SUPPLEMENTARY MATERIAL S1: Recharge and GARDENIA calculation code

Over the period 2006 to 2021, highest average rainfall is in November (109 mm/month on average) lowest in April (40 mm/month on average). The natural recharge of the water table takes place mainly during the winter period from October to March, when the PET values are low and the precipitations are higher (Figure S1). From 2017 to 2021 the average annual rainfall is 825mm. Precipitation is minimum in 2018-2019 with a total of 628 mm and maximum in 2020-2021 with a total of 952 mm.

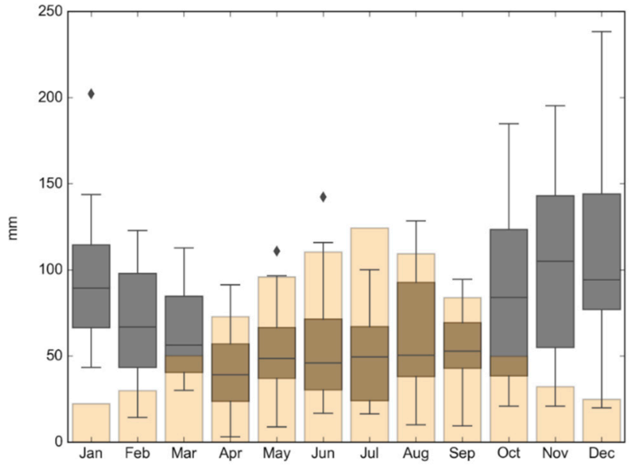

Figure S1. Monthly inter-annual variations calculated over the period from 2006 to 2021 at the Gouville-Sur-Mer station.

The Rain—Evapotranspiration hydro-climatic balance and then the natural recharge is calculated from a global hydrological watershed model GARDENIA (Thiéry, 2009, 2010, 2014-2021, 2015) which simulates, through a succession of reservoirs (**Figure S1**), the main mechanisms of the hydro-climatic balance in a watershed. The results of this balance are identical in all cells of the domain belonging to the same meteorological data and the same "soil" parameters. Transfers from one reservoir to another are governed by physical laws controlled by their parameters (soil retention capacity, transfer times, overflow thresholds, etc.) evaluated by adjustment on a series of observations (water flows in a stream, piezometric levels).

The standard GARDENIA code calls upon three reservoirs:

- A "soil" compartment: the "superficial" U reservoir submitted to evapotranspiration,
- An intermediate compartment (or Unsaturated Zone): the H reservoir (<u>H</u> as <u>H</u>ypodermic) that produces runoff,
- An underground compartment: The G reservoir, corresponding to groundwater.

When the GARDENIA module is coupled to an aquifer system, there is no underground compartment in GARDENIA as this compartment is replaced by MARTHE's aquifer cells.

The superficial reservoir (U) represents the first decimetres of soil subject to vegetation action and evaporation. The capacity of U is the reserve available for evapotranspiration. The soil reservoir is fed by rain (and snowmelt in winter). It is subject to PET (Potential Evapo-Transpiration) and allows calculating the actual evapotranspiration AET and the "Net Rainfall". This "progressive soil reservoir" is based on quadratic laws in terms of the saturation rate of the reservoir.

Satur = Filling of the reservoir / Capacity of the reservoir:

- If rainfall exceeds PET:
  Net Rainfall = (rainfall - PET) x $Satur^2$
- If PET exceeds rainfall:
  AET = (PET - rainfall) x Satur x (2 - Satur).

The Reservoir H represents the unsaturated zone. The water height it contains at a given moment is noted H. It is fed by "Net Rainfall" water coming from the near-surface reservoir, and it is emptied by two components:

- Percolation towards groundwater following a linear law (exponential draining) of a temporal constant THG (with dt = duration of time step):

$$ALIMG = \frac{H.dt}{THG}$$

- Runoff QH, following a non-linear law controlled by the RUIPER parameter; this parameter (RUIPER for "Runoff-PERcolation") is the water height in reservoir H, for which the percolation ALIMG is equal to runoff QH:

$$QH = \frac{H.dt}{THG.RUIPER/H}$$

Runoff QH predominates when reservoir H has a high filling ratio. However, the percolation ALIMG predominates when the reservoir H has a low filling ratio. The ratio QH / ALIMG is equal to the H / RUIPER ratio. The functioning of reservoir H thus resembles that of a progressive overflow sill at an average RUIPER height, but with a more realistic representation of the flow, in two components that are not mutually exclusive.

Reservoir H only serves for transferring water. It determines the distribution of net rainfall, coming from the near-surface reservoir, into runoff and recharge.

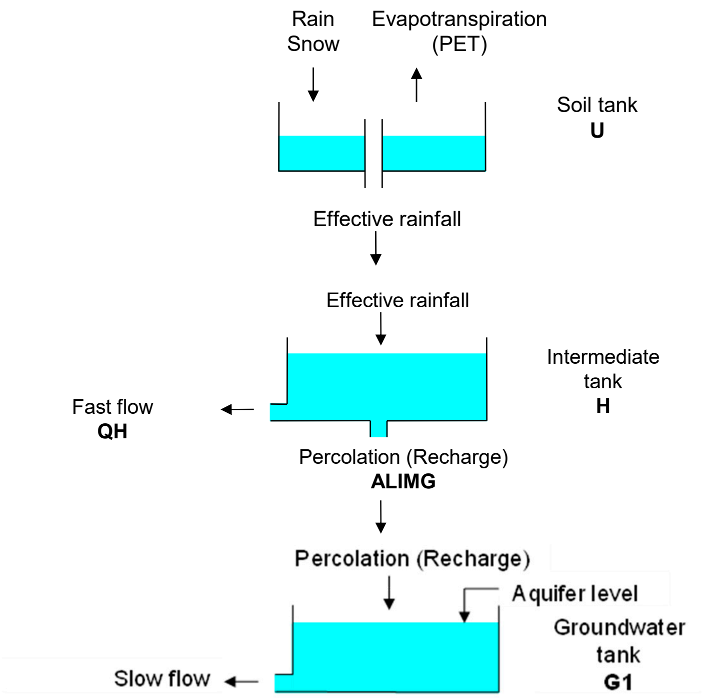

Figure S2. Complete GARDENIA hydro-climatic balance scheme (Thiéry, 2014)

The G1 groundwater reservoir produces the slow flow. It generally represents the aquifer. The level of water it contains at any given time is noted as G1. It is supplied with recharge by the intermediate reservoir H. It is emptied at a basin outlet in the form of a slow flow QG1, following an exponential emptying law of time constant TG1 :

$$QG1 \ = . \frac{G1\, dt}{TG1}$$

Table S1. Gardenia parameters applied in the calculation of natural recharge in Agon-Coutainville

Recharge area	**Capacity (reservoir U)**	**RUIPER parameter (Reservoir H)**	**THG parameter (Reservoir H)**
Indirect recharge from the Estern watershed	600 mm	2 mm	3 months
Direct recharge on the sand dune aquifer	196 mm	9995 mm	3.8 days

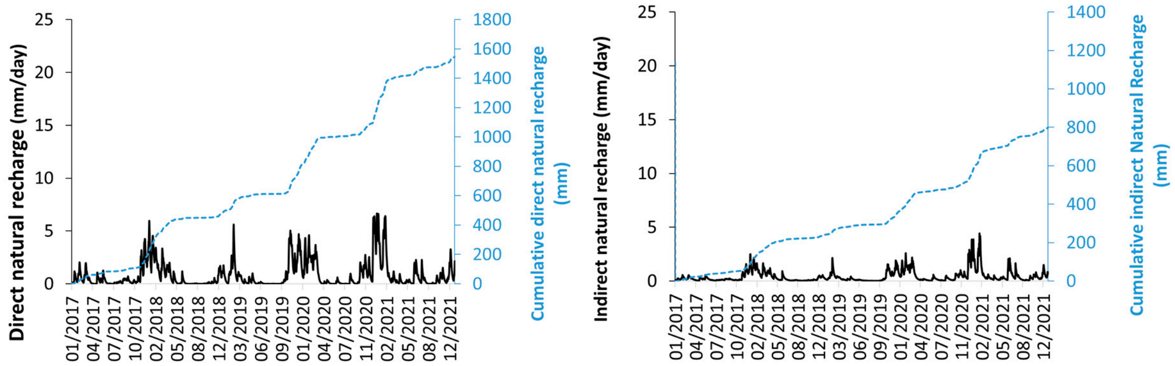

Figure S3. Estimation of "direct" natural recharge on the dune aquifer (left) and local natural recharge on the eastern edge of the aquifer by runoff (right).

Thiéry, D. (2009) – Modèles à Réservoirs en Hydrogéologie. in Traité d'hydraulique environnementale – Volume 4 - Modèles mathématiques en hydraulique maritime et modèles de transport. Tanguy J.M. (Ed.) - Éditions Hermès - Lavoisier. Chapitre 7 pp. 239-249. ISBN 978-2-7462-2006-5.

Thiéry, D. (2010) – Modélisation des Ecoulements Souterrains en Milieu Poreux avec MARTHE. in Traité d'hydraulique environnementale – Volume 9 – Logiciels d'ingénierie du cycle de l'eau. Tanguy J.M. (Ed.) - Éditions Hermès - Lavoisier. Chapitre 4 pp. 77-94. ISBN 978-2-7462-2339-4.

Thiéry, D. (2014-2021) – Logiciel GARDÉNIA, version 8.2 - Mise à jour version v8.8. Guide d'utilisation. Rapport BRGM/RP-62797-FR, 140 p., 74 fig., 2 ann. http://infoterre.brgm.fr/rapports/RP-62797-FR.pdf. (Access January 2020).

Thiéry D. (2015) - Validation du code de calcul GARDÉNIA par modélisations physiques comparatives. Rapport BRGM/RP-64500-FR, 48 p., 28 fig.

SUPPLEMENTARY MATERIAL S2: CATHERINE AND TIDAL LEVEL SIMULATION

The Catherine software (Thiéry, 2012) allows the calculation of piezometric level variations at a point of a groundwater table whose diffusivity is known and which is bordered by a boundary (river, lake, sea) whose temporal variations in water level are known. The variations in recorded levels and tides allow the parameter $Di = T/S$ to be optimised, with T the transmissivity and S the storage coefficient, so that the tidal signal at the limits of the model allows a modelled time series to be obtained via the diffusivity of the aquifer. The optimisation is done by dichotomy method. The correlation coefficient between modelled and observed is calculated by the square root of the Nash coefficient (Nash and Sutcliffe, 1970).

As the Agon-Coutainville site does not have a tide gauge in place, the coastal water level data for this site are reconstructed, following a method already used at the Gâvres site in the Morbihan (Idier et al., 2020). This method is based on the joint use of the FES2014 tidal component database (Lyard et al., 2021), which has a global coverage with a spatial resolution of 1/16°, and altimetry reference data (RAM, 2020). The FES2014 database was used to reconstruct and predict the tidal signal (relative to the mean level) at about 3 km from the Agon-Coutainville site over the period 2010-2021, at a time step of 10 minutes. The water levels thus obtained include only the tide, without taking into account either the effects of rises or the effects of waves. In order for these data to be positioned in the same vertical datum (mASL) as the piezometric and topographic data, they are then converted into altitude (mASL) in relation to the French IGN69 datum from the Maritime Altimeter References (RAM, 2020) at the Granville tide gauge (located approximately 25 km to the south), the closest tide gauge where the average level information in relation to the IGN69 datum is available.

The correlation coefficient (square root of the Nash coefficient) with the observed piezometric levels obtained is 0.85 with a diffusivity parameter calibrated at 1.5 10^{-2} $m^2.s^{-1}$. The diffusivity parameter is higher than expected (3.0 10^{-3} m^2/s) with the hydrodynamic parameters of the dune aquifer with a conductivity of 10^{-3} $m.s^{-1}$, an aquifer thickness of 10 m and a porosity of 0.3.

Idier D., Rohmer J., Pedreros R. *et al.* Coastal flood: a composite method for past events characterisation providing insights in past, present and future hazards—joining historical, statistical and modelling approaches. Nat Hazards (2020). https://doi.org/10.1007/s11069-020-03882-4.

Lyard, F.H., Allain, D.J., Cancet, M., Carrère, L., Picot, N., 2021. FES2014 global ocean tide atlas: design and performance. Ocean Sci. 17, 615–649. https://doi.org/10.5194/os-17-615-2021

Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I — A discussion of principles. J. Hydrol. 10, 282–290. https://doi.org/10.1016/0022-1694(70)90255-6

RAM, 2020. Références Altimétriques Maritimes, Ports de France métropolitaine et d'outre-mer Cotes du zéro hydrographique et niveaux caractéristiques de la marée. SHOM.

Thiéry, D., 2012. Code de calcul CATHERINE - Principe et mode d'emploi. (No. BRGM/RP-61430-FR).

SUPPLEMENTARY MATERIAL S3: Sensitivity

The sensitivity analysis aims to study the impact of the choice of the different hydrodynamic and hydrodispersive parameters and boundary conditions. The tested parameters are presented in Table S2. For each model, just one parameter is modified and the flow velocity and STWW proportion are calculated and compared to the calibrated model for the 4 main flow lines.
Changes in stream boundary conditions (0.4 cm drop in water level and 1 m increase in stream bottom depth) and direct natural recharge (10% direct recharge) do not significantly modify the average flow velocities (-2 to 5%) and average STWW proportions (-1 to +5%) in the aquifer calculated on flowlines 1, 2, and 3 (Table S2). Only the proportions of STWW on the flowline 4 are lowered by 18% by the increase of the depth of the Goulot streambed. The simulations of changes in sea boundary conditions (Harbour not considered) modify the velocities (decrease up to 20% mainly on the flowline #3 and flowline #4) and modify the proportions of STWW (increase of 17% on the flowline #3 and decrease of 17% on the flowline #1 and flowline #4). For the modifications of the indirect natural recharge, taking into account the seasonality of the inputs modifies slightly the velocities on flowlines 1, 2,3 and 4 (-2 to +8%) and the proportions of STWW on flowlines 1,2 an 3 (-4% to +8%) but more strongly on flowline #4 (-19%). The modification of the indirect natural recharge by selecting a constant fixed hydraulic head modifies more strongly the velocities (-10 to +29%) and the proportions of STWW (-30 to +12%).
Changes in hydrodynamic parameters strongly impact velocities. The general decrease of the hydraulic conductivity in the dune aquifer from $2.0 \cdot 10^{-3}$ $m.s^{-1}$ to $2.0 \cdot 10^{-4}$ $m.s^{-1}$ induces a decrease of 85% compared to the velocities of the calibrated model. The assumption of a hydraulic conductivity considered homogeneous on the whole domain at $2.0 \cdot 10^{-3}$ $m.s^{-1}$ (initially calibrated at $5 \cdot 10^{-6}$ $m.s^{-1}$ for the aeolian sands), induces an increase of the velocities mainly for the flowline #1 of 45% and for the flowline #2 of 26%. Few differences are observed for the flowline #3 and flowline #4.
The choice of a porosity of 20% for the whole domain (initially of 10% for the aeolian sands), modifies very little the velocities and the proportions of STWW. Nevertheless, for a porosity of 35%, the calculated velocities decrease by 41% to 42% for the four flowlines. The longitudinal dispersivity parameter, α_L - increased to 100 m (calibrated to 10 m) - decreases the proportion of STWW in the aquifer by 18%, 16%, 35% and 2% on the respective flowlines #1, #2, #3 and # 4.

Table S2. Average flow rates and average proportions of STWW in the aquifer from 2017 to 2021 for the baseline model and other models with different parameters for the main flowlines from the different infiltration basins 1, 2, 3 to the Goulot stream (Flowlines 1, 2, 3) and from the Goulot stream to the coastline (Flowline 4). Differences from the reference model results are indicated in percentage via the color scale (from +100% in blue to -100% in red).

Model	Model modifications	Groundwater velocities (m/d)				STWW proportions (-)			
		Flowline 1	Flowline 2	Flowline 3	Flowline 4	Flowline 1	Flowline 2	Flowline 3	Flowline 4
Calibrated model	-	***2.48 ± 0.97***	***2.67 ± 0.91***	***3.03 ± 0.93***	***3.77 ± 1.27***	***0.86 ± 0.14***	***0.91 ± 0.07***	***0.77 ± 0.15***	***0.6 ± 0.05***
River 1	River water level lowered by 0.4 m	2.49 ± 0.98	2.71 ± 0.93	3.07 ± 0.90	3.67 ± 1.27	0.85 ± 0.15	0.91 ± 0.07	0.76 ± 0.16	0.63 ± 0.05
River 2	Riverbed lowered from 0.5 m to 1.5 m from topography	2.45 ± 0.97	2.58 ± 0.90	3 ± 0.95	3.95 ± 1.26	0.88 ± 0.12	0.91 ± 0.06	0.78 ± 0.15	0.49 ± 0.06
Natural recharge 1	-10% recharge	2.48 ± 0.98	2.67 ± 0.91	3.01 ± 0.91	3.75 ± 1.26	0.87 ± 0.14	0.91 ± 0.06	0.78 ± 0.15	0.61 ± 0.05
Sea	No harbour limit conditions	2.41 ± 1.00	2.48 ± 1.04	2.41 ± 1.01	3.2 ± 1.34	0.72 ± 0.26	0.89 ± 0.07	0.9 ± 0.04	0.5 ± 0.15
East recharge 1	From constant recharge value to seasonal variations of indirect recharge	2.52 ± 0.96	2.66 ± 0.89	3.06 ± 0.91	3.45 ± 1.32	0.93 ± 0.05	0.9 ± 0.07	0.74 ± 0.17	0.49 ± 0.12
East recharge 2	From constant recharge to calculated recharge with a fixed hydraulic head (4.5 mASL)	3.21 ± 0.97	2.98 ± 0.91	2.52 ± 0.93	3.37 ± 1.27	0.97 ± 0.14	0.88 ± 0.07	0.76 ± 0.15	0.42 ± 0.05
Hydraulic conductivity 1	From $K = 2{\cdot}10^{-3}$ to $2{\cdot}10^{-4}$ $m.s^{-1}$ (recent dunes)	0.39 ± 0.02	0.42 ± 0.03	0.55 ± 0.02	0.63 ± 0.13	0.49 ± 0.14	0.54 ± 0.05	0.67 ± 0.06	0.03 ± 0.00
Hydraulic conductivity 2	Homogeneous K : from $5{\cdot}10^{-6}$ $m.s^{-1}$ to $2{\cdot}10^{-3}$ (aeolian sands)	3.6 ± 1.35	3.37 ± 0.87	2.96 ± 0.75	3.56 ± 1.98	0.81 ± 0.17	0.72 ± 0.17	0.55 ± 0.2	0.45 ± 0.14
S_L, porosity 1	Homogeneous S_L, porosity: from 0.1 to 0.2 (aeolian sands)	2.48 ± 0.97	2.67 ± 0.90	3.04 ± 0.91	3.77 ± 1.27	0.86 ± 0.14	0.9 ± 0.07	0.76 ± 0.16	0.6 ± 0.05
S_L, porosity 2	Homogeneous SL, porosity: from 0.2 (recent dunes) and 0.1 (aeolian sands) to 0.35	1.43 ± 0.54	1.54 ± 0.5	1.76 ± 0.5	2.22 ± 0.77	0.94 ± 0.08	0.91 ± 0.04	0.8 ± 0.15	0.55 ± 0.05
α_L 100m		2.48 ± 0.97	2.67 ± 0.91	3.03 ± 0.93	3.77 ± 1.27	0.71 ± 0.12	0.76 ± 0.05	0.5 ± 0.15	0.48 ± 0.06

Differences (test/calibrated, %)	+100	+50	+25	0	-25	-50	-75	-100

SUPPLEMENTARY MATERIAL S4: Nomenclature

STWW : Secondary Treated Wastewater
WWTP : Wastewater treatment Plant
SAT : Soil Aquifer Treatment
MAR : Managed Aquifer Recharge