PegOpera, a Software Suite dedicated to Surface Water Quality Assessment in the framework of the European WFD

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Introduction

The Pegase Model (focus on Surface Water Quality)

Working Scheme & specificities (loads)

Results and Applications (from stakeholders)

How to improve Diffuse loads

GW coupling

Conclusions

Major Principles
Major differences in terms of
driving forces (punctual, variability …)
spatial and temporal scales
behaviour of the basins/rivers

Introduction

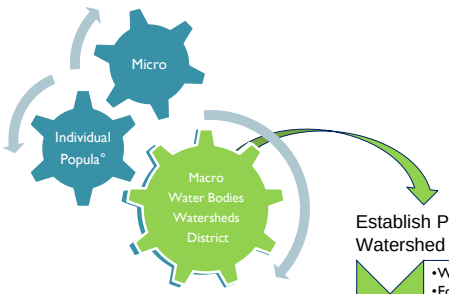
Integrated Modelling Basin / River

WFD 2000/60/CE imposes (amongst other)

- Good Ecological Status for all WB in all member states
  - Rivers, lakes, Costal areas, Wtelands, GW, soils, pools, …
  - Ecology ← Physicochemical / Morphology / Biological
- For each District, an analyse of major characteristics (« State of the art »)
- Impact study of human activities on water resources
- Monitoring Network
- Management plans + related Measures to achieve good status objectives
- A list of the areas requiring special attention (protection)
- Economical analysis (related to water uses)

Thoughts

Modelling
Representation at Different scales



Needs

- Diagnostic
- Integrated approach
- Surface Water Quality
- Impacts on ecosystems
- Holistic vision
- District (e.g. Meuse)
- (Surface) Water Bodies
- Major parameters + Micropolluants … ?
- Bioaccumulation

Establish Pressure/impact relationships of the Watershed

- P
  - •Watershed representation
  - •Ecosystem description
  - •Sources identification
- Model
  - • Modelling : Hydro / Loads / Quality / …
- Qua
  - • Qualité physico-chimique

Introduction

Integrated Modelling Basin / River

Establish Pressure/impact relationships of the Watershed

- **P**
  - Watershed representation
  - Ecosystem description
  - Sources identification
- **Model**
  - Modelling : Hydro / Loads / Quality / …
- **Qua**
  - Qualité physico-chimique

Introduction

PEGASE Model

Planification Et Gestion de l'ASsainissement des Eaux
Planning and Management of Water Purification

OBJECTIVES

- Better understand the mechanisms of the hydro-system
- Quantify "pressure-impact" relationships
- Ease decision making (DSS)
- Structure knowledge (including "Input Data")

1) *Simulation of surface water quality*

- ✓ Relation Watershed / Rivers (→ extending "river" models)
- ✓ Taking into account all Pertinent Pollutants loads and Discharges
  - → data structuration
- ✓ Representation of the Aquatic Ecosystem and the Water Quality (O2, C, N, P, …)
- ✓ "Refined" description of river tree (>> Thousands of rivers)

→ Deterministic model and physically based

2) *Operational Decision Making Tool for*

- ✓ Purification and Depollution
- ✓ Management of aquatic environment quality / WFD / Management plans …

DCE

→ Continuous interaction with users

Introduction

PegOpera : a Water Quality Model

- Integrated model for rivers & watershed
- Complete Description of ecosystems (phytoplankton, bacteria...)
- Coherent and complete modelling of loads and discharges

Accurate Simulations for a few km² → several 100 000 km²
"Refined" Description of river tree (>> Thousands rivers)

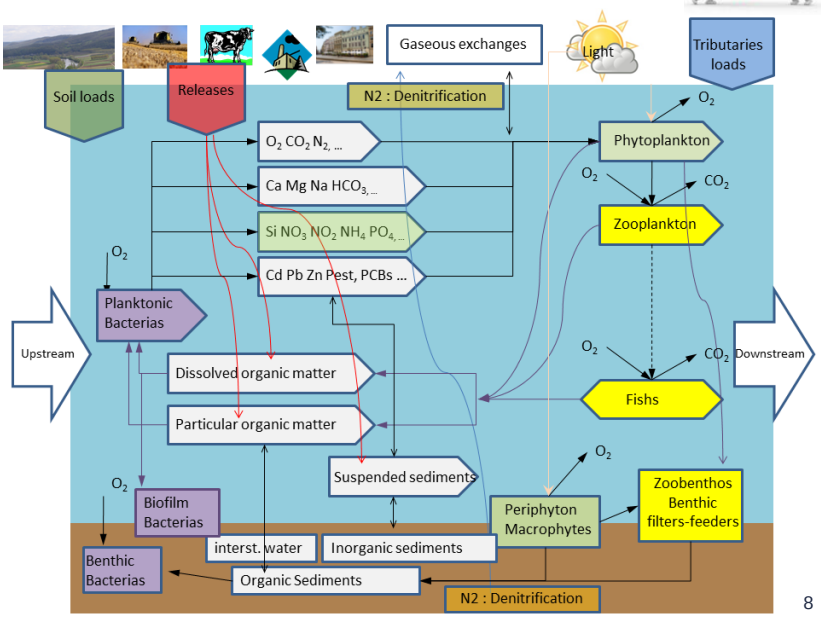
Results
- Stationary and/or nonstationary Simulations (several CPU hours)
- Globalisation of results per river, water bodies, basin, …
- Calculation of statistics for comparison
- (p90, mean, median, …)

✓ User-friendly interface
✓ Linked to GIS
✓ Complementary Modules → WFD (cost/efficiency, balance, ...)
✓ Numerous IO Format
✓ Coupled to hydrogeological/ hydrological/meteorological/… Modules if necessary
✓ Open MI Compliant

Used by the Administrations

Introduction

PegOpera : a Water Quality Model

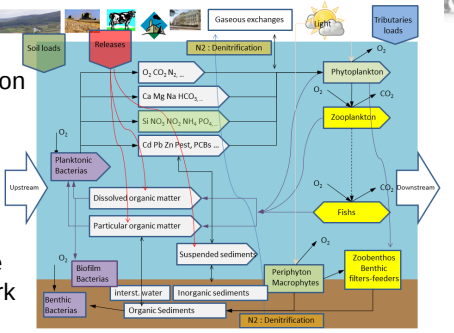


Introduction

PegOpera : a Water Quality Model

Processes

- primary production
- mortality, biomasses respiration
- degradation organic matter
- nitrification, denitrification
- reaeration
- sedimentation



Variables

- flows, velocities, transfer time in the hydrographical network
- temperature
- concentrations : **OM, DOC, POC, COD, BOD, NH_4, NO_2, NO_3, N_{Kj}, P_{tot}, PO_4, dissolved O_2 (daily average, min, max)**
  biomasses
  micropollutants (Heavy metals, …)

Results

- Flows, temperatures, concentrations, …
  - At each “Pegase node” of the modelled river network (hundreds of rivers)
  - For each day of simulation (daily average)

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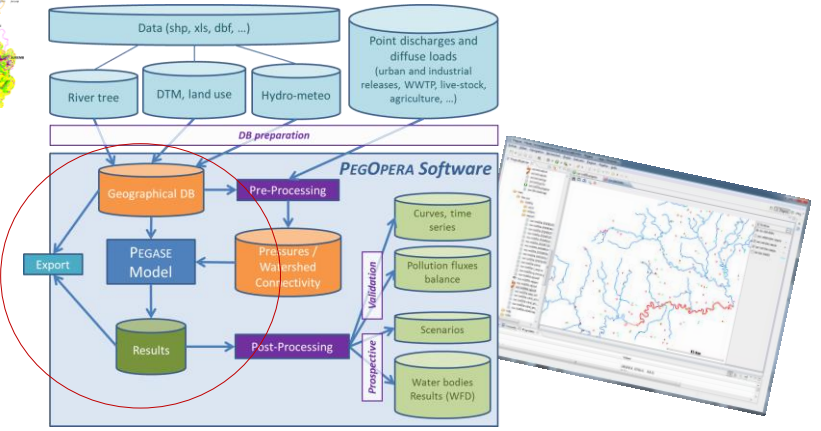
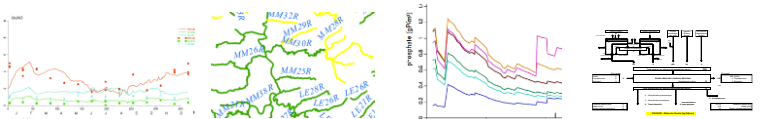
Introduction

PegOpera : Input Data and Results





Validating Simulation | Water Bodies Results | Scenarios | Pollution Fluxes/Balances

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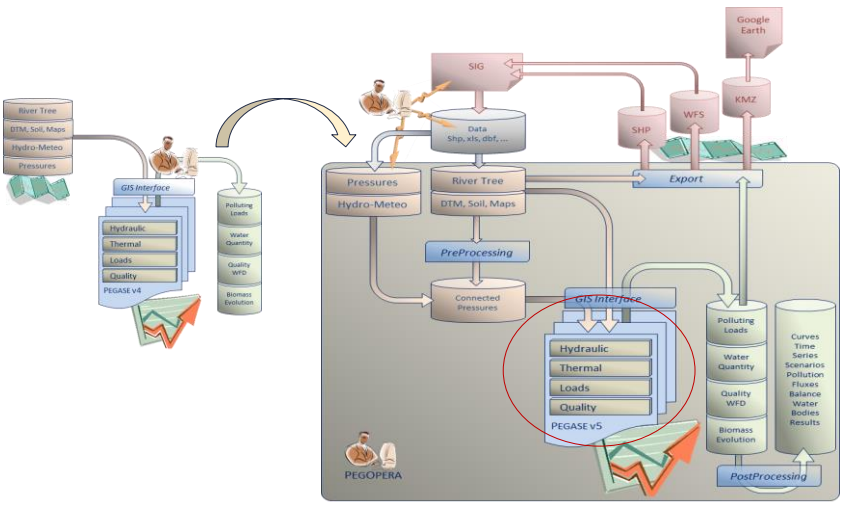
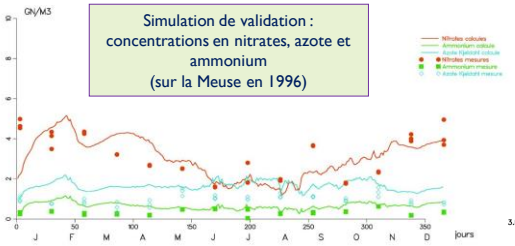
Introduction

PegOpera Working Scheme

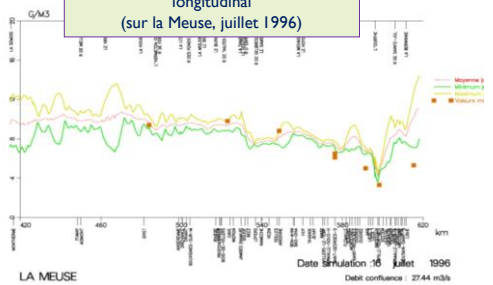


Applications

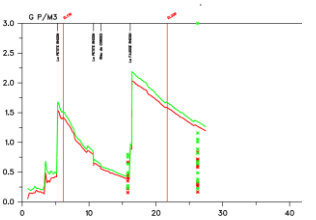
Pegase Model Results



Simulation de validation :
concentrations en nitrates, azote et ammonium
(sur la Meuse en 1996)



Simulation de validation :
concentrations en oxygène, profil longitudinal
(sur la Meuse, juillet 1996)



Simulation de validation :
Phosphore, Longitudinal
P90 valeurs calculées
Valeurs mesurées
(sur la Rhosne, 2009)

Applications

Results [Variables]

- Flows, stages, velocities, … in the river network (Δ x ~ 200 m)
- Ecosystem and water quality variables (daily average) :
  - Biomasses (bacteria, phytoplankton, …)
  - Concentrations (BOD, COD, DOC, N, P, O_2, µpollutants…)
  - Loads to water surfaces, fluxes
- Statistical values (p90, average, max, …), globalization per waterbody
- Quality indexes (*Seq-Eau like*) : scale 1 - 100

Bad	Poor	Moderate	Good	High

- Presentation of results :
  - 2D maps (coloured codes for a visualization « per class »)
  - Longitudinal profiles (for each river), time series (for specific points)
  - Comparison with measurements (→ validation)
  - Comparison of scenarios
  - Balances of fluxes
  - Export (xls, dbase, shp, kml, …)

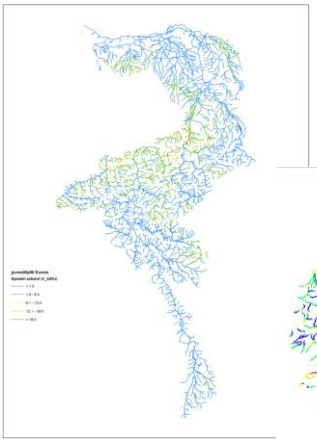
NB. Water quality measurements are only used for validation

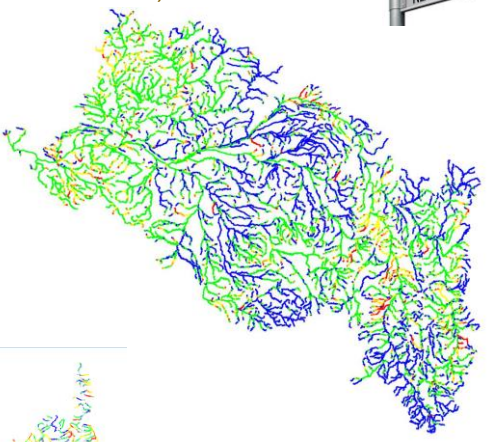
Applications

Pegase Model Results (Watershed/River)

Qualité maps

Application transnationale : DHI de la Meuse (F, B, Lux, D, NL)

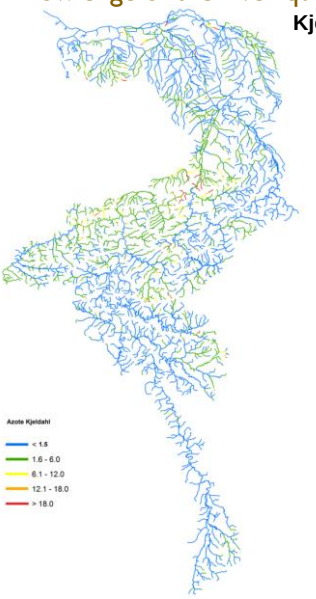




Carte de qualité du réseau hydrographique : indice SEQ-Eau matières organiques (Bassin de la Loire)

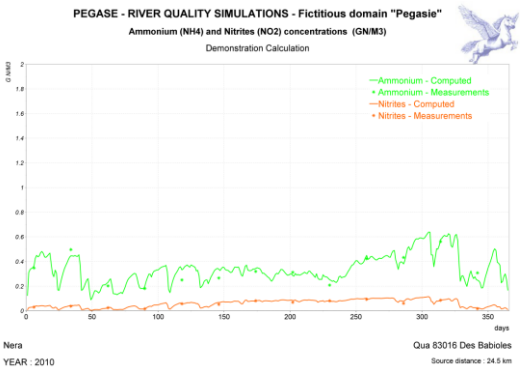
Applications

Type of Results
WFD → State of the art
Knowledge of the river quality even where there are no measurements



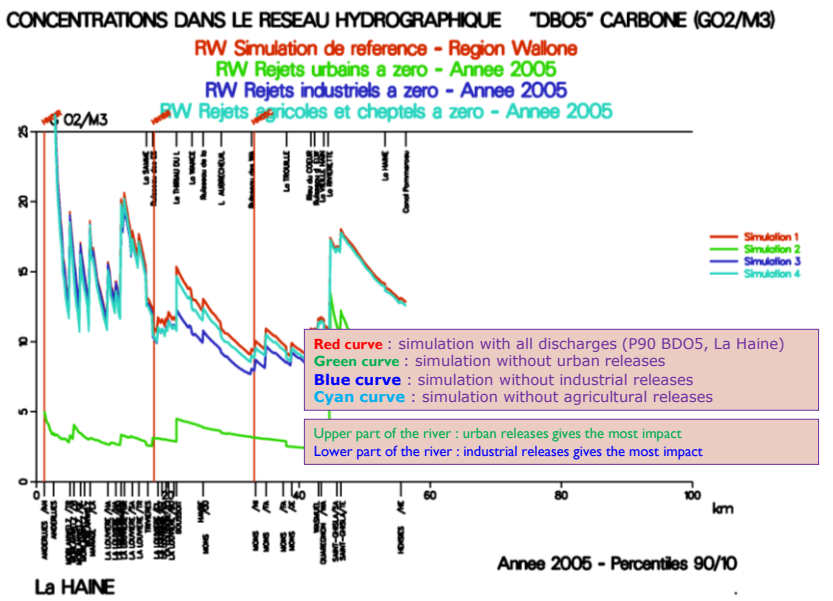
Kjeldahl Nitrogen p90 concentrations, Meuse basin

Validation : comparison of results with measurements



Applications

Results [Pressure / Impact analysis]

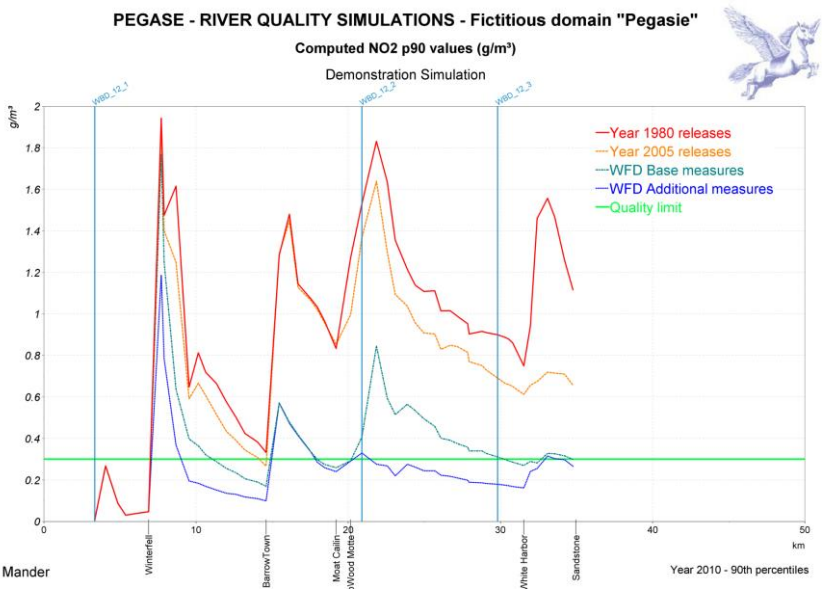


Red curve : simulation with all discharges (P90 BDO5, La Haine)
Green curve : simulation without urban releases
Blue curve : simulation without industrial releases
Cyan curve : simulation without agricultural releases

Upper part of the river : urban releases gives the most impact
Lower part of the river : industrial releases gives the most impact

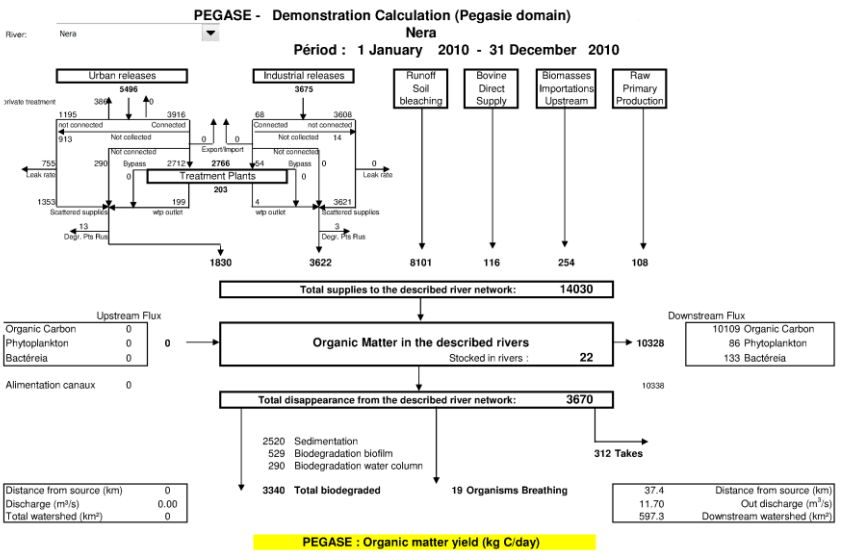
Applications

Results [Comparison of scenarios]



Applications

Results [Balance Sheet]



Theory

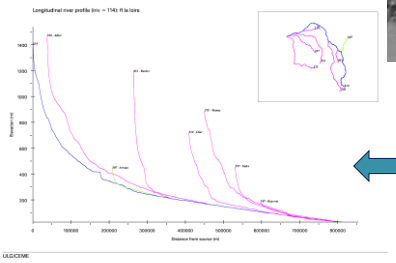
Data

Geographical Data
- Hydrographic network
- Digital Elevation Terrain
- Soil Occupation (Corine)

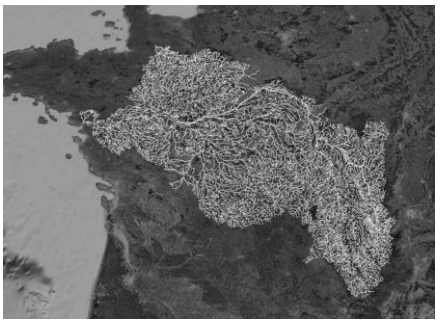
Hydrometeo Data
- River flows
- Daily water temperatures
- Insolation

Pre-Processing of Geographical data

Length profile of the Loire river and its main tributaries



Detailed description of the river Network
Ex : The Loire river (France)
- 118 000 km²
- 5560 rivers, 51720 km of rivers
- 138 800 « result nodes »



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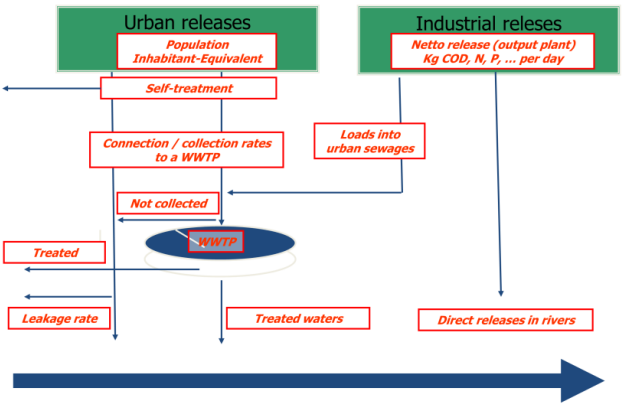
Theory

Loads and Discharges

- Urban releases
- Industrial releases
- Live-stock
- Diffuse loads (soil)

Point releases



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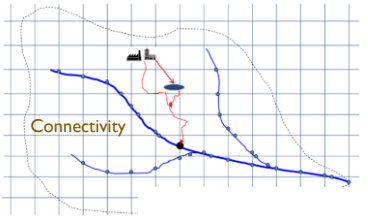
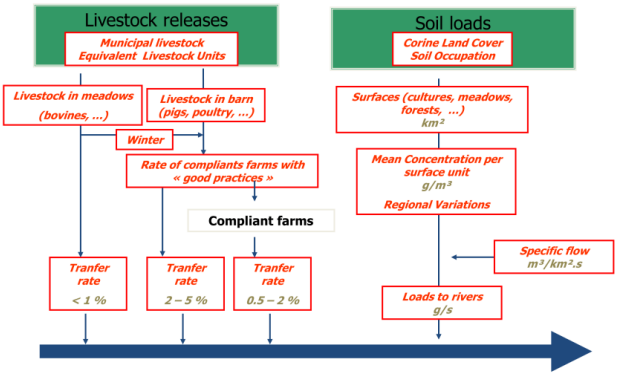
Theory

Diffuse Loads



Diffuse loads include Soils, Hydrogeological exchanges, riparian areas, …

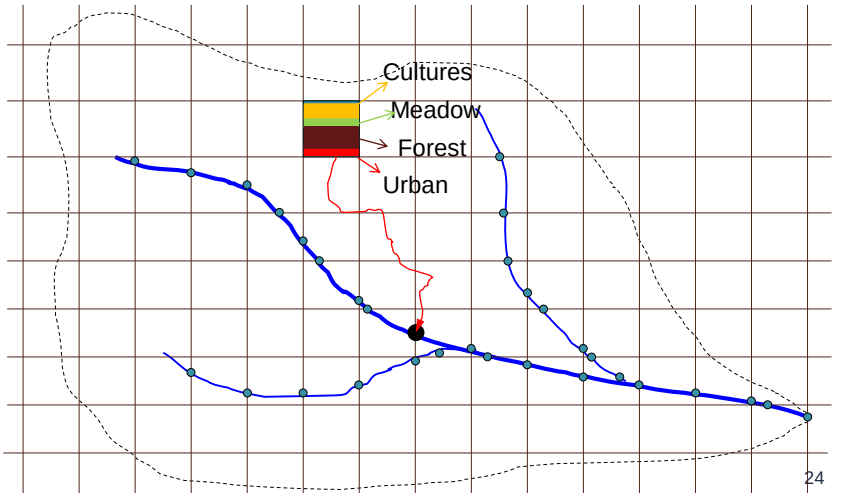
Diffuse loads



Theory

Diffuse Loads

They are associated to major land uses



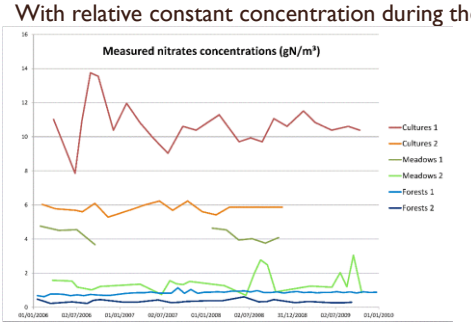
Theory

Diffuse Loads → Land uses

They are associated to major land uses

	mg/l	Culture	Meadow	Forest
C org. Dissous				
	assimilable	0,80	0,80	0,80
	non assimilable	1,60	1,60	2,60
C org. Particulaire				
	assimilable	0,50	0,50	0,50
	non assimilable	1,00	1,00	2,00
N org. Dissous				
	assimilable	0,40	0,40	0,20
	non assimilable	0,40	0,40	0,20
N org. Particulaire		0,20	0,50	0,12
Ammonium		0,05	0,05	0,02
Nitrates		7,50	3,00	1,50
P org. Dissous		0,02	0,02	0,005
P org. Particulaire		0,07	0,03	0,03
Orthophosphates		0,10	0,04	0,01

With relative constant concentration during the year



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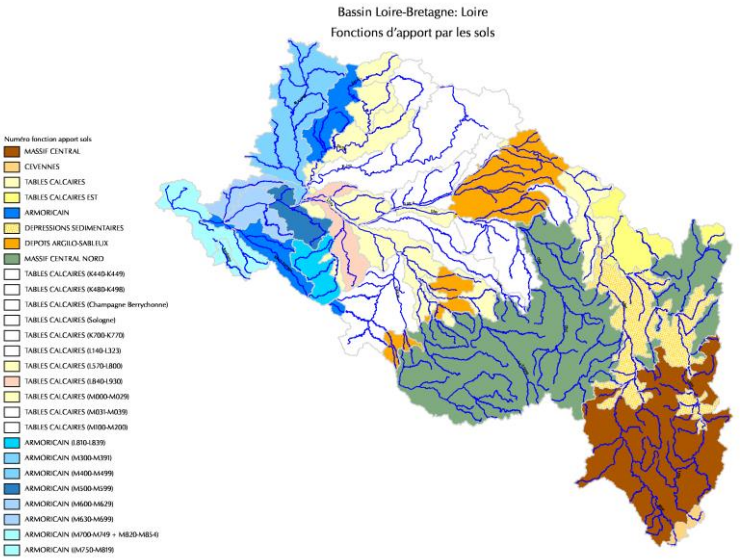
Theory

Diffuse Loads → Regional Soil Functions

Soil function are regionalized
(they may vary depending on soil types …)



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Theory

How to improve Diffuse Loads

They can be estimated

- Usually from upstream river concentration in small watershed characterised by homogeneous (and/or predominant) land uses
- From other compartment models (soils, hydrogeology, …)

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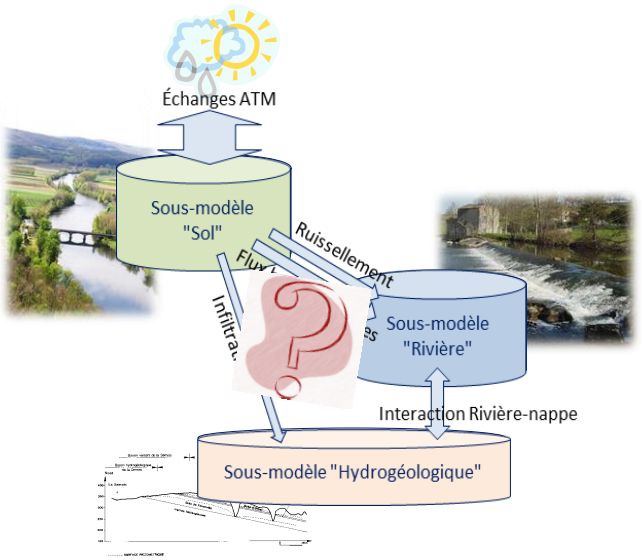
Theory

Compartmented Hydrological System



How can we integrate ?
≡ How can they (the models) communicate ?

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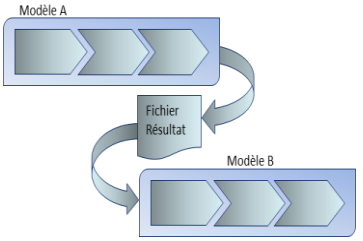
Theory

Integration

With or without interface

External Coupling



A Results → B Data

Sequential Runs

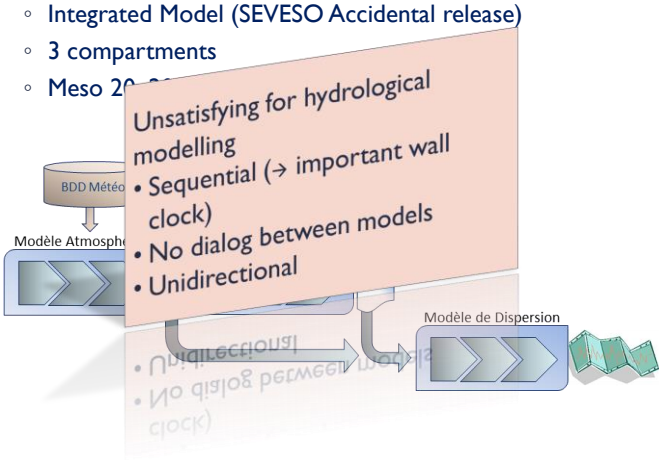
Exchange of Files

Applications

External Coupling

Sevex Project (DSS)

- Integrated Model (SEVESO Accidental release)
- 3 compartments
- Meso 20



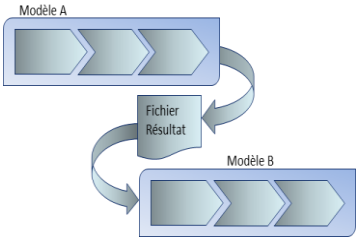
Ulg, UCL, FPMs ← DGRNE, IBM

Theory

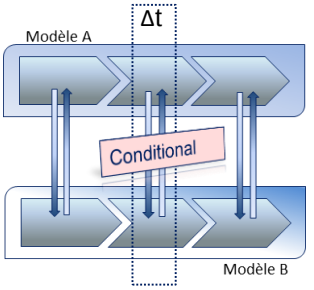
Integration

With or without interface

External Coupling



Internal Coupling
Direct or through interface



A Results → B Data ⇒ Direct Communication

Sequential Runs ⇒ Parallel runs

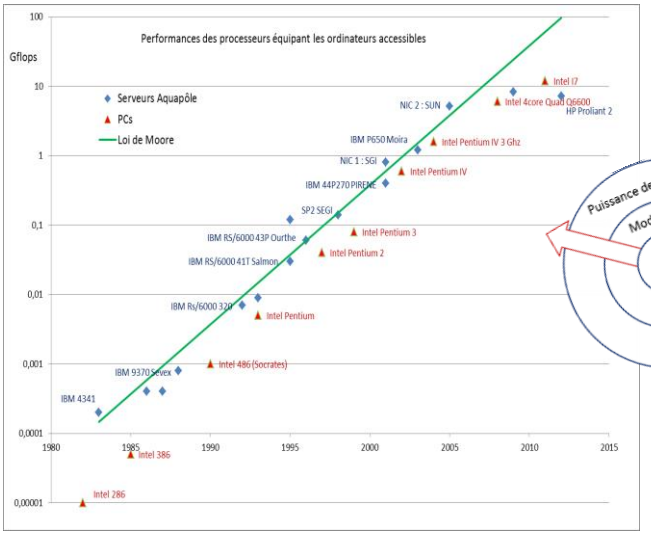
Exchange of Files ⇒ Bidirectional communication

All integration modes are compatibles (external, direct internal, interfaces, ..)

Theory

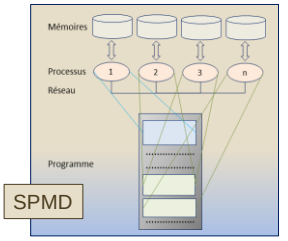
Hardware evolution

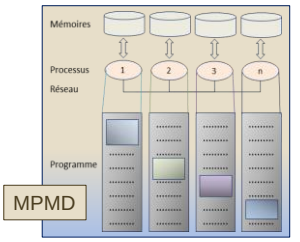
- Monoprocesseurs → multiprocesseurs
- Constant evolution of the Available Calculation performances (Power) between1990 et 2010 ~ 10,000
- Now from ~10 Gflops/proc to ~100 Gflops tot (HP Proliant Moirab)

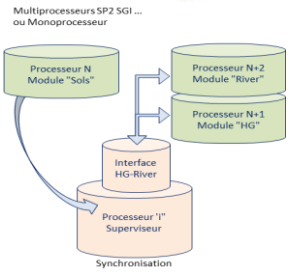


Theory

Classification







Each Process (or part of a program) is executed on its own DB
The variables of the programmes are Private (reside in each local proc. memory)
Exchange of data (between 2 procs.) through IPC dialog

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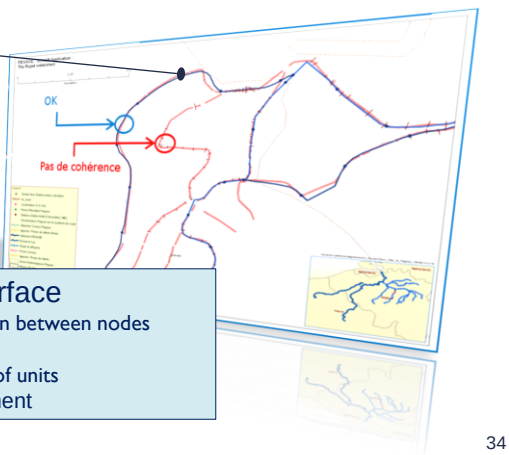
Theory

Integration Constrains

Model Characteristics :

- Different numerical schemes
- Different spatial representations (scales & morphologies)
- Different temporal scales (Internal & to communicate)
- "Own" DB to harmonise (e.g. River Height / nudes HG)

To each Δt
For each
node



Coupling Interface

- Link/interpolation between nodes
- Temporal Scale
- Transformation of units
- Data management

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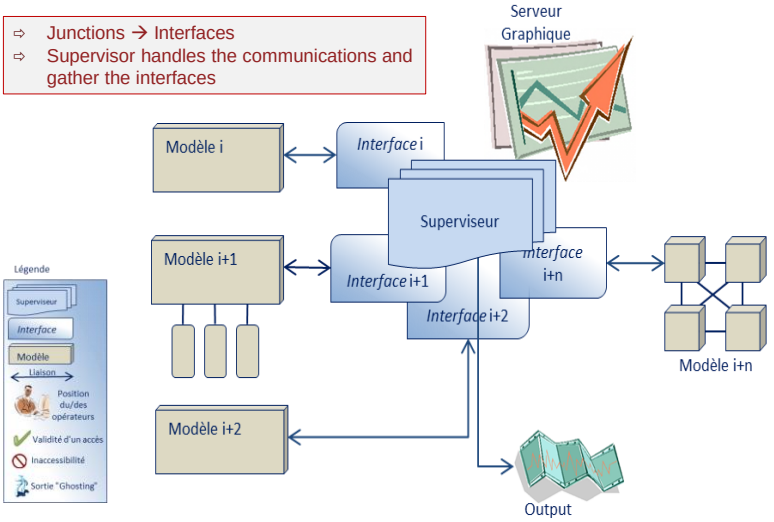
Theory

Architecture

Communication between Models

- Structure and reduce the complexity (of implementation)
- Cilitate synchronisation (of the communications)
- Optimise and reduce execution time (of the integrated model

⇨ Junctions → Interfaces
⇨ Supervisor handles the communications and gather the interfaces

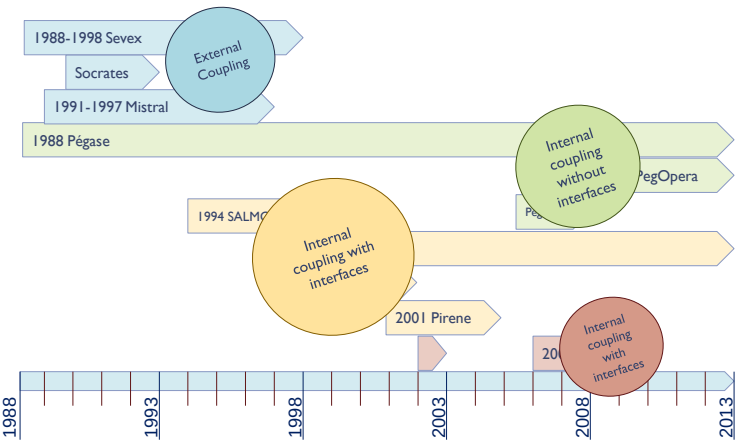


Applications

Integrated modelling Experiences

ULiege

- Environmental Centre → CEME → R&D Unit of Aquapôle
- 11 Projects (21 major declinations and 30 secondary's)



Applications

SSTC (CG/DD/08) Project

Modélisation intégrée du cycle hydrologique dans un contexte de changements climatiques

(Water Cycle Integrated modelling in a Climate Change Context)

- *3 Belgian Basins (different dynamics)*
- *3 different models and comparison of their respective "answers"*
- *Selection of IPCC scenarios (1998-2002) (Intergovernmental Panel on Climate Change) → downscaling*

BV/Modèles	IRMB	MIKE-She	MOHISE
Gette à Budingen (576 km²) 24 Rivières, 231 km	X	X	X
Geer à Kanne (466 km²) 11 rivières, 148 km	-	X	X
Ourthe orientale à Mabompré (315 km²), 41 rivières, 213 km	X	-	X

Model IRMB (IRM/KMI)
Model MIKE-SHE (ILWM/KUL)
Model MOHISE (Ulg, HA-FUSAG, KUL)

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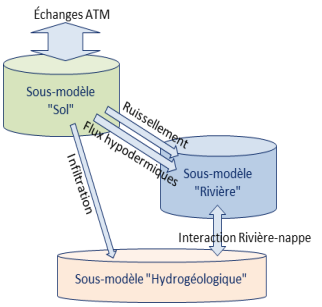
Applications

MOHISE integrated model : processes

MOdèle Hydrologique Intégré de Simulation du cycle de l'Eau

- Compartmented models (assignation/processor)
  - Soils : EPIC-Grid (HA FUSAG)
  - HG : MODFLOW / SUFT3D (LGIH)
  - Rivers : RIVER (CEME)
- Transfers
  - BV → River (runoff, HR, HL)
  - BV → Hydrogeology : Infiltration
  - Hydrogeology ↔ Rivers (depending on H_{RIV} H_{PIEZO})



3 simulation scenarios
3 effective periods of 27 years (1969 - 1996)

Ulg (LGIH, FUSAG, CEME) ← SSTC (CG/DD/08)

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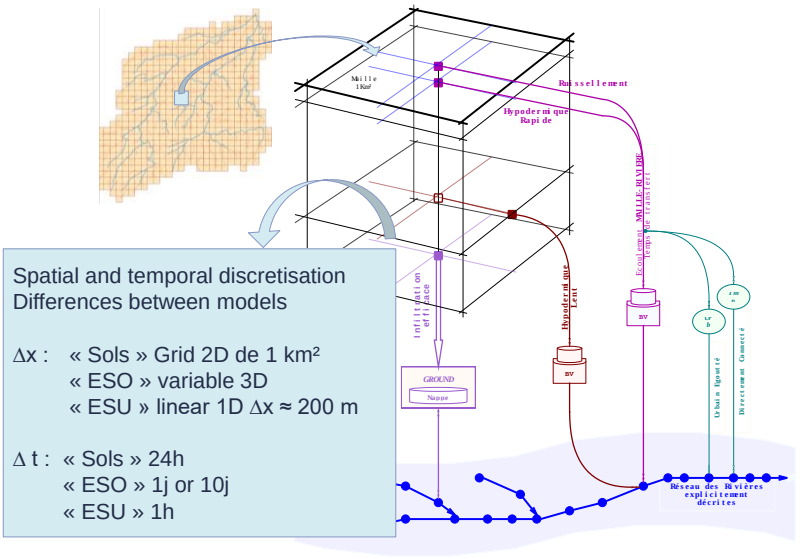
Applications

MOHISE integrated Model

Transfers and discretisation



Spatial and temporal discretisation
Differences between models

Δx : « Sols » Grid 2D de 1 km²
« ESO » variable 3D
« ESU » linear 1D Δx ≈ 200 m

Δ t : « Sols » 24h
« ESO » 1j or 10j
« ESU » 1h

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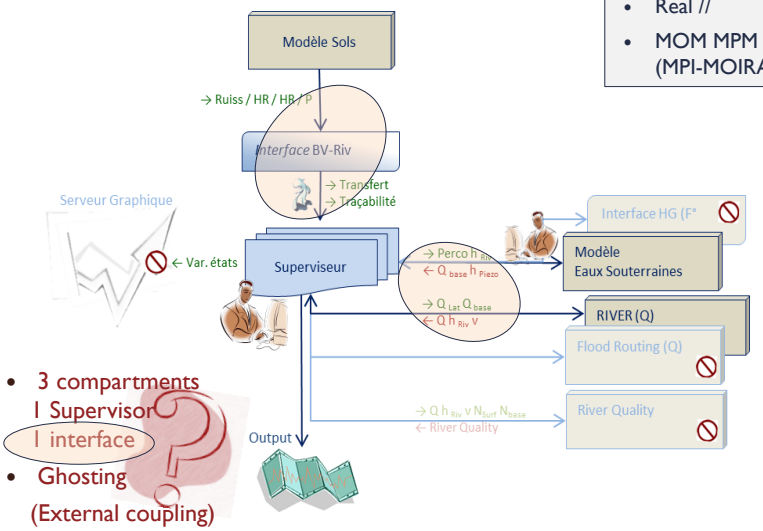
Applications

MOHISE Architecture

- Internal Coupling with interface
- MPMD Type
- Real //
- MOM MPM (MPI-MOIRA)



- 3 compartments
  1 Supervisor
  1 interface
- Ghosting
  (External coupling)
- Bidirectional exchanges

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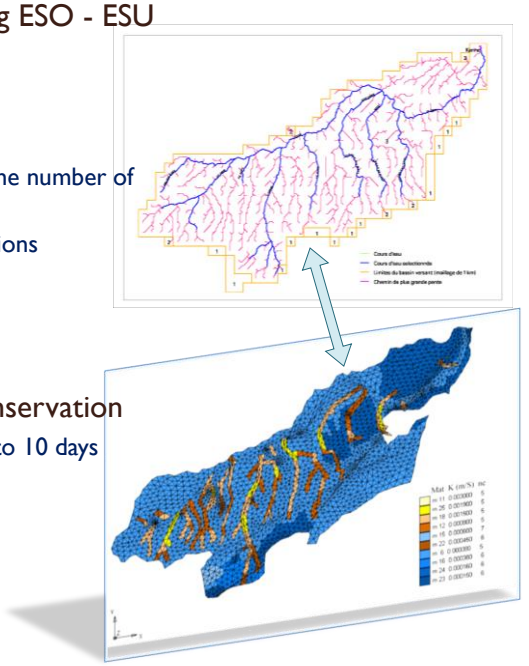
Applications

Pre-processing MOHISE
Bidirectional coupling ESO - ESU

- Verifications and Corrections
  - Improvement of the number of modelled rivers
  - Altimetry corrections
- Coupling
  - MODFLOW
  - SUFT3D
- Check fluxes conservation
  - Exchange from 1 to 10 days



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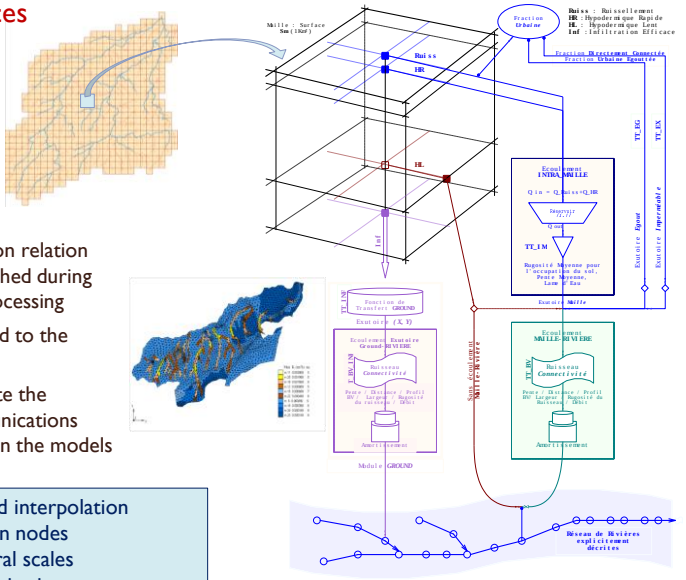
Theory

Interfaces



- Based on relation established during pre-processing
- Adapted to the models
- Facilitate the communications between the models

- Link and interpolation between nodes
- Temporal scales Harmonisation
- Units Transformation
- Common data management

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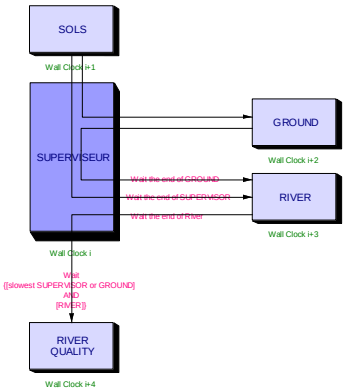
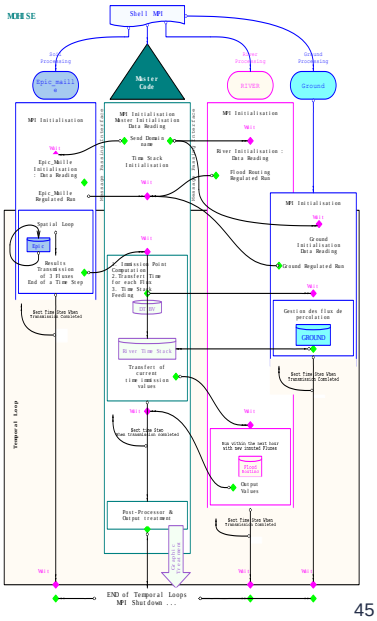
Simulations

The Supervisor and the Synchronisation





- Handle the different execution times between the models
- (identify and) orchestrate the communication sent/reception

→ Impose synchronisation (barriers)

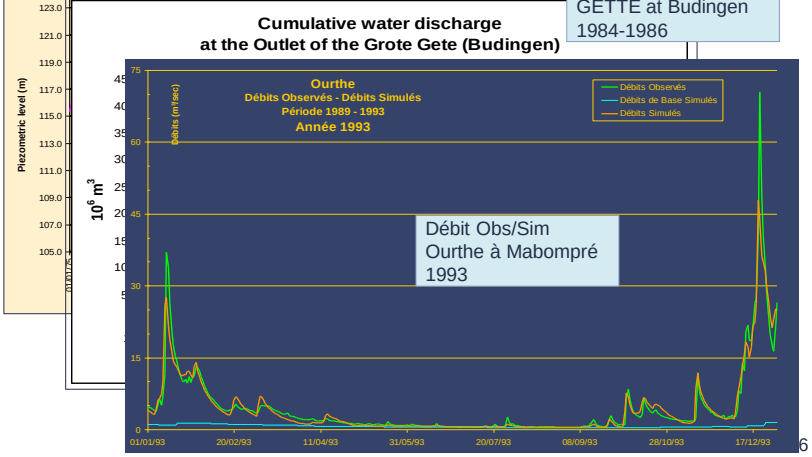
Use of MPM Library : MPI-MOIRA

Simulations

Integrated Results
Historical Simulation
1971 – 1995

Piezo Height
GEER weel F06
1975-1996

Cumulated outflow
GETTE at Budingen
1984-1986



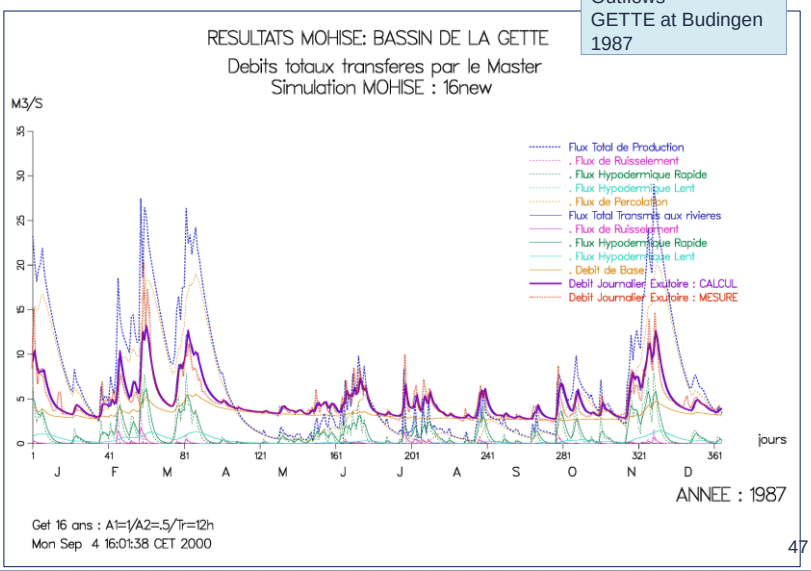
Débit Obs/Sim
Ourthe à Mabompré
1993

Simulations

Integrated MOHISE Results

Track of the transfered fluxes at the interfaces

Outflows
GETTE at Budingen
1987



Simulations

Integrated Results : Comparison

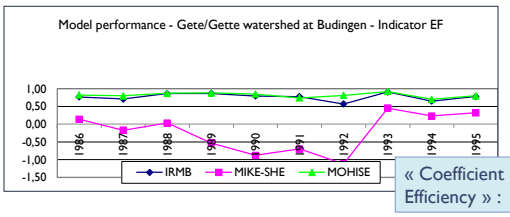
Mean annual discharge
Mean monthly discharge
Statistical criteria (5)
Extreme value (min/max)
Fréchet (min.) and Gumbel (max.) regression
Percentiles 5 and 95 (annual)
Daily hydrographs for the years 1989 and 1995
Piezometric level time series

BV/Modèles	IRMB	MIKE-She	MOHISE
Gette	X	X	X
Geer	-	X	X
Ourthe orientale	X	-	X

MOHISE, MIKE-SHE et IRMB

Performances indicators « outflows » (Calculated over the 365 annual values, 1986-1995)

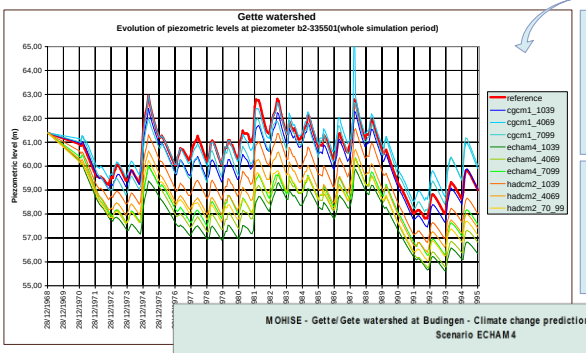
MOHISE is the only Model which runs on the 3 basins



« Coefficient of Efficiency » : EF → 1.

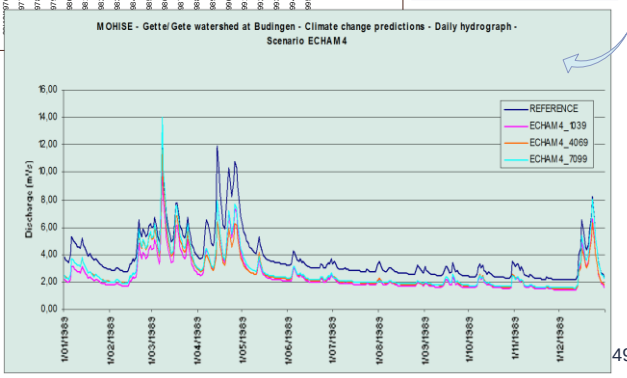
Simulations

Integrated Results: Climate Change impacts



H Piezo
GETTE weel B2-335501
1968-1995
- Reference
- 3 Scenarios
- 3 periods

Outflow GETTE 1989 at Budingen
- Reference
- ECHAM4
- 3 periods



Applications

How to improve Quality integrated modelling

Observation

- The previous integrated Mohise model concern Quantity
- Due to the large amount of needed data, involved parameters, heterogeneous domains, uncertainties, differences between major prevailing processes, … Integrated Quality models difficult to developed
- Cal/Val as well

→ Pragmatic method (external coupling)

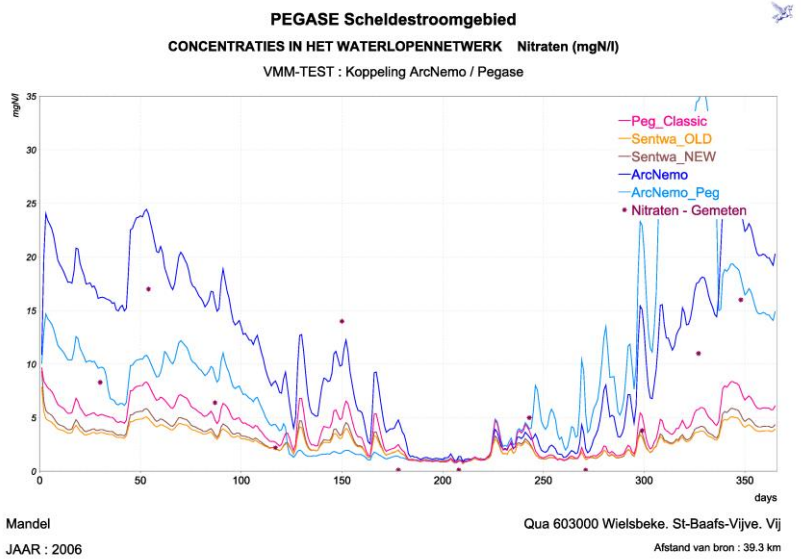
Pegase already coupled with

- SENTWA, Arcnemo (Flanders, Scheldt, Meuse, Yearly and Monthly values)
- Stics/Modcou (Seine-Normandie, yearly values)
- Swat (Oued Joumine, Tunisia, yearly, monthly and daily values)
- Epic …
- Pirene Project …

Applications

Quality integrated modelling : Sentwa/Arcnemo

Yearly and monthly values
Annual NO3 Concentrations
Different diffuse load calculations



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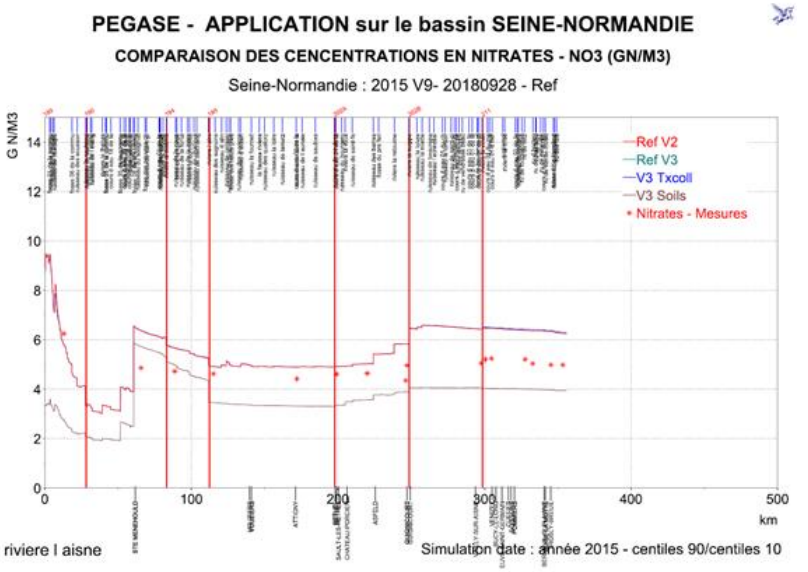
Applications

Quality integrated modelling : Stics/Modcou

Yearly values
P90 For NO3 Concentrations
Different diffuse load calculations



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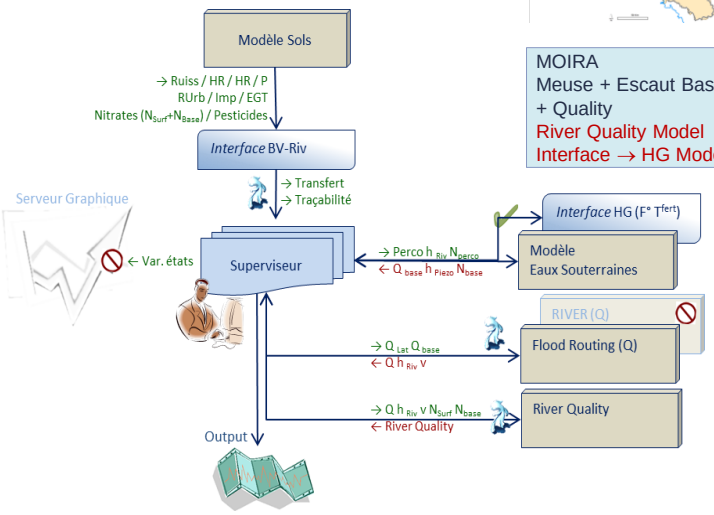
Applications

PIRENE Project (MOIRA Model)

"Modèle hydrologique intégré pour les ressources aquatiques" (Integrated Hydrological Model for aquatic resources)

MOIRA
Meuse + Escaut Basins
+ Quality
River Quality Model
Interface → HG Model



Ulg (HE-GEOMAC, FUSAG, CEME, HACH, HG-FPMS) ← Région wallonne

Applications

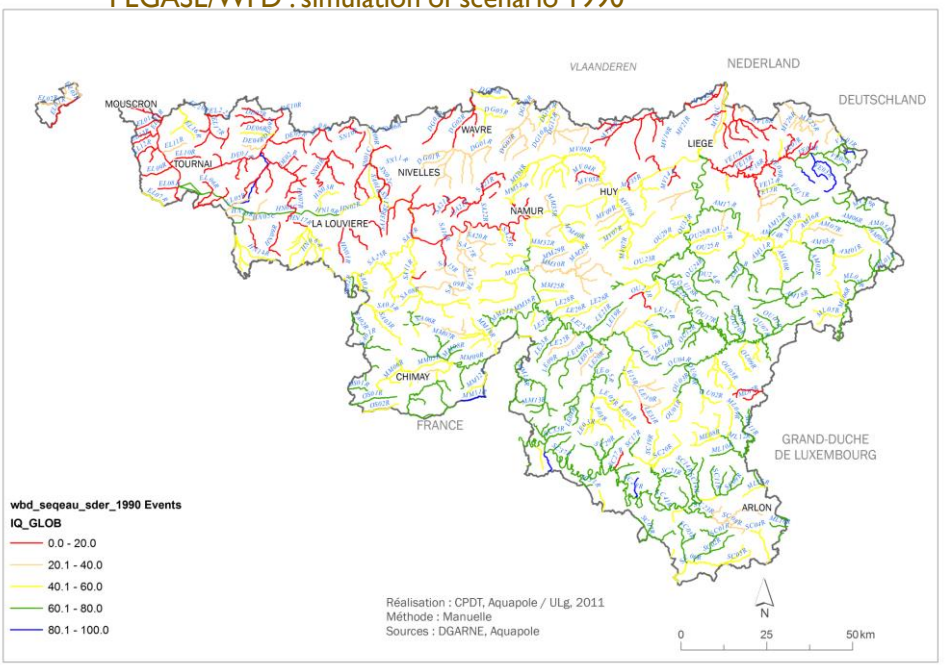
How to improve Diffuse Loads

Improvements

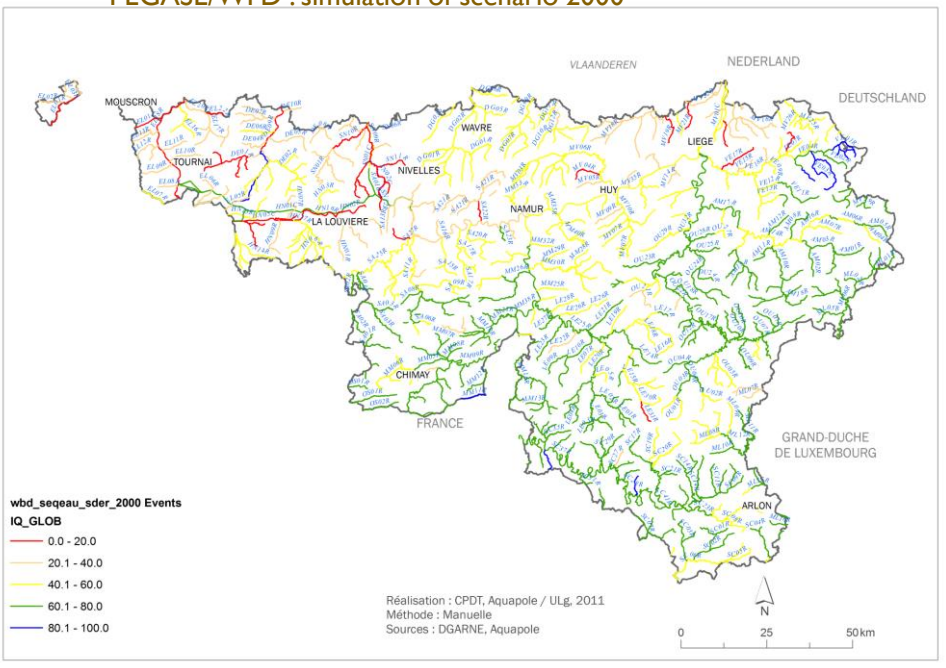
- Using regional soil functions
- Calibrated from upstream homogeneous watersheds
- Calibrated by output of other models
- Directly calculated by [internal/External] coupling

And then a few additional results …

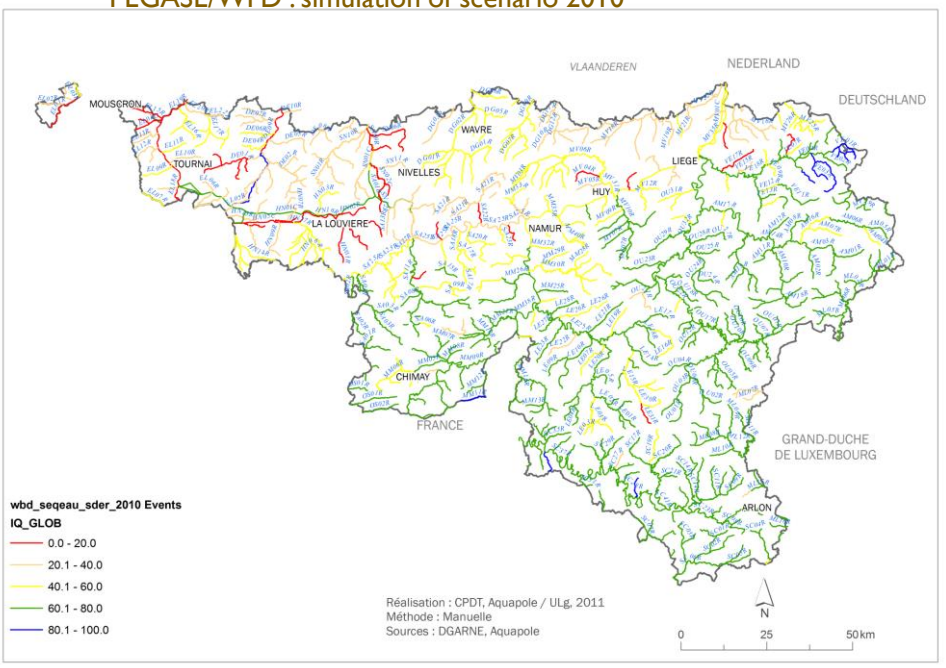
PEGASE/WFD : simulation of scenario 1990



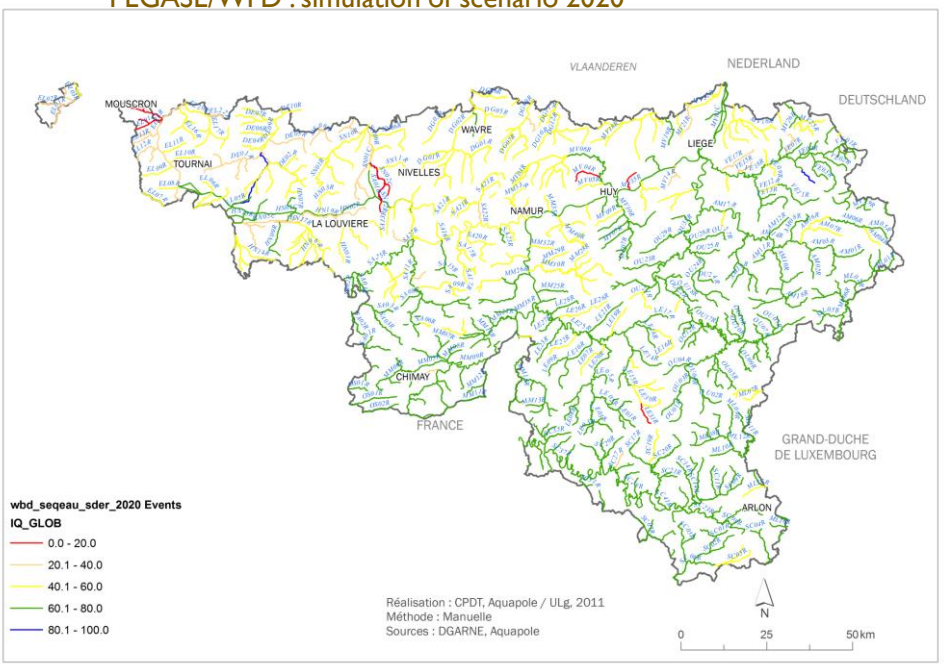
PEGASE/WFD : simulation of scenario 2000



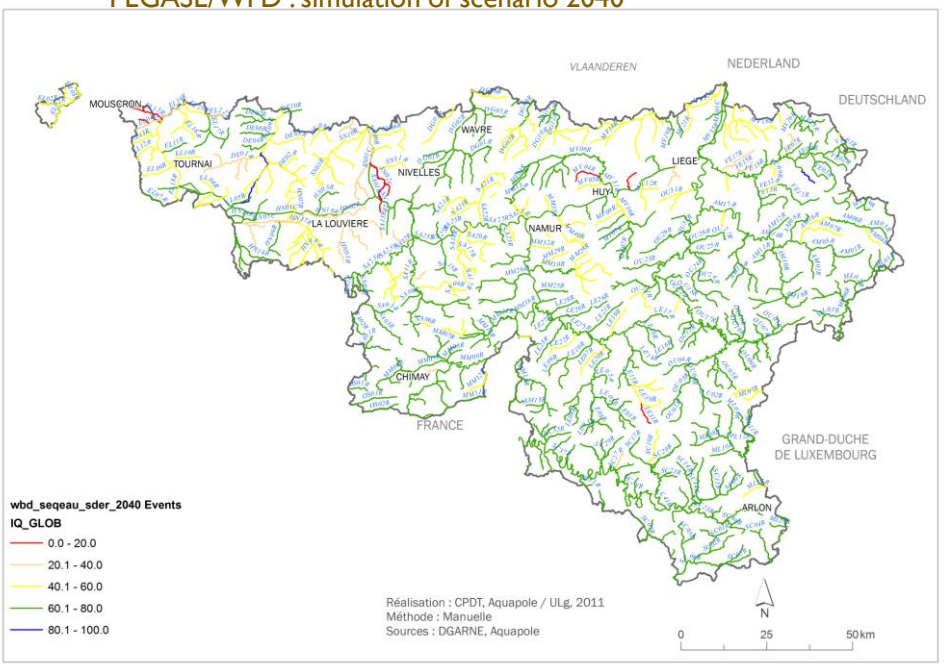
PEGASE/WFD : simulation of scenario 2010



PEGASE/WFD : simulation of scenario 2020



PEGASE/WFD : simulation of scenario 2040



Conclusions

PegOpera Software Suite

PEGASE allows assessing the physico-chemical quality of surface water bodies [thanks to the validation process]

It allows assessing the impact of the releases [on the WB Quality status]

It allows building scenario to estimate the expected status of the WB

It allows setting up the programs of WFD measures

⇨
- Reinforcement of the Monitoring system by providing additional information (spatially and temporally)
- Structuration of the knowledge (numerical database building)
- Tool in establishing the priorities of the intervention programs of the Administrations (selectivity of operations)
- Support to the development of the state of the art [Also at District Level, national or international (Meuse, Scheldt, Mosel, …)]

⇨ The PegOpera Software Suite is relevant in the Framework of the European WFD

Conclusions

Thanks for your attention

Source : Erik Johansson, 2017

Conclusions

Acknowledgements

- La Direction Générale Opérationnelle de l'Agriculture, des Ressources naturelles et de l'Environnement (DGARNE, DGO3) du Service Public de Wallonie (http://spw.wallonie.be/?q=dgo3)
- La Politique Scientifique Fédérale (http://www.belspo.be/)
- Le Service d'Études Hydrologiques (SETHY), Direction Générale Opérationnelle de la Mobilité et des Voies Hydrauliques (DGO2) du Service Public de Wallonie
- (http://voies-hydrauliques.wallonie.be/opencms/opencms/fr/index.html)
- Electrabel SA et son Centre de Recherches Laborelec
- (https://www.electrabel.be/fr/particulier/energique/article?article=laborelec)
- L'Agence de l'Eau Rhin-Meuse (http://www.eau-rhin-meuse.fr/)
- Fondation IBM International (http://www.research.ibm.com/)
- L'Agence de l'Eau Artois-Picardie (http://www.eau-artois-picardie.fr/)
- Le programme LIFE Européen (http://ec.europa.eu/environment/life/)
- Le programme FEDER de l'Union Européenne ((http://europe.wallonie.be/)
- La Vlaamse MilieuMaatschappij (http://www.vmm.be/)
- L'Administration de la Gestion de l'Eau du Grand-Duché du Luxembourg (http://www.eau.public.lu/)
- La Province du Luxembourg (http://www.province.luxembourg.be/fr)
- Waterboard Roer & Overmaas (http://www.overmaas.nl/algemene_onderdelen/english)
- Belgische Provincie van Limburg (http://www.limburg.be/)
- Nederlandse Provincie van Limburg (http://www.limburg.nl/)
- L'Union Européenne, UE (http://europa.eu/)
- L'Association Intercommunale pour la Protection et la Valorisation de l'Environnement en province de Luxembourg (http://www.aive.be/)
- L'Agence de l'Eau Loire-Bretagne (http://www.eau-loire-bretagne.fr/)
- L'Agence de l'Eau Adour-Garonne (http://www.eau-adour-garonne.fr/fr/index.html)
- L'INERIS, Institut National de l'EnviRonnement Industriel et des RisqueS (www.ineris.fr)
- WBI, Wallonie-Bruxelles International (www.wbi.be/)
- Le plan Marshall du Gouvernement Wallon (http://planmarshall2vert.wallonie.be/)
- Le Programme Européen InterReg (http://www.interreg-fwvl.eu/fr/index.php)