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Felisa E. Gomba[1], Ronald L. Orale[2], Ralph S. Uy[3]

ABSTRACT

This paper discusses the use of stochastic process in the analysis of the water resources data for Catbalogan City water supply resource planning with the objective to determine the water availability and engineering measures based on the rainfall and streamflow variables. The operational model for water supply system was formulated The rainfall and streamflow were the variables that have stochastic in character and stochastic process can be applied. Thus, the historical rainfall record for the 20-year period was collected from secondary source to determine the low flow water inputs. The streamflow was collected and observed through scientific method based on the time series data of rainfall. Results of the study may be used as decision planning tool for the Catbalogan water supply planners and technical personnel from other water districts to determine the quantity of water resources at any given time.

I. Introduction

The availability of water in water supply system is essential in the delivery of the required volume of water to the serviced community. Philippine urban water supply is mainly provided by about 612 water districts under the authority of Local Water Utilities Administration, or by more than 1000 local government-operated water utilities that lack skills in handling new water supply projects (ADB Review 2006). Water supply scarcity is experienced in most water districts in the country especially during the period of dry season that they could not deliver the required water volume consumption of the human society. The world projections virtually show that all of the countries' available water resources could be exploited by 2030(Basson, et.al,, 1997). Strategies for sustaining the water resources for distribution require intensive management tools and physical understanding of hydrological nature that affect the water availability.

The domain of water resources management is influenced by hydrological processes that its effectiveness necessitates the application of mathematical relationships and theories. The availability, utilization, and distribution of water resources in space and time are highly variable and fundamentally affected by hydrologic factors that time series data are required for the analysis. These variations in water resources whose values changes with time have stochastic character and stochastic process can be applied. Hence, this paper discusses the

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application of stochastic process to water supply system management that may be valuable tool to planning and decision-making in water distribution.

II. Objectives

This study was guided by the following objectives:

- to formulate an operational model of the water supply system for stochastic application;
- to establish water supply time series data for rainfall and streamflow; and
- to apply stochastic process to estimate the water availability at low flow.

III. The Catbalogan Water Resources Supply

The Catbalogan water supply is supplied from two water sources, namely: a) Masacpasac sub-surface channel; and b) Karamayon spring water. Masacpasac is the main water source, and karamayon is used when the water flow at Masacpasac is low and less than 10 liters per second.

Masacpasac was discovered by the Americans in 1945, located at Barangay Kawayan, Catbalogan City, at about 4.5 kilometers from the City proper of Catbalogan. It is a sub-surface channel with an approximate length of 50 meters, mean width of 8 m, and mean depth of 2.20 m. It has an approximate area of 185.2 square meters with an elevation of 155 m above sea level. Figure 1 shows the inside view of the Masacpasac sub surface channel. The estimated flow of Masacpasac water source taken at the distribution site is 20 liters per second for dry season to 40 liters per second for wet season. During April and May, the observed dry season, Masacpasac water source maintains an average depth 1.32 meters.

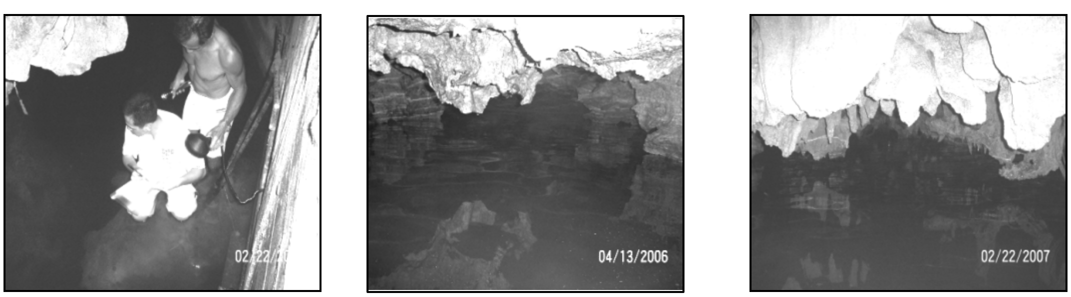


Figure 1. The inside view of the Masacpasac water source sub-surface channel

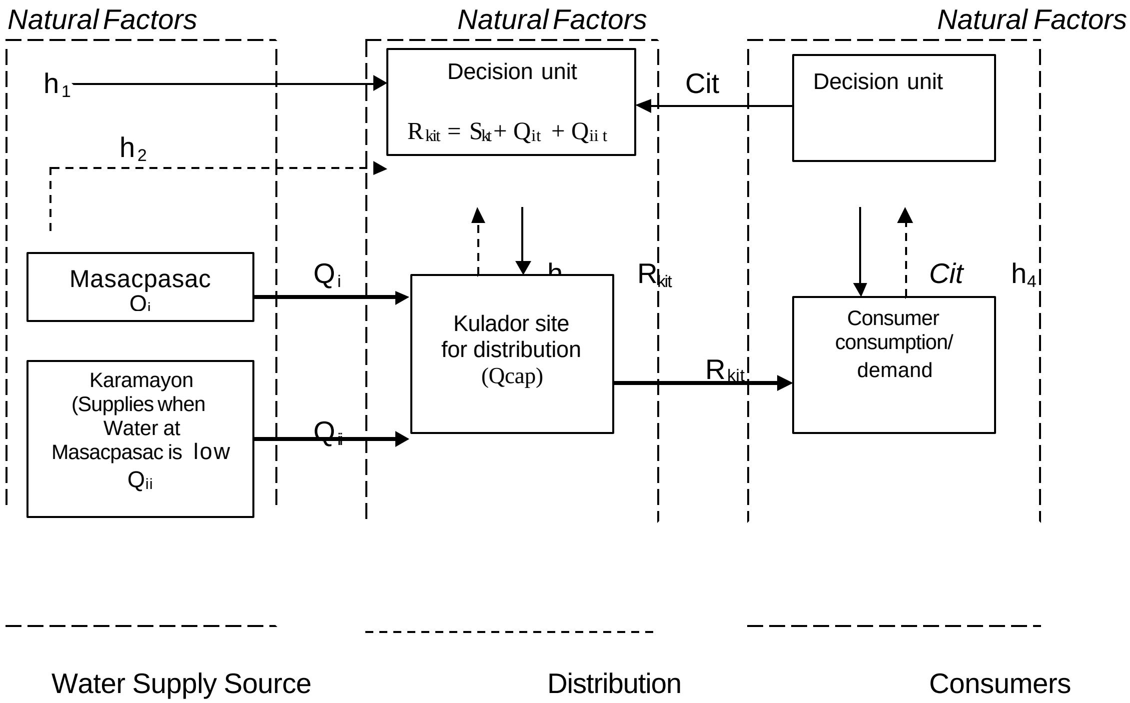
The Karamayon spring water source was utilized for water supply in 1995 to answer the increasing demand of water in Catbalogan due to increase in population growth. It supplies Catbalogan when the water at Kulador from Masapasac is low. It is located at Barangay Lobo, approximately 12 kilometers from Catbalogan City proper with an elevation of 84.12 m. It has a recorded stream flow of 40–60 liters per second. The water from this source is utilized using an electric-powered pump which involves high operational cost.

IV. Operational Model of Water Supply System of Catbalogan

Physically, the water from Masacpasac sub-surface channel and Karamayon flow to the treatment plant at Kulador at about 1.8 kilometers from Masacpasac and 7 kilometers from Karamayon on a rugged terrain. At Kulador, the water is treated with ordinary chlorination process and distributed immediately to the consumer. There is no water detention tank of the chlorinated water.

The water supply system of Catbalogan is shown in Figure 2, wherein it shows the interlinked flow systems and variables of the water supply. It has three sub systems, namely: the system at the source which is affected by natural factors; the system at the distribution which is technology dependent and affected by natural factors; and the system at the consumers which is affected by natural factors as well.

The water sources have two major variables. These are rainfall and stream flow.



Legend:

Flow of water - - - - - - - information from observations — — · Boundary of the system

Figure 2: The natural flow of water supply distribution

Where:

i = current number of years
j = current number of time units within the year
T = temperature
n = terrain
h_1 = information from observation such as rainfall
h_2 = information on the water supply momentarily available
h_3 = information on the distribution system
h_4 = information of the natural factors affecting the distribution operation
Q_i = the amount of water released to Kulador from Masacpasac source
Q_{ii} = the amount of water released to Kulador from Karamayon source
R_{kit} = the amount of water(flow) may be released from Kulador source to the distribution
S_{kt} = the probability of initial storage
$S_{l,\ t+1}$ = the probability of remaining water after the release or the final storage in period t
Q_{it} = the probability of inflow to Masacpasac due to rainfall
Q_{cap} = the capacity of the Kulador treatment and distribution facilities
E_{it} = the possible effect of evaporation and seepage losses
C_{it} = Data on water demands/consumption including the water quality

V. General Theory and Concept of Stochastic Process

In statistics, stochastic means being or having a random variable, but in hydrology (study of water movement in earth), it has been used in a special way to refer to a time series which is partially random. A stochastic process, or sometimes random process, is said to be stochastic when its future cannot be predicted exactly from its past; describing an event or process that involves random or probability chance (Water words dictionary:www.nv.gov/water). A stochastic relationship is assumed to be inexact and therefore it involves formulation of error term which is used to account for the inexact portion of the term (Tijms, 2003:11). The general theory of stochastic process contains four parts, namely: a) the measurable structure of stochastic process; b) the section theorem, which provides an approach of studying properties of a stochastic process through values taken at stopping time; c) the projection theory of measurable processes which is generalization of the conditional expectation in probability theory; and d) the dual projections of finite variation processes, which are defined via projection of random field (Kannan & Lakshmikantham, 2003:52)

Let (?, F) be a measurable space and the measurable function is {X_t, t ? ? }, defined on (?, F), where ? is a time parameter set. If ? is an interval of R = (- 8, 8), (X_t) is called a process in continuous time. If ? is a subset of N = { 0.1, 2, ….}, (X_t) is called a process in discrete time.

A process in discrete time is the simplest possible case for a stochastic process which amounts to a sequence of random variables known as a time series. The random variation is usually based on fluctuations observed in historical data for a selected period using standard time-series techniques. Distributions of potential outcomes are derived from a large number of simulations (stochastic projections) which reflect the random variation in the inputs.

Loucks, Stedinger, and Haith (1981: 116) stressed that historical rainfall or stream flow at a particular site are sequence of observations called time series and an observed time series is said to be one realization of stochastic process. The concept of stationary stochastic process is used in this study. Stationary stochastic process means that the probability distribution of the process is not changing over time.

Let X(t) stationary stochastic process, then

$$F_{X(t)}[X(t)] = F_x[X(t)]$$

if the process is strictly stationary, the joint distribution of the random variables $X(t_1),\ldots, X(tn)$ is identical to the distribution of $X(t_1 + t), \ldots\ldots, X(t_n + t)$ for any *t*; the joint distribution depends only on the differences ti – tj between the times of occurrence of the events. The mean(μ_x) and variance (s^2_x) are

$\mu_x = E[X(t)]$ and $\sigma^2_x = Var[X(t)]$ independent of time t

The autocorrelations, the correlation of *X* with itself are given by

$$?_x(k) = \frac{Cov[X(t), X(t+k)]}{\sigma^2_x} \qquad \text{for any positive integer k}$$

Loucks, et.al(1981:171) provided the following formulas for observations done in realization of stochastic process were used.

Let {*Xt*} be the observed values of a stationary stochastic process. The sample mean:

$$\bar{x} = 1/n \mathop{?}_{i=1}^{n} x_t$$

is an unbiased estimate of the mean of the process μ_x, because

$$E[\bar{X}] = 1/n \mathop{?}_{i=1}^{n} E[X_t] = \mu_x$$

The correlation structures from the autoregressive Markov model was used

$$Var(\bar{X}) = \bar{=} \quad E[(X - \mu_x)^2]$$

and the autocorrelations $?_x(k)$ can be estimated as

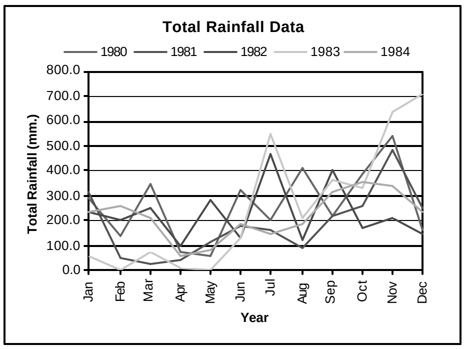
$$?_x(k) = r_k = \frac{\mathop{?}_{i=1}^{n}(x_{t+k} - \bar{x})(x_t - \bar{x})}{\mathop{?}_{i=1}^{n}(x_t - \bar{x})^2}$$

VI. The Stochastic Process Applied to Water Supply Planning

Stochastic process is significantly used in hydrology as decision-making tool to estimate the water supply availability. In water resource planning, the planners do not know what future flows or precipitation(rainfall) events will occur, but they can assume that these events will have the same stochastic properties as the observed historical record(Linsley, 1988:374). In this case, rainfall and stream flow are two variables which influenced the water availability in the Catbalogan water supply system.

Historical Rainfall Data

The historical rainfall records for the past 20 years of Catbalogan City are shown in Figures 3a to 3n. The rainfall data shown in these figures are presented in five-year period which shows the total rainfall and minimum rainfall.



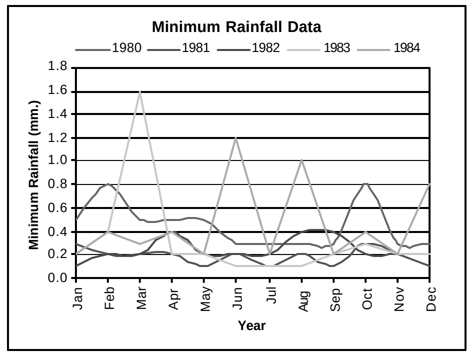
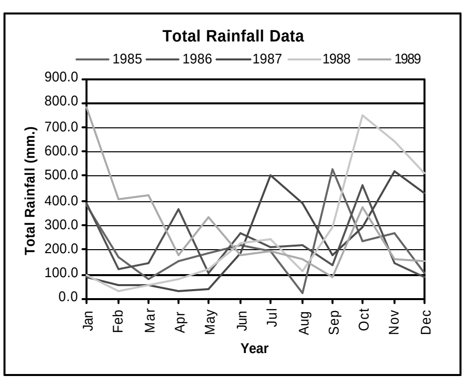


Figure 3a. Total Rainfall Data (1980-84) Figure 3b. Minimum Rainfall Data(1980-84)

Figures 3a and 3b showed the rainfall record for the year 1980 to 1984 in terms of total rainfall and minimum rain. It can be seen from these that there was almost no rain in the months of April and May for the year 1983. From these figures, it was recorded that the rainfall for the months of April and May for period 1980 to 1984 behaved almost the same and the minimum rainfall value range from 1.6 mm to 0.



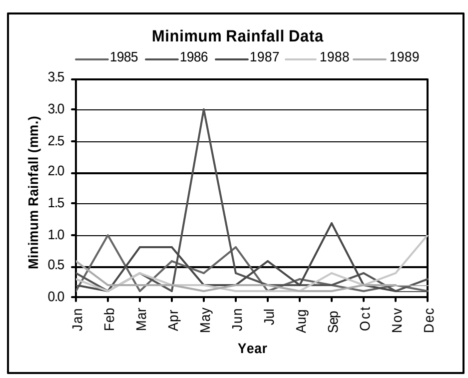
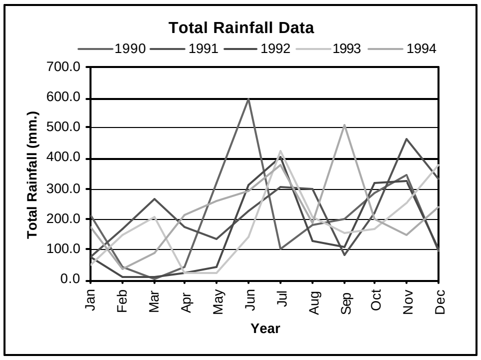


Figure 3c. Total Rainfall Data (1985-89) Figure 3d. Minimum Rainfall Data(1985-89)

Figures 3c and 3d show the rainfall records for the period from 1985 to 1989. It is reflected from these figures that there was rain throughout the year and the minimum rainfall occurred in the months of April and May. However, in year 1987 the minimum rainfall for the month of May was recorded at 3.0 mm.



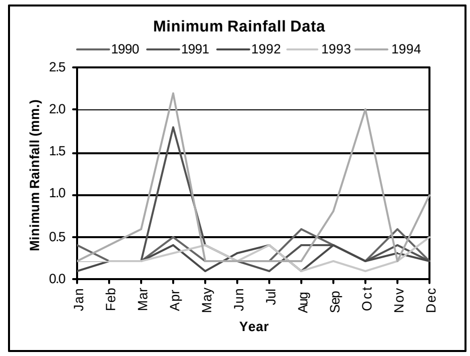
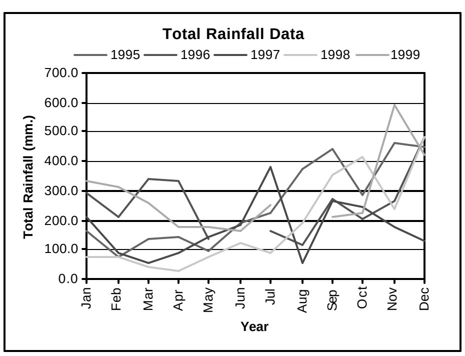


Figure 3e. Total Rainfall Data (1990-94) Figure 3f. Minimum Rainfall Data(1990-94)

The rainfall records from 1990 to 1994 are shown in Figures 3e and 3f and the minimum rainfall were recorded in the months of April and May and has a value from 2.9 mm to 0. Figures 3g and 3h showed the rainfall records for the period of 1990 to 1994. It can be gleaned from these figures low rainfall generally occurred in the months of April and May and the minimum rainfall was very low with a value range of 2.5 mm to 0.



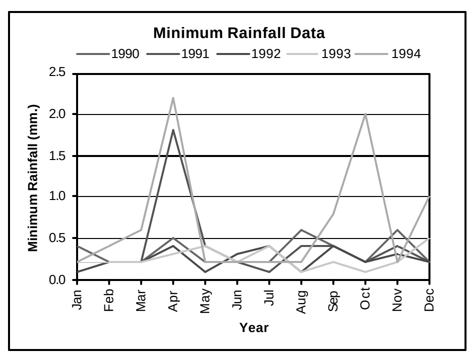
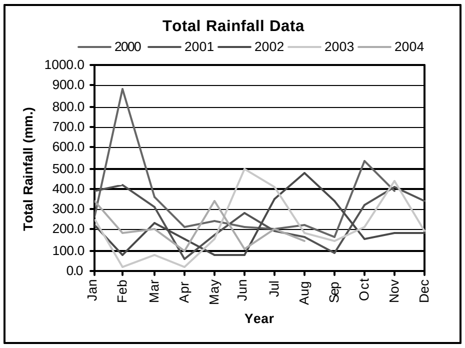


Figure 3g. Total Rainfall Data (1995-99) Figure 3h. Minimum Rainfall Data(1995-99)

Figures 3m and 3n showed the rainfall records for the period of 2000 to 2004. These records were taken to determine the variability of the rainfall records because for this period climate change is significantly felt by any natural system especially water resources. It can be picked up from these figures that rainfall in April and May were low and minimum rainfall has value range from 2.0 mm to 0.



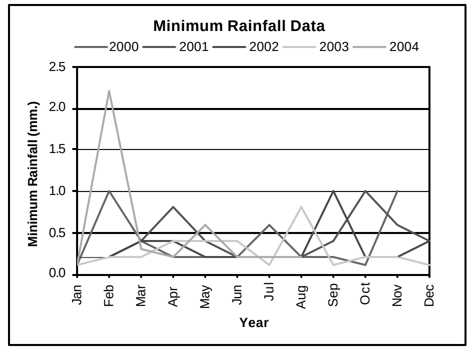


Figure 3m. Total Rainfall Data (2000-2004) Figure 3n. Minimum Rainfall Data(2000-2004)

The trend obtained from the 20-year period rainfall information served as the basis for the establishment of the observation design. The observations were taken independently at single observation. The stream flow was observed at minimum rainfall. Based on observations at the Masacpasac water source, rainfall is closely related to its streamflow. It is observed that during heavy rainfall the water level in the sub-surface channel, rapidly increases and the streamflow at Masacpasac increases as well. This observation is supported by the claim Katz, et.al.(2002:1295) that streamflow, a variable that is closely related to rainfall.

Sub-surface Channel Streamflow

The sub-surface channel flow or stream flow is important information to the stochastic process. The streamflow data was correlated to the rainfall records, wherein time series rainfall data at the same time was validated. The streamflow was recorded on daily basis starting 0400 hours to 1900 hours using the methods discussed in Hauer and Lamberti(1996). The streamflow observations were done during peak hour of water supply consumption from 0600 hours to 0900 hours at water supply source. The technical observation at Kulador was done simultaneous with the observations at the Masacpasac and Karamayon.

The streamflow data at Masacpasac is shown in Tables 1a which was obtained on field observation taken on a 3-hr period relative to the rainfall record of the day of observation done during the month of May.

Table 1a. The Mean of the Streamflow and Rainfall Data at Masacpasac Water Source

Hour	Day 1		Day 2		Day 3		Day 4	
	Rainfall mm	Flow (Qi) lps	Rainfall mm	Flow (Qi) lps	Rainfall mm	Flow (Qi) lps	Rainfall mm	(Qi)lps
6 am	0	10	3	18	0	15	0	10
7 am	0	8	6	15	0	10	0	10
8 am	0	7	3	15	0	8	0	8
9 am	0	8	5	18	0	8	0	10

It can be read from Table 1a that the streamflow is strongly influenced by rainfall. The streamflow increases as the rainfall increases.

The streamflow data at the Karamayon is shown in Table 1b which was observed and recorded simultaneous with the observation at the Masacpasac source.

Table 1b. The Mean of the Streamflow and Rainfall Data at Karamayon Water Source

Hour	Day 1		Day 2		Day 3		Day 4	
	Rainfall mm	Flow (Qii) lps	Rainfall mm	Flow (Qii) lps	Rainfall mm	Flow (Qii) lps	Rainfall mm	(Qii)lps
6 am	0	48	3	62	0	55	0	44
7 am	0	40	6	56	0	50	0	42
8 am	0	40	3	50	0	50	0	40
9 am	0	40	5	50	0	50	0	40

The streamflow at Karamayon was high, however, it was still strongly influenced by the amount of rainfall. It can be read from Table 1b that when there was rain, the streamflow increases.

Table 1c. The Mean of the Streamflow and Rainfall Data at Kulador

Hour	Day 1		Day 2		Day 3		Day 4	
	Rainfall mm	Flow (Qi) lps	Rainfall mm	Flow (Qi) lps	Rainfall mm	Flow (Qi) lps	Rainfall mm	(Qi)lps
6 am	0	68	3	76	0	70	0	64
7 am	0	62	6	67	0	64	0	60
8 am	0	60	3	62	0	60	0	60
9 am	0	60	5	62	0	60	0	60

The streamflow at the distribution site which is Kulador is also measured simultaneous with the measurement and observation at the Masacpasac and Karamayon water sources. It can be picked up from Table 1c that the streamflow increased.

However, stochastic process cannot be applied because there is no sufficient data due to lack of documentation on the stream flow for the past 25 years.

When rainfall and streamflow data are available, these will be statistically analyzed by finding the mean, variance, and correlation using the formulas stated above and probability distributions will be established to compute the parameters. From these data, formulation of stochastic functional relationship will be done based on Figure 1. However, in this paper stochastic cannot be applied, because there is no sufficient time series data of streamflow. The time element for the establishment of the data is limited and this data cannot be correlated with the existing rainfall data.

VII. Conclusion

Masacpasac water supply source is a major source of water for Catbalogan Samar and Karamayon is the alternative water supply source. It is strongly influenced by rainfall, since, flow decreases when there is no rain within the area. There was no sufficient water resource information for Masacpasac since the time it was discovered as a source of water supply for Catbalogan. Streamflow records, terrain and topography and other physical information were not available during the conduct of the study that historical data on these variables were not established. Thus, stochastic process was not successfully applied. However, the established stochastic relationship developed in this paper will be applied as soon as sufficient data will be available.

VIII. Recommendations

Water resources management and planning requires sufficient historical information, thus, it is strongly recommended that water users such water districts should develop a program on proper and appropriate documentation for time dependent parameters. Stochastic process is effective when there is sufficient and well documented hydrologic and time series data such as rainfall and streamflow, hence, engineers and technical personnel of water supply agencies should be provided with appropriate training on water resource information gathering and documentation.

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