortante horizontal
- Difusión
- Disipación

Transporte de sedimentos

Ecuación de conservación del sedimento

$$(1-p)\frac{\partial Z_b}{\partial t}+\frac{\partial q_{sb,x}}{\partial x}+\frac{\partial q_{sb,y}}{\partial y}=D-E$$



V1.0: diámetro uniforme

Transporte de sedimentos

Carga de fondo

MEYER-PETER & MÜLLER
(corrección Wong y Parker)

APLICACIÓN

Gravas hasta 30 mm

FORMULACIÓN

$$q_{sb}^{*} = 3.97 \cdot \left(\tau_{bs}^{*} - \tau_{c}^{*}\right)^{3/2}$$

VAN RIJN

APLICACIÓN

Arenas y gravas

FORMULACIÓN

$$T < 0.3 \quad \rightarrow \quad q_{sb}^{*} = 0.053 \cdot \frac{T^{2.1}}{D_{*}^{0.3}}$$

$$T > 0.3 \quad \rightarrow \quad q_{sb}^{*} = 0.100 \cdot \frac{T^{1.5}}{D_{*}^{0.3}}$$

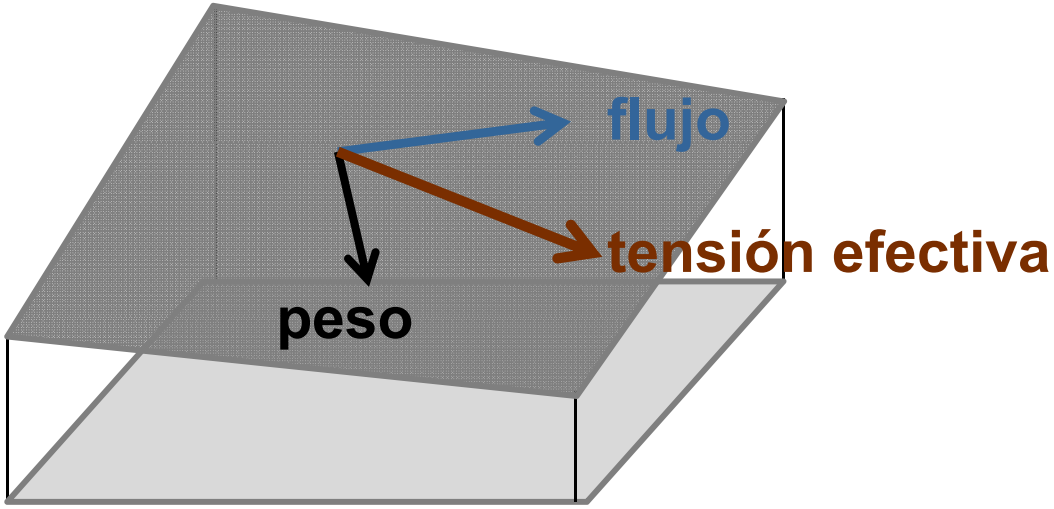
$$T = \frac{\tau_{bs}^{*} - \tau_{c}^{*}}{\tau_{c}^{*}}$$

Transporte de sedimentos

Carga de fondo
Pendiente de fondo

Consideración tanto de la pendiente transversal como longitudinal

Tensión efectiva de fondo = Tensión ejercida por el flujo + componente del peso



Transporte de sedimentos

Transporte en suspensión

Ecuación de transporte turbulento en suspensión

$$\frac{\partial hC}{\partial t}+\frac{\partial hU_xC}{\partial x}+\frac{\partial hU_yC}{\partial y}=\underbrace{\frac{\partial}{\partial x_j}\left(\left(\Gamma+\frac{\nu_t}{S_{c,t}}\right)h\frac{\partial C}{\partial x_j}\right)}_{\text{Difusión turbulenta}}+\underbrace{(E-D)}_{\text{Resuspensión/ deposición}}$$

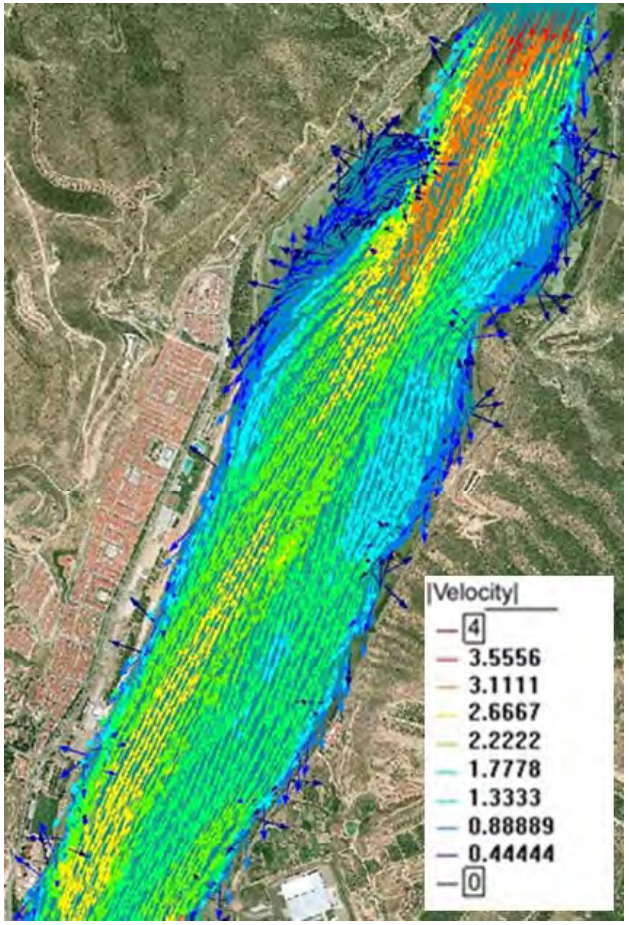
Difusión turbulenta → Módulo Turbulencia

Resuspensión/ deposición → Ecuación Conservación Sedimento

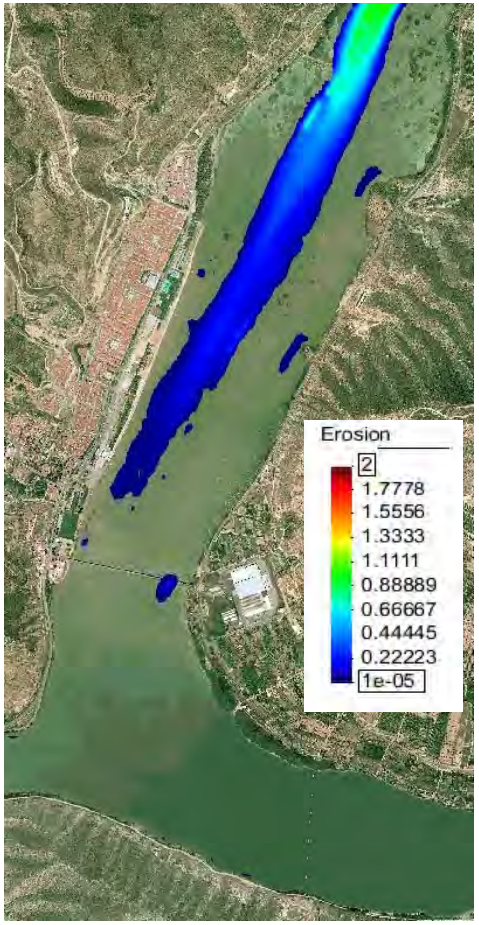
- **Resuspensión/deposición**:
  - → Van Rijn
  - → Smith
  - → Ariathurai y Arulanandan

Transporte de sedimentos

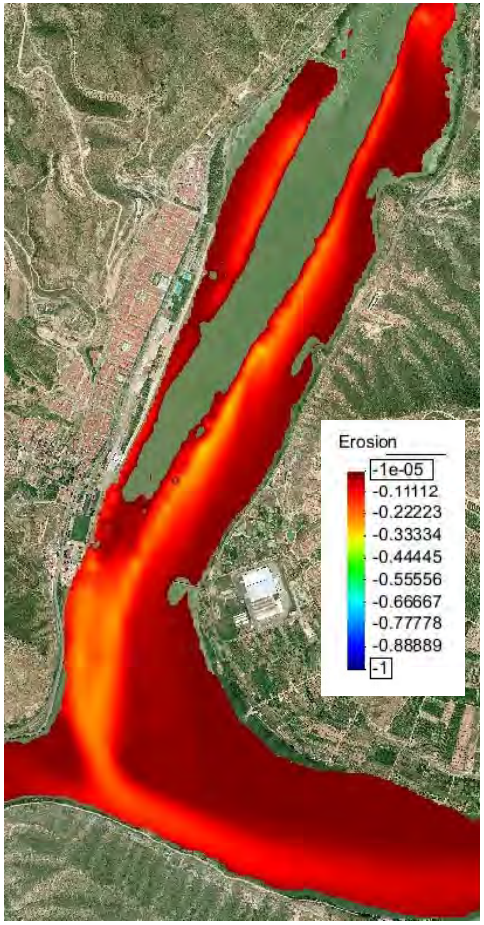
Transporte en suspensión



Hidrodinámica



Erosión



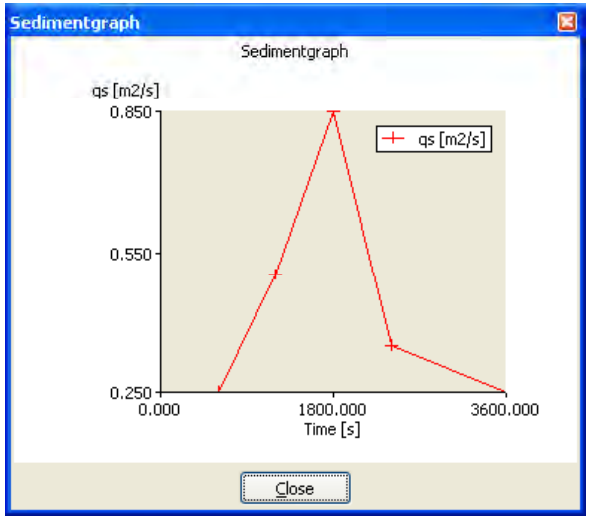
Sedimentación

Transporte de sedimentos

Condiciones de contorno

Entradas:

- **Capacidad de arrastre**
  - → Meyer-Peter Muller / Van Rijn
- **Concentración**
- **Sedimentograma**
- **Aguas claras**
  - → Caudal sólido nulo



Salidas:

- **continuidad del sedimento**

Interfaz gráfica

Basado en GiD: pre/postprocesador gráfico de propósito general para simulaciones numéricas.

www.gidhome.com

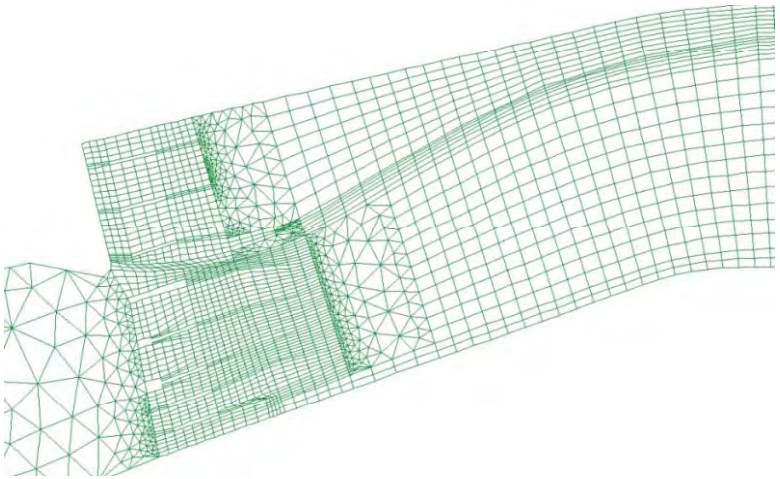
- Preproceso: entrada gráfica de datos
- Proceso: simulación hidráulica
- Postproceso: visualización de resultados

Iber está en español e inglés.

Actualmente Iber está disponible para Windows

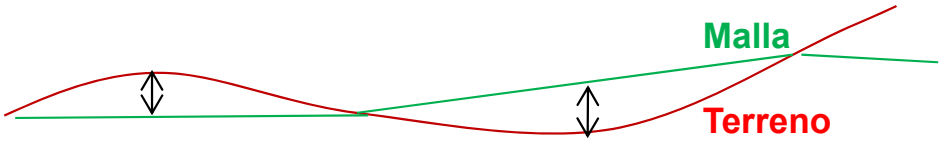
Preproceso

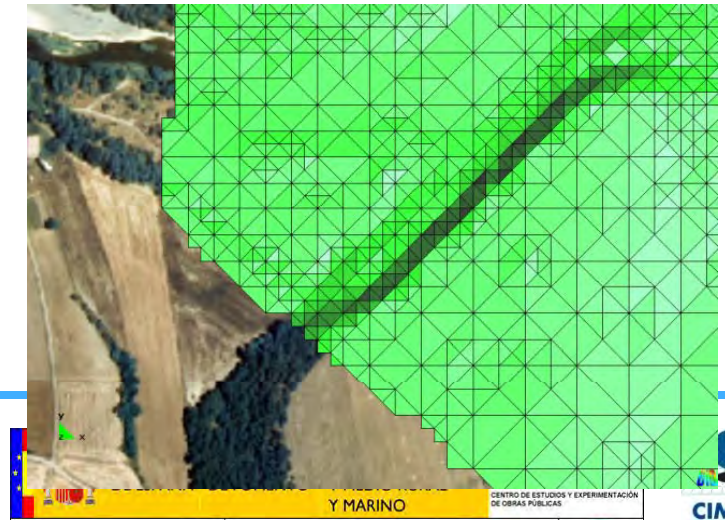
DEFINICIÓN MANUAL DE LA MALLA (herramientas estándar GiD)



MALLADO CON TRIANGULOS RECTANGULOS

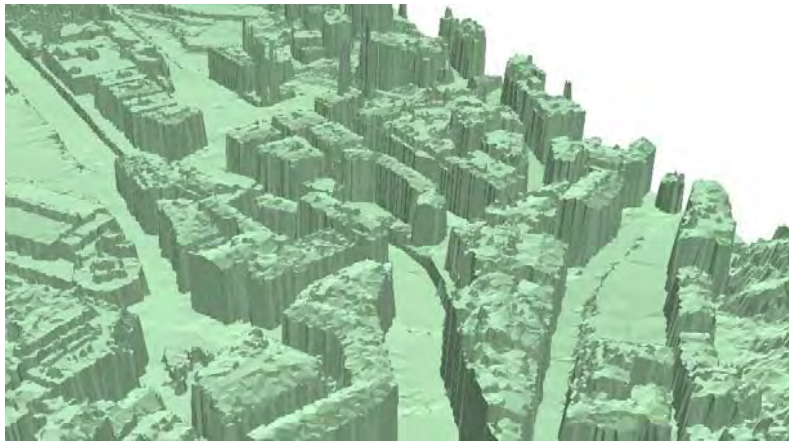
(error cordal)

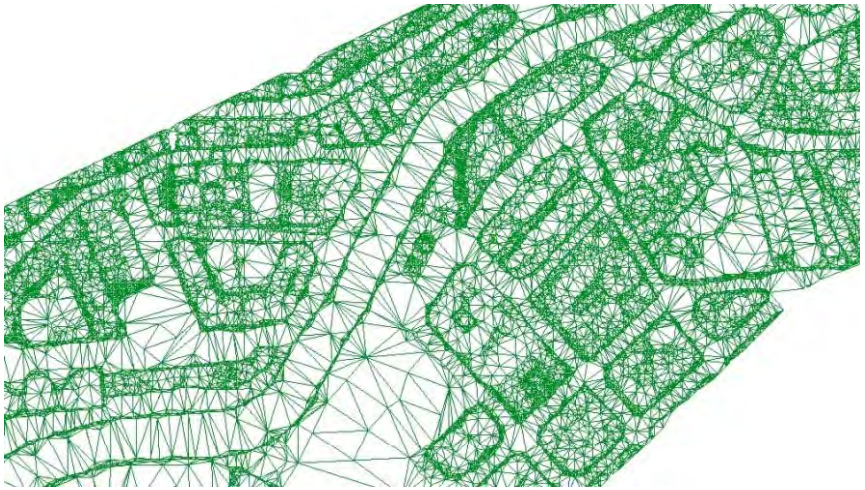




Preproceso

USO DE *TIN* COMO MALLA

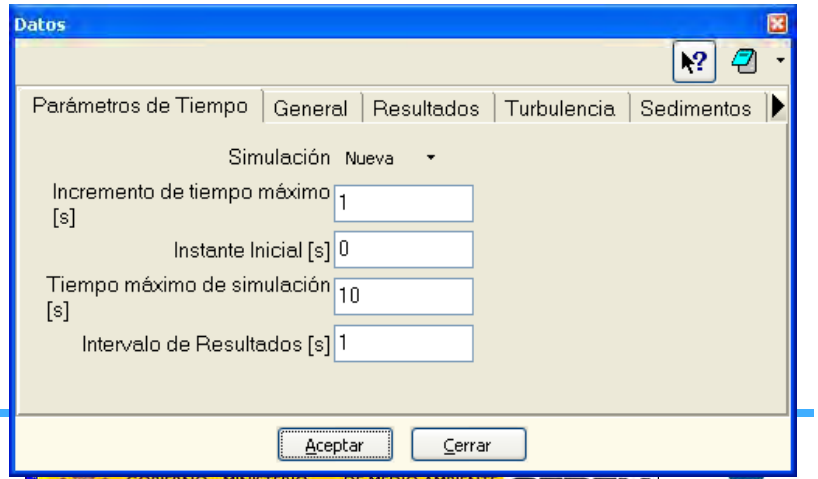




TERRENO COMO SUPERFICIES Y MALLADO CON ERROR CORDAL

Proceso

- Cálculo paralelo: elección número de procesadores
- Visualización de resultados “en marcha”
- Reinicio de un cálculo interrumpido
- Primero orden/alta resolución (rápido/preciso)
- Definición umbral secado/mojado
- Modelo de turbulencia



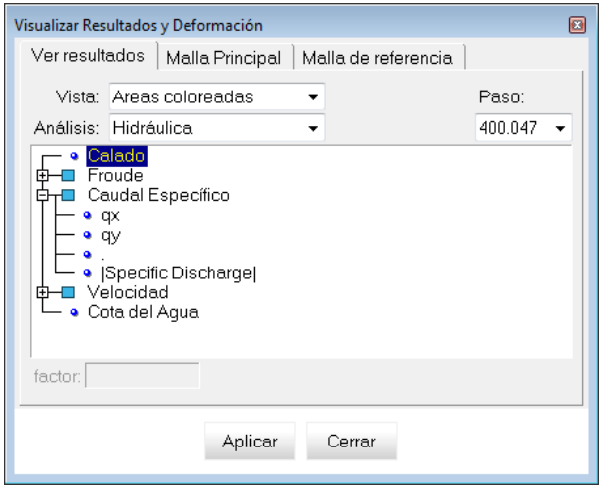
Postproceso

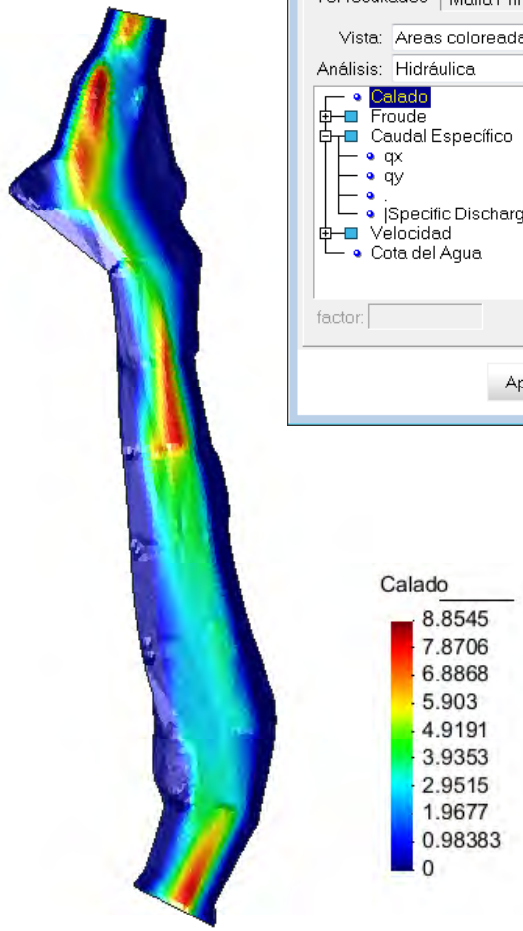
Resultados básicos:

- Calado
- Caudal específico
- Velocidad
- Cota de agua
- Froude

Resultados adicionales:

- Máximos
- Riesgo
- Capacidad de arrastre
- Courant

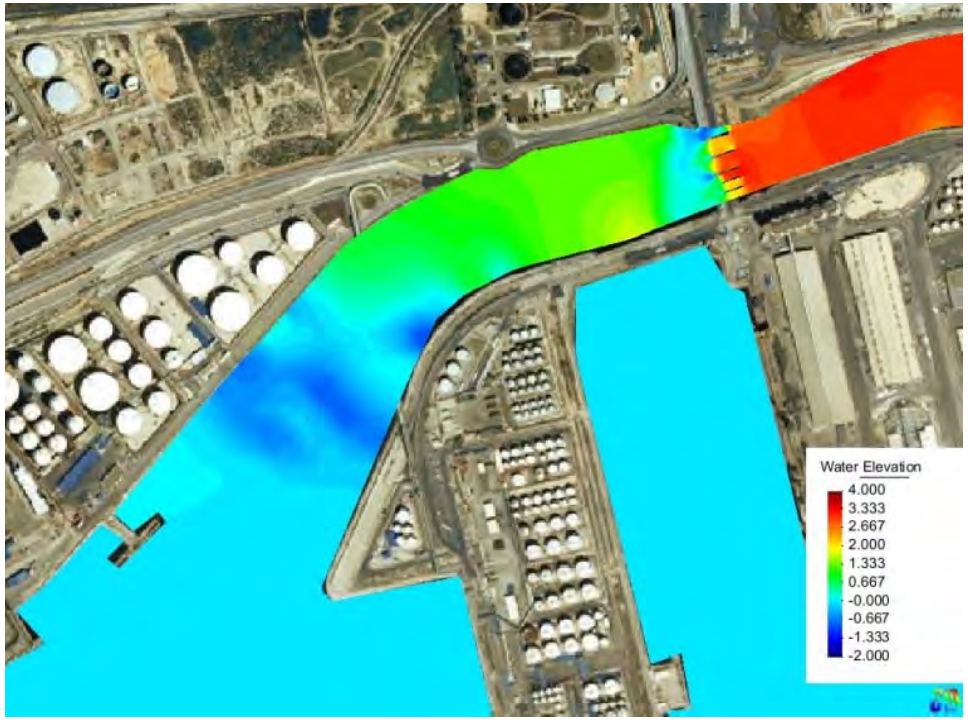




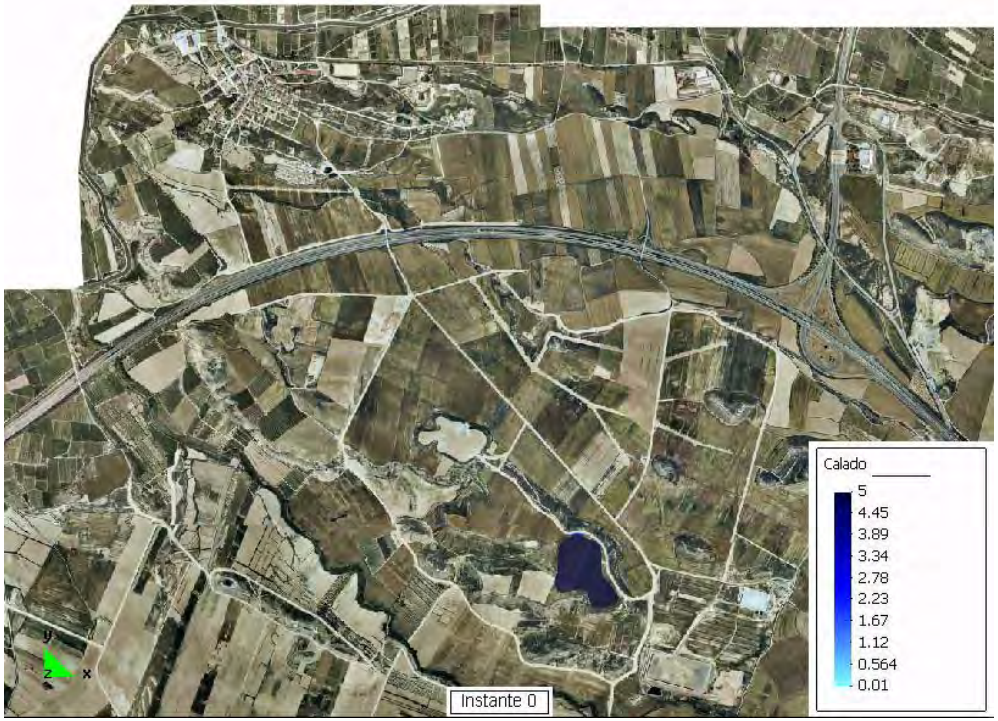
- lluvia, caudal sólido, erosiones, concentración de contaminantes, etc.

Postproceso

Resultados



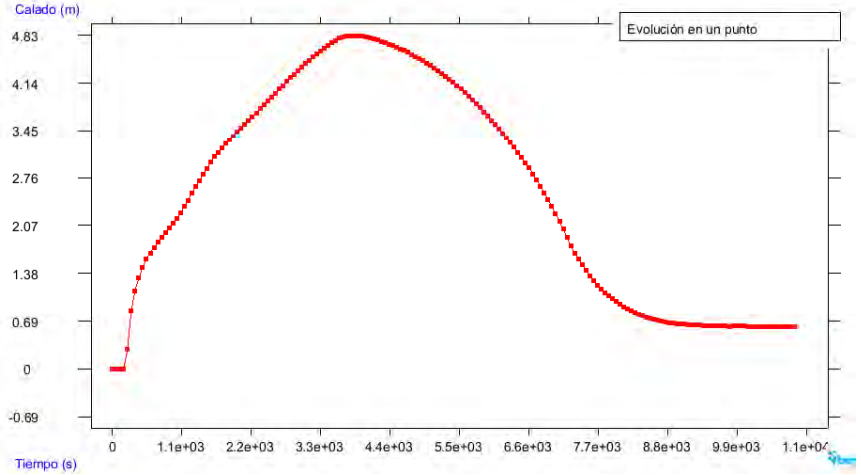
Escalas de colores

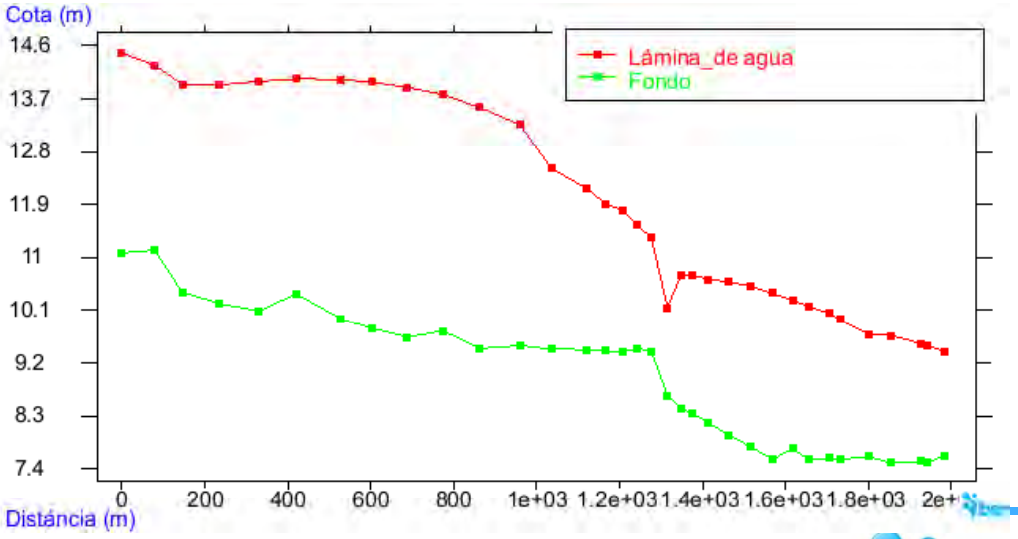


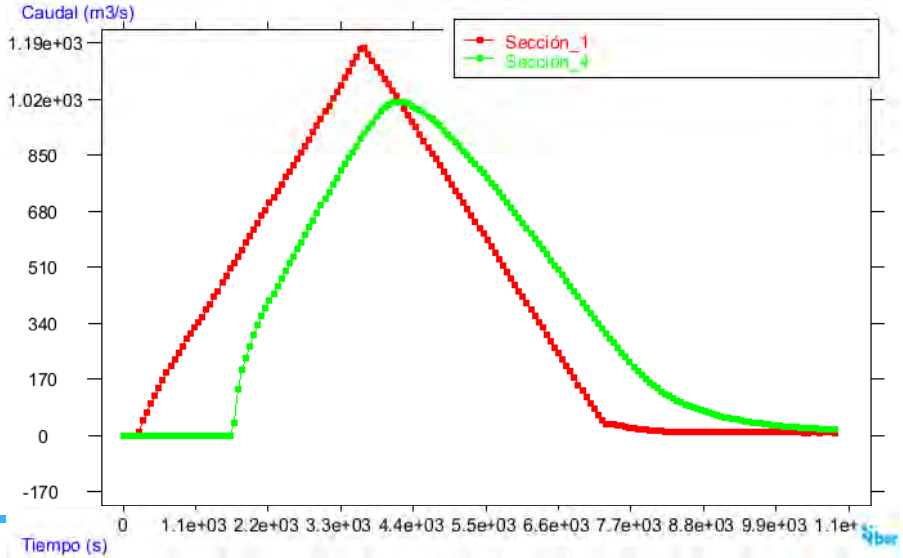
Animaciones

El modelo Iber
Interfaz gráfica

Postproceso



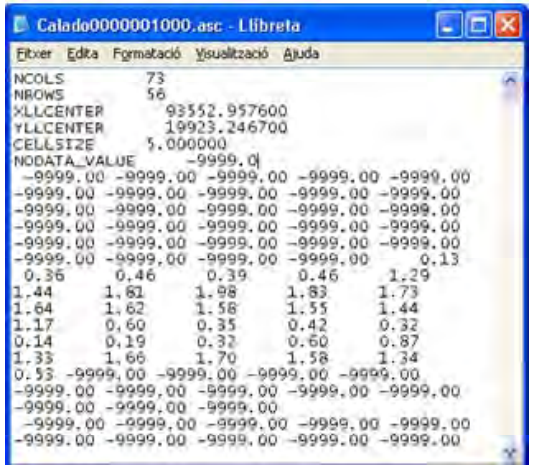




Perfiles

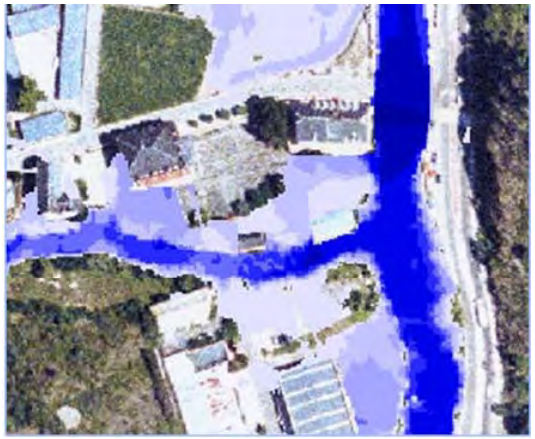
Sondas e hidrogramas

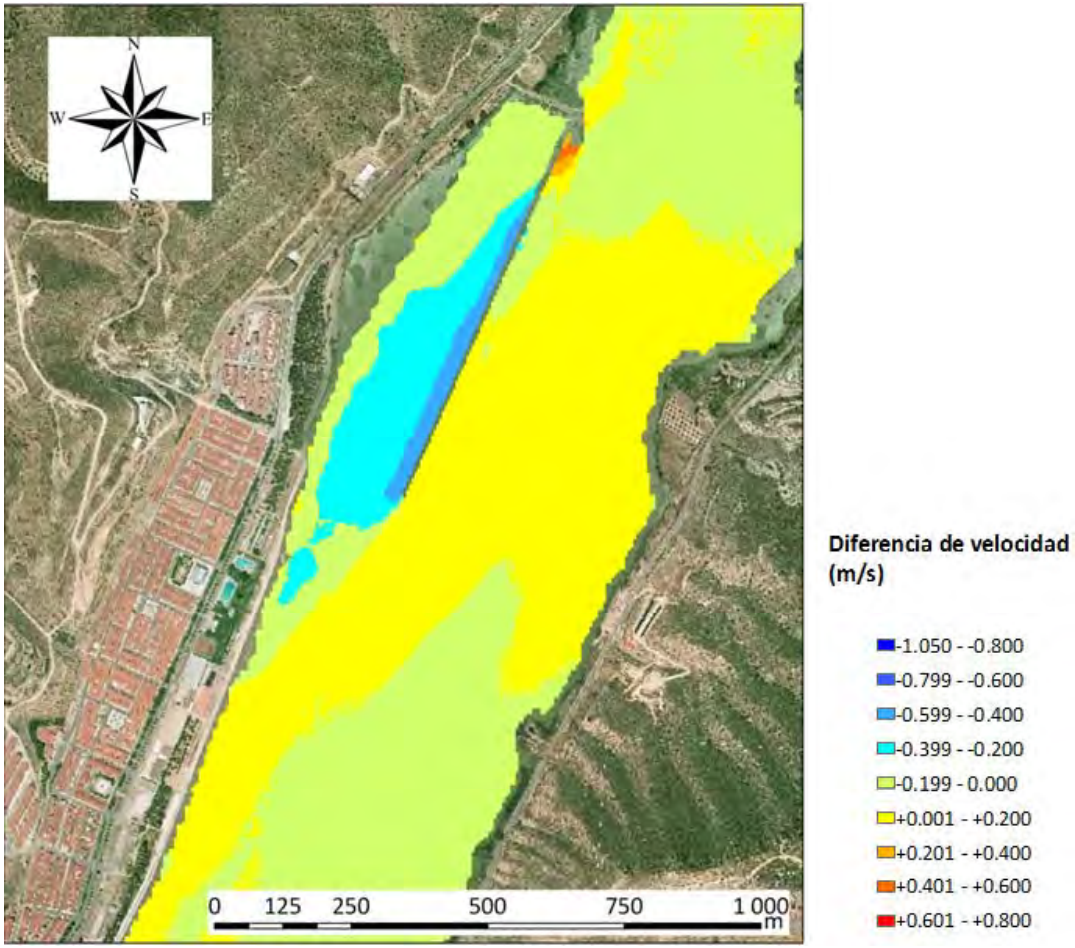
Exportación de resultados a GIS


Calado0000001000.asc - Llibreta

Fitxer Edita Formatació Visualització Ajuda

```
NCOLS          73
NROWS          56
XLLCENTER        93552.957600
YLLCENTER        19923.246700
CELLSIZE       5.000000
NODATA_VALUE        -9999.0
 -9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00      0.13
 0.36      0.46      0.39      0.46      1.29
1.44      1.81      1.98      1.83      1.73
1.64      1.62      1.58      1.55      1.44
1.17      0.60      0.35      0.42      0.32
0.14      0.19      0.32      0.60      0.87
1.33      1.66      1.70      1.58      1.34
0.53 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00
 -9999.00 -9999.00 -9999.00 -9999.00 -9999.00
-9999.00 -9999.00 -9999.00 -9999.00 -9999.00
```





Interfaz gráfica

Zona de flujo preferente

T=100 años

RD 9/2008
Modificación RDPH

Vía de intenso desagüe

- $\Delta Z_s < 0.3$ m (0.1 - 0.5)

Riesgo de daños para personas y bienes

- h > 1 m
- V > 1 m/s
- q > 0.5 m^2/s

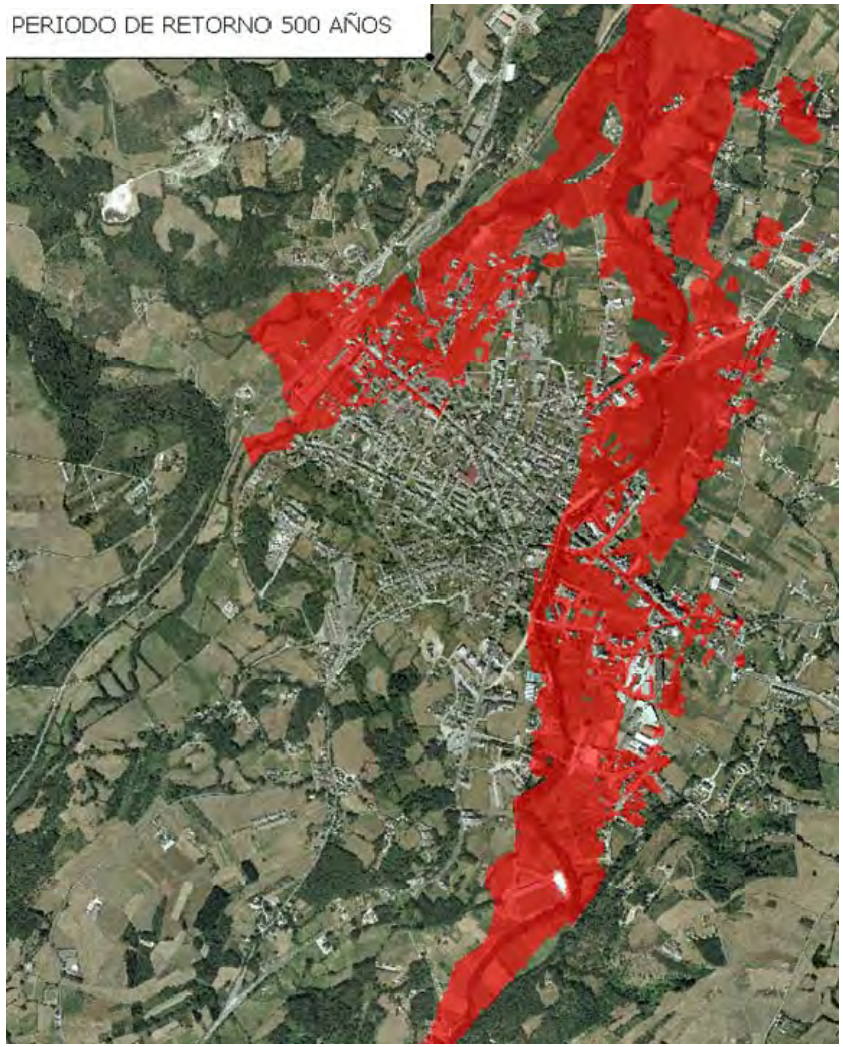
Zonas inundables

T = 500 años

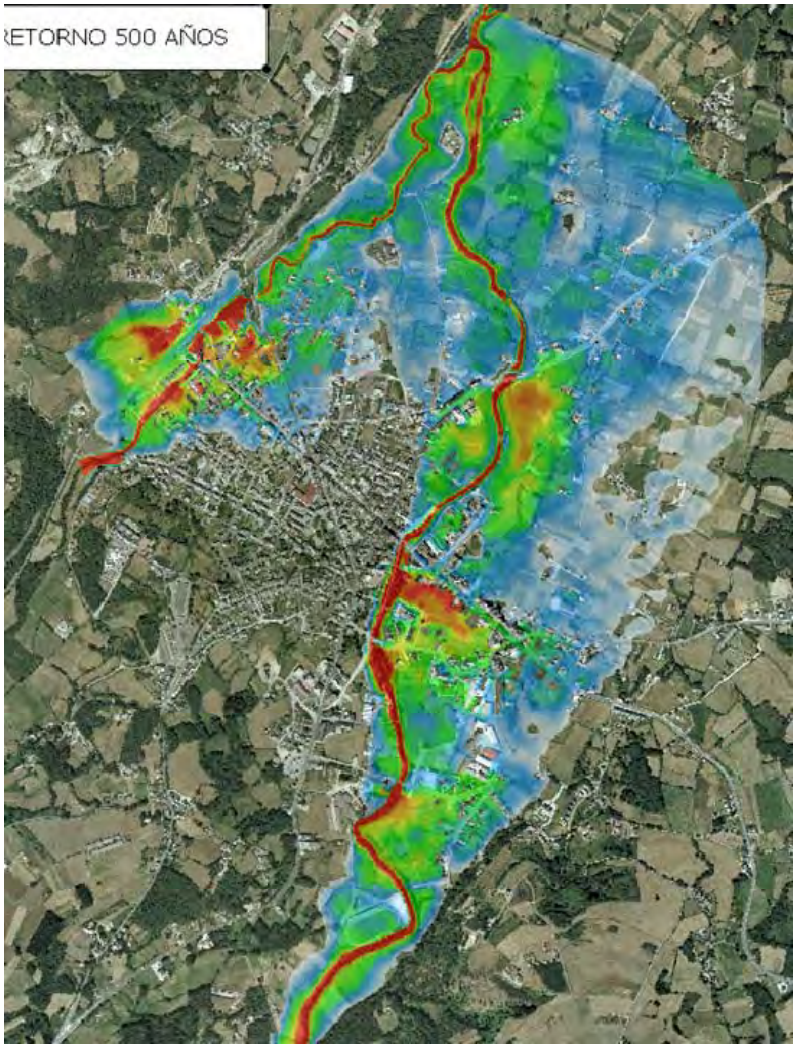
- **h > 0 m**

El modelo Iber
Interfaz gráfica

Zonas de riesgo

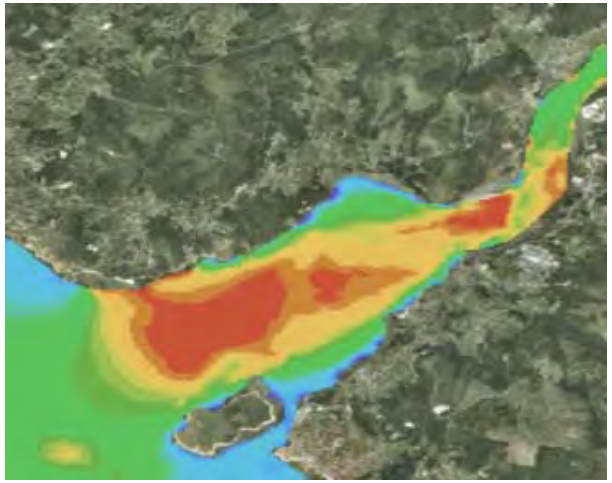


Zonas inundables



Desarrollos futuros

Módulos en desarrollo



TRANSPORTE DE SEDIMENTOS

- Mezclas de sedimento
- Acorazamiento
- Estabilidad de márgenes
- Erosión por flujos secundarios en meandros

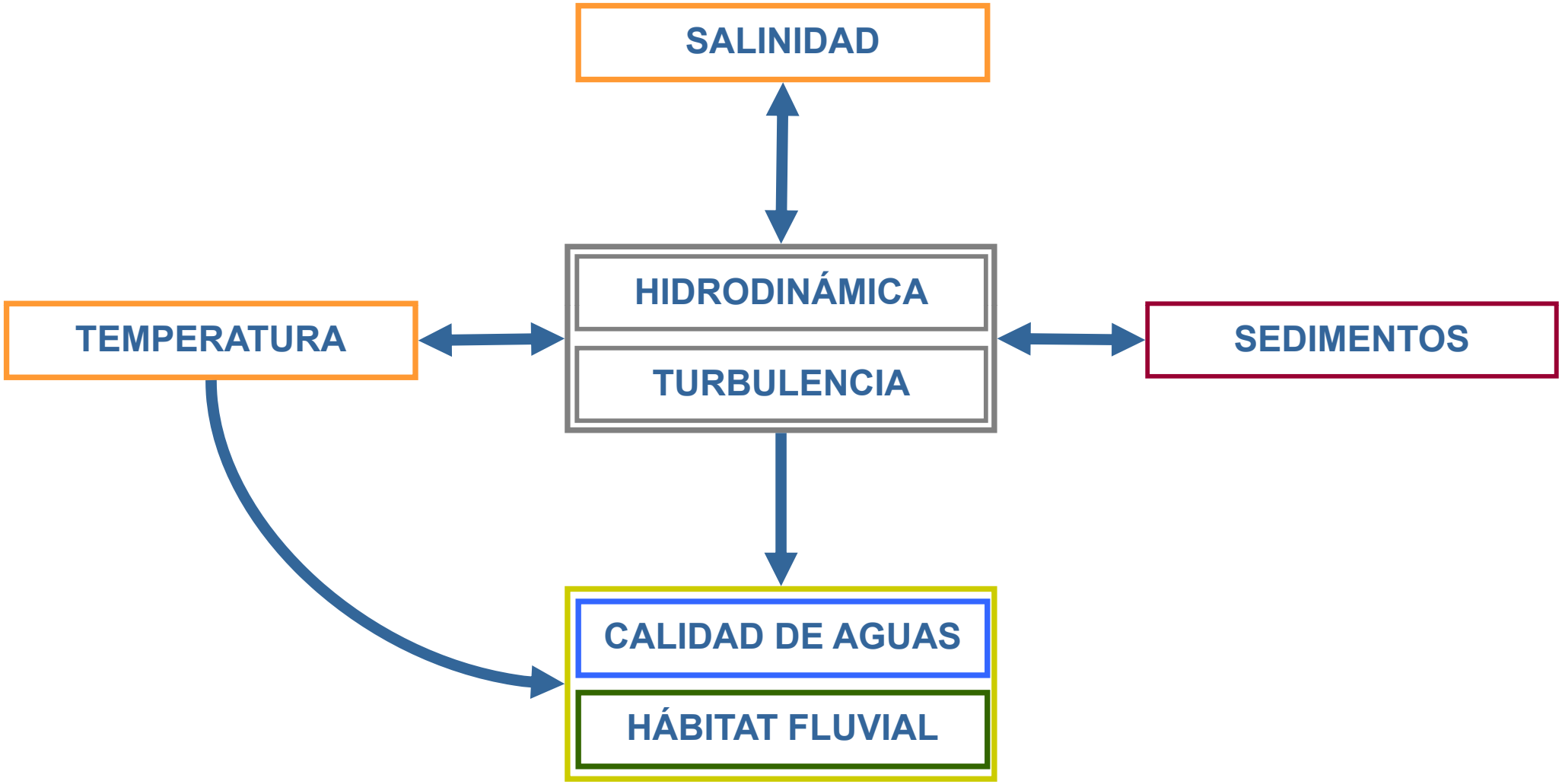
CALIDAD DE AGUAS

- OD, MO, Nitrógeno, CF

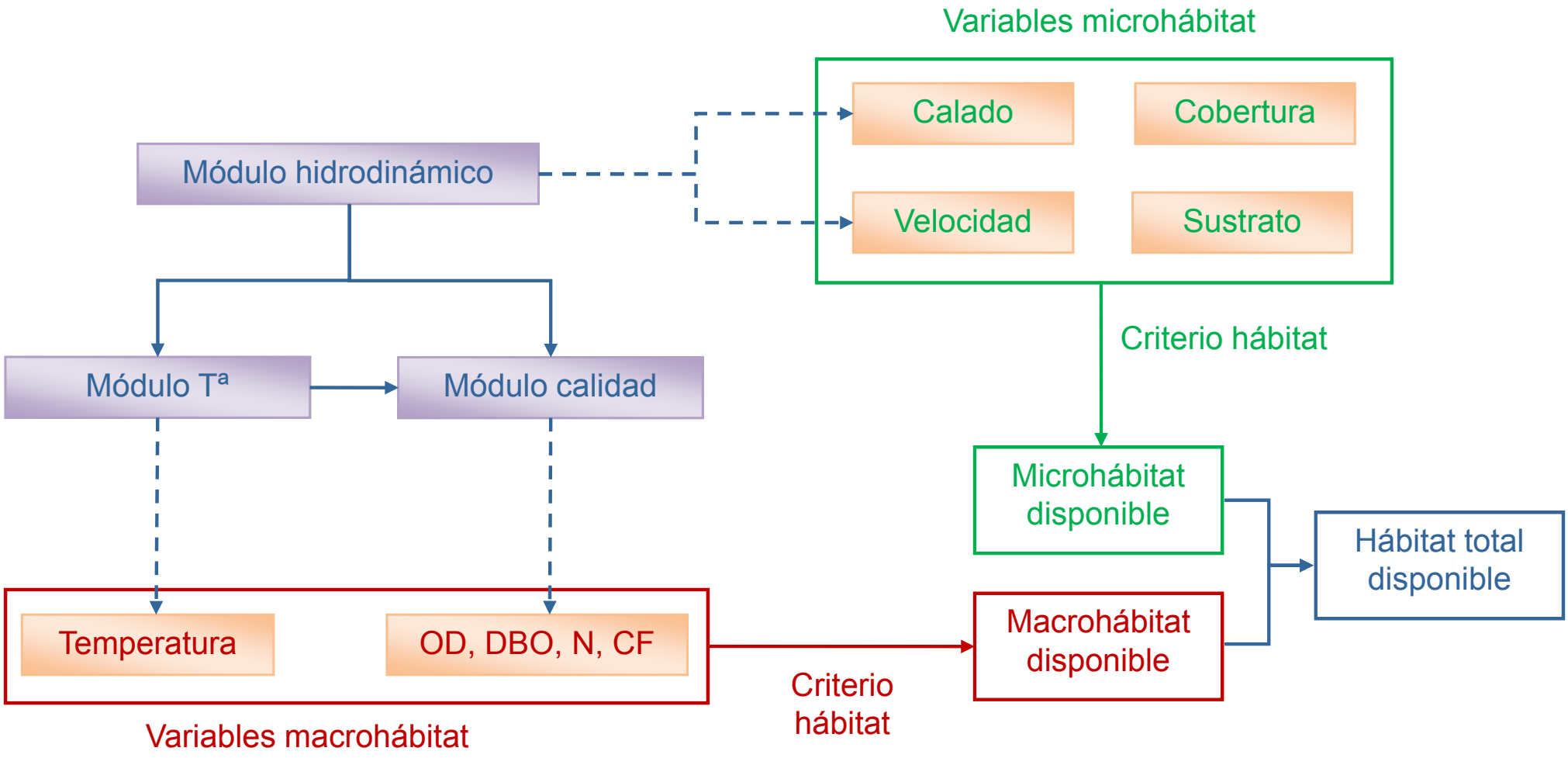
HÁBITAT FLUVIAL

- Caudales ecológicos
- Métodos hidrobiológicos

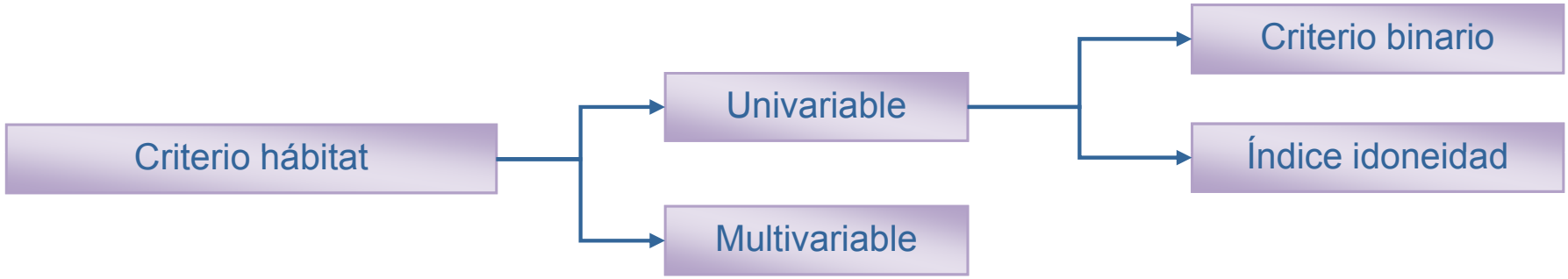
El modelo Iber
Desarrollos futuros

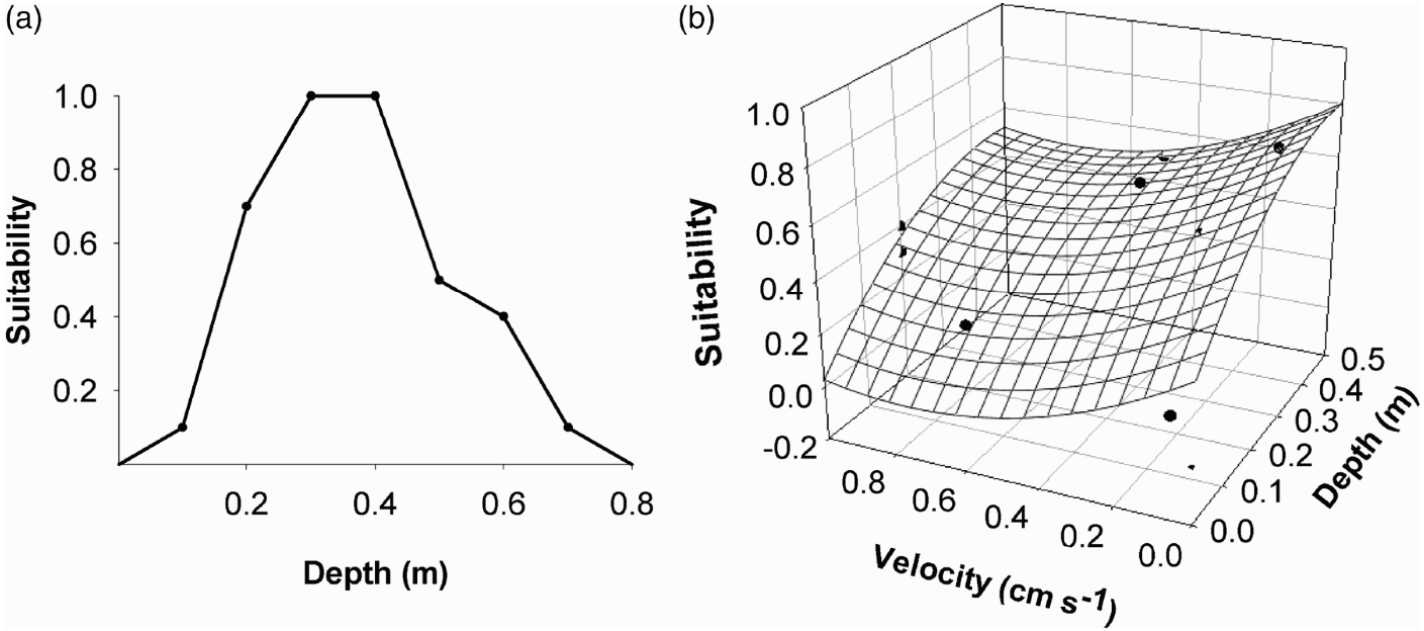


Hábitat disponible

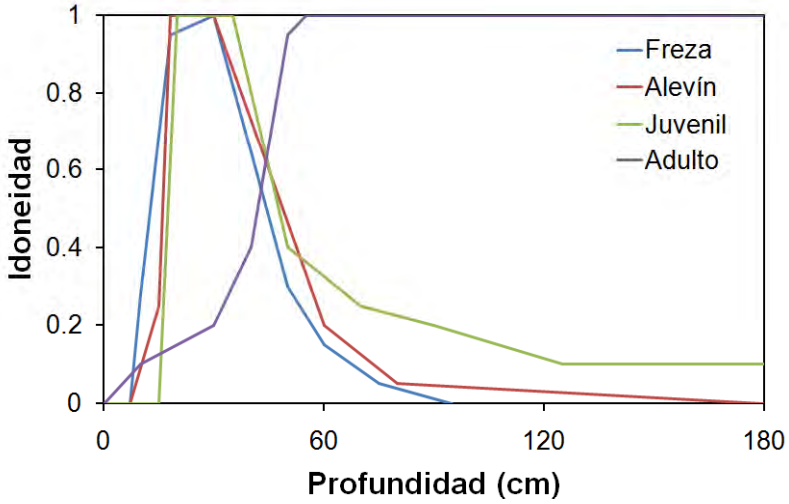


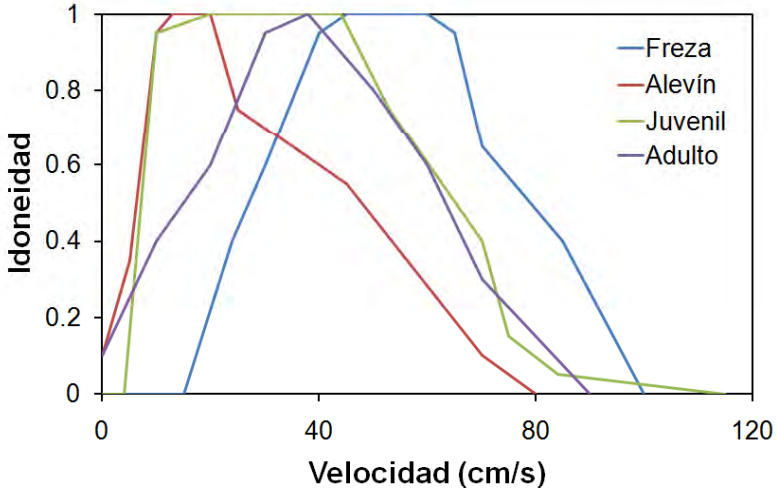
Criterios de hábitat

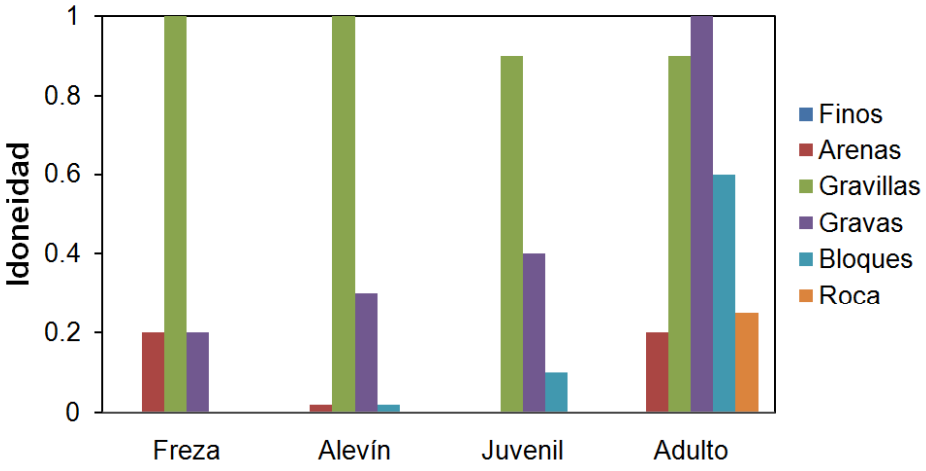




Curvas de idoneidad de la trucha arco iris







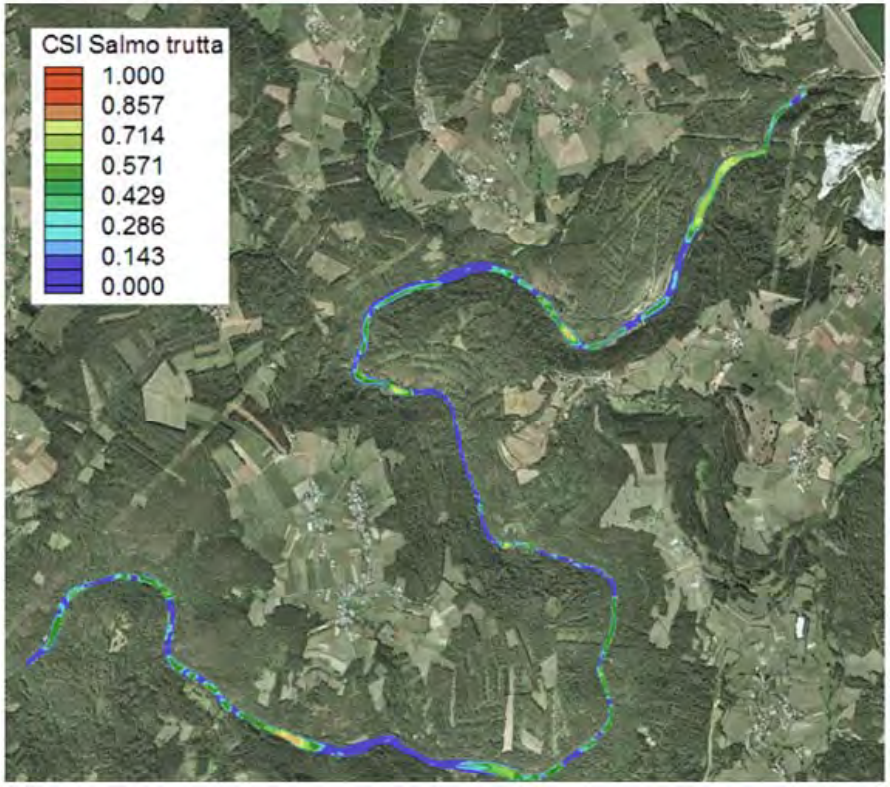
$$I = I(v)\cdot I(h)\cdot I(s)\cdot I(c)$$

$$I = \left[I(v)\cdot I(h)\cdot I(s)\cdot I(c)\right]^{1/4}$$

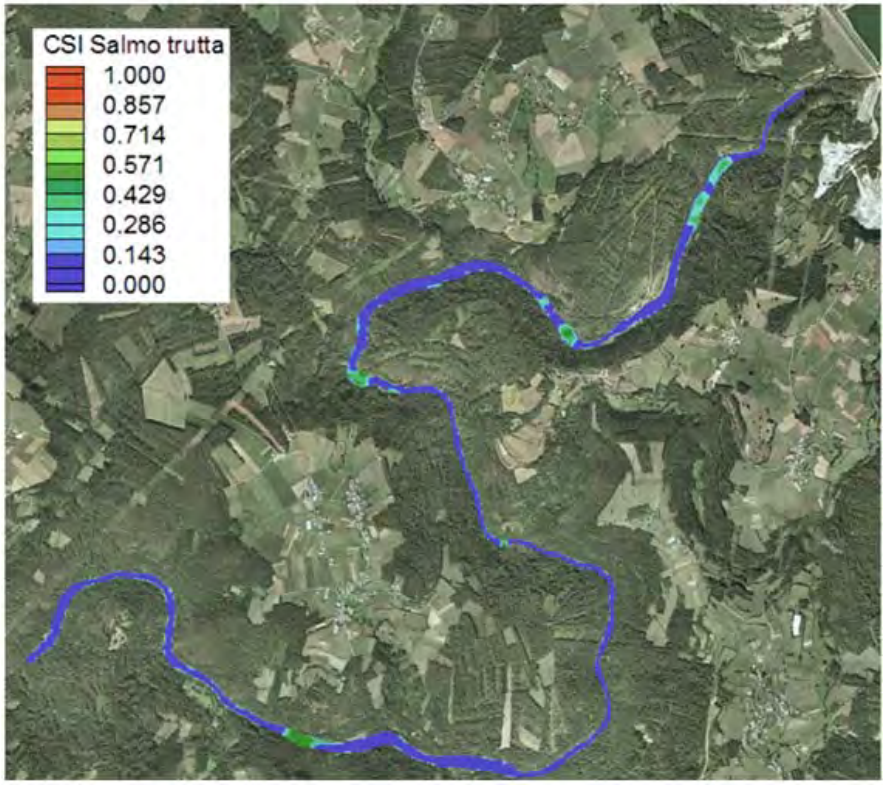
$$I = \min\left[I(v), I(h), I(s), I(c)\right]$$

Trucha común - Adulta

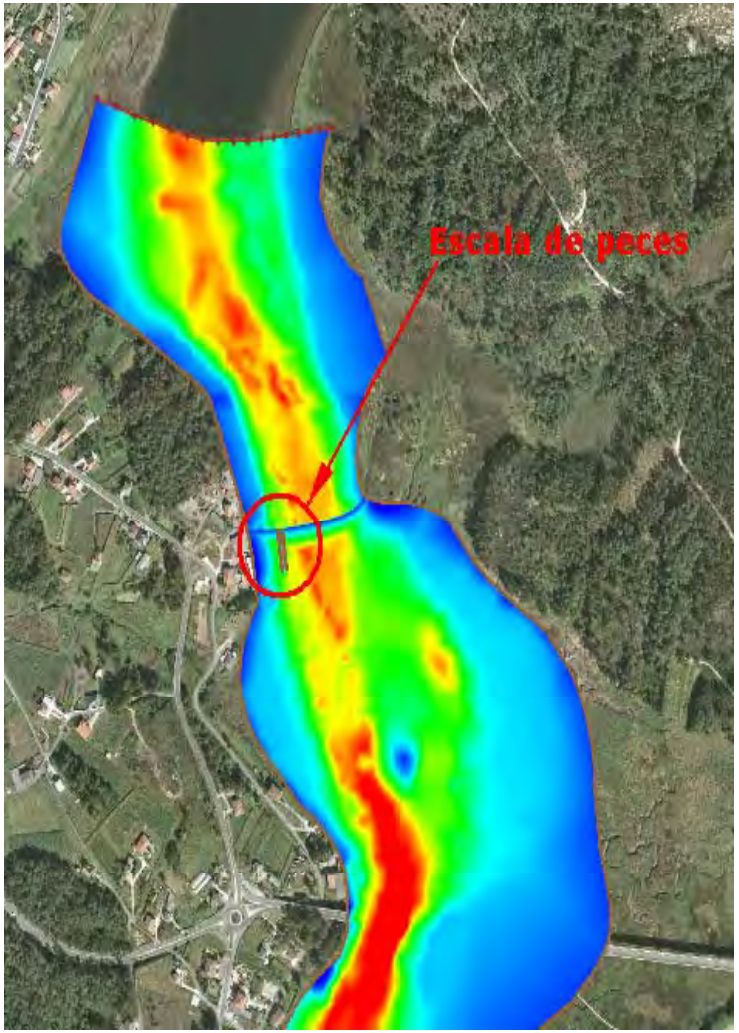
Q = 15 m³/s

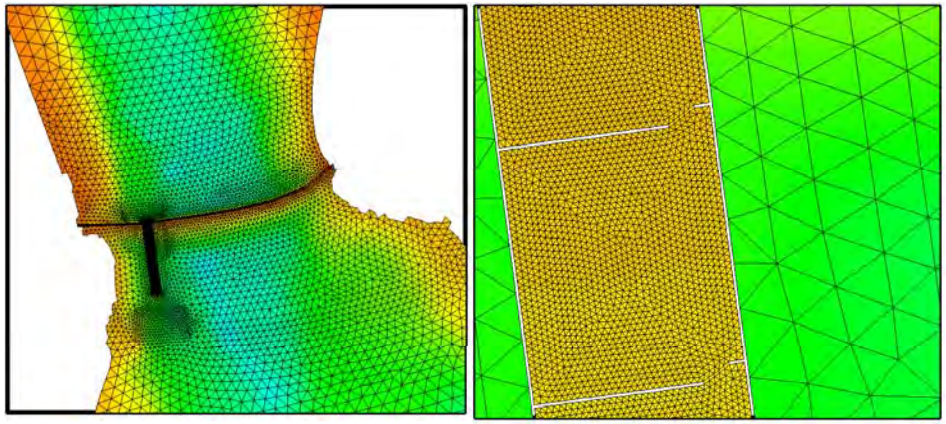


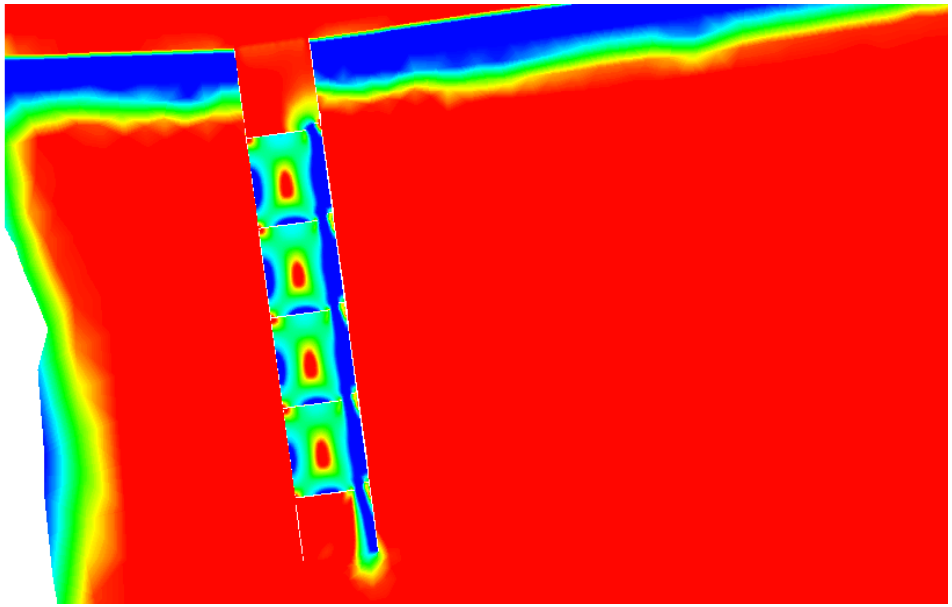
Q = 120 m³/s



Determinación del nivel de estrés en pasos restringidos

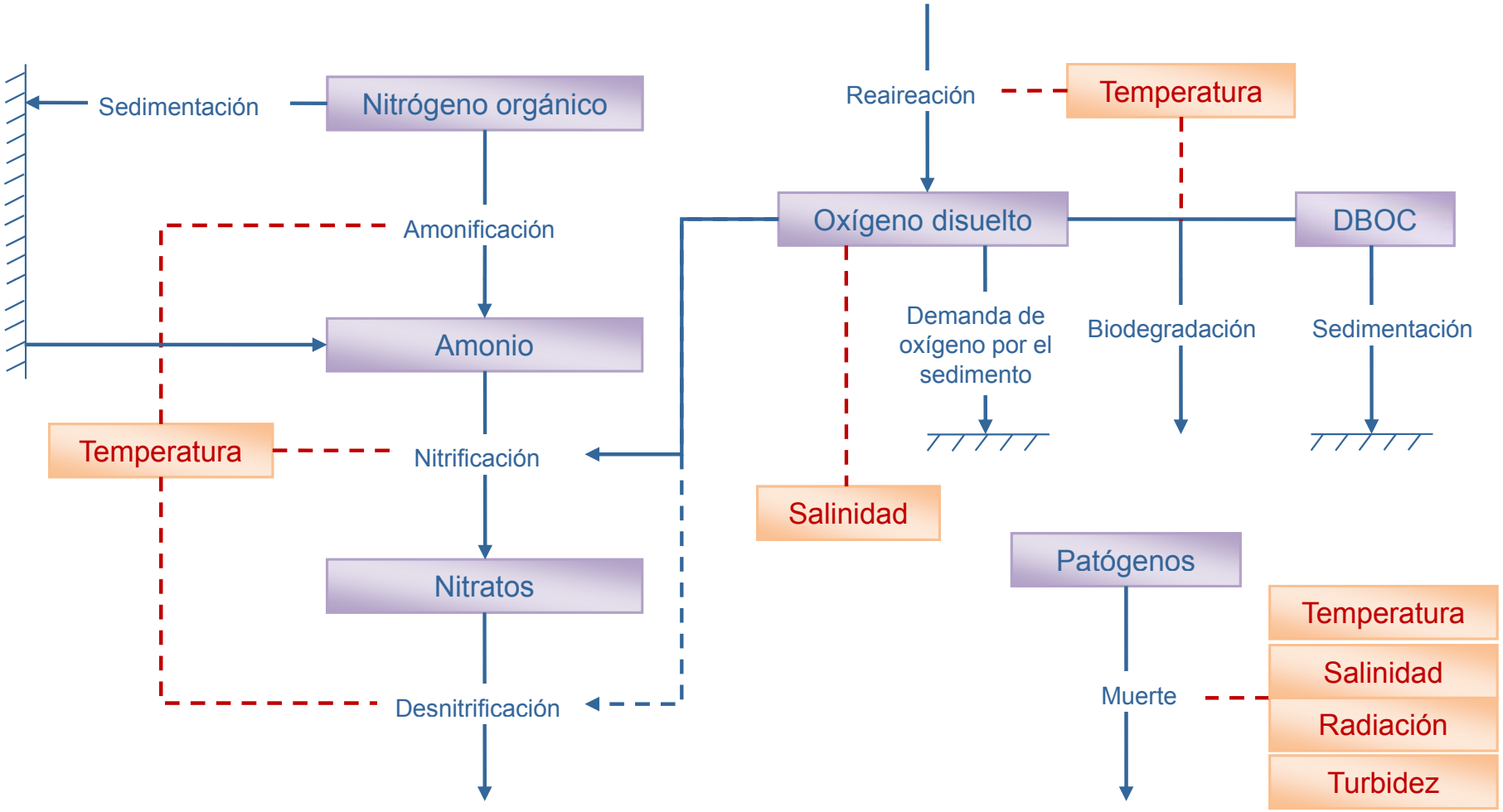






El modelo Iber
Calidad de agua

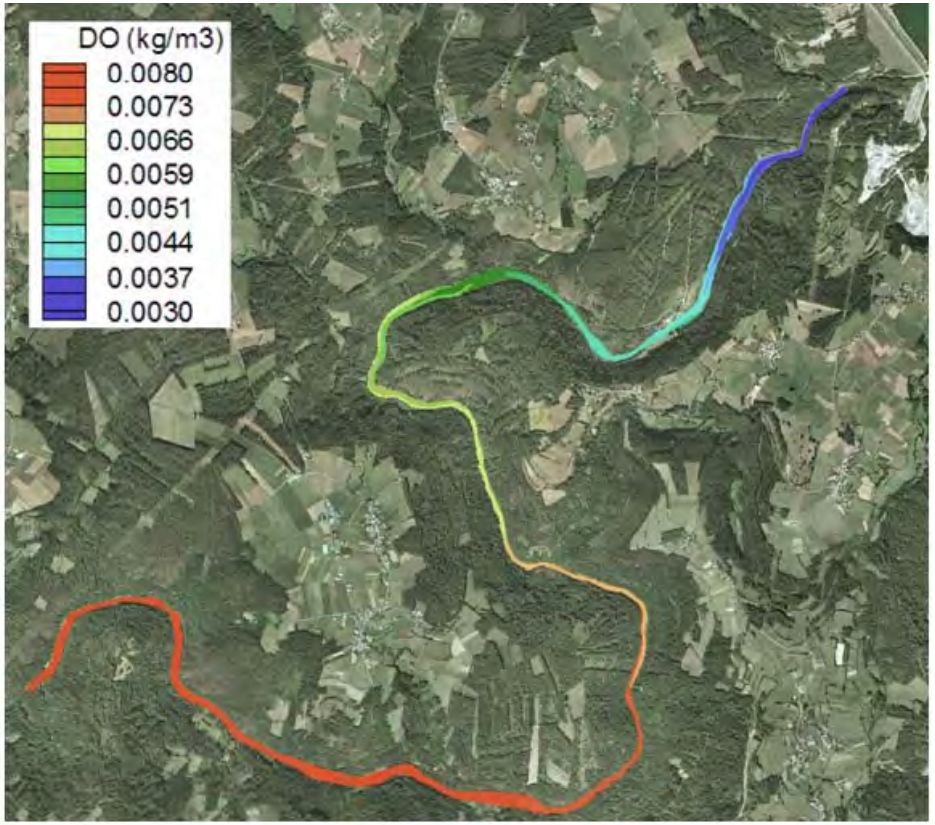
$$OD + DBO + N_{org} + NH_4 + N0_3$$



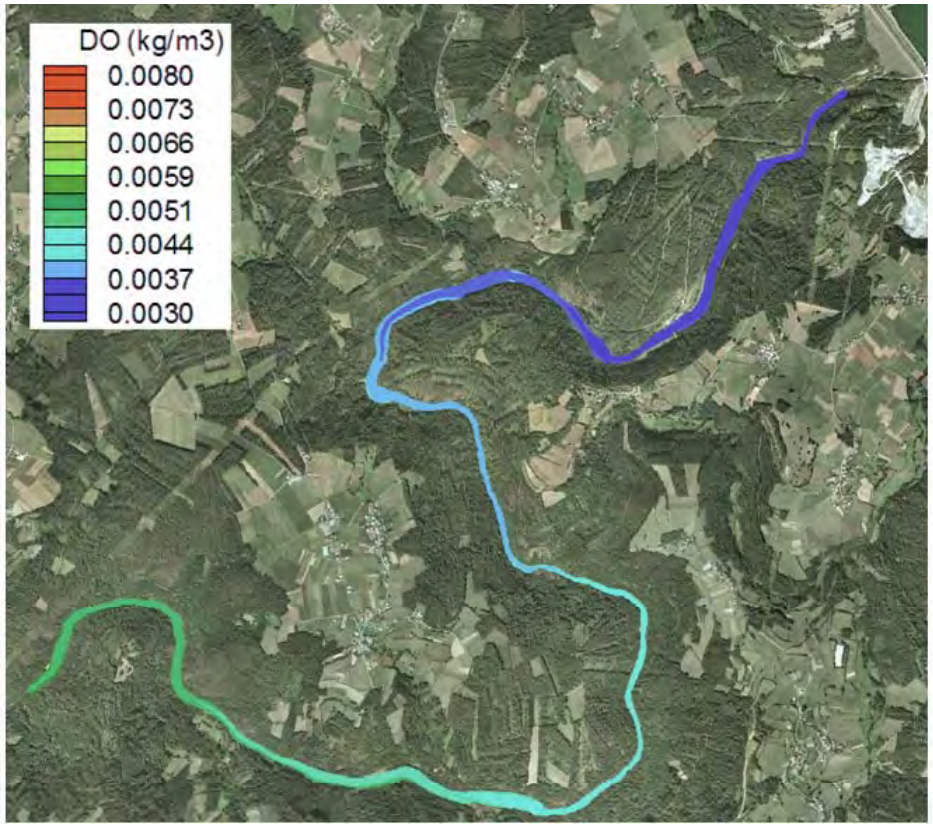
Calidad de agua

Evolución del nivel de oxígeno disuelto

Q = 15 m³/s

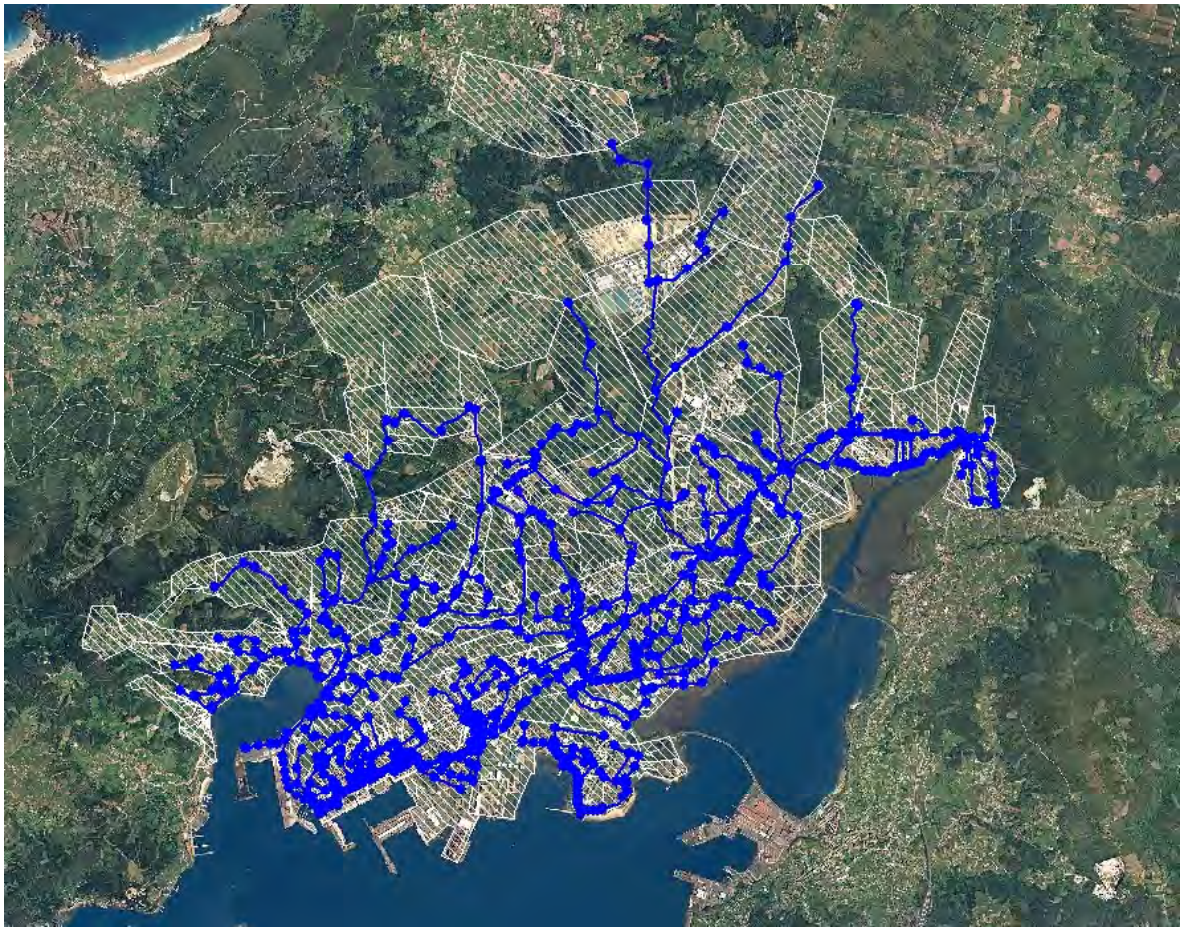


Q = 120 m³/s

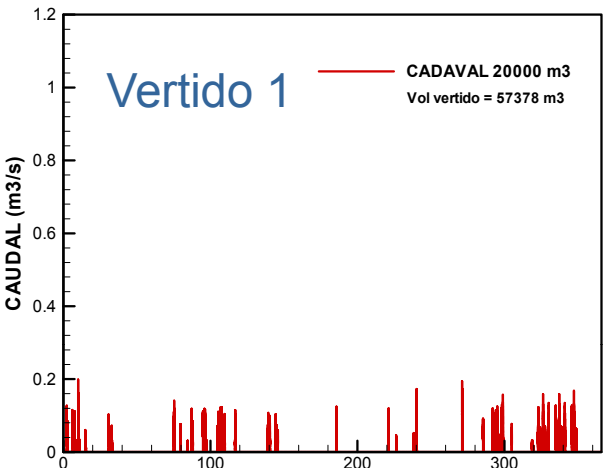


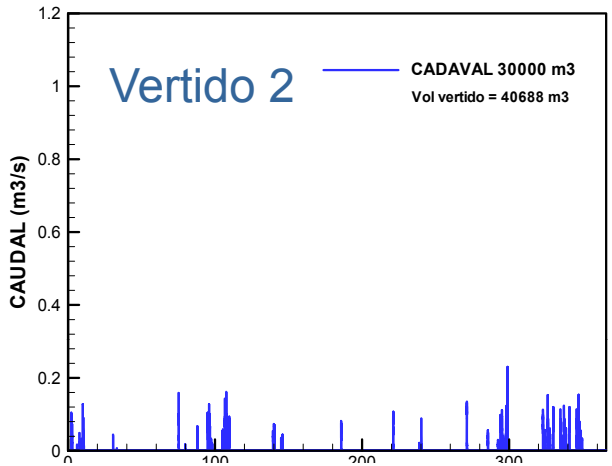
Contaminación bacteriana por vertidos de saneamiento

Red de drenaje

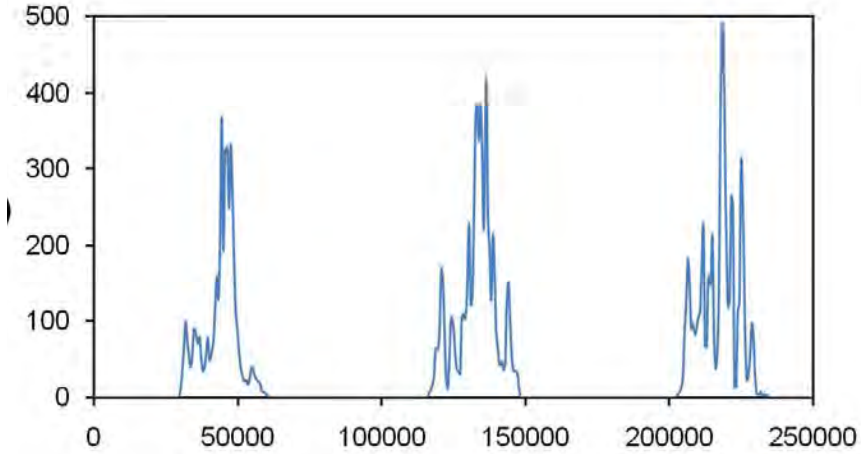


Contaminación bacteriana por vertidos de saneamiento

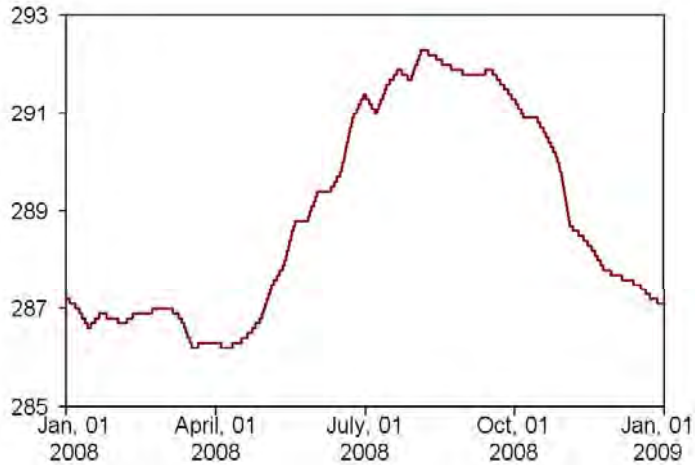




Radiación solar superficial (W/m^2)

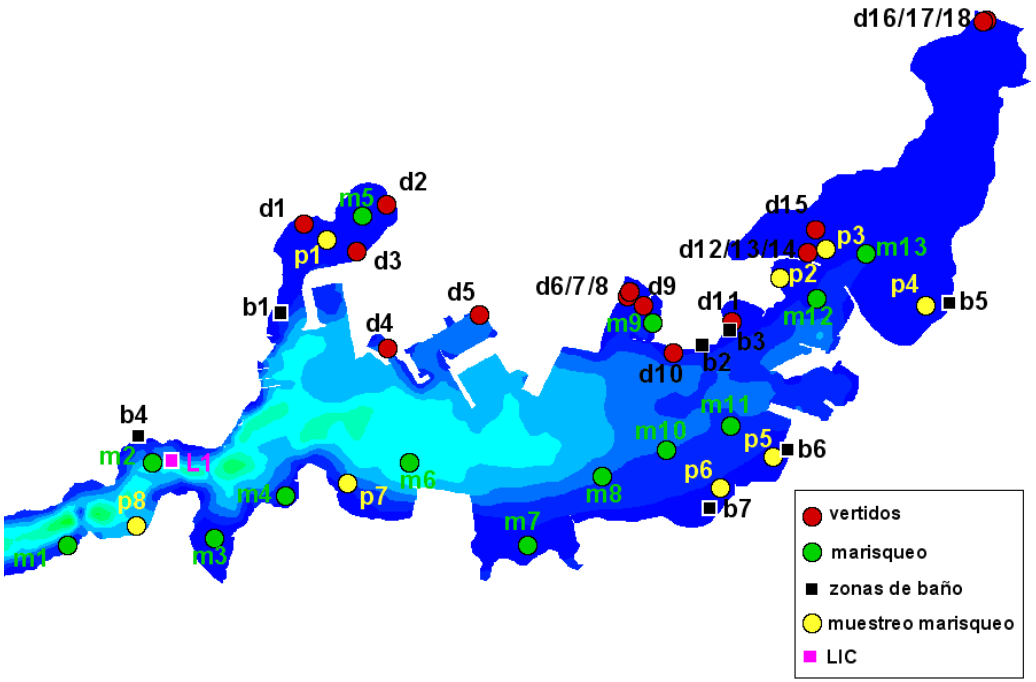


Temperatura SST (K)

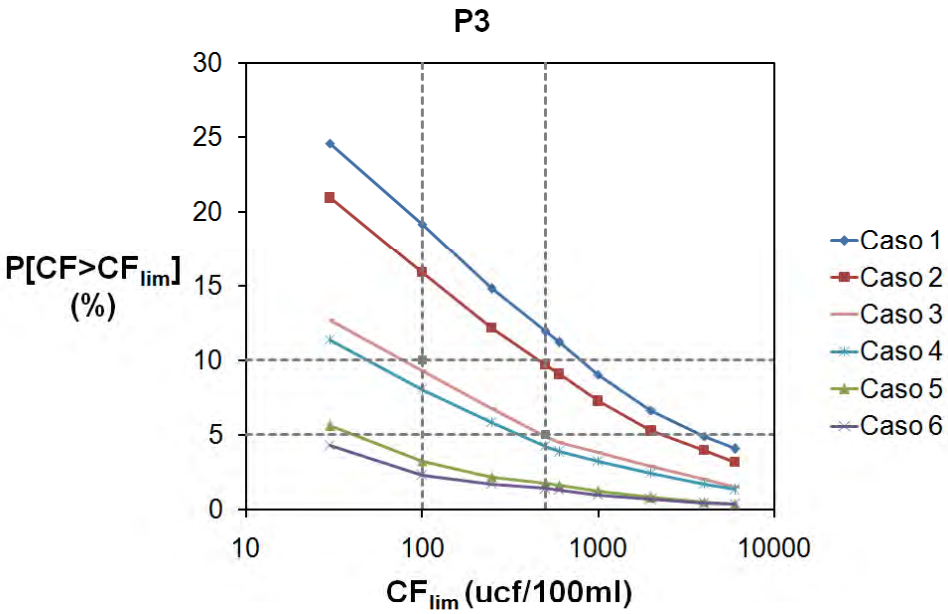


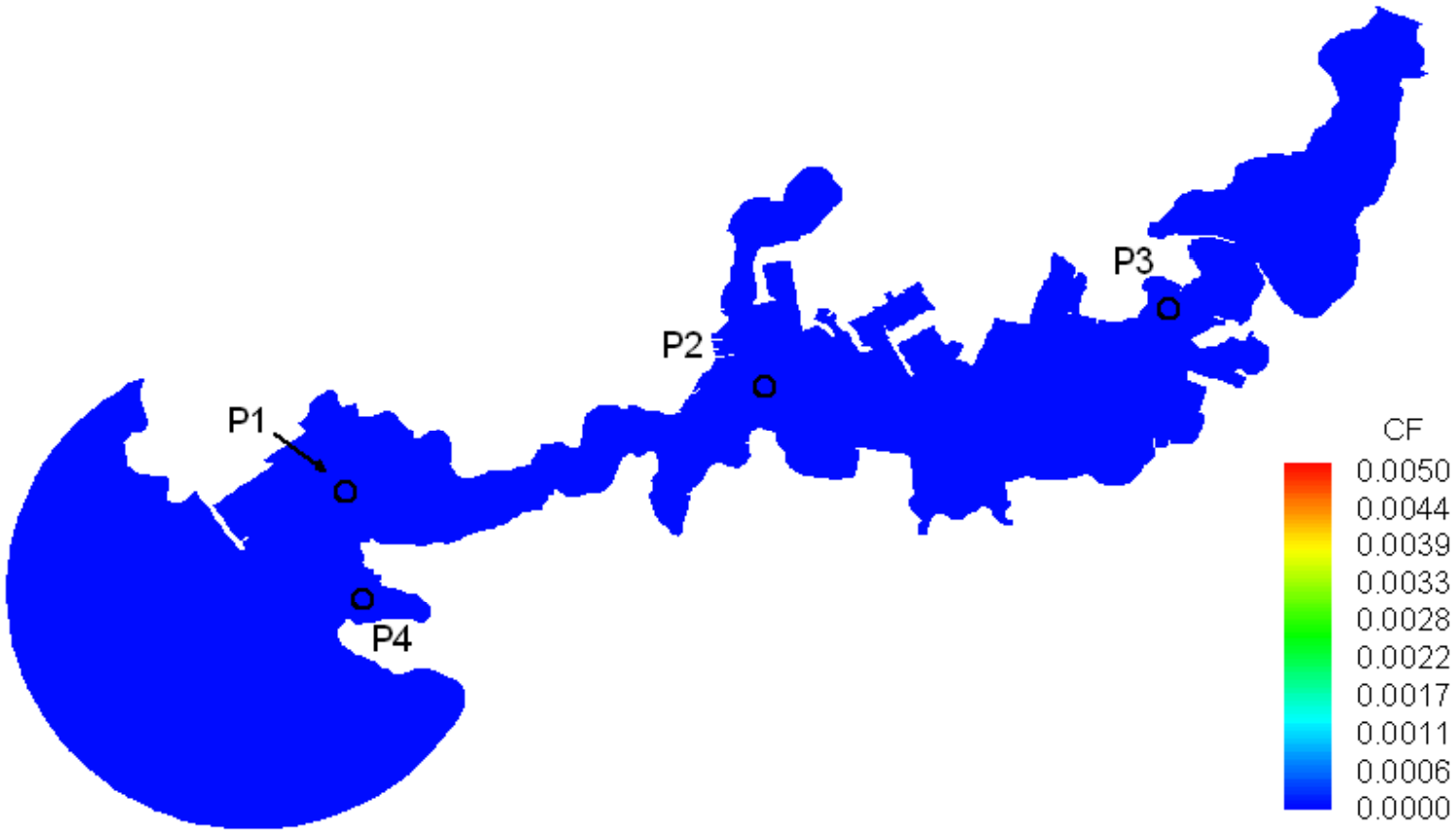
Contaminación bacteriana por vertidos de saneamiento

Puntos de vertido y de control



Probabilidad anual excedencia CF_{lim}



CF_{lim} (ucf/100ml)	$P[CF>CF_{lim}]$ (%)
100	10
500	5

Contaminación bacteriana por vertidos de saneamiento