

# GESS



## Stochastic Synthetic Streamflow Generator

### Overview

Stochastic models are often fitted to historical time series of river flows in order to produce Synthetic Streamflow Scenarios - SSS. These SSS are used as input data for simulation/optimisation models that support operational decisions for water or energy systems.

The SSS are sampled from probability distributions conditioned to the available information, such as recent streamflows and recent measurements of macroclimatic variables, such as sea surface temperature - often associated with the occurrence of El Niño or La Niña events that, in turn, are correlated with lower or higher than average streamflows.

GESS adopts an auto-regressive model and uses “El Niño information” to refine the parameter estimation process for each time step. Univariate or multivariate SSS produced by GESS can be used directly by SDDP. GESS has also been integrated with river basin management systems.

GESS has the “telescopic” feature, which allows the production of coherent SSS with different time steps. For example: daily SSS for the immediate future, weekly SSS for the next few months and monthly SSS for the longer term.

GESS has a user friendly graphical interface that controls a database that manages the study cases. There are two main functions:

- production of synthetic streamflow scenarios;
- forecast analysis - comparison of the SSS with the actually observed time series.

For the second function, various statistical tests are calculated in order to verify the quality of the SSS in a user friendly environment with the automatic preparation of graphics in Excel for the selected statistics.

## Methodology and modelling

Fig.1 illustrates the overall functionality of GESS. From the historic time series of streamflows, GESS selects the appropriate model, estimates the parameters for the selected model and generate SSS that can be used in simulation / optimisation systems. Finally, there is a verification module where statistics of interest are compared from the SSS and the historic.

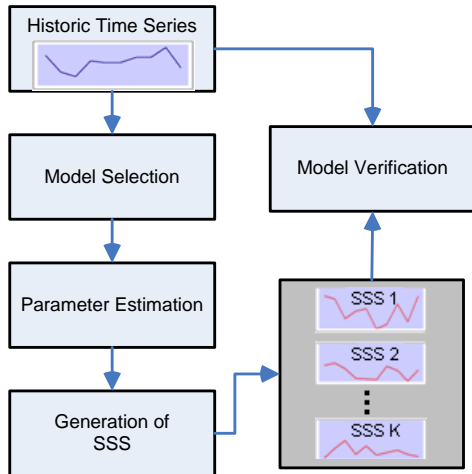


Fig. 1: GESS Methodology Overview

GESS applies a periodic autoregressive model – PAR(p) for each hydrological station in each stage (month or week) in order to reproduce the serial correlation of streamflows. In this model, the SSS of a station in period  $t$  are given by a linear combination of the past streamflows plus a random innovation  $\varepsilon_t$ , as shown next:

$$Z_t = \phi_1 Z_{t-1} + \phi_2 Z_{t-2} + \dots + \phi_p Z_{t-p} + \varepsilon_t \quad (1)$$

Where values  $Z_{t-k}$ ,  $k=0, \dots, p$ , are the standardised (mean 0, unit variance) streamflows  $Q_t$ , given by:

$$Z_{t-k} = [Q_{t-k} - \mu_{s(t-k)}] / \sigma_{s(t-k)} \quad (2)$$

And  $\mu_{s(t-k)}$  and  $\sigma_{s(t-k)}$  are the mean and standard deviation values of the streamflows in stage  $s(t-k)$ , respectively.

Thus, in each stage, parameters  $\phi_k$ ,  $k=1, \dots, p$  are estimated from the historical time series such that the squared sum of the residuals  $\varepsilon_t^T \varepsilon_t$  is minimum.

The order  $p$  of the PAR(p) model is either selected by the user or automatically determined based on statistical tests for the independence of the residuals.

When considering the effects of climatic events, such as *El Niño*, to further condition the SSS, GESS *weights* the different years of the historic streamflows in proportion to the similitude of the current selected macroclimatic conditions with the corresponding condition of each year of the historic time series. In this approach, the parameters vector  $\phi$  is calculated as:

$$\phi = (X'WX)^{-1} (X'WY) \quad (3)$$

Where  $W$  is the diagonal weight matrix,  $X$  is a matrix whose columns  $k$  are the historical streamflows of stage  $t-k$ , and  $Y$  is a vector with the historical streamflows of stage  $t$ .

The cross correlation between streamflows of different hydro stations is obtained by the calculation of a *load* matrix  $L$ , such that when applied to a vector of *uncorrelated* random values, produces a vector of values which reproduce the cross correlation observed in the historic time series.

When producing the SSS, GESS:

- samples an innovation vector  $v_t$
- multiplies this vector by a load matrix  $L$ , obtaining a vector of cross-correlated innovations  $\xi_t$
- uses the PAR(p) model (1) in each hydro station, using  $\xi_t$  in place of  $\varepsilon_t$ . The parameters of the PAR(p) model are determined from (3)
- uses (2) to obtain streamflow  $Q_t$  from  $Z_t$
- Update the past conditions based on the recently generated stream flow.

Repeats (a)-(e) for the different scenarios and moves on to the next period  $t+1$ .

## Model Input and Output

### Input

- Historical time series, in monthly and weekly time steps. Daily inflows needed if the telescopic option is used.

- Historical climate data (such as IOS, SST, Nino3+4, and others) in either monthly or weekly time steps
- Mean production factor of the set of hydro power plants associated with the hydrological station for which SSS will be produced, enabling the calculation of the equivalent energy inflow to the system

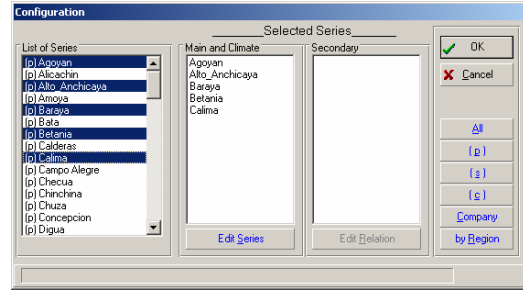


Fig. 4: Selection of hydrological stations

**Output**

- Synthetic streamflow scenarios in three different formats: Excel, (Plain/ ASCII) files and SDDP external format
- Statistical tests in Excel based-macros that measure the overall quality of the synthetic inflow scenarios

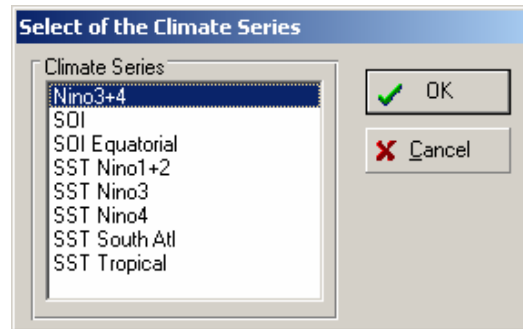


Fig. 5: Selection of macroclimatic variables

**Graphical User Interface**

GESS has a user friendly interface designed to control the parameters of the hydrological studies, as shown in Figs. 2-6.

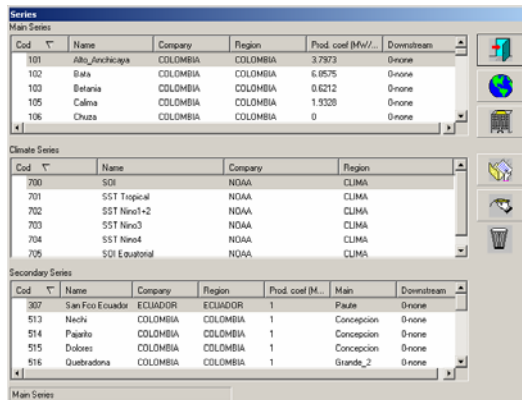


Fig. 2: Database of hydrological stations and macro-climatic series

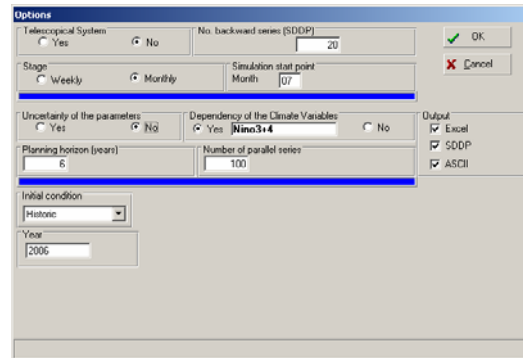


Fig. 6: Selection of the study parameters

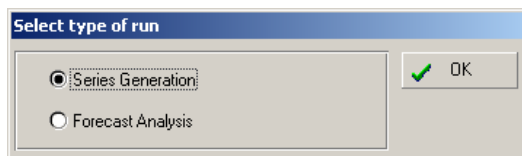


Fig. 3: Selection of type of run

**Integration with external models**

GESS produces SSS that can be directly used by SDDP. It has also been integrated with a general river basin management system which is in use for operating hydro power plants and pumping units in the Paraiiba do Sul river basin (Brazil).

GESS has also been integrated with external systems - not developed by PSR - such as one in use by the water and sanitation company of São Paulo.

GESS has been integrated by Studio PSR, as shown next.

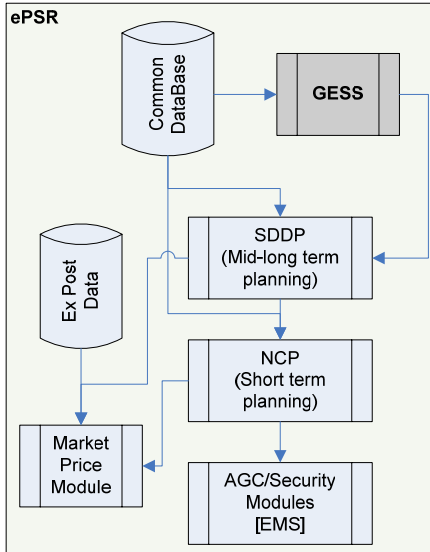


Fig. 7: GESS integrated in ePSR

### Applications of the model

GESS is currently used by the energy planning state authority of Colombia (UPME) as an input to SDDP in long term studies. GESS is also used by utilities in Colombia, such as ISA and ISAGEN. The dispatch centre of Ecuador (Cenace) uses GESS with SDDP integrated by the Studio PSR framework (Figure 7).

### Example Case Study

GESS has been used to estimate the probability of droughts in Colombia caused by El Niño events [Kelman, J.; Vieira, A. M.; Rodriguez Amaya, J. E. - *El Niño influence on streamflow forecasting*. Stochastic Hydrology and Hydraulics, vol. 14, n. 2, 2000]

Fig. 8 shows the cumulative distribution function (CDF) for the total energy inflow to Colombia for Sept.1997– Feb 1998 (dry sequence in Colombia due to El Niño). These CDFs were constructed based on a 1000 SSS produced by GESS, with and without the use of climatic information.

Figs. 8 and 9 show the percentiles of the sample of synthetic energy inflows produced by GESS for the Colombia system during the months of the 1997 El Niño event, with and without the use of climatic variables, as well as the historic values.

Fig. 10 shows that the probability of occurrence of what actually became reality would be close to zero, according to the CDF of total energy inflow derived from 1000 scenarios produced without climatic information. In the context of hypothesis testing, this would be a sufficient condition for rejecting this set of scenarios. On the other hand, the same probability would be close to 0.30, a very reasonable value, according to the CDF derived from 1000 scenarios produced with the climatic information (Sea Surface Temperature 1+2).

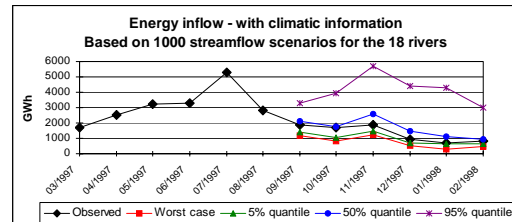


Fig. 8: GESS with climatic information

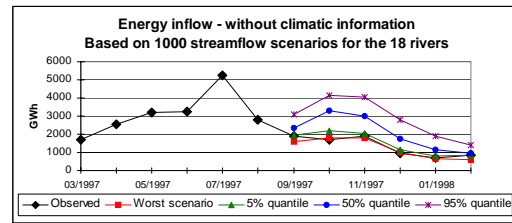


Fig. 9: GESS without climatic information

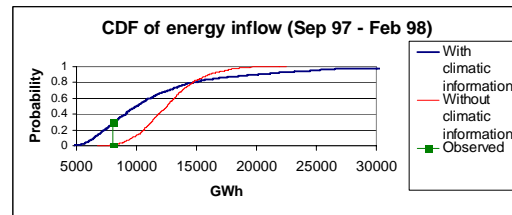


Fig. 10: CDF for the total energy inflow

### Contact

PSR  
 Suite 1402  
 Rua Voluntários da Pátria 45  
 Botafogo, 22270-000  
 Rio de Janeiro - RJ  
 BRAZIL

Tel: +55-21-3906.2100  
 Fax: +55-21-3906.2121  
 E-mail: psr@psr-inc.com  
 URL: www.psr-inc.com