Université de Liège

Projet Interreg IVB Amice

AC6 : Methodology for the hydraulic simulation of the Meuse from spring to mouth

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I. INTRODUCTION

Hydraulic modelling is necessary for the identification of future consequences of floods and low-flows. Models already exist in the countries and regions of river Meuse. Presently, each hydraulic model is based either on the outputs of rainfall-runoff models or on statistical hydrological data. The hydraulic models along the Meuse do not use the flow rates or water levels from upstream or downstream models. Therefore, Action 6 of the Amice Project works on ensuring the compatibility of these models and will perform the first international run of hydraulic models on river Meuse.

Based on a comprehensive synthesis of the main characteristics of available hydraulic data and models throughout the international course of river Meuse (section II), a methodology has been set up for the comparisons, the exchange of outputs, and the hydraulic run itself (section III). This document is a refined description of the methodology already discussed with the Amice partners during a meeting in Metz on 11 March 2010.

While elaborating the methodology, attention has been paid to take benefit as much as possible of existing modelling procedures in each country and region, while fitting in with the timetable of the Amice project.

II. AVAILABLE DATA AND MODELS: A SYNTHESIS

At the beginning of February 2010, a questionnaire was sent to all partners acting in this part of AC6. It consisted in 11 questions addressing issues such as models available in each country and region, commonly used hydrological variables, reaches covered by hydraulic modelling and considered gauging stations. This section provides a summary of the main results collected, while further details are given in appendix.

In the sake of conciseness, the following abbreviations have been used to refer to involved countries and regions: F (France), W (Wallonia), FL (Flanders), NL (The Netherlands) and GE (Germany).

II.1 Available models

For the main river bed, all models solve the Saint-Venant equations (1D) or the shallow water equations (2D). The models used are 1D in F, FL and NL, whereas GE uses a coupled 1D-2D approach and W a full 2D model. The floodplains are represented differently depending on the region: F and FL use storage cells/compartments, NL use cross sections, while 2D modelling is used in W and GE.

Unsteady simulations are performed in F, FL and NL, using hydrographs as upstream boundary conditions. In contrast, W and GE run steady simulations. This difference in modelling approaches is substantiated by differences in the Meuse catchment topography, such as narrow and steep valleys in the Ardennes, compared to wider and flatter floodplains in other areas. The resulting storage capacity of the floodplains is of course far more limited in the former case compared to the later [1].

Although other friction formulae are also available in several models (W, GE, NL), Manning formula is exploited in all of them.

II.2 Topographic data

All hydraulic models represent both the main course of the river and the floodplain topography. Types of available topographic data extend from simple cross sections to detailed Digital Elevation Models (DEM) in the floodplains and, to some extent, in the main riverbed.

In brief, following data are used to describe the main river bed:

F: DEM (resolution: 5x5 m)

W: sonar bathymetry (resolution: 5x5 m, original data 1x1m)

FL: cross sections every 100m

NL: DEM (resolution: 5x5 m)

GE: cross sections every 100m

On the other hand, the floodplains are described as follows:

F: DEM (resolution unknown)

W: laser DEM (resolution: 5x5 m, original data 1x1m)

FL: laser DEM (resolution: 5x5 m) and photogrammetry

NL: laser DEM (resolution: 50x50 m)

GE: laser DEM (resolution: 5x5 m, 2x2m in the future)

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II.3 Covered reaches

The course of river Meuse is almost completely covered by existing hydraulic models, from Neufchâteau (upstream end of the French model) down to Keizers Veer close to the north sea (downstream end of the Dutch model). The German model is run on river Rur, a tributary flowing into river Meuse in Roermond.

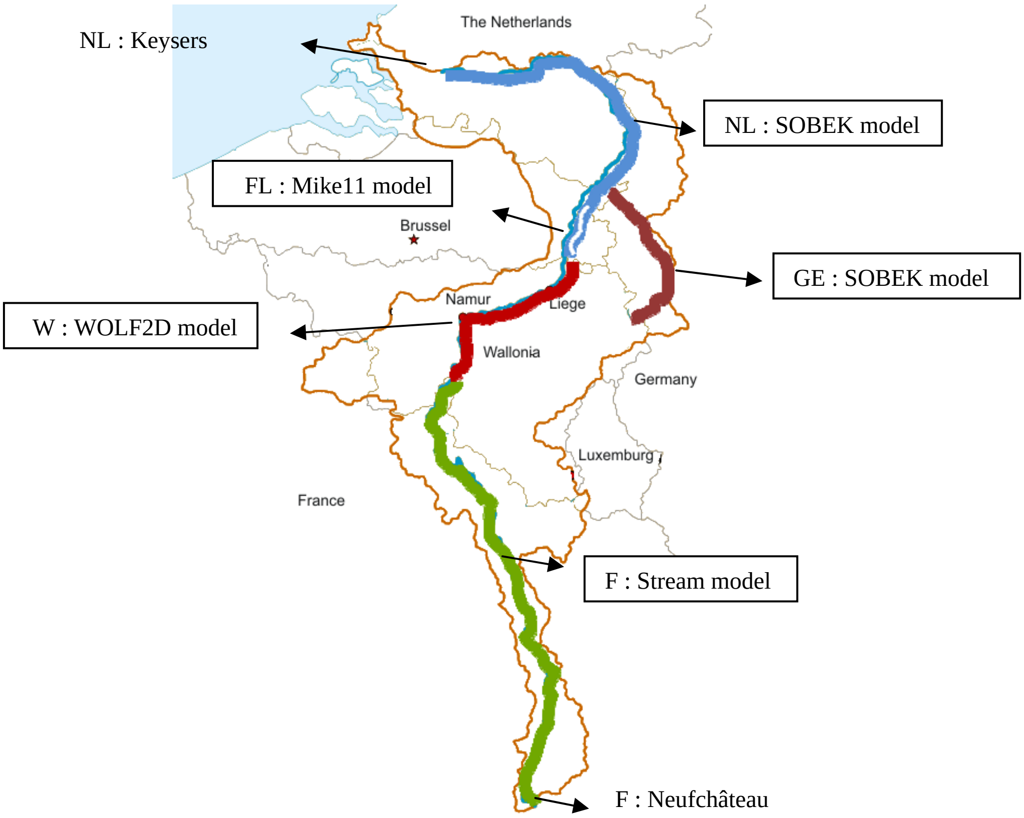

Figure II-1 : Covered reaches and corresponding hydraulic models.

II.4 Hydrological data and statistics

The main gauging stations used to collect time series of flow rates are listed in Figure II-2. All stations have recorded historical data extending over a period ranging between 25 and 50 years, except Borgharen where the Meuse discharge has been recorded for 100 years. These time series are the basis for calculating upstream boundary conditions for the hydraulic simulations, either in the form of statistical values or through the shape of the inflow hydrograph when needed.

In Amice, the discharge for a return period of 100 years, calculated from maximum annual hourly discharges (Q_{100}), was selected as the consensus reference hydrological variable for high flows, as mentioned in AC3 meeting reports (meeting in Metz on 3 September 2009) and in the end report of Ac3.

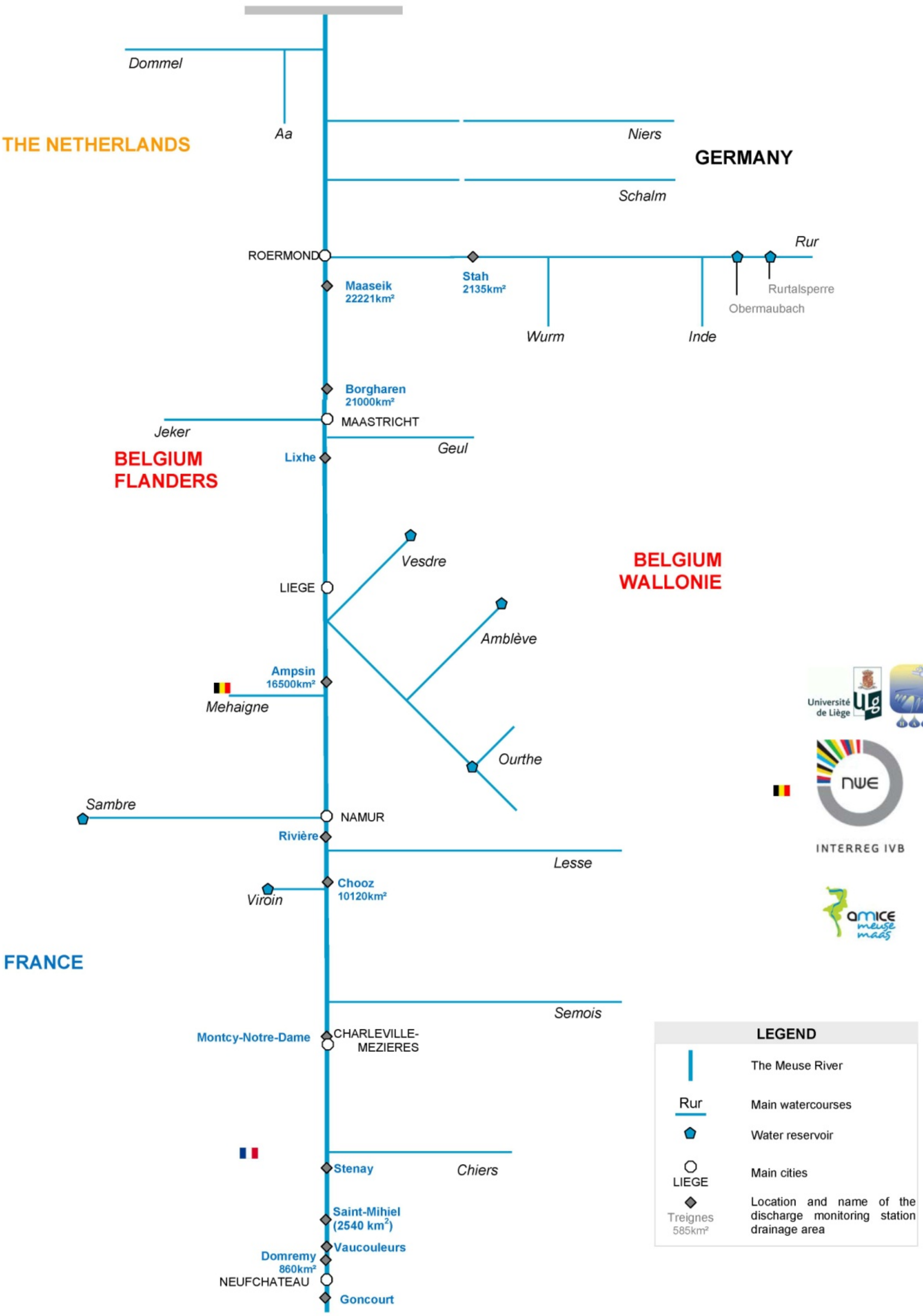

Figure II-2 : Main gauging stations along river Meuse and Rur.

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The Q_{100} value at each border and the shape of the hydrograph prescribed in current unsteady models are summarized below:

- In F, the shape of the hydrograph is based on the 1995 flood. The peak value in Chooz is 1650 m³/s.
- In W, the discharge is steady and it is raised after the 3 main tributaries. Q_{100} value in Chooz is 1645 m³/s, 2005 m³/s between the Lesse and the Sambre, 2328 m³/s between the Sambre and the Ourthe, 3184 m³/s between the Ourthe and Lixhe.
- In NL, the shape of the hydrograph is based on the regression of river stage measurements. The Q_{100} peak value in Lixhe is 3109 m³/s.
- In FL, the hydrograph is bell-shaped. The Q_{100} peak value in Maaseik is 3550 m³/s.
- In GE, steady discharge is assumed and the Q_{100} value in Stah is 176 m³/s.

Hence, measured and statistical discharges at borders are found to differ by no more than 2 to 3% at Lixhe and less than 1 % at Chooz.

Besides, all models handle inflows from tributaries and, in all of them, free surface elevation can be prescribed as a downstream boundary condition using stage-discharge relationships.

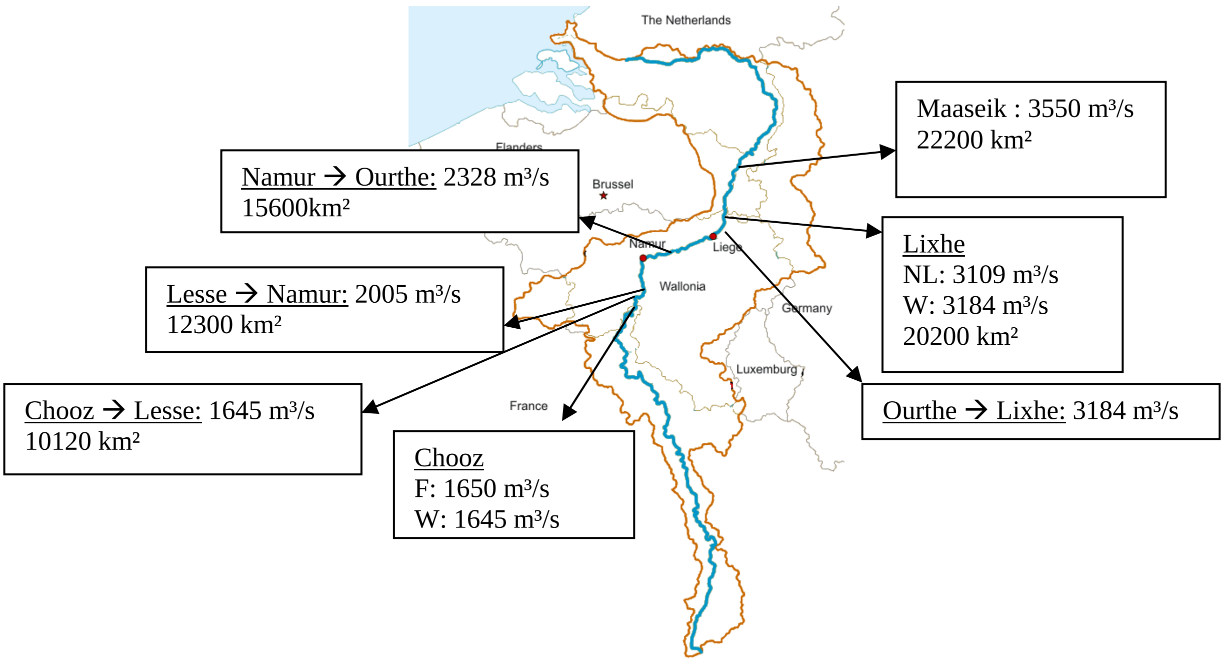

Figure II-3: Q_{100} discharge and catchment area for each considered reach of the Meuse.

III. COMMON METHODOLOGY FOR HYDRAULIC MODELLING

The questionnaire has shown that existing models cover nearly the whole Meuse from spring to mouth. It has also revealed the numerous similarities between the hydraulic models used in the Meuse catchment, whereas a key difference remains between steady and unsteady modelling approaches. Therefore, a procedure is defined hereafter to combine the existing models, accounting for the need to interconnect data and results from both steady and unsteady models and to ensure continuity of the water levels at borders.

III.1 Necessary boundary conditions

The set of mathematical equations solved by the models requires suitable boundary conditions (BC) for the flows in river Meuse (usually subcritical) to be properly simulated. Discharge is generally prescribed as upstream BC, either in the form of a steady value or as an inflow hydrograph, while water depth or free surface level is prescribed as downstream BC.

These BC are given by measured data or scenarios at the outer limits of the simulation, i.e. in Neufchâteau (discharge) and at Keysers Veer (water level). All other BC depend on the results of the other models. As an example the discharge in Chooz for the W model should be given by the discharge computed by the F model. The water level for the F model at Chooz should depend on the water depth computed there by the W model. The same applies at Lixhe for the W and the FL, NL models as well as in Roermond for the NL and GE models.

III.2 Steady or unsteady simulations?

F, FL and NL models are unsteady and use thus hydrographs as upstream BC, while the B and GE models are run in a steady mode. The common methodology to be followed in AC6 accommodates this difference in modelling procedures. Indeed, both a full steady and a full unsteady simulation would neither be feasible nor provide optimal results in the framework of AMICE.

A fully unsteady simulation procedure would imply that all computational models are linked and run simultaneously in order to transfer continuously the boundary data (water level and discharge) from one model to the next. Such coupling of the models is out of the scope of AC6. In addition, this approach would lead to the following additional drawbacks:

(i) Unnecessary unsteady modelling in parts of W, where storage capacity of the floodplains is low. As a consequence of this low storage capacity, Figure III-1

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demonstrates for the flood of 2003 that any damping of the hydrograph is produced,

(ii) Difficulty in having the different partners set up and run their models in parallel to use optimally the available time.

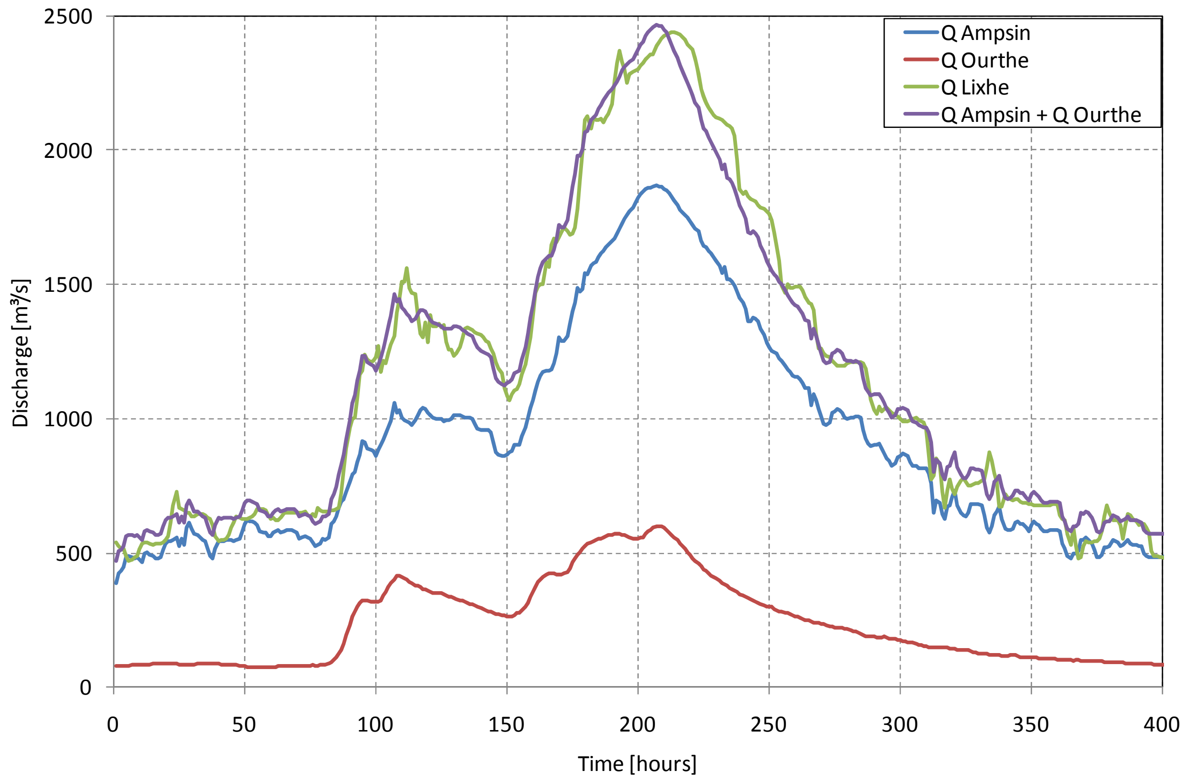

Figure III-1 : Comparison of hydrographs on the downstream part of the Meuse in Wallonia.

Similarly, a full steady approach would not prove satisfactory. It would require inferring discharge values at a number of points along river Meuse and running the models sequentially from downstream towards upstream. The water level in Lixhe would be deduced from the modelling results in NL and FL, and transferred to the W model. Subsequently, the water level computed by the W model would be transferred to the F model at Chooz.

In addition, transient simulations are necessary to represent damping of flood hydrographs in F, FL and NL due to the generally significant storage capacity of floodplains models in these regions. As such, a full steady simulation would also lead to sequential runs of the different models (i.e. NL, FL models first, W, GE model next and finally F model), which would prevent an optimal use of available time.

The common modelling procedure will thus combine unsteady and steady modelling, depending on existing practice in each region and in accordance with the storage capacity of the floodplains, while enabling parallel (instead of sequential) runs of the models and ensuring reasonable continuity of the results at the borders.

III.3 Motivation and overall procedure

Since a purely sequential run of the hydraulic models in the different regions would lead to a suboptimal use of the time available, the common modelling methodology will avoid it by running the models, in a first step, with boundary conditions prescribed from available measured data instead of transferred from one model to the next.

This turns out to be the only feasible approach since hydraulic models for fluvial flow conditions require boundary conditions both at their upstream and their downstream ends. Therefore, running sequentially the models from upstream (spring) towards downstream (mouth) would also fail to satisfactorily transfer the necessary boundary conditions between the different models. Direct coupling of all models was not considered as feasible in Amice.

Therefore, a two-step procedure will be followed here:

1. hydraulic models will first be run in each region separately, based on measured data;
2. next, consistency of the simulation results at the borders between models will be checked, and, if necessary, a second run of (sub-)models will be undertaken accounting for boundary conditions transferred from the adjacent models.

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III.4 Handling boundary conditions

Downstream

Answers to the questionnaires have revealed that high values of historical discharges are present in the recorded data at the gauging stations (3056 m³/s in Lixhe and 1560 m³/s in Chooz during the flood of 1995) as well as at Roermond (NL), Linne (FL) and KeysersVeer (NL). Only limited extrapolation of the corresponding stage-discharge relationships will be needed to provide the necessary boundary conditions (Figure III-2).

At the end of the first run of the models, computed water depths will be compared at the borders of the models. If substantial differences are observed, a second run of the models will be performed to restore the continuity of the free surface across the borders in the final results. This re-run is expected to be limited in spatial extension due to the limited distance along which the boundary conditions have a significant influence on water elevation.

Upstream

Peak discharges during Meuse floods usually last several hours. At the borders, the steady discharge value of the W model will thus be assumed equal to the peak value of the corresponding unsteady model (F, FL or NL). The same holds for the GE and NL models in Roermond.

During AC3, Q_{100} (maximum annual hourly discharge of 100-year return period) was selected as the reference variable for high flows in AMICE. As shown in section II.4, a very satisfactory agreement was found on this reference value at the F-W and W-NL borders.

According to the results of AC3, two perturbation factors (for 2020-2050 and 2070-2100) based on the transnational climate scenario have been identified. These perturbation factors are noted here respectively $PF^{20\text{-}50}$ (+15%) and $PF^{70\text{-}00}$ (+30%). Consistently with AC 3, Q_{100} will be further used as reference value in AC 6 and hydraulic simulations will be conducted for Q_{100} modified by the two perturbations factors $PF^{20\text{-}50}$ and $PF^{70\text{-}00}$ (Figure III-3)[1].

In the case of unsteady models (F, FL, NL), the hydrograph reaching the perturbed peak value will be calculated following the current procedure in each region and country for a Q_{100} hydrograph. Similarly, all models will vary the discharge to account for the main tributaries, in accordance with present practice in each region and country. Attention will be paid to

[1] The Q_{100} discharge at borders is the average of values coming from each country

maintain continuity at the borders (Figure III-4) in order to deliver continuous inundation maps.

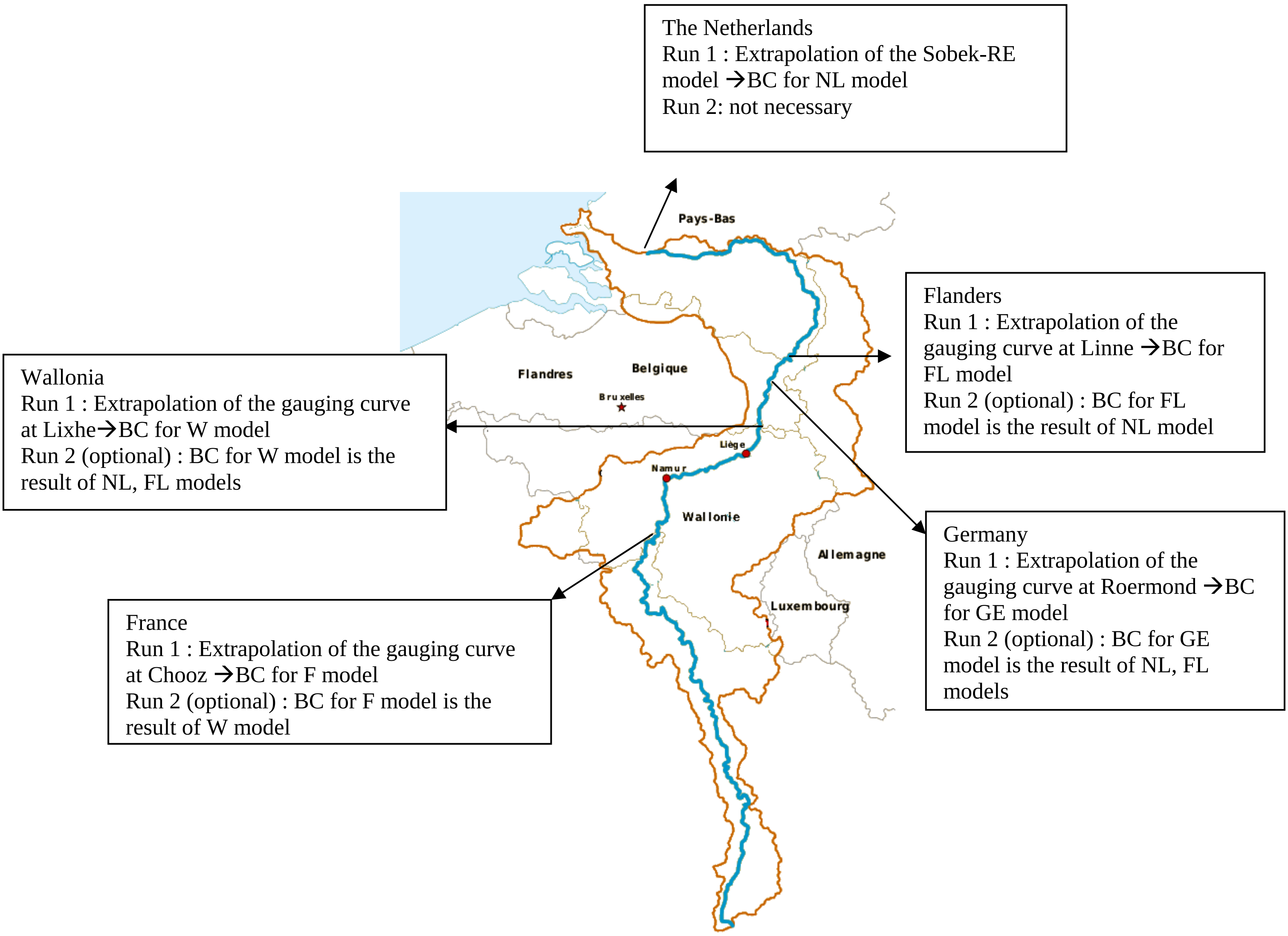


Figure III-2 : Downstream BC for each model

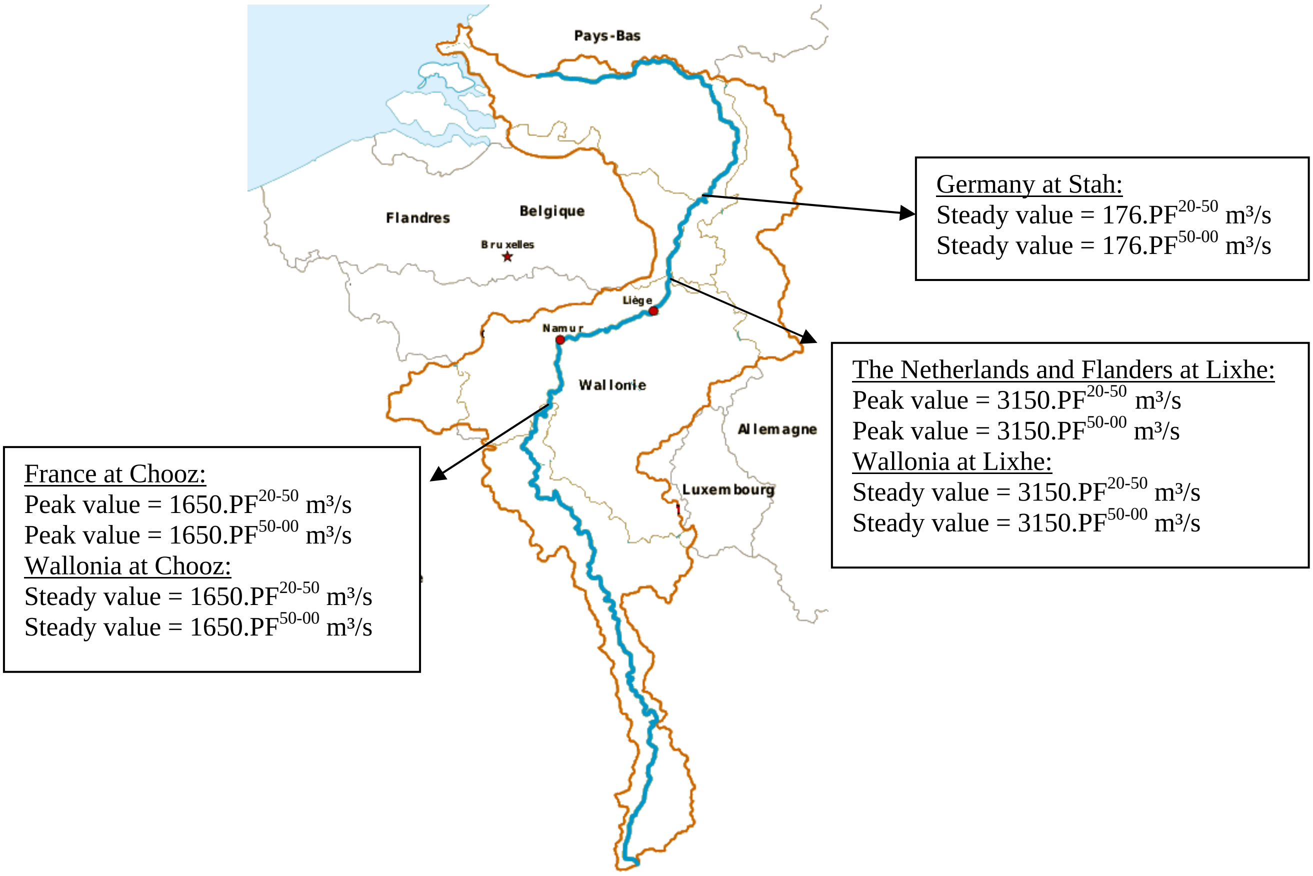


Figure III-3 : Modified 100-year flood discharge at borders

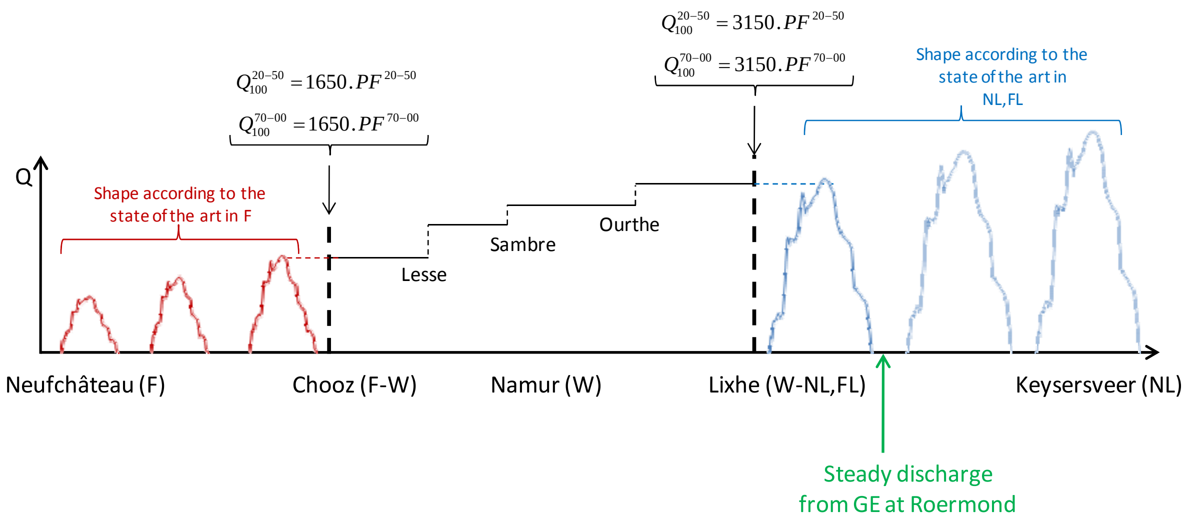


Figure III-4 : Sketch for discharge repartition along the Meuse

III.5 Number of discharge values available for hazard modelling

AC7 needs inundation maps computed for a relatively high number of return periods, while, considering the time available for AC6, hydraulic simulations will be performed for a limited number of modified statistical discharge values.

However, in each region and country, inundation maps already exist for a number (N) of discharges Q_{0i}, corresponding to known return periods in the present situation T_{0i}. Using outcomes of AC3, namely the statistical relationships between return period and discharge for climate change scenarios, these same values of discharge Q_{0i} may be associated to different return periods T_{CCi} accounting for the considered climate change scenario.

As a result, even if a limited number M of discharges are simulated in AC 6 (e.g. $M = 2$: $Q_{100} \times PF^{20\text{-}50}$ and $Q_{100} \times PF^{70\text{-}00}$), they simply provide additional results to be combined with the set of inundation maps already available in each region and country. This whole set of $M + N$ results may be assumed to belong to a new statistical series (corresponding to a given scenario) and, using the results of AC 3, the $M + N$ results can be assigned a modified return period. AC 7 will thus benefit from the whole set of $M + N$ inundation maps to evaluate inundation hazard.

For instance, inundation maps exist in W for at least four different discharge values. Combined with two new results from AC6, a total of six pairs “return-period - inundation map” will eventually be available to conduct risk analysis within AC 7 (Figure III-5).

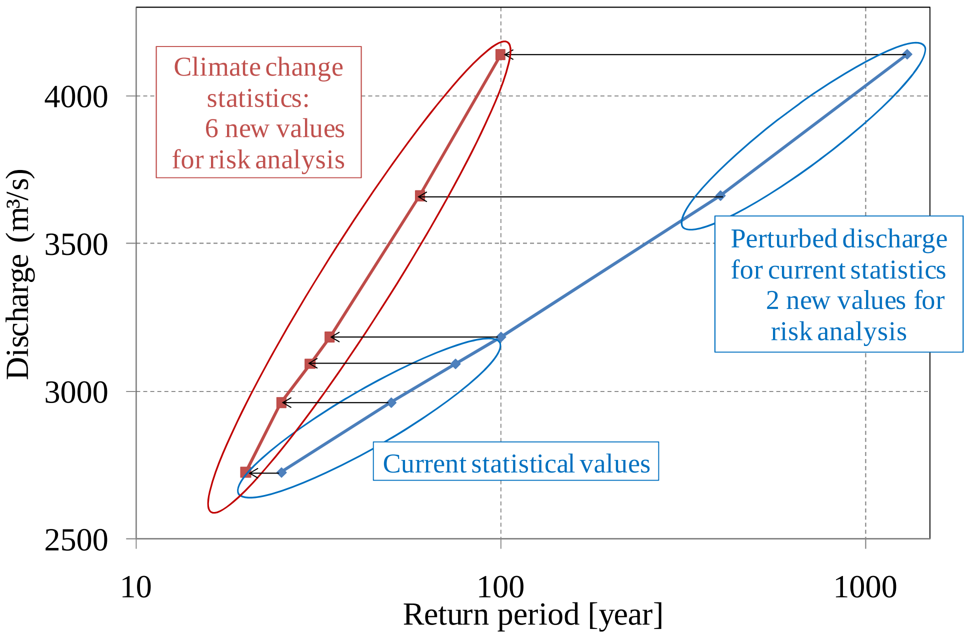


Figure III-5 : Discharge modelled in Amice in the framework of “climate change statistics”

III.6 Time table

May 2010	Decision on perturbation factors from AC3
June 2010	Meeting in Maastricht (AC6, AC7). Discussion and consensus on the methodology for hydraulic modelling
December 2010	Meeting to compare results at borders from the first run of the models
January 2011	If needed, second run of the models with updated boundary conditions
February 2011	Final results of the hydraulic modelling

Feasibility of this timetable must be confirmed (during the meeting in Maastricht) by each partner in accordance with its own resources.

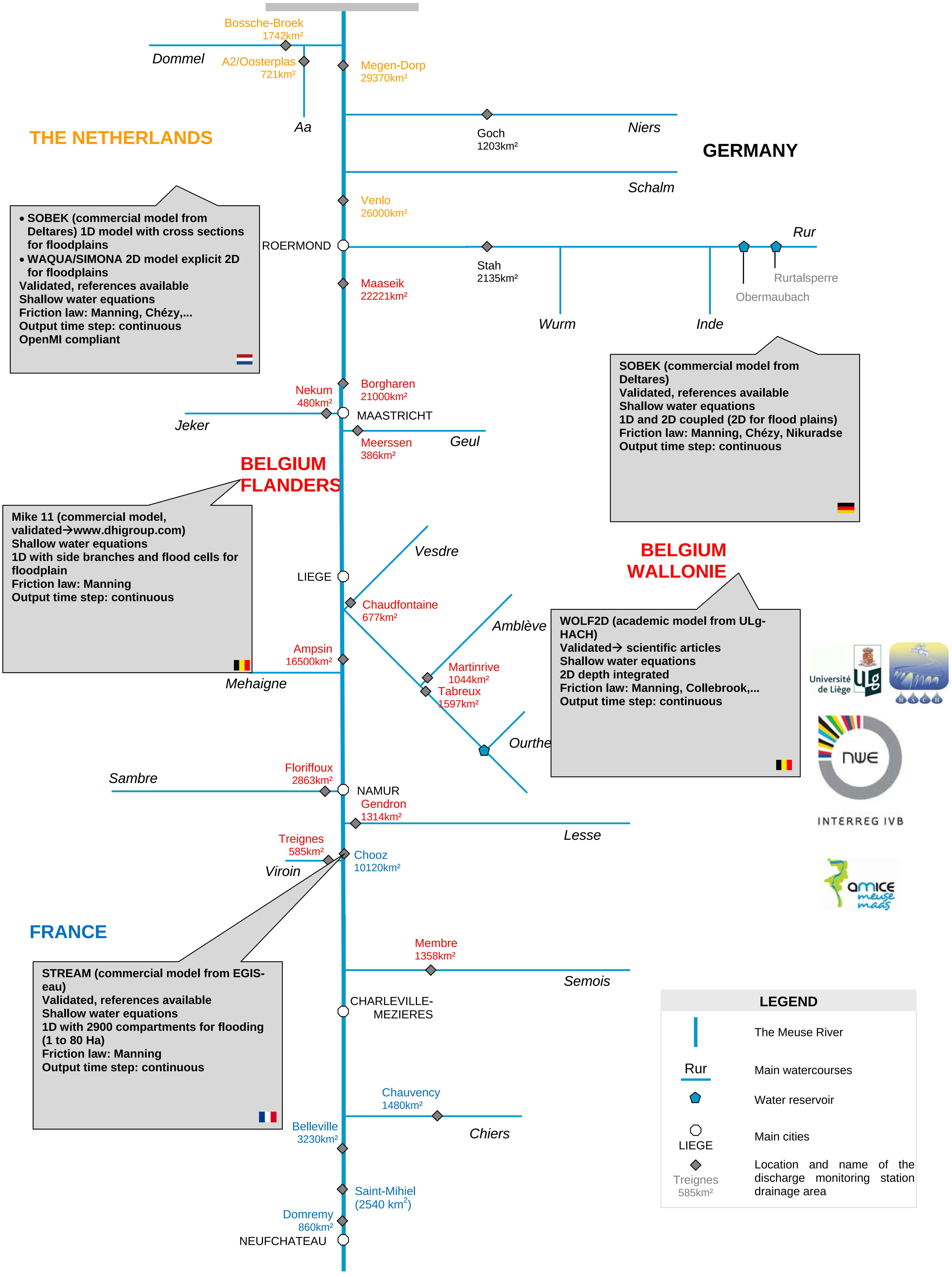
IV. APPENDICES: SYNTHETIC MAPS

1. Hydraulic models
2. Topographic data
3. Covered reaches and validation
4. Gauging stations and statistical laws
5. Q_{100} values and boundary conditions

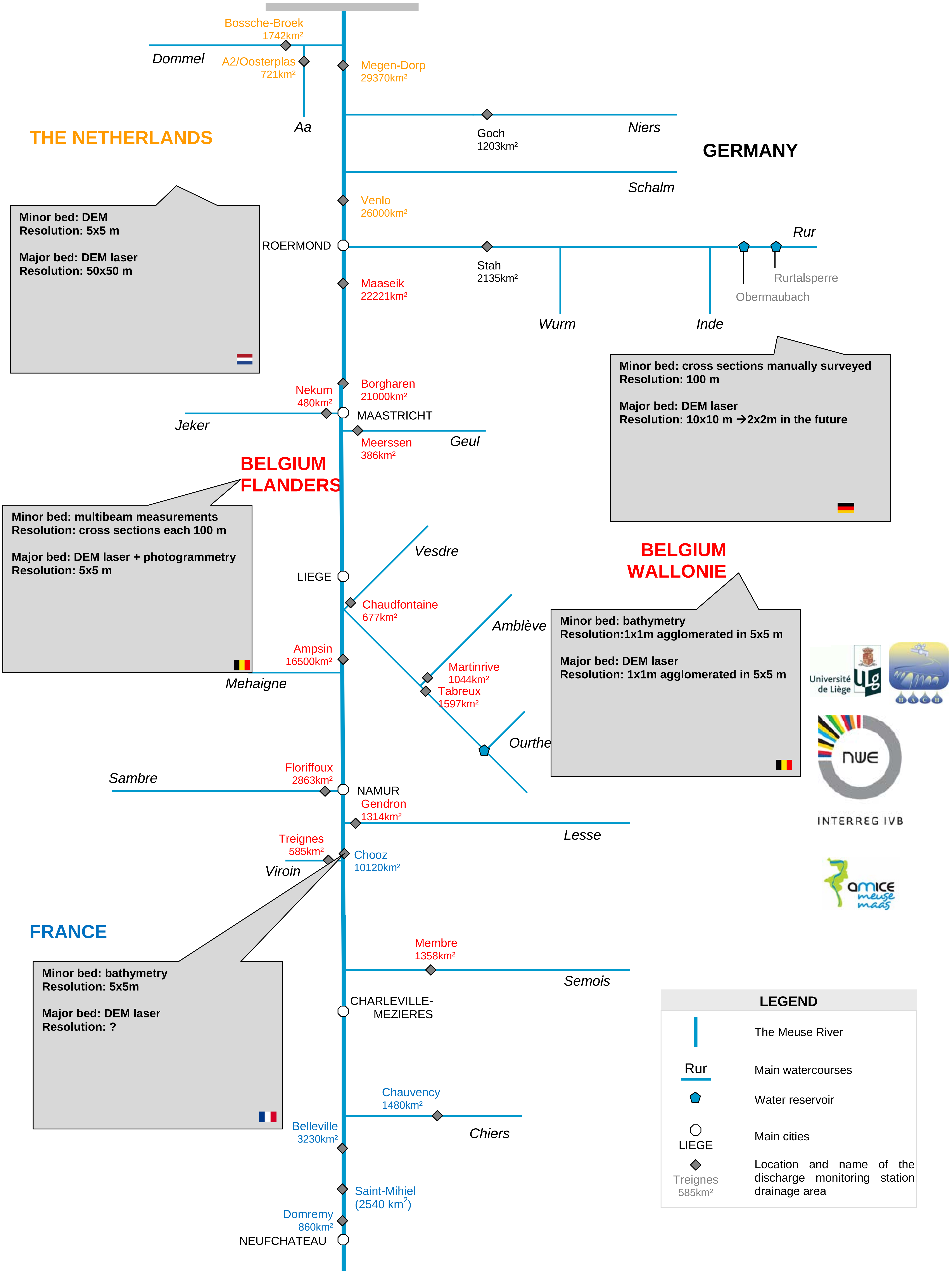
V. REFERENCE

[1] Wit, M. J. M., H. A. Peeters, P. H. Gastaud, P. Dewil, K. Maeghe and J. Baumgart. *Floods in the Meuse basin: event descriptions and an international view on ongoing measures*. Intl. J. River Basin Management, 5(4). 279-292, 2007.

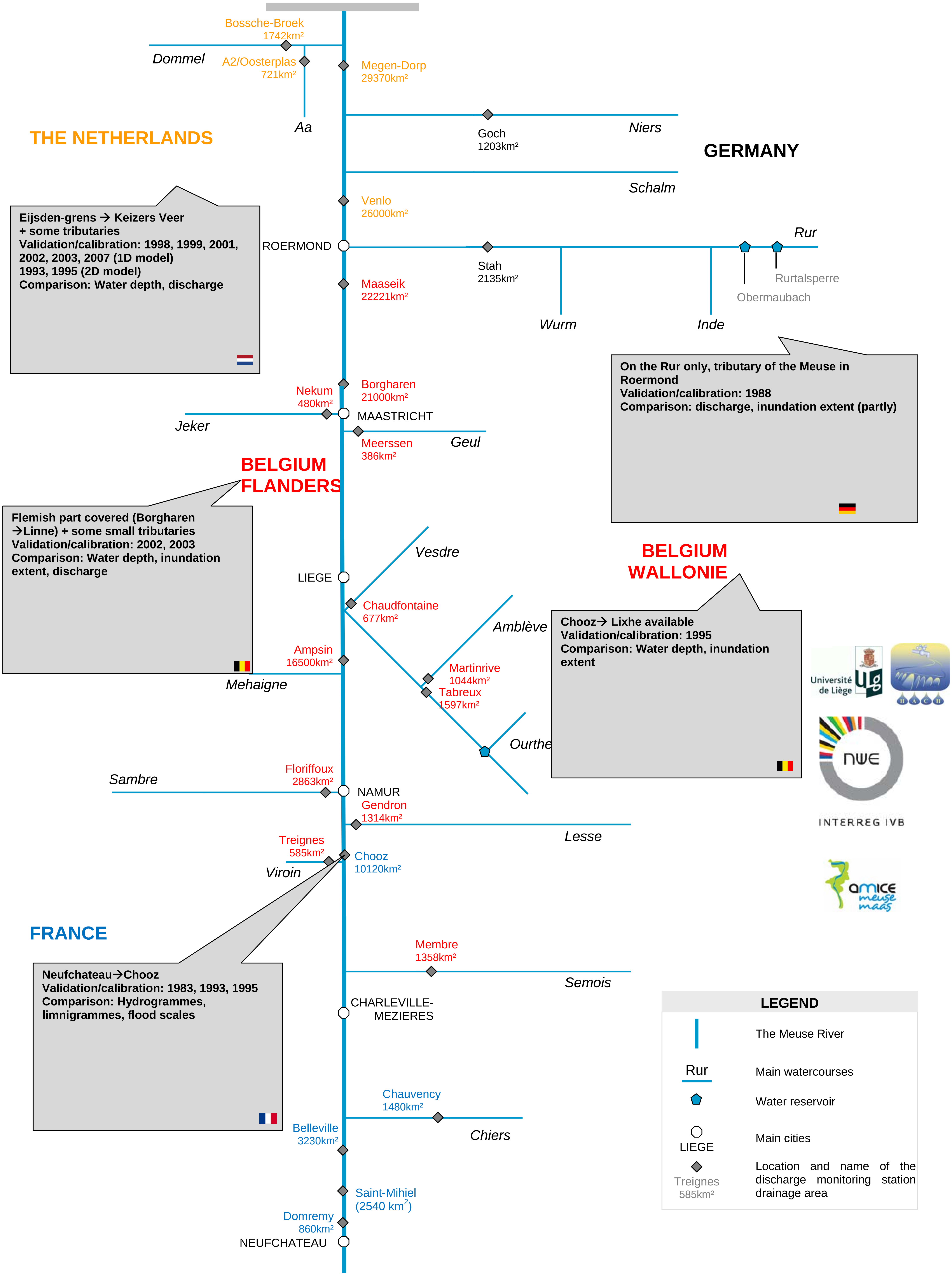
SYNTHESIS OF HYDRAULIC MODELS



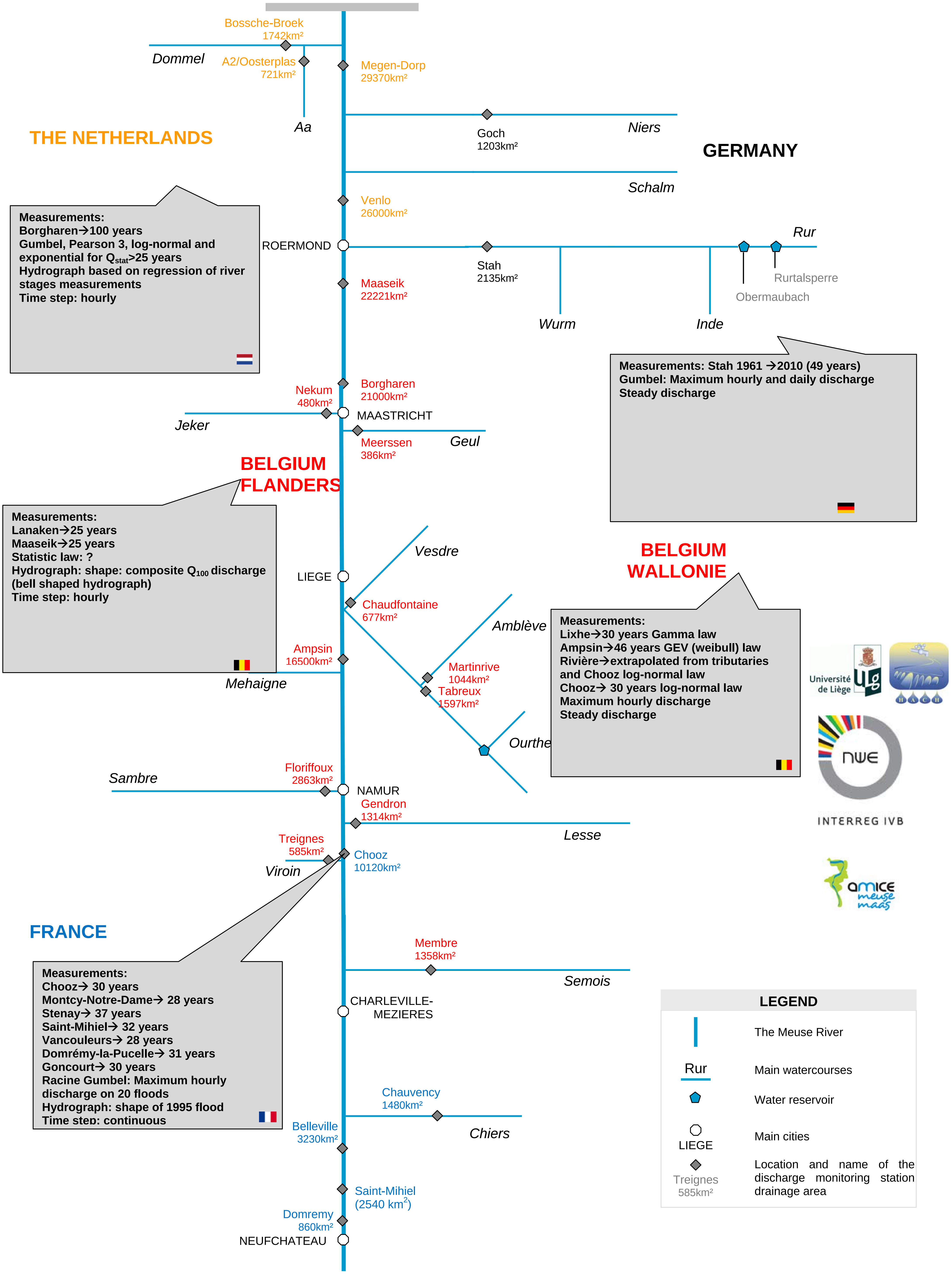
SYNTHESIS OF TOPOGRAPHIC DATA



SYNTHESIS OF VALIDATION/CALIBRATION, REACHES COVERED



SYNTHESIS OF MEASUREMENTS, STATISTICAL LAWS



SYNTHESIS Q_{100} VALUES AND BOUNDARY CONDITIONS