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TRADE-OFF ASSESSMENT OF SIMPLIFIED ROUTING MODELS FOR SHORT-TERM HYDROPOWER RESERVOIR OPTIMIZATION

JULIO ISSAO KUWAJIMA (1); DIRK SCHWANENBERG (2,3); RODOLFO ALVARADO MONTERO (2); FERNANDO MAINARDI FAN (4) AND ALBERTO ASSIS DOS REIS (5)

(1) UNIVERSIDADE DE SÃO PAULO (USP), ESCOLA DE ENGENHARIA DE SÃO CARLOS (EESC), BRAZIL (JULIO.KUWAJIMA@USP.BR),
(2) UNIVERSITY OF DUISBURG-ESSEN, INSTITUTE OF HYDRAULIC ENGINEERING AND WATER RESOURCES MANAGEMENT, ESSEN, GERMANY
(3) DELTARES, DELFT, THE NETHERLANDS
(4) INSTITUTO DE PESQUISAS HIDRAULICAS (IPH), PORTO ALEGRE, BRAZIL
(5) COMPANHIA ENERGÉTICA DE MINAS GERAIS S.A. (CEMIG), BELO HORIZONTE, BRAZIL

1-) INTRODUCTION

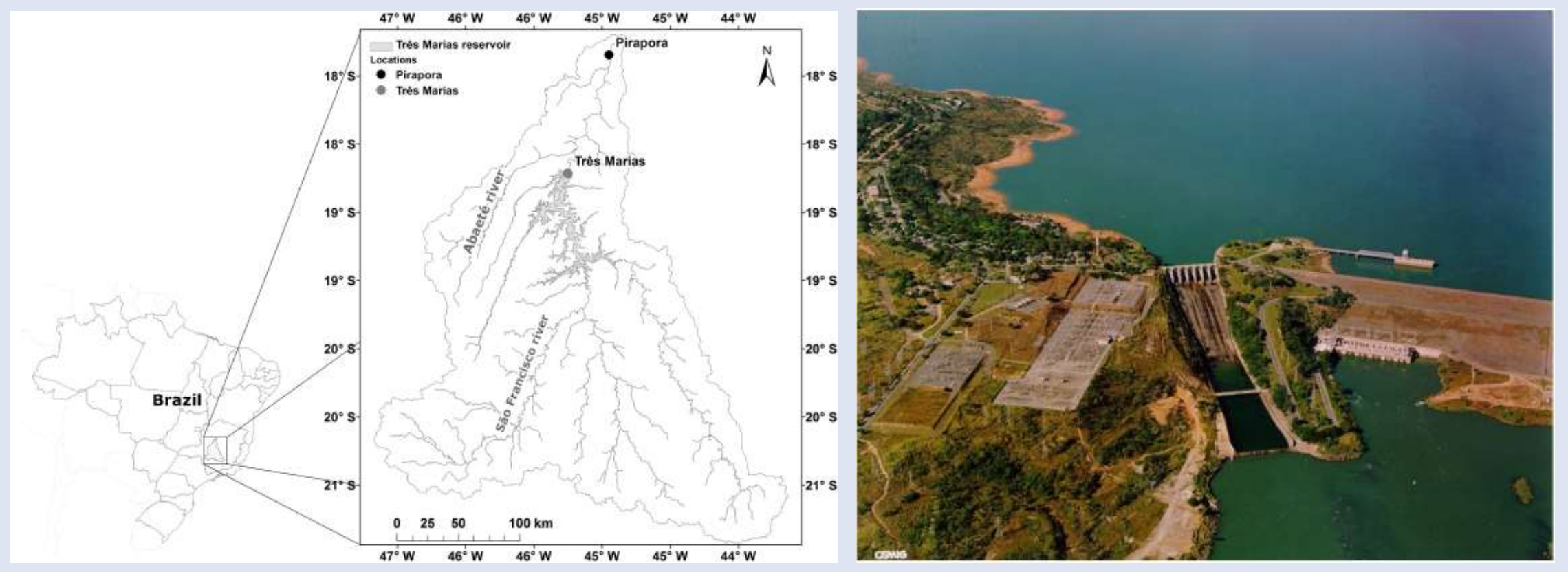
Short-term reservoir optimization, or model predictive control (MPC), integrates model-based forecasts and optimization algorithms to meet multiple management objectives: water supply, navigation, hydroelectricity generation, environmental obligations and flood protection. It is a valuable decision support tool to handle water-stress conditions or flooding events, and supports decision makers to minimize their impact.

If the reservoir management includes downstream control, for example for mitigation flood damages in inundation areas downstream of the operated dam, the flow routing between the dam and the downstream inundation area is of major importance.

The Três Marias hydropower reservoir is located in the Upper São Francisco River in the center of Minas Gerais state, Brazil, with a drainage area of approximately 55,000 km² (Figure 1). The region of interest in this use case extends to Pirapora city, located 120 km downstream of the reservoir. With a total storage of 19.5×10⁹ m³ and total installed capacity is 396 MW. (6 x 66 MW), The hydropower dam serves multiple purposes: hydropower generation, flood control, navigation, municipal and industrial water supply and irrigation. Its operation is responsible for flood control and mitigating flood inundation at the city of Pirapora.

For Brazilian standards, this watershed is covered by a dense network of meteorological and fluviometric gauges. Many of them include telemetry with real-time data available from the National Water Agency (Agência Nacional de Águas – ANA) and CEMIG.

Figure 1 – Location of the Três Marias Reservoir Watershed and detail of the Hydropower dam.



2-) METHODS

I-) Saint-Venant Equations

I.a-)Continuity Equation

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

Conservation form

$$\left.\begin{aligned}&\frac{\partial(Vy)}{\partial x}+\frac{\partial y}{\partial t}=0\\&V\frac{\partial y}{\partial x}+y\frac{\partial V}{\partial x}+\frac{\partial y}{\partial t}=0\end{aligned}\right\}$$

Non-conservation form (velocity is dependent variable)

I.b-)Momentum Equation

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

Local acceleration term; Convective acceleration term; Pressure force term; Gravity force term; Friction force term

$$\frac{\partial V}{\partial t}+V\frac{\partial V}{\partial x}+g\frac{\partial y}{\partial x}-g(S_o-S_f)=0$$

Kinematic Wave
Diffusion Wave
Dynamic Wave

II-) Reservoir Routing

$$I_{(t)}-Q_{(t,h)}=\frac{\partial s_{(h)}}{\partial t}$$

$$Q(h,dg)=Q_c(h,dg)+Q_u(h)$$

III-) Muskingum-Cunge*

Equivalent to the knematic wave

$$\frac{\partial S}{\partial t}=I-Q$$

Continuity Equation

$$s=k[\varepsilon I+Q(1-\varepsilon)]$$

Storage Relation in a channel reach

$$Q_{j+1}^{n+1}=C_1Q_j^n+C_2Q_j^{n+1}+C_3Q_{j+1}^n$$

The finite difference formulation

k, storage coefficient
ε, weighting factor
I, inflow rate to the reach
O= Outflow rate from the reach

$$C_1=\frac{-2\varepsilon\Delta x+c\Delta t}{2\Delta x(1-\varepsilon)+c\Delta t}$$

$$C_2=\frac{2\varepsilon\Delta x+c\Delta t}{2\Delta x(1-\varepsilon)+c\Delta t}$$

$$C_3=\frac{2\varepsilon\Delta x-c\Delta t}{2\Delta x(1-\varepsilon)+c\Delta t}$$

$$c=\frac{\partial Q}{\partial A}\Big|_{j,n}\qquad q=\frac{Q}{B}\Big|_{j,n}$$

$$k=\frac{\Delta x}{c}\qquad \varepsilon=\frac{1}{2}\left[1-\frac{q}{S_0c\Delta x}\right]$$

A,flow area
B,top width

The unsteady open channel flow in river reaches can be described by the one-dimensional Saint-Venant equations. These mathematically complex equations, can be simplified to speed up the computation for optimization procedure, four different routing models are assessed, each using a different flow routing equation (Table 1). The aim of the paper is to asses their implementation concerning the predictive control . Another strategy to limit the model runtime is a schematization on a course computational grid (Table 2).

Table 1 – Models and their respective flow routing methods.

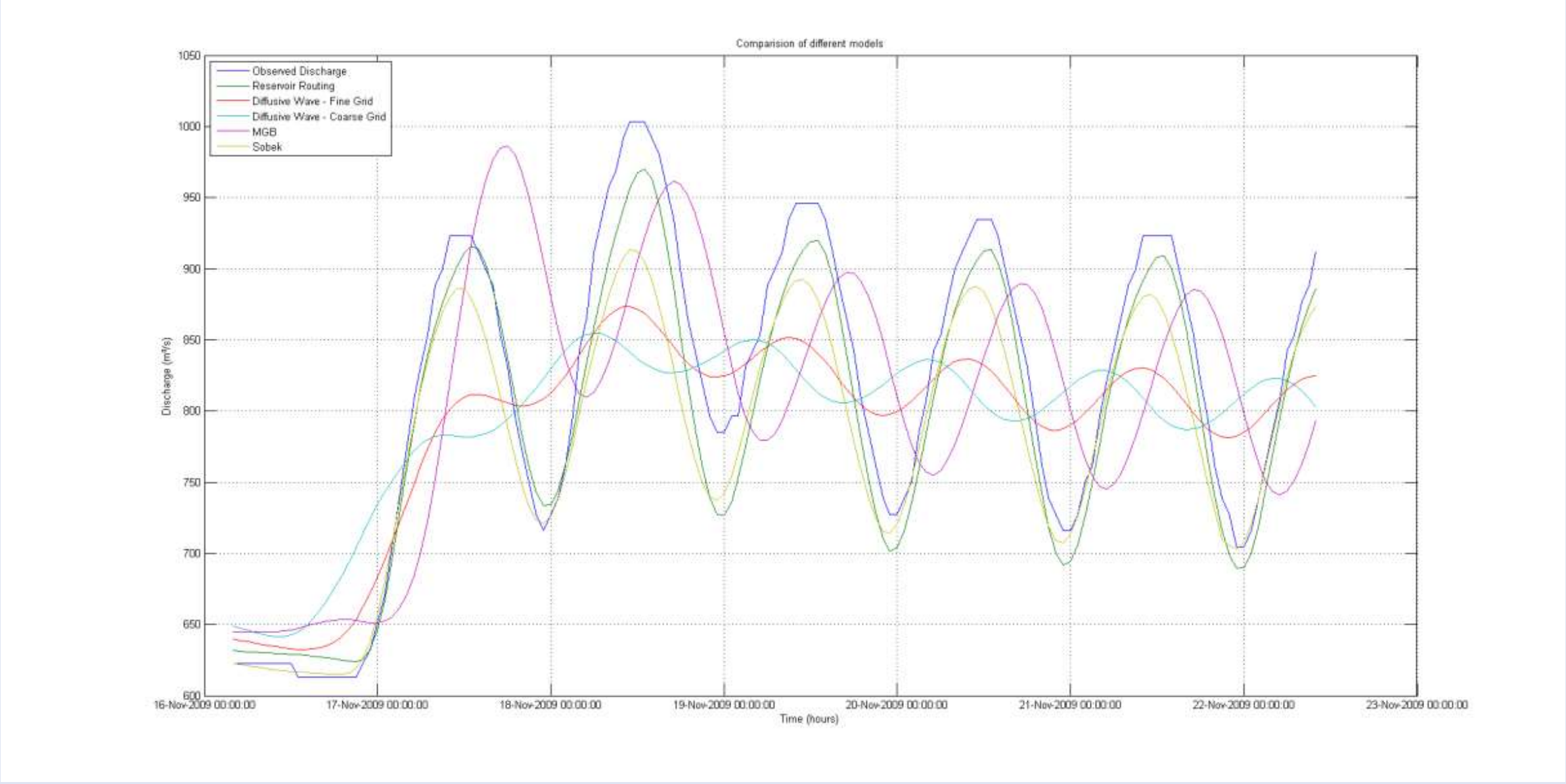
Model	Governing Equation
SOBEK	Full-Dynamic
MGB-IPH	Muskingum-Cunge*
RTC-Tools Diffusive Wave	Diffusive Wave
RTC-Tools Reservoir Routing	Reservoir Routing

Table 2 – Spatial schematization for SOBEK and RTC-Tools Diffusive Wave .

Model	N° Nodes
SOBEK	146
RTC-Tools Diffusive Wave (Finer Grid)	14
RTC-Tools Diffusive Wave (Coarser Grid)	6

3-)RESULTS

Graph 1 – Model comparison .



Graph 2 – Model Diffusion .

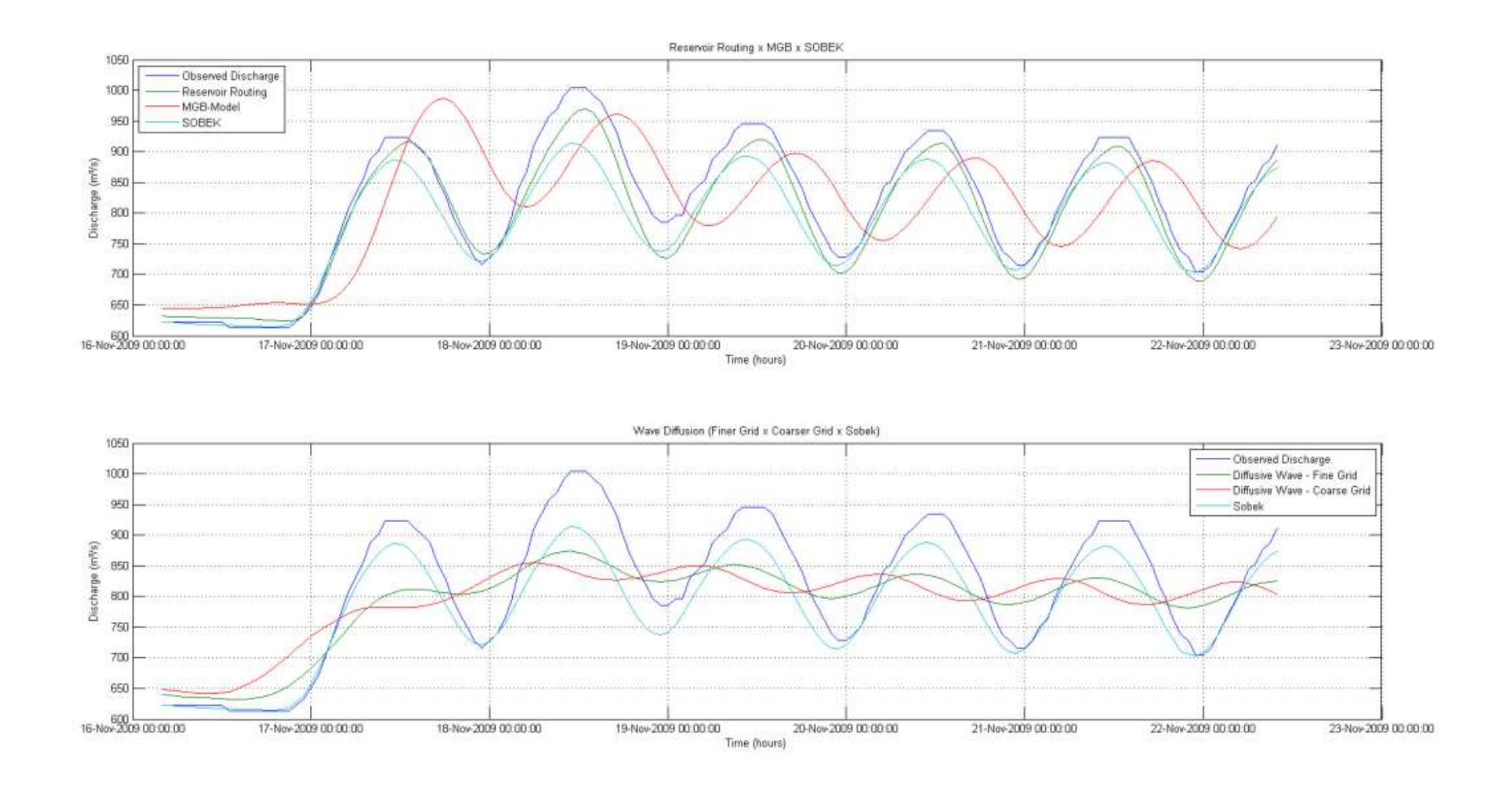


Table 3 – Performance Indicators

Model	CPU Performance (ms)	Bias	RMSE	R²	NSE
MGB	359	13,329	120,937	0,960	0,958
SOBEK	135175	-22,55	105,256	0,966	0,983
Reservoir Routing	156	0,030	68,273	0,980	0,980
Diffusive Wave - Coarse Grid	1887	0,210	76,620	0,975	0,975
Diffusive Wave - Fine Grid	1903	0,091	70,929	0,978	0,978

4-)CONCLUSION

In the graphs 1 and 2 shows that whereas the SOBEK model is able to propagate sharp discharge gradient downstream, the diffusive wave model is damping these gradients significantly. The reservoir routing and the MGB results present a better representations of peak flows and abrupt flow changes, however the MGB model has a time step fit asynchrony.

The overall model accuracy between the Diffusive Wave models (Coarser Grid and Finer Grid) and the more sophisticated SOBEK model are comparable, a lower performance was assessed for the MGB model, and a better performance for the Reservoir Routing (Table 3). In the same table shows the CPU performance of the chosen models even though SOBEK and the finer grid Diffusive Wave model was able to obtain better performance indicators they require more CPU effort.

The Diffusive Wave damping occurs due to the course spatial schematization, which introduces significant numerical diffusion into the solution. This is a major drawback, in particular if the reservoir release has steep gradients which we often find in hydropower reservoirs.

In the reservoir routing model, which is also schematized on a course grid, we counteract this drawback by modeling parts of the river reach by advection. This results in an excellent ratio between model accuracy / robustness and computational effort making it the approach of choice from the predictive control perspective.