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ASSESSING THE CONTRIBUTION OF THE MAIN AQUIFER UNITS OF THE LOIRE BASIN TO RIVER DISCHARGE DURING LOW FLOW

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1 INTRODUCTION

The Loire River has a very variable discharge which might evolve in response to climate changes. Reservoirs have been built in the upper valley in order to sustain low flow during droughts. The evolution of low flows is a key issue for the industry such as electricity production from nuclear power plants which uses water from the Loire River for cooling. To assess the evolution of Loire discharge during low flow, it is necessary to have a good estimate of the contribution of a complex aquifer system to the river discharge. This work aims at building a distributed physically-based model of the Loire basin taking into account interactions between surface and groundwater.

2 SITE DESCRIPTION

2.1 The Loire basin

The Loire basin covers an area of 117 000 km². The length of the main stream is about 1000 km. At the upstream part of the basin, the landscape is mountainous reaching the altitude of 1700 m. Conversely, the central part is flater with elevation ranging from 50 to 150 m above sea. Land use is mainly divided into agriculture (73 %) and forest (22 %). The remaining consists in urban area (4 %) and water surface (1 %) [1]. Pluviometry is characterised by heavy precipitations in the upper part of the basin (above 1000 mm per year) and lower rainfall in the middle part (400-500 mm per year)[2].

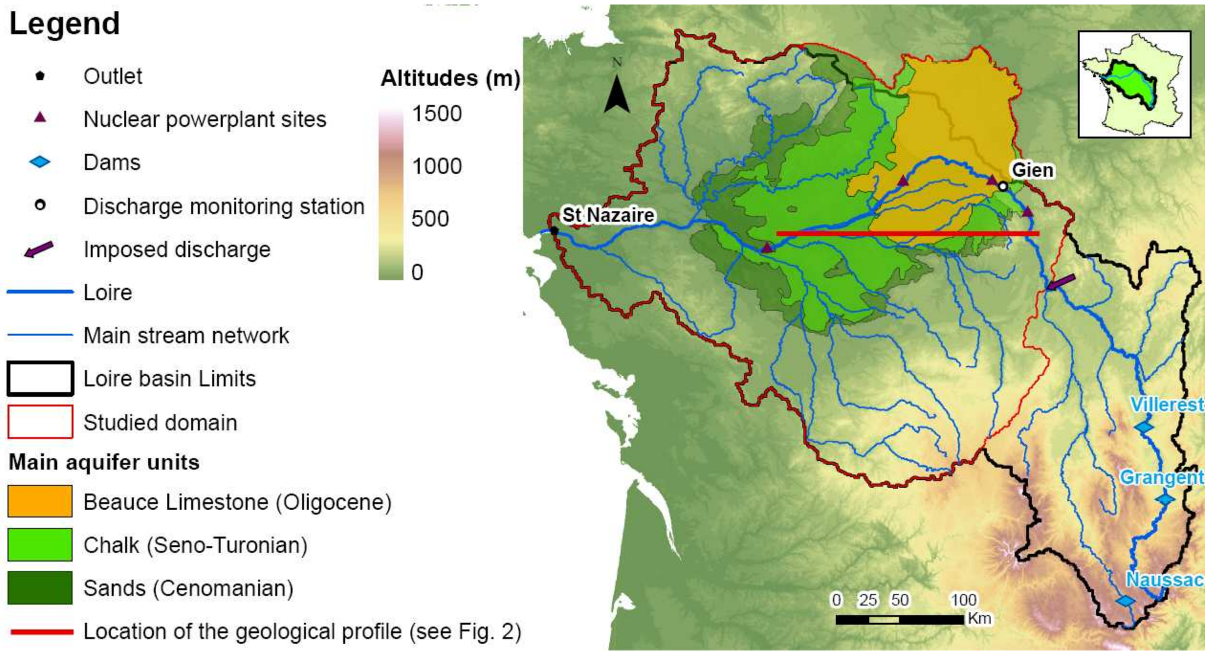

Figure 1: General situation of the Loire Basin

2.2 Hydrology

The Loire hydrological regime is pluvial, with a high water level period in winter and a low water level period in summer. The inter-annual mean discharge at the outlet (Saint-Nazaire) is around 900 $m^3.s^{-1}$, decreasing from 1800 $m^3.s^{-1}$ in January to 250 $m^3.s^{-1}$ in August [3].

To maintain a minimum discharge of 60 $m^3.s^{-1}$ at Gien during low flow, reservoirs have been built in the upstream part of the basin (Fig. 1).

2.3 Hydrogeology

The central part of the basin overlaps the Parisian sedimentary basin. In the model, the aquifer system is discretized in three main overlaying aquifer units (Fig. 1 and 2): Beauce Limestone (Eocene-Oligocene), Chalk (Seno-Turonian) and Sands (Cenomanian). These aquifer units, which cover an area of about 35 000 km², contribute to the Loire discharge.

2.4 Studied domain

The underground Loire basin is wider than the surface one. To ensure consistent boundary conditions, the simulated domain has been extended to rivers draining these units where an imposed hydraulic head is assumed. In addition, the upstream part of the basin does not include wide aquifer and the Loire discharge is mainly driven by reservoir discharge during low flow. Thus the upstream part of the basin is not simulated and the upstream discharge of the studied domain is imposed at the Cours-les-Barres gauging station, downstream the main dams (Fig. 1).

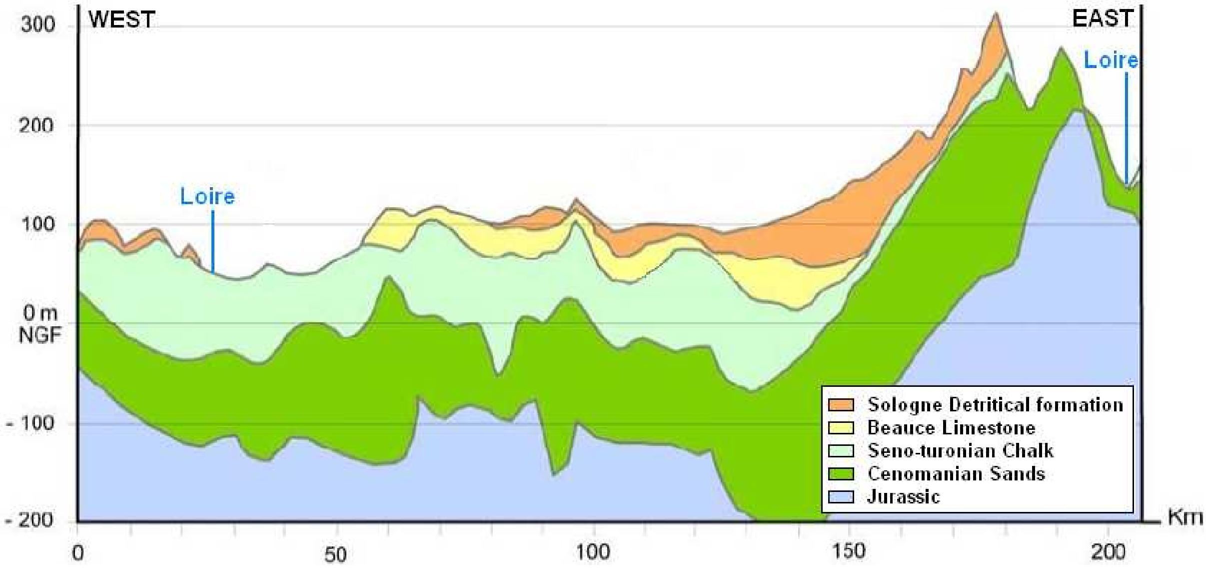

Figure 2: Geological profile of the center part of the basin (red line on Figure 1)[4].

3 PRINCIPLE OF THE HYDROGEOLOGICAL PART OF THE PLATFORM EAU-DYSSÉE

The platform Eau-Dyssée couples existing specialized models to assess water resources in the basin. The water cycle in this case study is simulated with four components: surface water balance, surface routing, river network routing and groundwater dynamics.

3.1 Surface water balance component

The water balance is computed on units derived from the intersection of land use units and geological units. The surface component computes the water balance by splitting precipitation into evapotranspiration, surface runoff, infiltration and soil stock using an eight-parameter conceptual model [5]. The input data set consists in a meteorological database (precipitations and potential evapotranspiration) with a daily time step and a spatial resolution of 8 km×8 km coming from the Safran procedure of Météo-France [2].

3.2 Surface routing component

HydroDEM software [6] derives a drainage network from a DEM. A relative transfer time to the outlet, based on topography, is computed for each cell [7].

Each river cell is the outlet of a sub-basin of surface cells. A relative transfer time to river cell is computed for each surface cell by substracting to the relative transfer time of the cell the relative transfer time of the associated river cell. This relative transfer time to river is converted into a time by multiplying by the global concentration time of the basin. An isochronal zone is defined by the number of time steps necessary for water from a surface cell to reach its associated river cell.

The surface runoff partitioned by the water balance component is transported to its corresponding river cell in the number of time step corresponding to its isochronal location.

3.3 River network component

The stream routing component [8] is based on the Muskingum routing scheme. Muskingum supposes a linear relationship between the volume (V) in a cell and the incoming (Q_{in}) and outcoming flow (Q_{out}):

$$V=K*(X*Q_{in} + (1-X)* Q_{out}) \tag{1}$$

where K is a transfer time [s] and X a centering parameter [adimensional].

In this paper, the transfer time K is based on morphological data by substracting to the relative transfer time of a river cell the one of its directly downstream river cell. This difference is then multiplied by the global concentration time of the basin (7 days).

3.4 Groundwater component

The groundwater model SAM [9,10] is a regional spatially distributed model that computes flows and hydraulic heads in the saturated zone. It solves the diffusivity equation [11] on a multilayered system. Its structure is built according to the geometry of the main aquifer units. In each aquifer, flows are bidimensional whereas they are vertically monodimensional in the aquitard between two horizontal layers. The groundwater head is dynamically coupled to the water level in surface "river cells". Exchanged discharges between aquifers and rivers are calculated using a river conductance factor.

4 IMPLEMENTATION ON THE LOIRE BASIN

4.1 Surface drainage pattern

The drainage pattern is obtained from a 1 km-DEM and the domain is divided into a grid of 63 234 squared cells of 1 to 64 km^2. There are 16 141 river cells among them.

4.2 Surface water balance units

The units where the hydrological balance is computed are determined by the intersection of the land use (Corine Land Cover, CLC [1]) and the geology (INRA Soil database [12]) using the GIS (Geographical Information System) software ArcGIS 9.3. Data extracted from CLC include 5 types of land use: agriculture, forest, artificialised territories, surface water and wetland. Data from INRA Soil data base uses 9 types of geology. After intersection, 22 production functions are defined. Their parameters were first derived from previous studies [13,14] and then fitted by trial/errors.

4.3 Estimate of Muskingum coefficient K and X in the river cells

As mentioned in 3.3, the Loire basin concentration time is 7 days leading to K ranging from 0 s (outlet) to 104 785 s with a mean value of 850 s. Extremes values were considered as not consistent, thus K coefficient has been limited between 500 s and 2000 s, equivalent to velocity ranging from 0.5 to 2 m.s^{-1}.

4.4 Hydrodynamic parameters

First estimates of hydrodynamic parameters were obtained from several specific studies focusing on different units composing our central aquifer system [15,16].

5 FIRST RESULTS OF CALIBRATION

The calibration period runs from the 1st August 1996 to the 11th July 2007. To assess simulation quality, criteria are used to compare simulated results with measured data. Bias, Nash and correlation between measured and simulated discharges at a daily time step are computed at 70 gauging stations. Bias, RMSE (Root Mean Square Error) and correlation between measured and simulated hydraulic heads are computed at 204 piezometers.

5.1 Global water discharge

A pre-calibration of surface component is carried out before introducting groundwater model. Gauging stations located out of groundwater influence zone are used to assess real evapotranpiration flux by balancing the measured water volume transiting at the station with the simulated one. This pre-calibration is applied by trial-errors method.

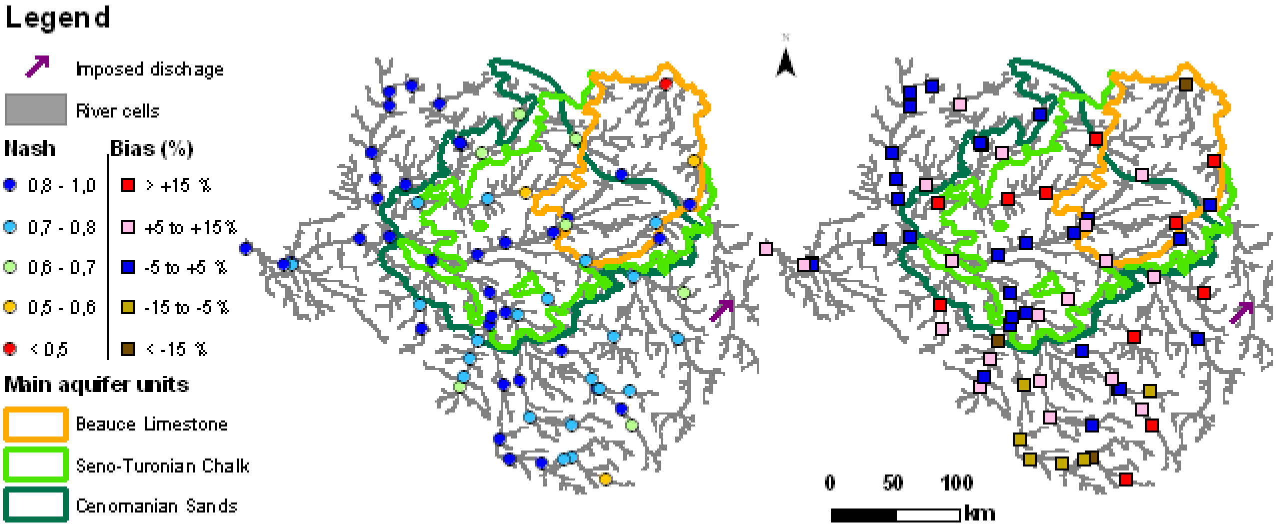

Figure 3: Nash criteria and Bias at observed gauging stations computed on a 10 years period

5.2 River discharge

The dynamics of river discharge distribution is pre-calibrated by fitting hydrographs at gauging stations (phasing of peaks and low flow values). At first, gauging stations located out of the aquifer zone are selected. After introducting aquifer units in the model, Nash criteria range between 0.88 and 0.98 along the river Loire (Figure 3) which is satisfactory (maximum Nash is 1). Some streams are strongly artificialised which explains poor Nash criteria below 0.6. Calibration of groundwater model should improve Nash in the central part of the basin.

Figure 4 displays the evolution of measured and simulated discharge at a daily time step at the outlet. Flood peaks are well phased which validates runoff velocity. Most of the peaks are overestimated, whereas low flow is slightly underestimated. It indicates that production functions have to be slightly recalibrated in terms of partitioning among runoff and infiltration. Discharge at the outlet is overestimated of 5.2 %. This difference, which is equivalent to an average discharge increase of 45 $m^3.s^{-1}$, is close to a first estimation of water consumption in the basin based on water withdrawals data (30 $m^3.s^{-1}$ over one year).

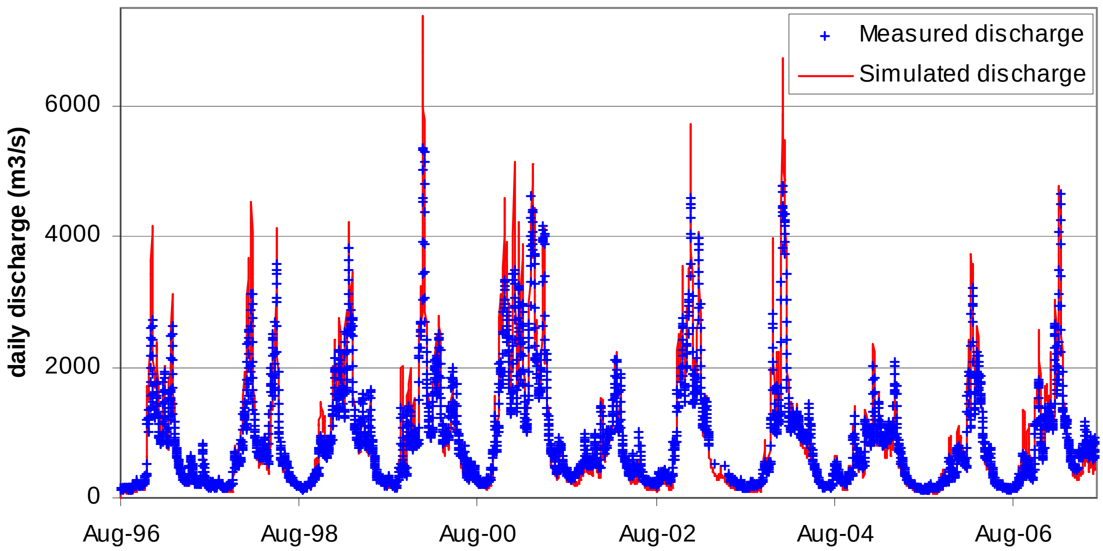

Figure 4: Daily discharge at Saint-Nazaire, outlet of the Loire basin (Bias = +5.2 %, Nash = 0.90)

5.3 Groundwater results

Two types of results are available: the evolution of hydraulic head at piezometers during the period of simulation and hydraulic head distribution at a specific date. The distribution of bias criteria resulting from a simulation based on hydrodynamic parameters coming from previous local studies is available on Figure 5. It highlights that the parameters distribution leading to a well fitted model is not unique [17,18]. Indeed, combining parameters sets coming from different studies does not work out well here. It means that these parameters do not lead to a satisfactory description of the functioning of the global hydrological system, even if they were considered as appropriate when considering each aquifer unit separately.

Bias distribution shows an overestimation of hydraulic head in the western part of the aquifer system whereas it is mostly underestimated in the northern part. It indicates that not only runoff/infiltration partitioning has to be improved, but also the parameters of the saturated domain. The first step will be to fit parameters of the saturated zone and then the ones of the production functions if necessary. This should also improve bias criteria at gauging stations located in the aquifer zone where discharge is overestimated (Fig 3).

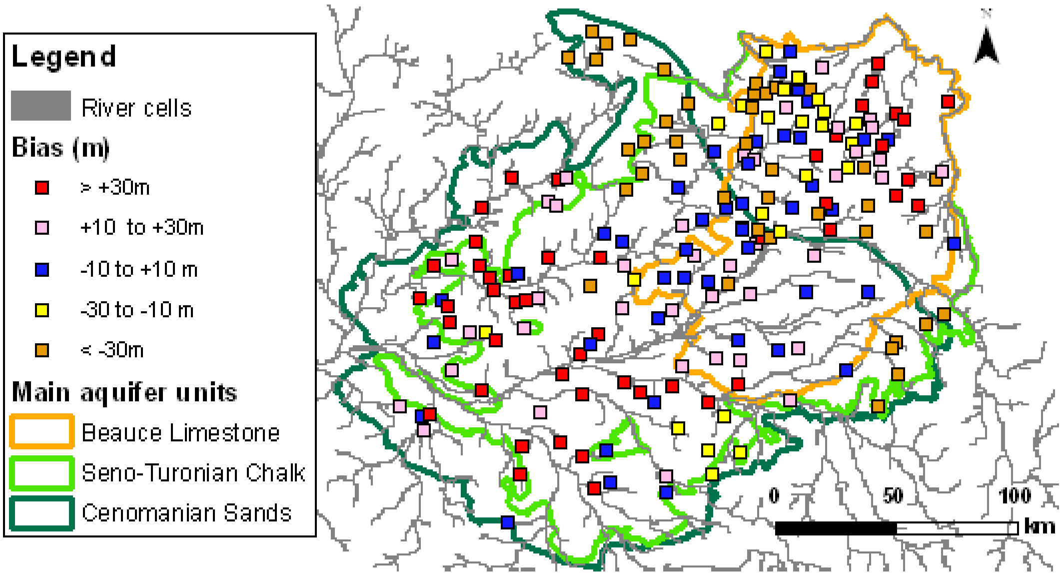

Figure 5: Bias computed between measured and simulated piezometric heads on a ten years chronicle

6 CONCLUSION

The objective of this study was to implement Eau-Dyssée platform on Loire basin using parameter coming from previous studies. Preliminary results indicate a good phasing of flood peaks but groundwater simulation with parameters from previous studies is not satisfactory. Calibration of hydrodynamic parameters will constitute the next step of this work. Objective functions will consist in bias and RMSE criteria and the comparison between hydraulic head distribution and reference piezometric map at a specific date. Further work will be to implement water withdrawals (irrigation, industries, and drinking water supply) within the model.

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