The lower Ebro River is experiencing a series of geomorphic and ecological alterations caused by human impacts. Water and sediment transfer in the lower Ebro River are altered by dams. The Mequinenza-Ribarroja-Flix dam-complex retain, on average, up to 90% of the suspended load (Vericat and Batalla, 2006).

Downstream from this dam-complex, frequent floods (e.g. Q2 to Q25) have been reduced by around 25% (Batalla et al., 2004).

Persistent low flows, excess nutrients (nitrogen, phosphorus) and high light availability (due to the lack of suspended sediment) have been discussed as the likely causes for the recent uncontrolled growth of macrophytes.

This massive development of macrophytes generates a series of ecological and socio-economic problems (Palau et al., 2004).

How to face this problem????

Controlled water releases, have been implemented (i.e. designed, monitored, and modelled) in the lower Ebro River since 2002, with the objective of removing the excess of macrophytes and keeping sedimentary activity in the channel. Here we present an integrated monitoring design to assess the effectiveness of flushing flows. This design is based in the following scheme:

- Monitoring and sampling
- Flushing flow design
- Modelling adverse geomorphic effects
- Design validation
- Flushing flow monitoring
- Flushing flow evaluation
(A) MONITORING AND SAMPLING

-Sediment Transport, Hydraulics and Morphosedimentary Dynamics-

Particle Sizes

Bed Incision

Bed Entrainment

Sediment Transport

Bathymetry

Topography
The design of flushing flows was based on mobilizing an active layer, equal the maximum root depth of the macrophytes. This was based on the Shields entrainment function (1936).

\[
\tau_c = \frac{g \cdot \rho_s \cdot \tau_c^* \cdot D_i}{\rho_v}
\]

\[
\tau > \tau_c \rightarrow D_i \text{ initial entrainment}
\]
Resulting peak flows were equivalent to the 1.5- to 2-year flood of the river’s post-dam flow series (i.e. ca 1350 m³s⁻¹).

FLUSHING FLOW DESIGN

Based on a specific objective and limitations.

MODELLING ADVERSE GEOMORPHIC EFFECTS - Based on Monitoring and Sampling.

\[ \tau = \frac{g}{D} \cdot \rho \cdot s' \cdot \tau^* \cdot D_i \]

\[ \tau = d \cdot g \cdot \rho \cdot s \]

Submerged Weight

Lift Forces

Tractive Forces

Sediment Transport

Hydraulics and Morphosedimentary Dynamics

Particle Sizes

Bed Entrainment

Bed Incision

Topography

Macrophyte

Removal

Release from Ribarroja Dam (m³ s⁻¹)

Time (hours)
Hydraulic modelling

Velocity

Discharge

Shear stress
Sediment transport modelling
Suspended sediment concentration

Bed load transport rate

Modelling geomorphic effects
Bed changes
(A) MONITORING AND SAMPLING - Sediment Transport, Hydraulics and Morphosedimentary Dynamics

(B) FLUSHING FLOW DESIGN - Based on a specific objective and limitations

(C) MODELLING ADVERSE GEOMORPHIC EFFECTS - Based on Monitoring and Sampling

(D) DESIGN VALIDATION - Based on adverse effects, flooding limitations and water availability

(E) FLUSHING FLOW MONITORING - Flushing Flow effects in Monitoring Sections
   a) Macrophyte density and topography
   b) Flow hydraulics
   c) Sediment transport

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a) Macrophyte density

Macrophyte densities were estimated in experimental sections before and after the FF by means of the backscatter of a sonar.

**Macrophyte densities**

- **Macrophytes estables**: 8.1%  
- **Macrophytes incipientes**: 3.3%  
- **Total macrophytes**: 11.4%
b) Flow hydraulics

A board-mounted ADCP was used to measure discharge and hydraulics in a monitoring section during the entire FF.

c) Sediment transport

**Suspended sediment concentrations in the lower Ebro River**

- Discharge (m$^3$/s)
- SSC Ribarroja
- SSC Valencia
- SSC Murcia
- SSC Murcia
- SSC Xerta

**Time (h)**

**Suspended Sediment Concentration (mg L$^{-1}$)**

- 0
- 20
- 40
- 60
- 80
- 100
- 120
- 140
- 160
(A) MONITORING AND SAMPLING - Sediment Transport, Hydraulics and Morphosedimentary Dynamics

(B) FLUSHING FLOW DESIGN - Based on a specific objective and limitations

(C) MODELLING ADVERSE GEOMORPHIC EFFECTS - Based on Monitoring and Sampling

(D) DESIGN VALIDATION - Based on adverse effects, flooding limitations and water availability

(E) FLUSHING FLOW MONITORING - Flushing Flow effects in Monitoring Sections

(F) FLUSHING FLOW EVALUATION - Based on flushing flow monitoring and post-sampling

\[ \tau_c = g \cdot \rho_s' \cdot \tau_{c*} \cdot D_i \]

\[ \tau_c = g \cdot \rho \cdot D_i \cdot p \cdot s \]
MACROPHYTES COVER EVOLUTION IN THE LOWER EBRO (2009-2010)

<table>
<thead>
<tr>
<th>Date</th>
<th>Macrophyte Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>08/07/2009</td>
<td>11</td>
</tr>
<tr>
<td>24/04/2010</td>
<td>12</td>
</tr>
<tr>
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</tbody>
</table>

**A) MONITORING AND SAMPLING** - Sediment Transport, Hydraulics and Morphosedimentary Dynamics

**B) FLUSHING FLOW DESIGN** - Based on a specific objective and limitations

**C) MODELLING ADVERSE GEOMORPHIC EFFECTS** - Based on Monitoring and Sampling

**D) DESIGN VALIDATION** - Based on adverse effects, flooding limitations and water availability

**E) FLUSHING FLOW MONITORING** - Flushing Flow effects in Monitoring Sections

**F) FLUSHING FLOW EVALUATION** - Based on flushing flow monitoring and post-sampling
Effectiveness of flushing flows (i.e. rate of macrophyte removal) attains 95%, but decreases substantially downstream.

Flushing flows exhibited high transport capacity for suspended sediment.

Fine to medium gravels are mobilized but bedload rates are typically low given the short duration of the events.

Flushing flows do not exhibit severe geomorphic impacts after evaluation.

Flushing flows are an important instrument of river management in rivers subject to regulation specially in large Mediterranean rivers such as the Ebro.
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- Elaboración de una metodología de base física para la preparación de crecidas generadoras aguas abajo de embalses: Aplicación al tramo inferior del río Ebro, CICYT (REN2001-0840-C02-01/HID)
- Diseño y análisis de crecidas generadoras como estrategia de reequilibrio hidrológico y sedimentario del curso inferior del río Ebro, CICYT (CGL2005-06989-C02-02/HID)
- Diseño y aplicación de crecidas generadoras como estrategia de reequilibrio hidro-sedimentario en ríos regulados, CICYT (CGL2006-11679-C02-01/HID)
- Encomienda de gestión relacionada con el medio ambiente en el marco del Proyecto ‘Modelo Conceptual para comprender el riesgo de los fangos tóxicos contenidos en el embalse de Flix. Propuestas para su estudio científico’, CSIC, 2006-2008
- Desarrollo y experimentación de un sistema de crecidas de mantenimiento en cascada con base en criterios físicos y económicos para la mejora hidrosedimentaria del bajo Ebro y sus principales afluentes, CICYT (CGL2009-09770 (subprograma BTE)
- Assessing and predicting effects on water quantity and quality in Iberian rivers caused by global change SCARCE, MICINN, Consolider Ingenio 2010 CSD2009-00065
- Diseño y monitorización de una crecida generadora en el río Ebro aguas abajo del sistema de embalses Mequinenza-Ribarroja, Endesa Generación SA, 2002-2011
- Análisis de la dinámica de las poblaciones de macrófitos en el tramo bajo del río Ebro. URS-España & Confederación Hidrográfica del Ebro, 2008-2010