EVALUATION OF WATER RESOURCES RELIABILITY IN MOROCCO

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ABSTRACT

The paper presents an approach for the evaluation of the reliability of water resources developed in support of the study of the new National Water Plan for Morocco, accounting for the uncertainty associated with recurring and prolonged drought cycles and the possible impact of climate change on water resource availability. The approach used so far for planning new projects in the country has been based on the application of deficit criteria expressed in the form of the acceptable frequency of supply deficits defined as a percentage of a preset demand level. Such criteria were applied for both domestic water supply and irrigation.

The approach presented in this paper is based on the concepts of stochastic hydrology and provides a probabilistic assessment of the available development and management options. The results of these simulations are analyzed to develop curves giving the base yield from storage dams as function of the target draft at different probability of exceedance levels. The same data are used to derive probability of exceedance curves for the firm yield of each reservoir. The present work introduces firm yield curves that define the volumes that are guaranteed at different levels of service, i.e. all the time, 9 out of 10 years, 4 out of 5 years, etc. The approach is illustrated through an example.

1 INTRODUCTION

The recently conducted study for the National Water Plan study addresses several fundamental issues ranging from institutional reform to the transition from supply to demand management in the context of a progressively liberalized economy. A key issue in preparing the study for the National Water Plan of Morocco was the assessment of the reliability of its surface water resources.

To better appreciate the context of the resource reliability assessment presented in this paper, we start by reviewing the conventional water resource management criteria used historically in Morocco and those envisioned for a future system oriented towards managing the scarcity of the water resources.

The conventional criteria used in the past for the evaluation of water resources development schemes in the regional master plans are strictly based on the management of the supply side, and can be summarized as follows:

- The demand is predetermined based on projections of agricultural production established in feasibility studies by government planners
- New projects should satisfy the demand with
  - A maximum acceptable deficit of 25% for domestic water supply systems and 50% for irrigation during periods of drought

    - A maximum acceptable deficit of 20% for domestic water supply systems and 32% for irrigation during normal hydrologic periods

    - The frequency of deficits should not exceed 10% for domestic water supply systems and 20% for irrigation

- The deficit is defined as the condition when the available supply satisfies less than 90% of the predetermined domestic supply demand, and less than 85% of the irrigation demand.

During the last few decades it has been progressively recognized that ignoring the demand side leads to inefficient allocation and use of limited and valuable water resources. Modern water resources planning and management recognizes the value of understanding and managing the demand side, which opens up an entirely new dimension in decision making and expands dramatically the range of available planning options, especially in areas where water scarcity is often viewed as a "structural" feature, which is now the case in most regions of Morocco.

The evaluation of water resources available in a system aimed towards managing their scarcity is envisioned to be based on the following criteria are in:

- The demand responds to the cost of water which reflects the scarcity and the reliability of the available resources

- In the context of water scarcity the price of water should reflect the marginal cost for water resources development.

- It is up to the users to define the optimal level of guaranty of water supply to them, expressed through their willingness to pay for the development of water resources providing this level of guaranty.

In such a system appreciating the reliability of each resource is essential in planning, as it affects the price of water, which in turn affects water demand, thus determining the desired level of new resource development. This is especially important in arid and semi-arid environments where assessing resource reliability is closely linked to understanding the hydrologic uncertainty and appreciating the length and frequency of drought conditions.

In this context the proper assessment of resource reliability becomes an important element of the evaluation of new water projects. This applies equally to projects aimed at satisfying domestic water supply needs, as well as projects serving primarily irrigated agriculture. A high degree of reliability is sought for resources aimed at providing drinking water. In a system where water is treated as an economic good, water pricing can be linked to the resource reliability. This is especially true for water used for irrigation. For example if a certain volume of water can be provided at a high level of guarantee, e.g. on the average nine out of ten years, then such a resource can be used to irrigate high value crops, such citrus, vineyard, apple orchards, etc. On the other hand, if a resource can be guaranteed at a much lower level, e.g. one in two years, then such a resource can be used only when available to grow low value crops such as cereals. The pricing of the water from each resource should reflect the value added by the water to the production of each crop. Water provided at a high level of guarantee used for arboriculture should carry a higher price than water offered at a low level of guarantee, and which may be used for cereals. In a system of genuine demand management the crop allocation would be optimized in a way reflecting the market conditions including the cost of developing new water resources and the reliability of the water they provide.

One of the strategic objectives of the national water plan is to lay the foundation for establishing a water pricing system that recognizes the value of the reliability of each water resource.

2 TWO APPROACHES TO RELIABILITY ASSESSMENT

The conventional approach to resource reliability assessment followed in past planning studies in Morocco consists of deterministic reservoir operation simulations using historic hydrologic data. This approach is quite limited and can lead to misleading conclusions regarding the reliability of the resource. A more complete assessment of resource reliability can be made using a stochastic approach, starting with the generation of synthetic flow data series, which are used in Monte Carlo simulations to obtain multiple estimates of the reservoir yield, and then analyzing the probability distribution of the estimated yield values.

The approach adopted in this study uses many of the concepts presented by Basson et al. (1994). We first define some key terms used in the following discussion. *Yield* is the volume of water abstracted from the reservoir in a any specific year in response to a demand. *Target draft* is the volume of water that the reservoir manager aims to draw in a year to satisfy the demand. *Base yield* is the lowest yield over a period of time and for a given sequence of inflows and a given target draft. The period of time used for the definition of the base yield is referred to as the *planning period*. Finally, *firm yield* is the maximum base yield that can be abstracted from a reservoir for a given sequence of inflows. The definitions of the target draft, yield, and base yield are illustrated in Figure 2, presented as part of the example introduced in the next Section.

We illustrate the difference between the two approaches through an example, which we also use to describe some new concepts.

3 THE DETERMINISTIC APPROACH

As an example we use the reservoir Bin El Ouidane in the Oum Er Rbia basin, located in the center of the country and on the west side of the Atlas Mountain. Bin El Ouidane was constructed in 1955 and has net storage capacity of 1207 Mm^3. Available hydrologic data at the time of the study consisted of a series of monthly streamflows for the period 1939-97. Reservoir operation studies were conducted with the River Basin Simulation model RIBASIM developed by Delft (1995), and with a specially written code (Bechtel/Maroc Développement (2000).

Figure 1, shows the simulated variability of the storage of Bin El Ouidane using the historic streamflow data and aiming at satisfying a constant annual demand of 945 Mm^3. The variability of the simulated storage reflects the variability of the hydrologic conditions during this period, which was characterized by long wet periods in the early 1940's, 60's and 70's, and periods of drought in the late 1940's and through the 80's and early 90's.

Figure 2 shows the variability of the annual yield of the reservoir from the same simulation. The constant annual demand of 945 Mm^3 is satisfied during the wet periods of the early 1940's and from the mid 50's till 1980, but the annual yield falls way short of the demand in the 1980's and early 90's.

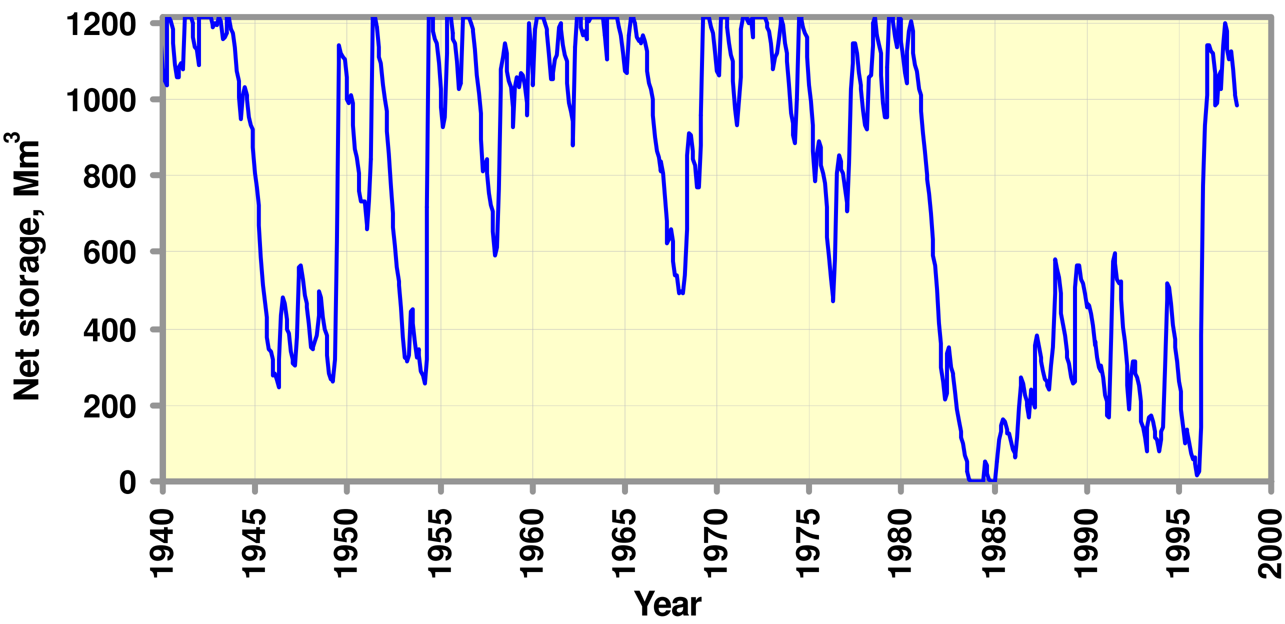

Figure 1. Simulated variability of the net storage of Bin El Ouidane based on hydrologic data for the period 1939-97.

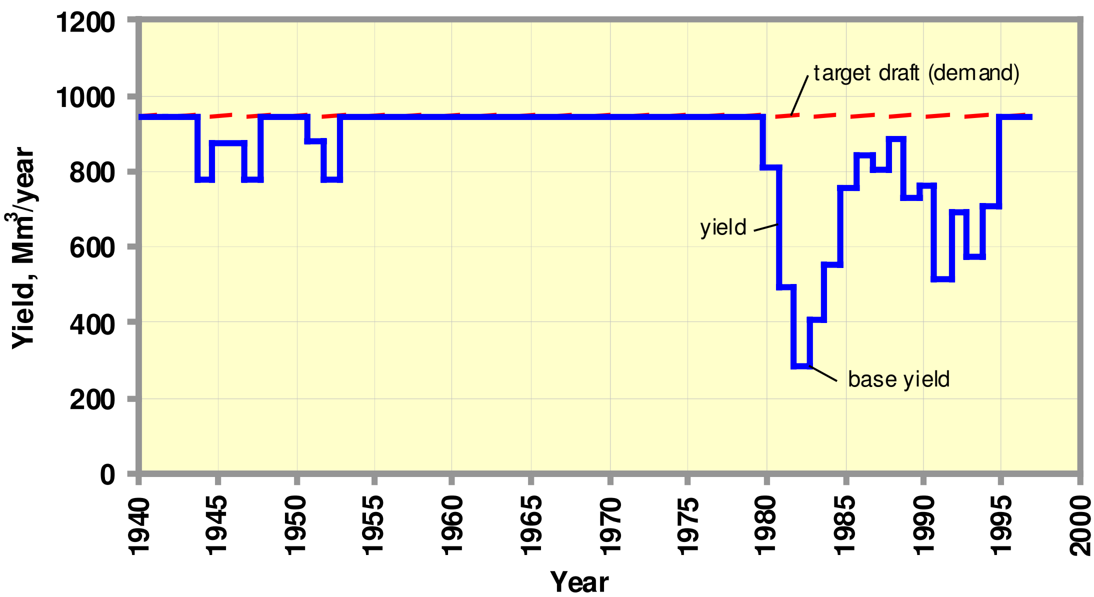

Figure 2. Simulated annual yield from the reservoir Bin El Ouidane based on hydrologic data for the period 1939-97, and a target draft of 945 Mm^3/year

The series of simulated annual yields shown in Figure 2 can be used to develop the probability of exceedance curve shown in Figure 3, which gives the probability that the annual yield is equal to, or exceeds a specific value.

For example, Figure 3 suggests that there is an 80 percent probability that the annual yield will exceed 775 Mm^3, or in other words on the average 4 out of 5 years the annual yield will exceed 775 Mm^3, and 1 in 5 years would be less than 775 Mm^3. From Figure 3 we can also estimate the probability of exceedance of the deficit, defined as the difference between the demand and the yield. Thus, Figure 3 provides the information needed to apply the conventional management criteria discussed in the Introduction. This approach to expressing the probability that the yield may meet or exceed a certain value is deterministic. It is based on the implicit assumption that hydrologic conditions in the future will be identical to those in the historic record, and it ignores the uncertainty in future hydrologic conditions. To illustrate this point we consider the historic record of streamflow data for Bin El Ouidane, and we work with a planning period of 20 years. If we split the available record of 59 years of data, into three periods, 1939-1957, 1958-77, 1978-97 (19, 20 and 20 years respectively), we obtain the three probability of exceedance curves for the annual yield shown in Figure 4. For comparison purposes in Figure 4 we also include the probability of exceedance curve based on the entire series of 59 years (shown in Figure 3)

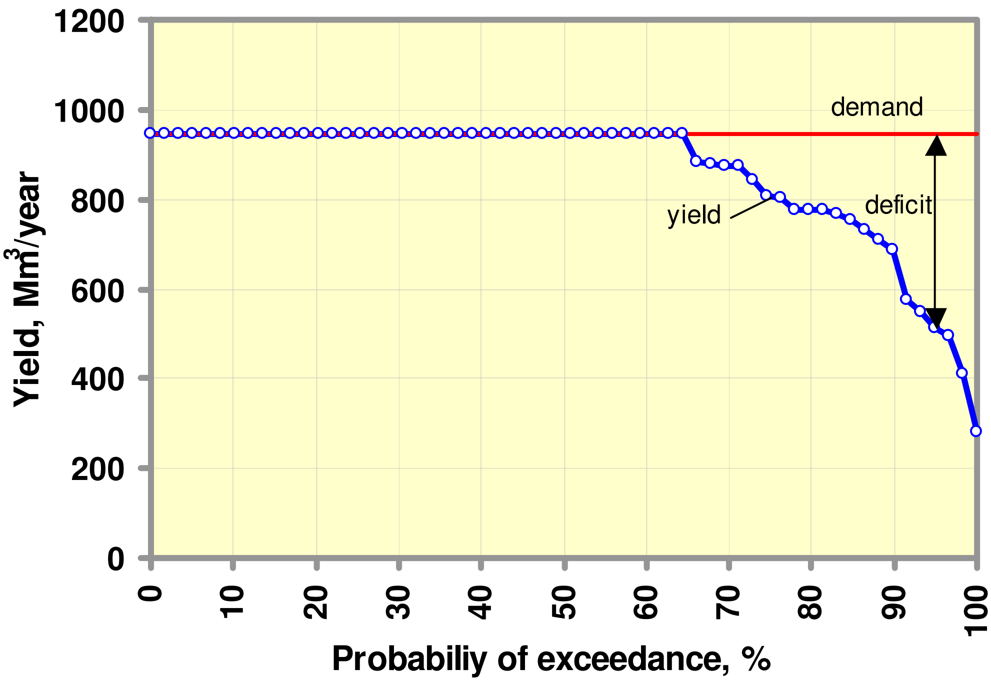

Figure3. Probability of exceedance of the annual yield based on a 59-year simulation using the available historic hydrologic data.

As can be seen in Figure 4, the probability of exceedance curves based on these three 20-year periods are quite different, and they are all different from the curve obtained based on the entire 59-year record. From Figure 4, based on the 1939-57 series we estimate that 1 in 5 years the yield would be less than 876 Mm^3, based on the 1958-1977 series we would estimate that the yield would be always 945 Mm3 and based on the 1977-97 series we would estimate that on the average 1 in 5 years it would be less than 575 Mm^3. This illustrates the dependence of the shape of the probability of exceedance curve on the specific record used and points to the need for using several hydrologic series to obtain a probabilistic estimate of this curve.

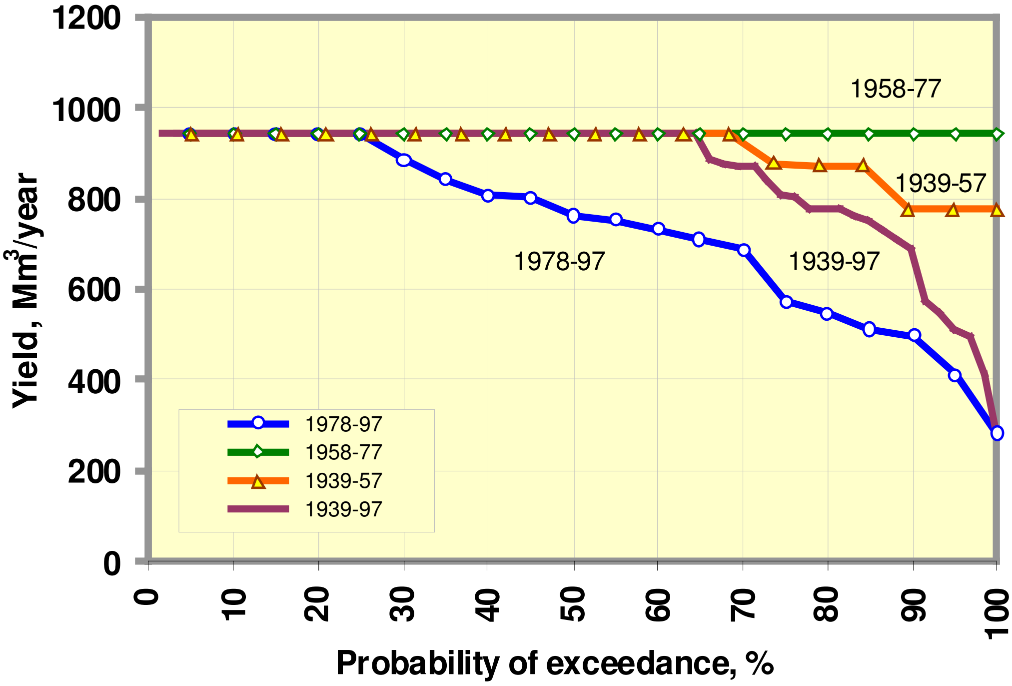

Figure 4. Probability of exceedance curves of the annual yield based on the historic streamflow data for three different 20-year periods (1939-57, 57-78, 78-97) and a 59 year period (1939-97)

4 THE STOCHASTIC APPROACH

Estimating the probability of exceedance of the yield based on a single, relatively short streamflow series does not account for the uncertainty in future flows. The yield that can be guaranteed at a certain level, e.g. 4 out of 5 years, can be better expressed by a probability distribution, rather than by a single value. This is made possible with the use of a stochastic approach based on a multiple simulations and the use of synthetic streamflow series.

Continuing with the example of the Bin El Ouidane reservoir, we use a synthetic series of 2000 years of monthly flows to simulate the operation of the reservoir over 100 twenty-year periods. The synthetic streamflows were generated with the code LAST (Lane, 1998). In order to better define the volume of water that can be guaranteed we construct the curve of the probability of exceedance of the base yield, shown in Figure 5. For comparison purposes Figure 5 shows also the probability of exceedance curve of the yield based on historic data from 1978-97, which is the driest of the three periods that the historic record was split to, and which was already presented in Figure 4. By its nature, the base yield probability curve obtained from the stochastic simulations gives a stricter estimate of the yield that can be guaranteed, than the yield curve based on hydrologic data from a single historic period.

Planning for the base yield may be too conservative and limit the possibilities offered by the water resources available a good part of the time. For example, if we are willing to plan on the basis of a yield that would be available only 9 out 10 years, we may ask what is the yield that on the average is available 9 in 10 years, and how much confidence we have in this estimate.

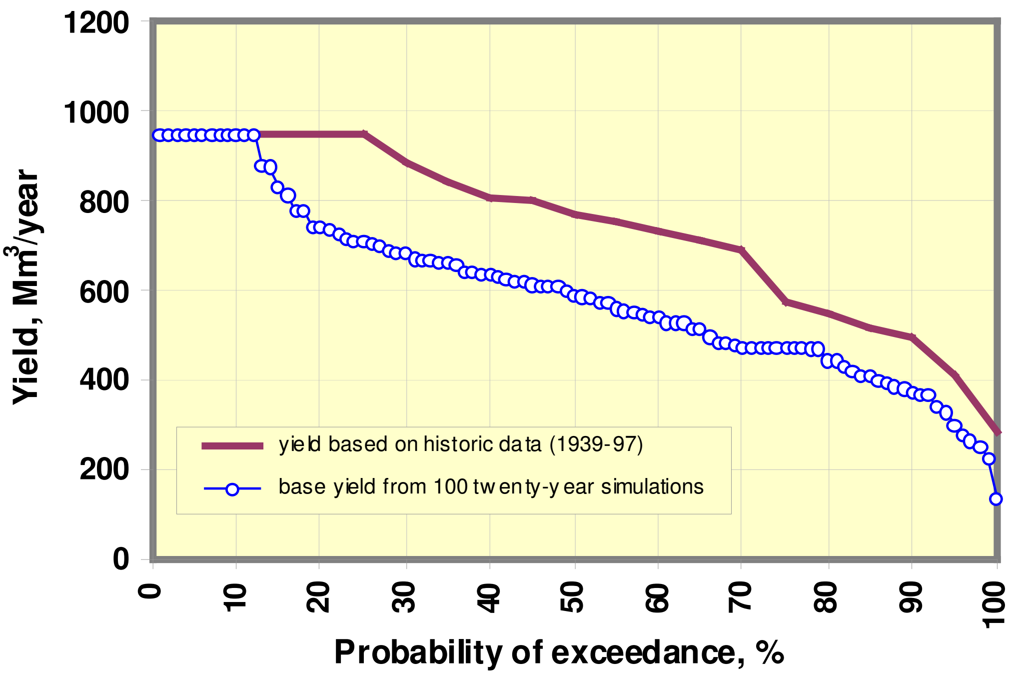

Figure 5. Probability of exceedance of the yield based on the historic data and probability of exceedance of the base yield based on 100 twenty-year stochastic simulations.

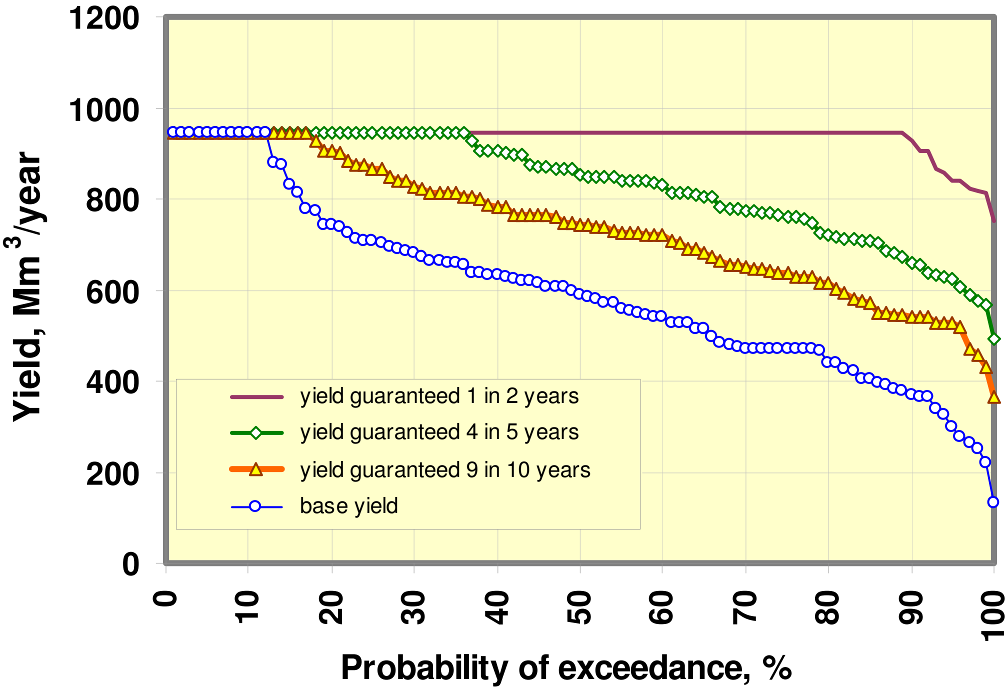

Figure 6. Probability of exceedance of the annual yield based on three different historic periods.

Analyzing the results of the stochastic simulations further we can estimate the yield that is met or exceeded 90%, 80% and 50% of the time, or on the average 9 in 10 years, 4 in 5 years and 1 in 2 years respectively. Ranking then these estimates we can construct the second probability of exceedance curve shown in Figure 6. To compare the results of the two approaches we consider again the example given earlier as part of discussion of Figure 3, where we saw that according to the deterministic approach 4 in 5 years the yield would exceed 775 Mm^3. The stochastic approach though suggests that the probability that the yield will exceed 775 Mm3 4 in 5 years is

70% (see 4 in 5 years curve in Figure 6). This means that there is a 30% probability that the yield is less than 775 Mm^3. From the same curve we also see that there is a 20% probability that 4 in 5 years the yield would be less than 723 Mm^3 and a 10% probability that it would be less than 662 Mm^3.

5 EFFECT OF THE RESERVOIR MANAGEMENT STRATEGY

The analysis and discussion presented so far was all for a single value of the target draft (945 Mm^3/year). The same analysis can be made for other values of the target draft. Lowering the target draft increases the yield during dry periods, but it does not utilize the resource at its fullest during wet periods.

If we repeat this analysis for different values of the target draft and plot them together we can see the full range of possibilities offered by different reservoir management strategies. Figure 7 shows a group of probability of exceedance curves for the base yield, i.e. the minimum yield in each of the 100 simulated 20-year periods. Each of these curves is for a different value of the target draft. The envelope of these curves, also shown in Figure 7, represents the firm yield which bounds the yield possibilities offered by the reservoir.

The firm yield curve constructed as the envelope of the base yield probability of exceedance curves represents the highest level of resource reliability. Similar curves can be constructed for other levels of supply reliability. For example, Figure 8, gives the probability of exceedance for the supply that can be guaranteed 9 in 10 years for different values of the target draft, and the envelope of these curves.

Figure 9 shows together the envelopes of the curves presented in Figures 7 and 8. These curves represent the upper bound of the yield possibilities at 100% and 90% level of guarantee for all potential reservoir management strategies. Figure 9 shows also similar curves for the yield possibilities at 80% and 50 % levels, i.e. the yields that can be guaranteed on the average 4 in 5 years and 1 in 2 years.

The preceding curves are based on simulations made under the assumption that reservoir management attempts to provide the target draft, without making any adjustments to account for the state of reservoir storage or to benefit from forecasts of hydrologic conditions for each upcoming season. Such adjustments offer a range of possibilities for improving the minimum reservoir yield, and are explored in the context of the method of operational management (gestion opérationnelle) developed by the Compagnie d'Aménagement des Coteaux de Gascogne (CACG) as described in Bechtel/Maroc Développement (2000).

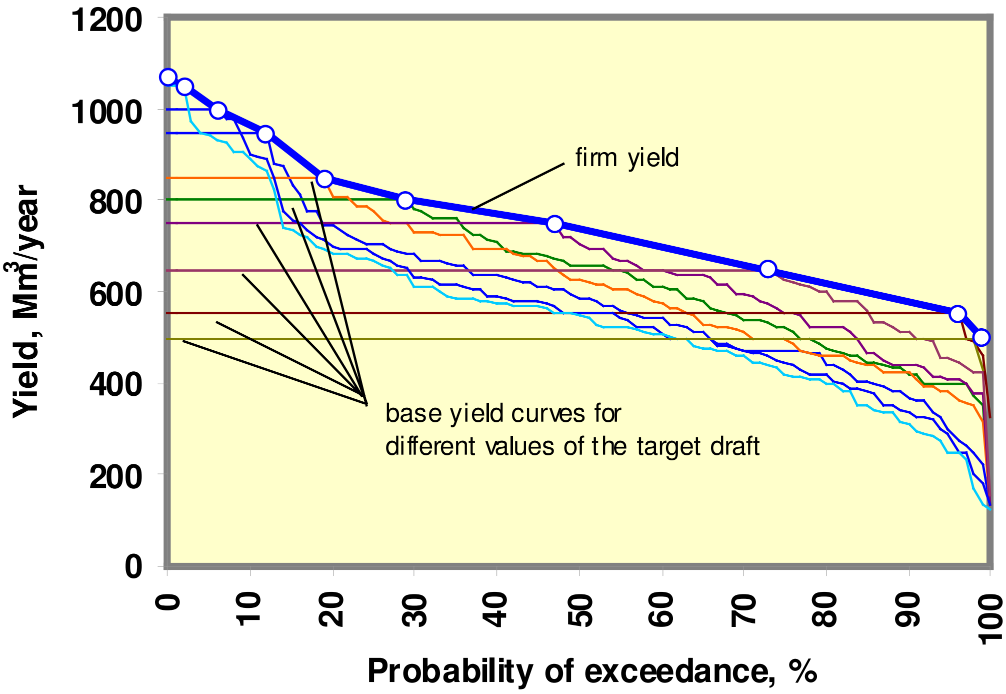

Figure 7. Curves of the probability of exceedance of the base yield for different values of the target draft, and the firm yield curve defined as the envelope of these curves

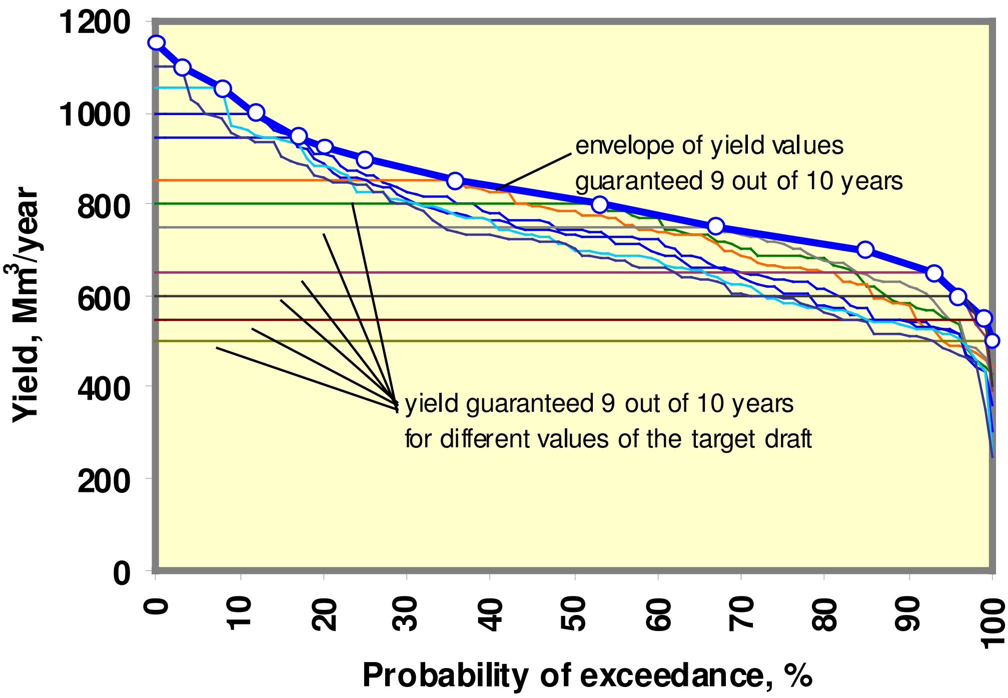

Figure 8. Curves of the probability of exceedance of the yield that can be guaranteed on the average 9 in 10 years. Each curve is for a different values of the target draft. The envelope of these curves is also shown

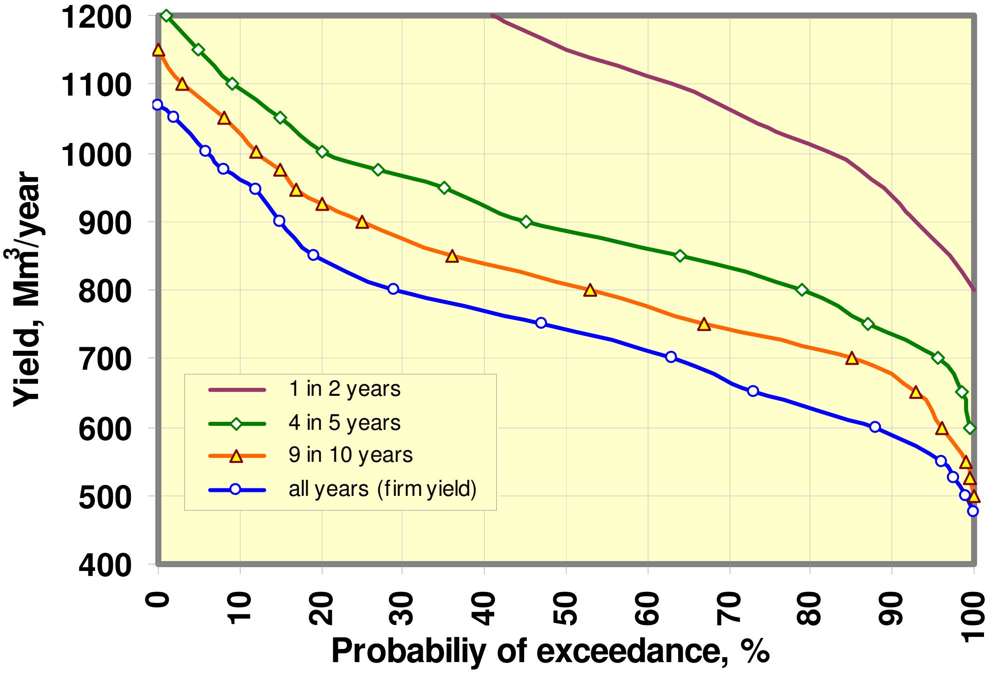

Figure 9 Firm yield curve and envelopes of the curves of the probability of exceedance of the yield that can be guaranteed on the average 9 in 10 years, 4 in 5 years and 1 in 2 years.

6 CONCLUSIONS

The assessment of resource reliability is a key element in the evaluation of new water projects, especially in countries and regions where the emphasis in water management is shifting from the supply side to the demand side. Two different approaches to resource reliability assessment, a deterministic and a stochastic approach, were presented and compared. The reliability of the resource obtained with the stochastic approach is more realistic, as this approach accounts for the uncertainty in future hydrologic conditions and provides probabilistic estimates of the frequency of exceeding given yield values.

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