Potential Entrapment of Oil in a Tidal Marsh in Long Island NY

Michel Boufadel (1) James W. Weaver (2)

1 Temple University, Dept. of Civil and Environmental Engg., 1947 N. 12th Street, Philadelphia, PA, 19122, USA
boufadel@temple.edu, Ph:(215) 204-7871; Fax: (215) 204-4696

2 U.S. Environmental Protection Agency, National Exposure Research Laboratory,
Athens, GA, USA

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Objectives

- Study hydraulics/biology of a tidal marsh
- Test modeling approaches for "what if?" type simulations
  - Simulating transport in the marsh
  - Studying characteristics of various types of models

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Numerical Modeling of Tidal Marsh

- Small tidal marsh on Southern shore of Long Island
  - Breeding area for
    - Silversides, shrimp, killifish
    - Crabs, turtles
  - Foraging Area
    - Ducks, geese
    - Raccoons, deer
- Surrogate location for oil spill “what if?” testing
- Freshwater inflow and tidal inflow of salt water (~20 g/L) from the Great South Bay

Lock Lake Tidal Marsh

- Remnants of an unbuilt coastal development
  - Excavated channel
  - Continuous freshwater inflow
- Size: 1 mile by 0.6 mile
- 2 main and two major side channels

Figure 1: Ortho-photo of the marsh, with the freshwater lake behind it. The arrow at the bottom left indicates North.

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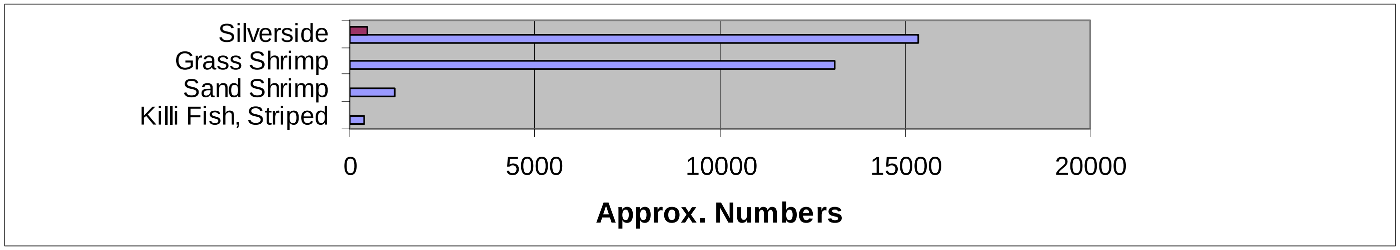
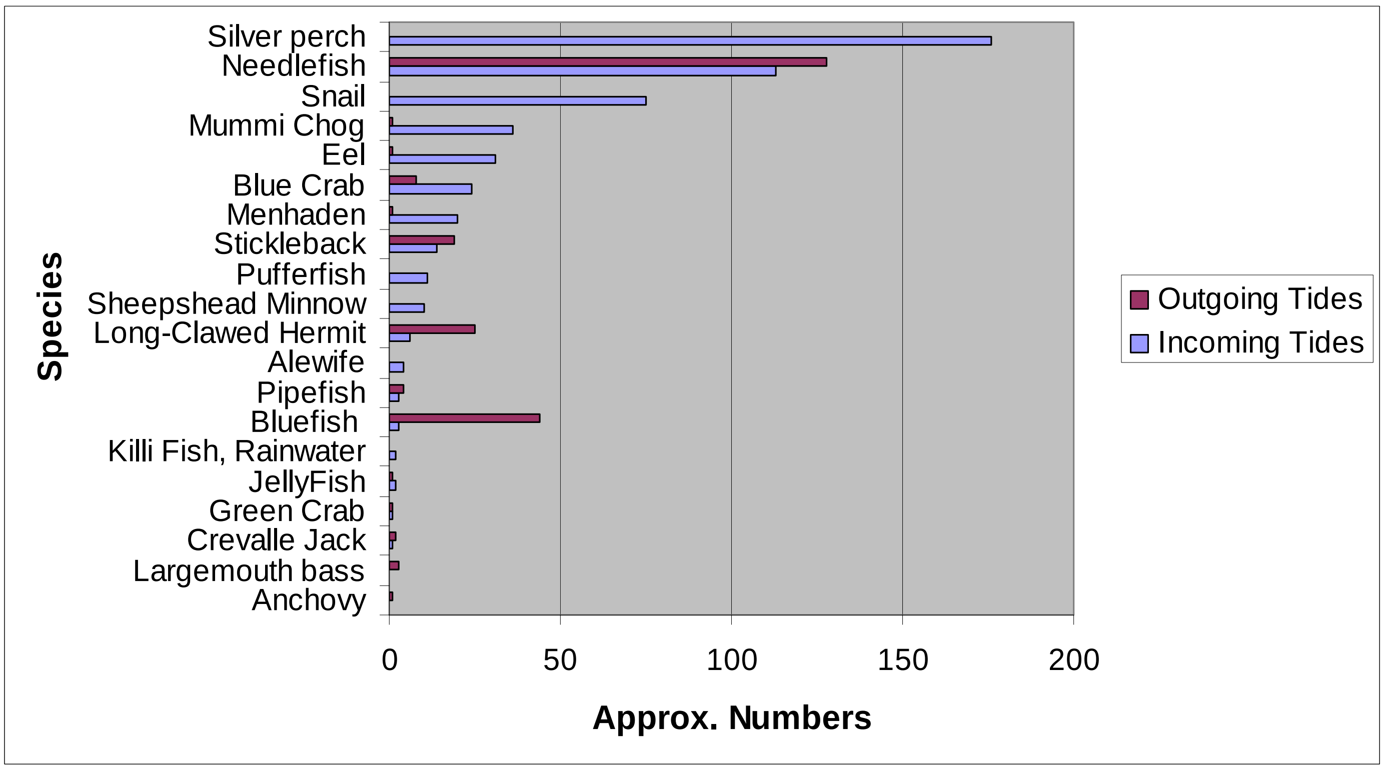
Fish Species Inhabiting Marsh 7-2003





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Fish Summary

- Species broadly adapted to
  - Salinity range
    - Brackish and marine water
    - Some to Fresh water
  - Temperature
    - Low: -2 °C to 10 °C
    - High: 20 °C to 42 °C

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MIKE 21 Equations

- MIKE 21 solves the hydrodynamic equations for 2-D (depth averaged) free surface flow.
  - Continuity (1): $$\frac{\partial \xi}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t}$$
  - Momentum Conservation (2)
  - Transport (1)

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Momentum Equations

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2 * h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}\right)+\frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right]-\Omega q-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}\left(p_a\right)=0$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2 * h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{yy}\right)+\frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right]-\Omega p-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}\left(p_a\right)=0$$

Symbol	Significance
$h(x,y,t)$	Water depth (=ζ-d, m)
$d(x,y,t)$	time varying water depth (m)
ζ (x,y,t)	Surface elevation (m)
$p,q(x,y,t)$	Flux densities in x and y directions($m^3/s/m$)=(uh,vh) (u,v)=depth averaged velocities in x and y directions
$C(x,y)$	Chezy resistance ($m^{1/2}/s$)
g	Acceleration due to gravity(m/s^{2})
$f(V)$	Wind friction factor
V, $V_x,V_y(x,y,t)$	Wind speed and components in x and y directions
$\Omega(x,y)$	Coriolis parameter, latitude dependent (s^{-1})
$p_a(x,y,t)$	Atmospheric pressure($kg/m/s^2$)
P_w	Density of water (kg/m^3)
x,y	Space coordinates(m)
t	time(s)
$\tau_{xx},\tau_{xy},\tau_{yy}$	components of effective shear stress

Transport

- 2D advection-dispersion equation
- Dissolved or suspended substances

$$\frac{\partial}{\partial t}(hc)+\frac{\partial}{\partial x}(uhc)+\frac{\partial}{\partial x}(vhc)=\frac{\partial}{\partial x}\left(hD_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(hD_y\frac{\partial c}{\partial y}\right)-Fhc+S$$

Simulation Parameters

- Grid Spacing
  - Δx=2.0 meter (360 grid points)
  - Δy=6.0 meter (246 grid points)
  - Δt= 1 second
- Simulation of 24 hours of real time
  - 4.5 hours (CPU)
- The boundary condition for north boundary is 0.9m, the boundary condition for south boundary follows tidal cycle.

Tidal Boundary Condition

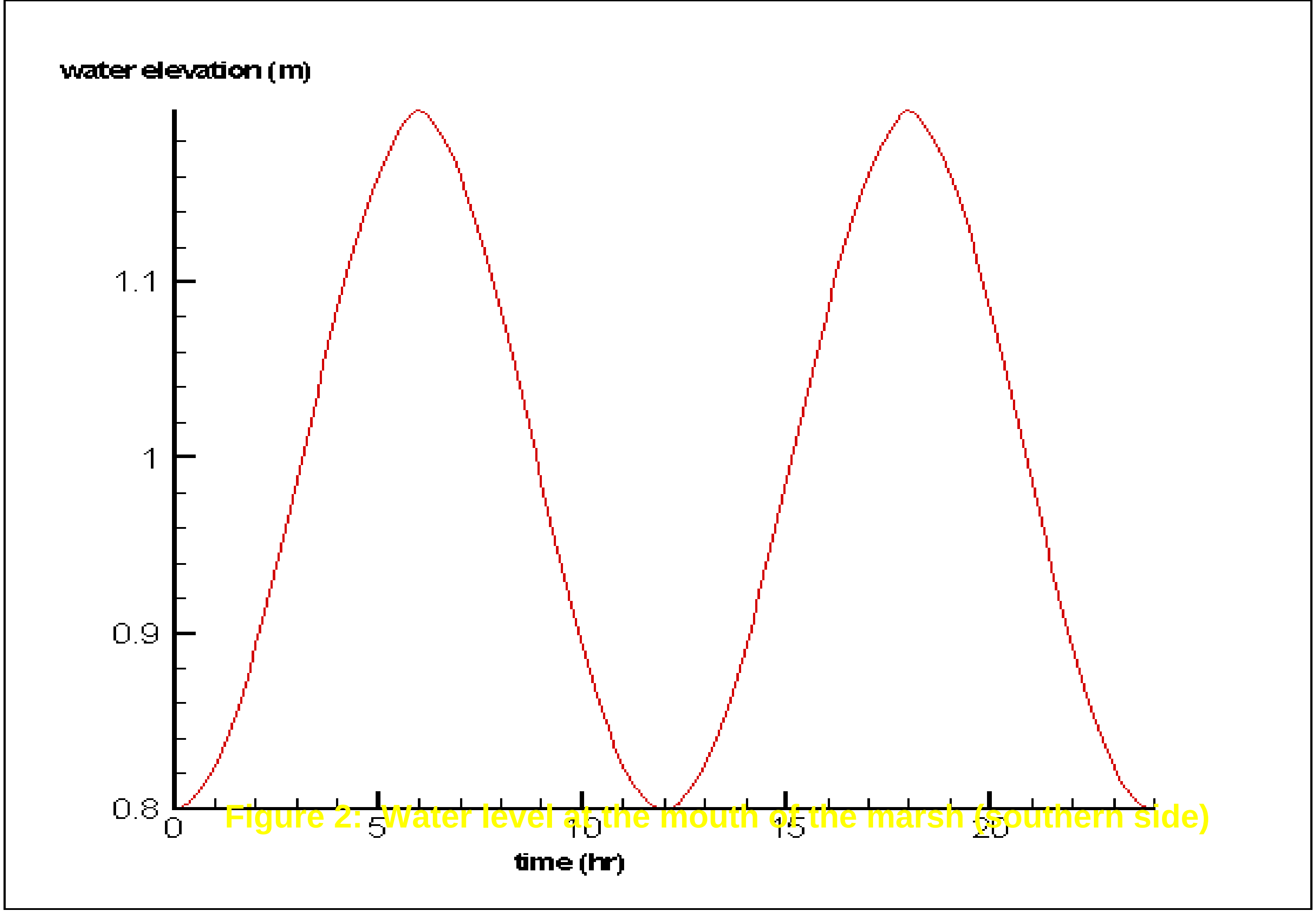


Figure 2: Water level at the mouth of the marsh (southern side)

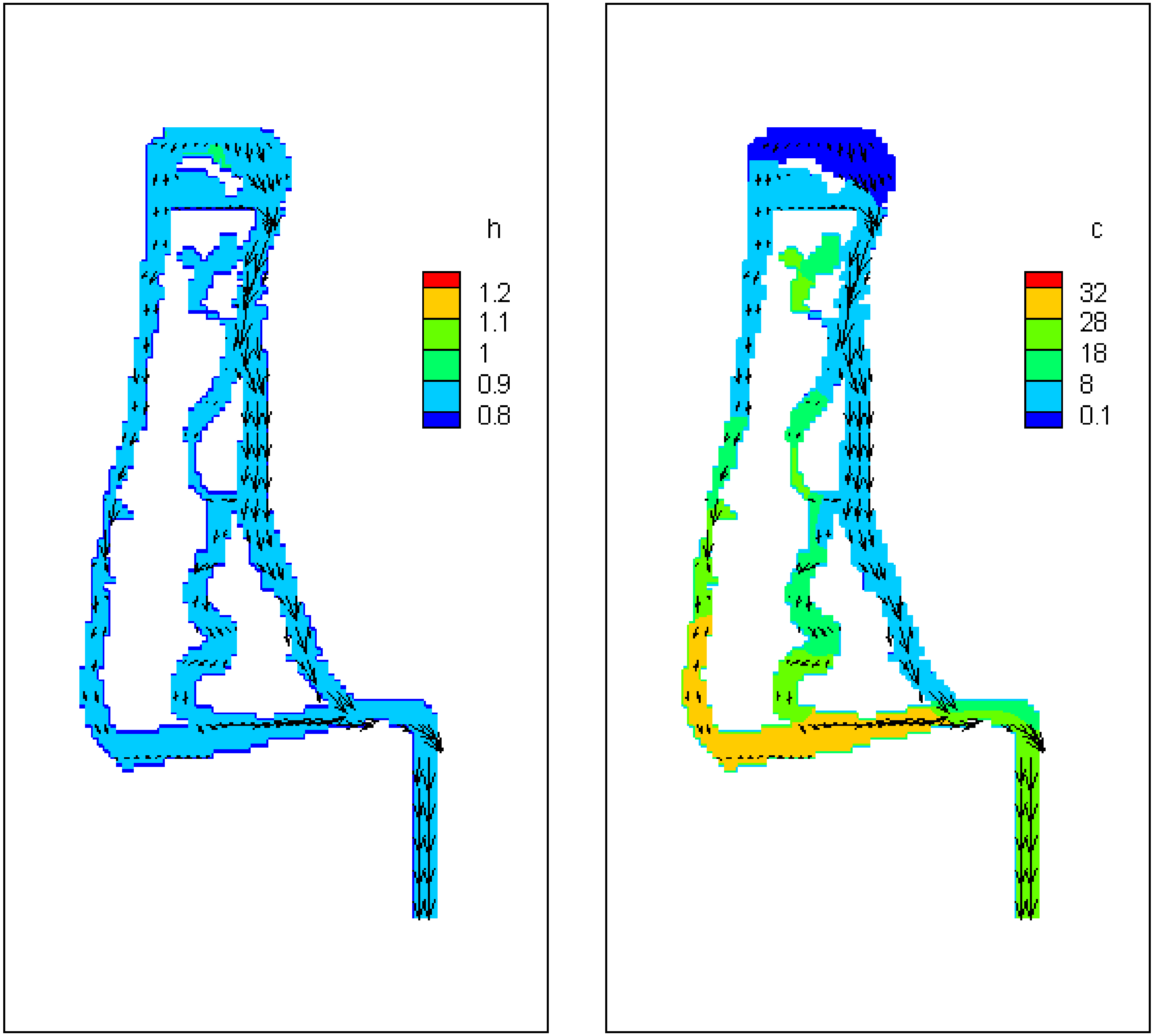


Figure 3: Time, 13:00. Water level (left panel) and concentration (right panel)

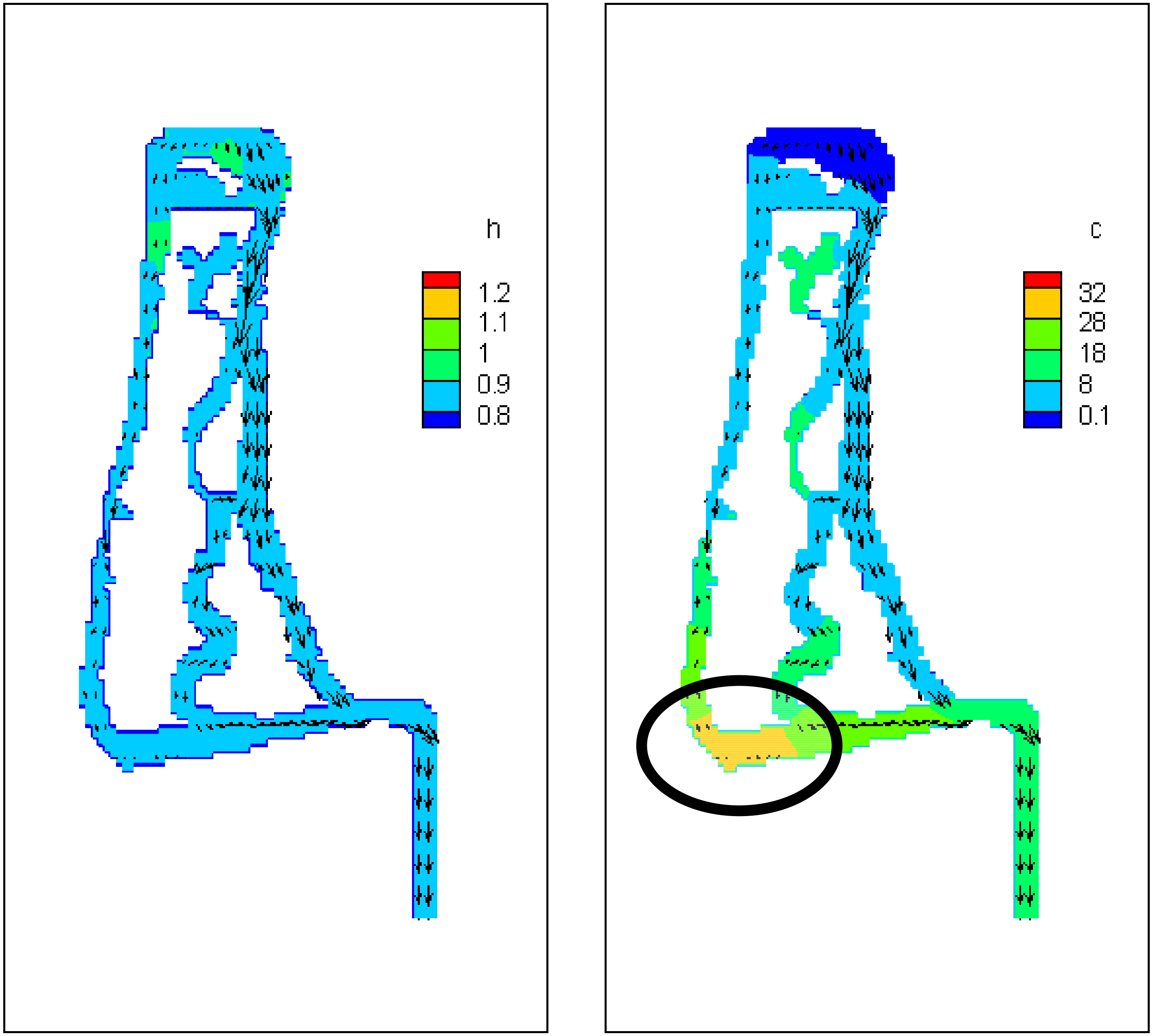


Figure 4: Time, 14:00. Water level (left panel) and concentration (right panel)

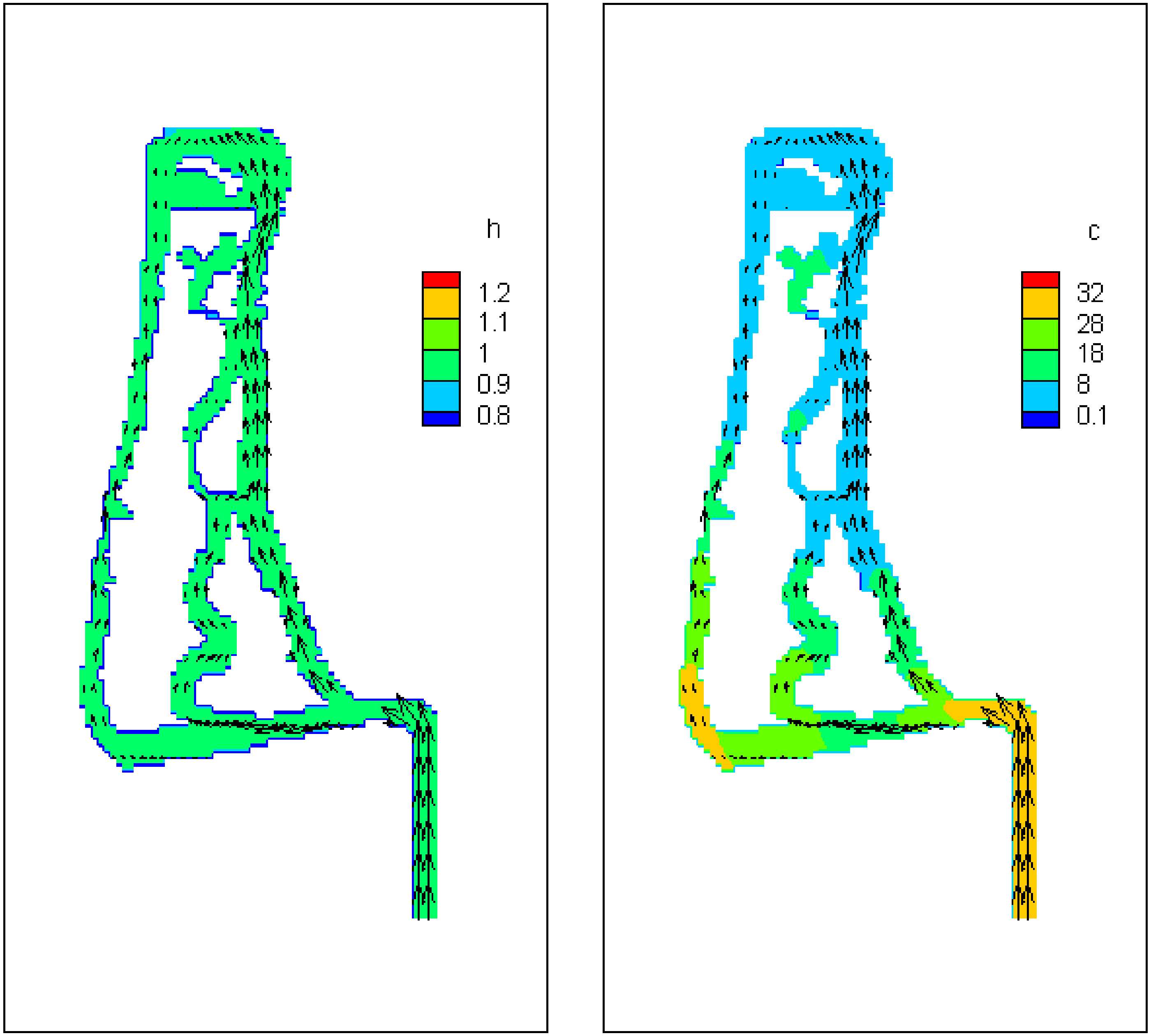


Figure 5: Time, 15:00. Water level (left panel) and concentration (right panel)

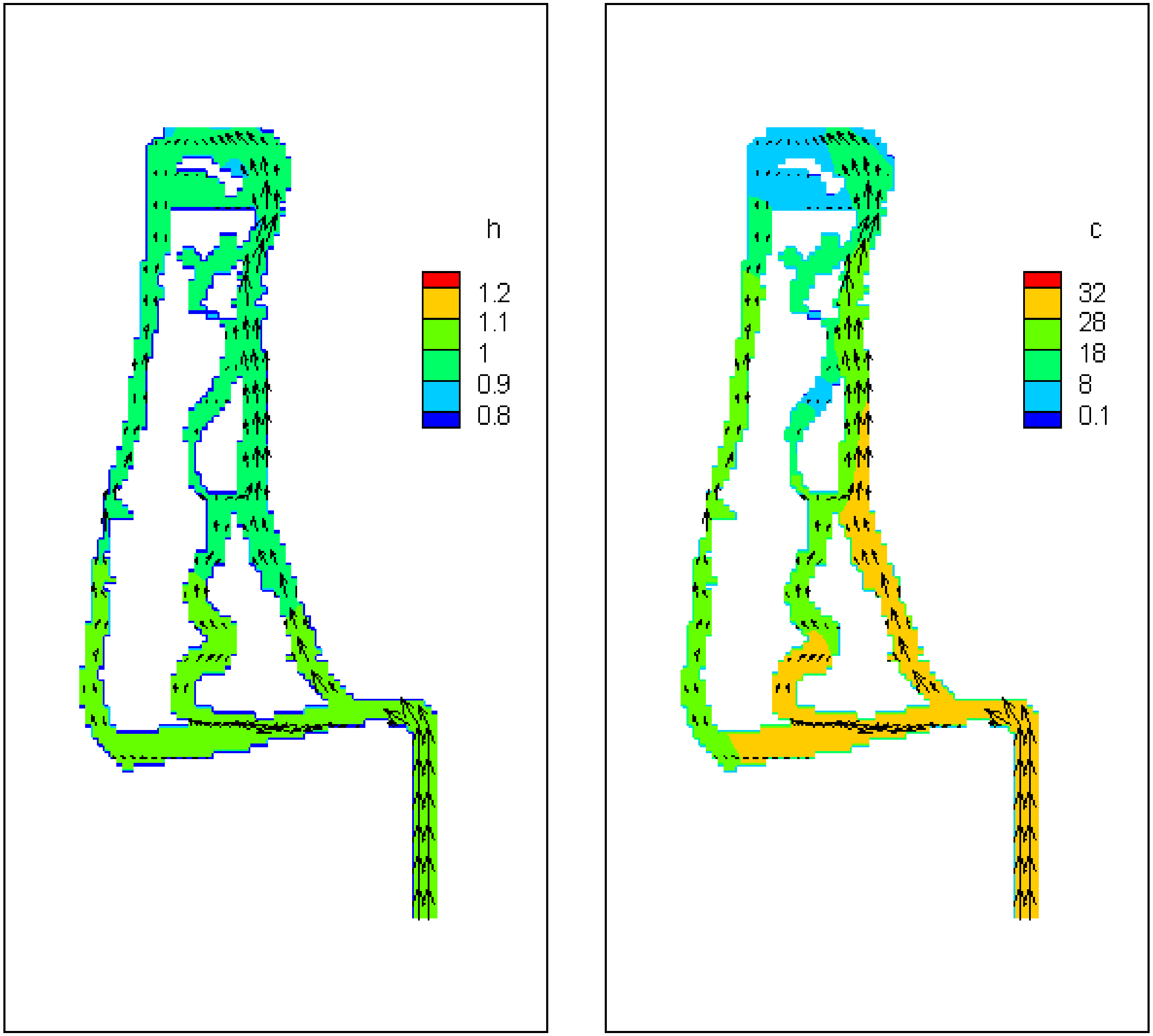


Figure 6: Time, 16:00. Water level (left panel) and concentration (right panel)

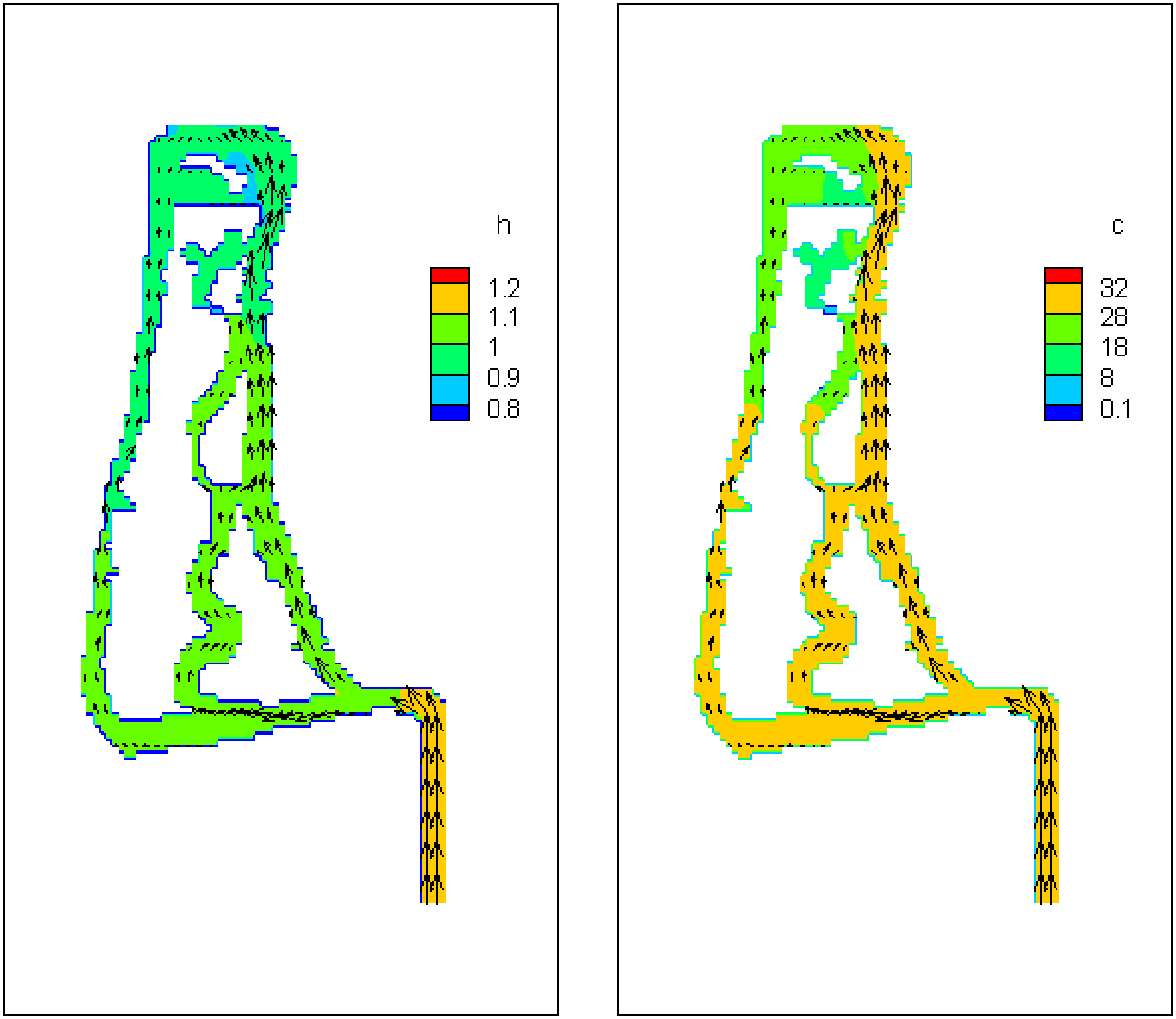


Figure 7: Time, 17:00. Water level (left panel) and concentration (right panel)

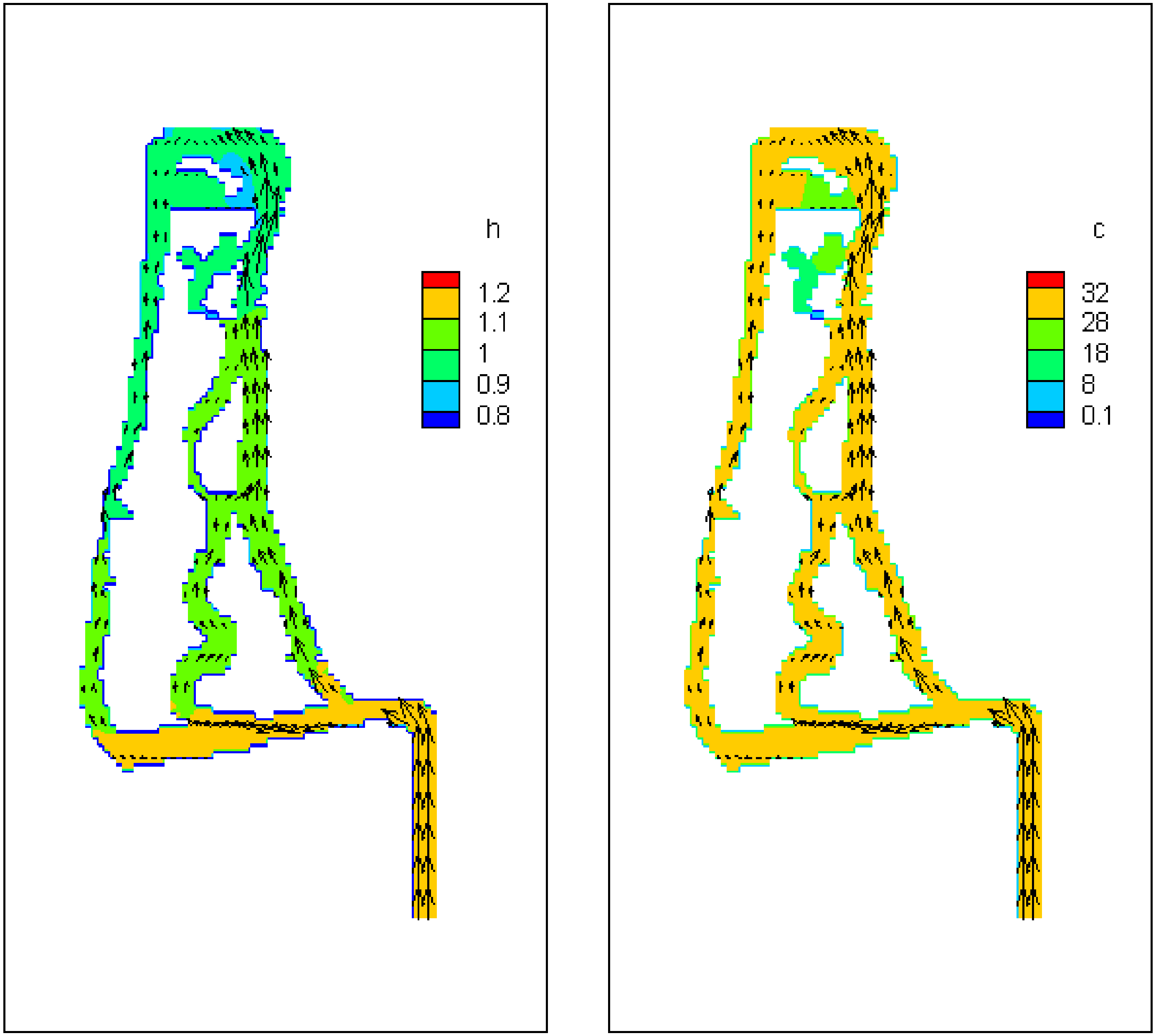


Figure 8: Time, 18:00. Water level (left panel) and concentration (right panel)

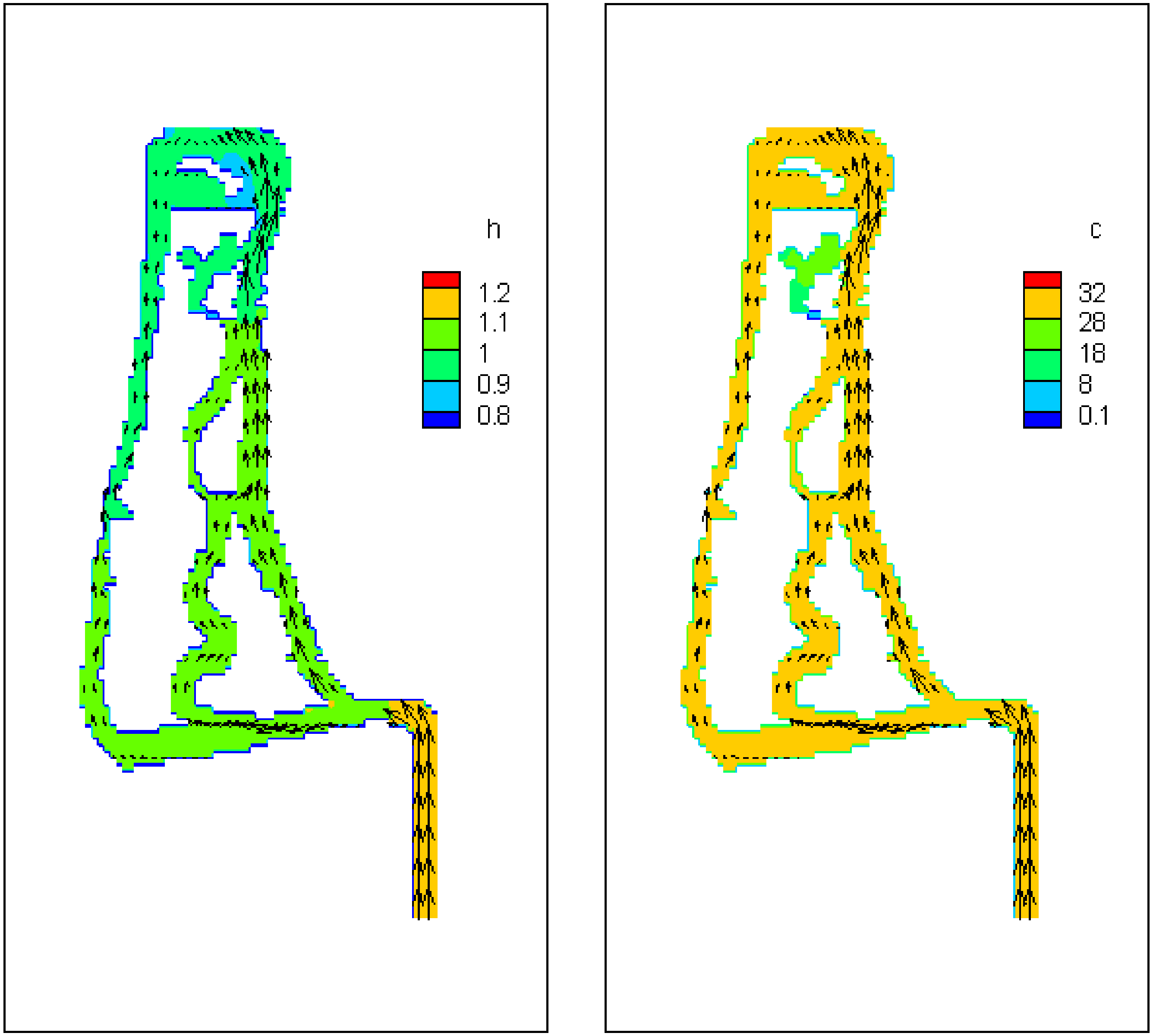


Figure 9: Time, 19:00. Water level (left panel) and concentration (right panel)

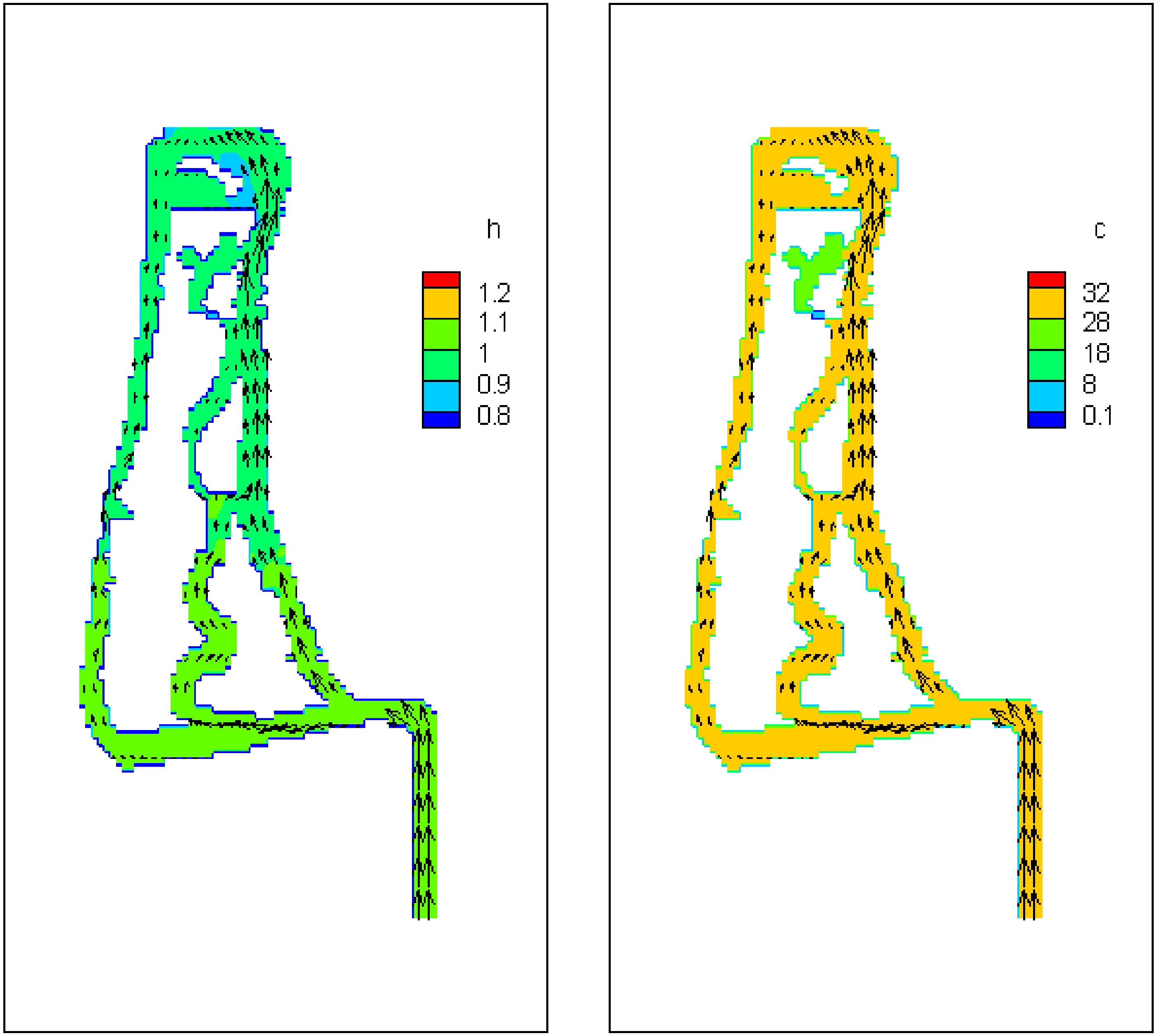


Figure 10: Time, 20:00. Water level (left panel) and concentration (right panel)

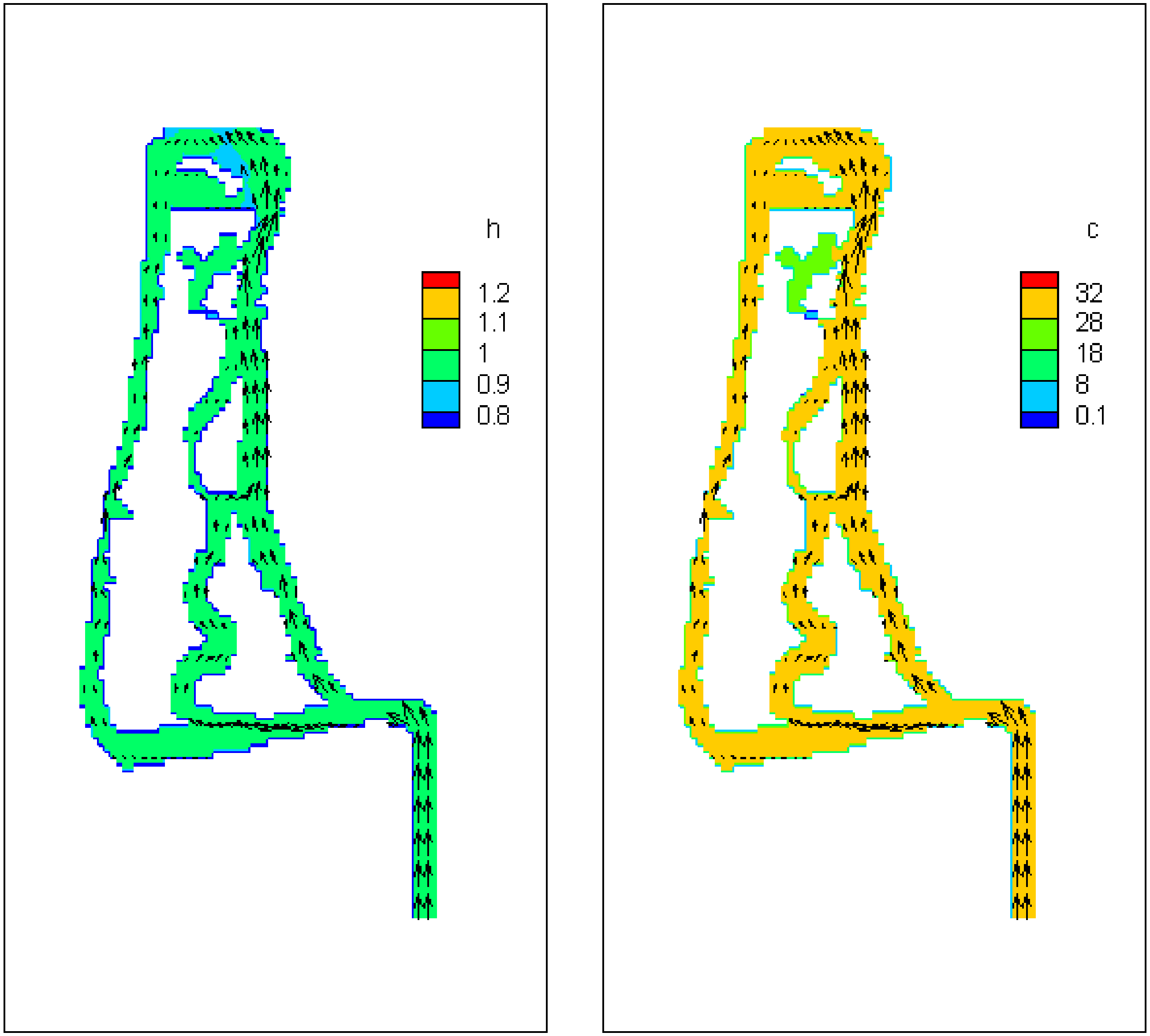


Figure 11: Time, 21:00. Water level (left panel) and concentration (right panel)

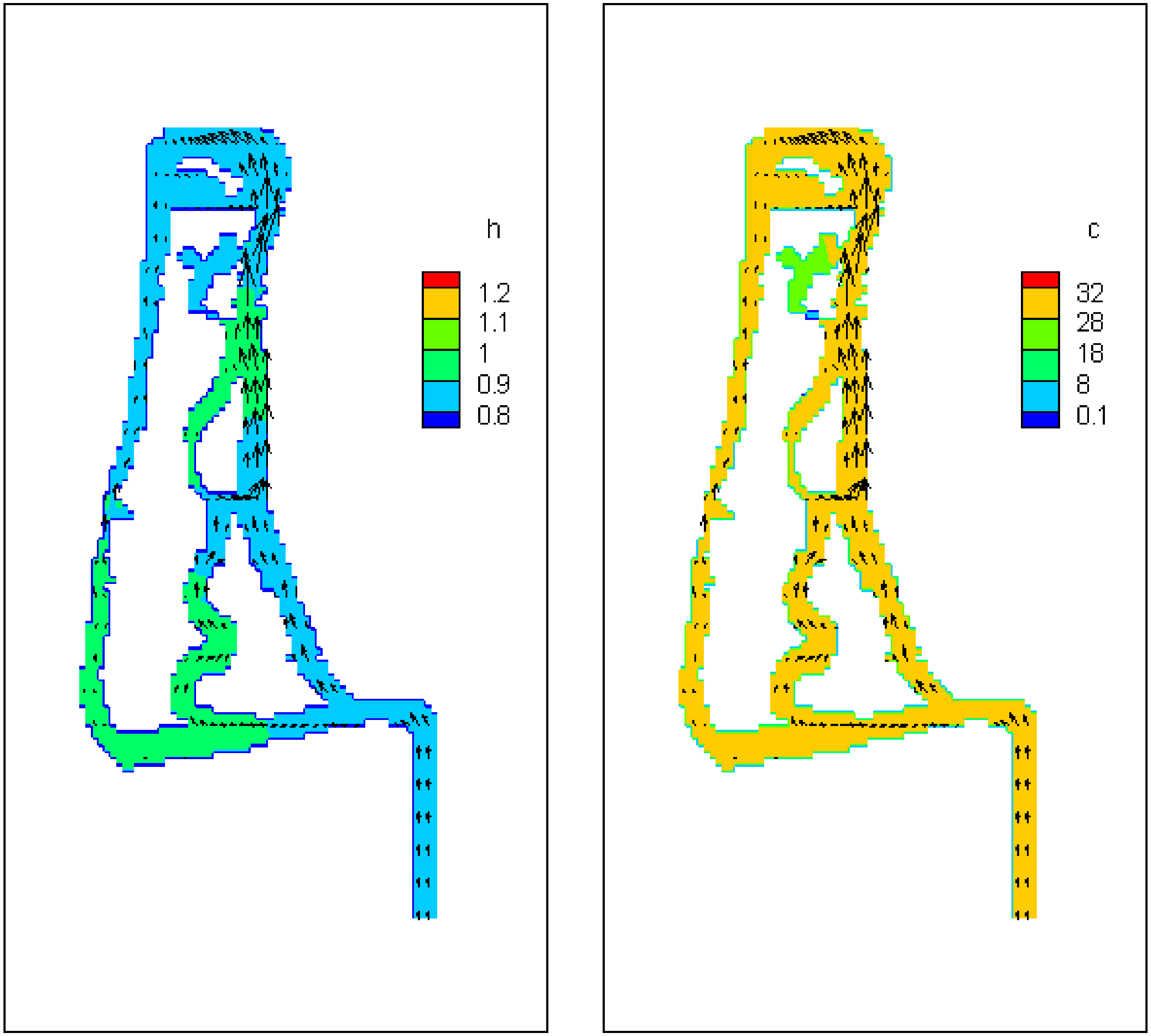


Figure 12: Time, 22:00. Water level (left panel) and concentration (right panel)

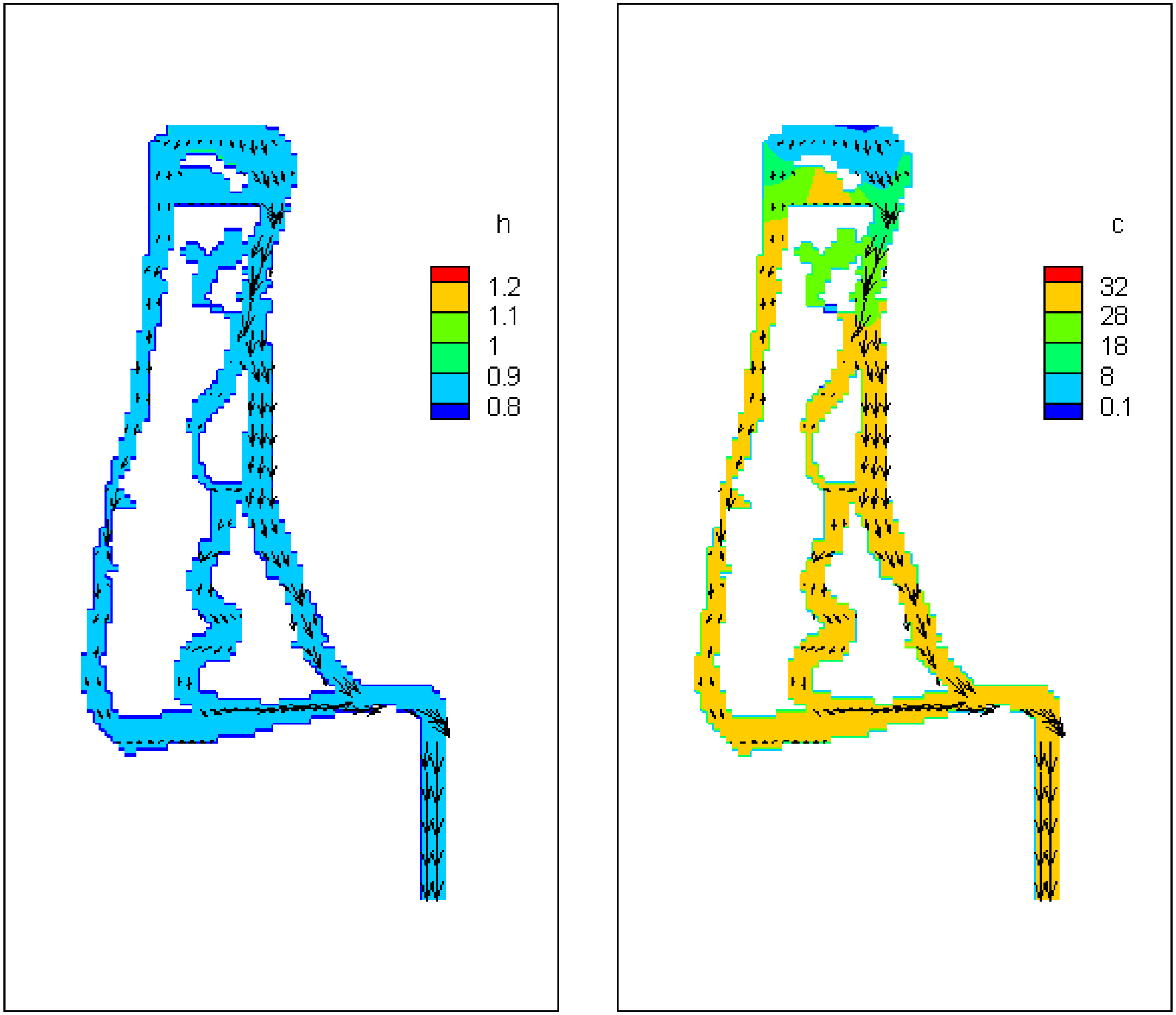


Figure 13: Time, 23:00. Water level (left panel) and concentration (right panel)

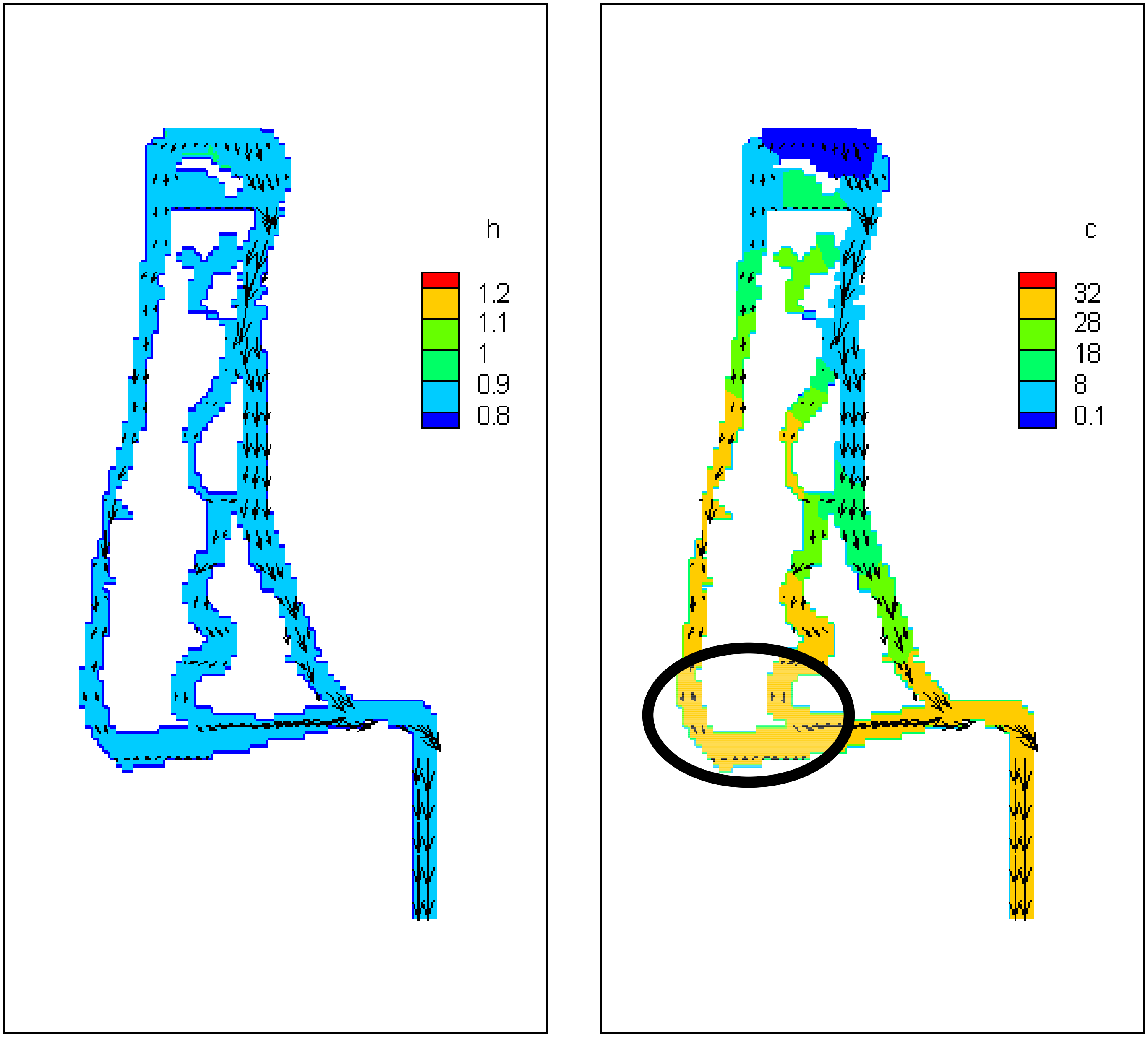
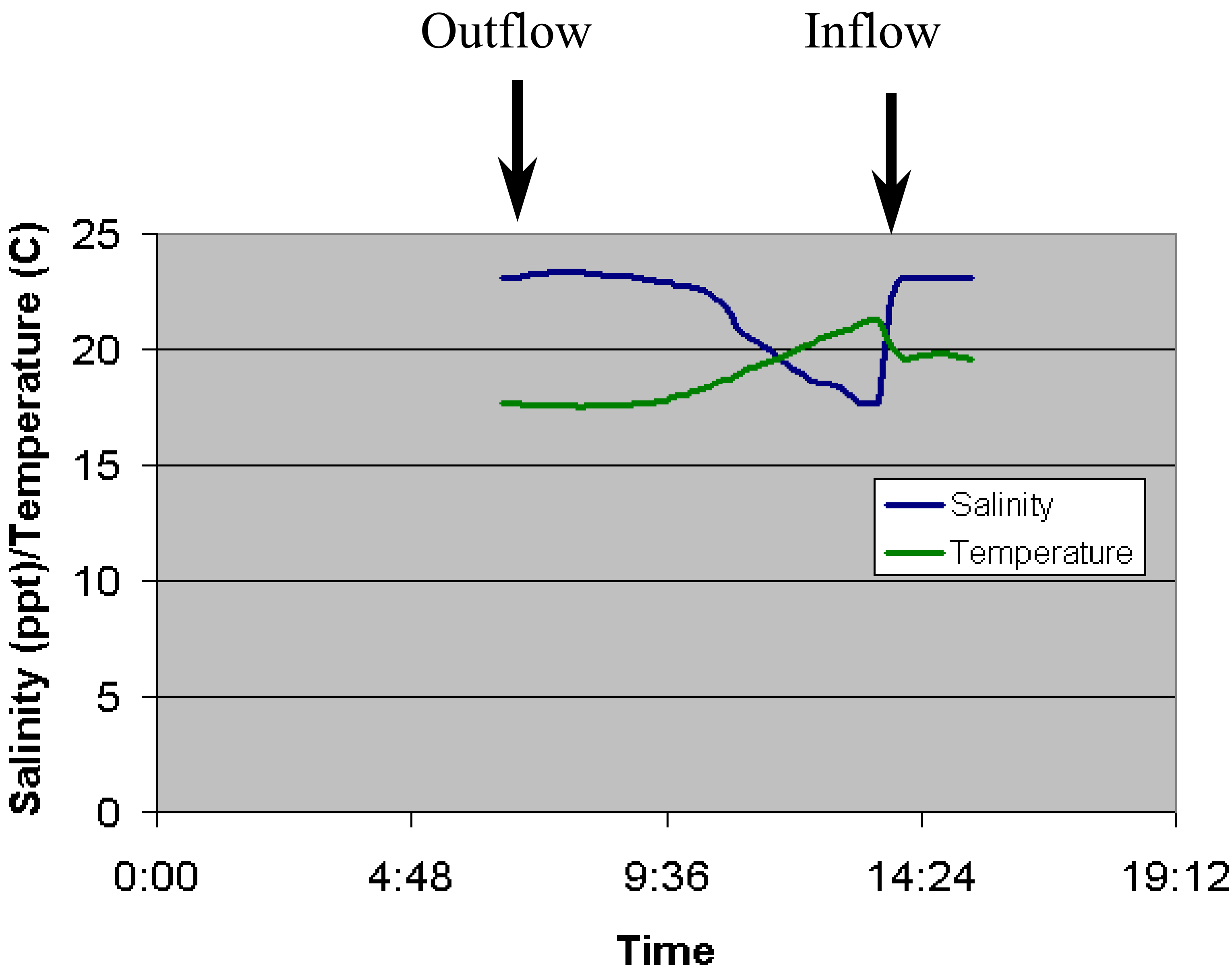


Figure 14: Time, 24:00. Water level (left panel) and concentration (right panel)



Outflow
Inflow
Salinity (ppt)/Temperature (C)
25
20
15
10
5
0
0:00
4:48
9:36
14:24
19:12
Time
Salinity
Temperature

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Conclusions

- Drastic alternation between seawater and freshwater within the tidal cycle.
- Orders-of-magnitude changes in fish populations over tidal cycle.

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Conclusions

- Flow and transport simulations are computationally intensive (only 5x faster than real time)
- Using saltwater as surrogate for oil (because it emanates from the sea side), one concludes that oil entrapment occurs within the marsh due to the fact that the marsh fills differently than it drains.
- Relying on “natural washout” might not be sufficient to remove the oil, and an additional remedial action would be needed.

Future Work

- Use of simulation results with EPA ERO^{3}S oil slick model (http://www.epa.gov/athens)
  - Test duration of entrapment
- Additional Field Verification

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