OPTIMAL MANAGEMENT OF THE ARTIFICIAL RESERVOIRS FOR THE PRODUCTION OF RENEWABLE ENERGY AND THE HYDRAULIC PROTECTION OF THE TERRITORY

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Artificial reservoirs are across the world, and their use spans from the traditional management of the water resource to flood reduction operations. The artificial reservoirs provide both direct and indirect benefits to the community. Direct benefits include supply of water for municipal, irrigation, industrial, and hydropower generation. Artificial reservoirs can also be used for recreational purposes and for flood control. Indirect benefits would lead to increased sustainability and natural habitat preservation downstream of the dam [1]. Usually, the presence of artificial reservoirs allowed the socio-economic development of the communities living downstream these infrastructures. But, in many cases, their presence had a significant impact on the surrounding environment, causing remarkable erosion phenomena in both rivers and shorelines downstream the dam. Moreover, it has been observed that the presence of artificial reservoirs caused alteration of the micro-climate of surrounding areas and a significant reduction of the environmental flow. However, the remarkable construction costs, the management issues, and the increased hydraulic risk for the community living downstream make the realization of new artificial reservoirs a complex task. Therefore, nowadays the realization of new artificial reservoirs must be justified only if great benefits are provided to nearby communities and the whole ecosystem. Artificial reservoirs could also be used to mitigate the effects of floods, thus reducing the damages to property as well as the loss of human lives. Nevertheless, this objective might seem in contrast with the traditional purposes of artificial reservoirs: namely, to preserve water volumes to satisfy the water demands by the surrounding communities. However, these contrasting objectives can be reconciled in some cases. Recently, a study commissioned by the Italian Dam Service (Servizio Dighe Italiano) to various Italian Universities (among which the University of Naples Federico II with working group lead by Prof. Domenico Pianese), showed the possibility of using big artificial reservoirs for both management of the water resources and flood attenuation was also demonstrated.

Therefore, in this framework, new rules for the efficient management of the water resource stored in existing artificial reservoirs are required, as their objectives might have changed over the time due to changes in their scopes (irrigation, industrial, hydropower, etc.) as well as in the volumes requested by users. These new management rules must be redesigned to account for the changes in users request, the climatic changes that have led to an increased variability of water resources over time, and to the increasing number of flood events caused by both climatic changes and anthropogenic activities. The main aim is to identify the optimal management rules for artificial reservoirs, given the storage capacity W*, and the time series of inflows. The optimal management could provide benefits to managing authorities and users, allowing an “economically convenient” and sustainable use of the water resource. Moreover, existing artificial reservoirs could considerably mitigate the detrimental consequences of floods. In the near future, especially in emerging countries, new artificial reservoirs will be built for irrigation and water supply for municipal and hydroelectric purposes. The design and optimal management of multi-purpose artificial reservoirs should be carried out taking into account both social and environmental impacts generated with their construction.

However, the optimal operation of artificial reservoirs is not an easy task as the combined management of both water resource supply and storage capacity can lead to conflicting objectives [2]. In the last 40 years, several methodologies have been developed for the optimal management of artificial reservoirs [3, 4], such as Dynamic Programming techniques [5, 6], Shuffled Complex Evolution [7], the Kidney Algorithm [8], the Grey Wolf Algorithm [9], etc. Recently, optimization techniques have been applied to balance the various users demand while ensuring environmental flows [10-12]. The reliability of the results obtained by optimization models is closely related to the robustness of the predictive models of water demands [13]. Genetic Algorithms (GAs) have been widely used for the optimal management of artificial reservoirs. These algorithms resemble the evolution of living species aiming at finding the optimal candidate solution [14-25].

The aim of this study is to identify and standardize innovative procedure to allow for the optimal management of the water resource and the storage capacity within existing artificial reservoirs. In particular, a new methodology is proposed to identify the optimal management rules for multi-purpose artificial reservoirs. The methodology determines the "optimal management rules" for one or more reservoirs arranged in series/parallel returning the maximum benefit. The long-term variability of inflows and flood events are taken into account as well. This model also takes into account the reservoir operations, such as supplying high-quality water to the different users (municipal, agricultural, industrial, and hydropower), preserving the fluvial ecosystems and the health of the aquatic species living downstream. Moreover, this model is also account for the reservoir capacity to attenuate floods, with subsequent risk reduction for the communities living downstream, and the opportunity to exploiting the water volumes within the reservoir for recreational activities. In addition, the aforementioned model includes the progressive silting of the reservoirs due to the sediments from the upstream basin. These sediments can be dredged, in order to restore reservoir original storage capacity, as well as be reused for shores nourishment operations or for the production of innovative materials for "eco-sustainable architecture" [26]. To simulate the filling or emptying of the reservoir, the methodology is based on a consolidated approach developed by Italian researchers known as "Reservoir water balance method" ("Metodo degli scarti cumulati"). In particular, the proposed methodology is coupled with a stochastic forecast model of the inflows and a Genetic Algorithm (GA) optimizer. In order to maximize the benefits from the water supplied by a stored volume W* within the reservoir, accounting for the possibility of using a portion W* for flood attenuation, the following steps are considered:

1. generation, through the use of stochastic models, of S sets of time series, of length "n" years, of: inflows at the reservoir [25]; equally likely flood events, obtained through the combined use of a PRPN-S type model (Poisson Rectangular Pulses Neymann-Scott.) and a runoff model chosen to best fit the case study; daily volumes of solid material tributary to the reservoir [27];
2. evaluation of the low-flows regime that should be allowed guaranteed in the riverbed sections downstream of the dam in different periods of the year [28];
3. evaluation of the maximum benefit, B_S, achievable for a specific sequence of discharges and for a specific "utilization law" of the artificial reservoir (i.e., for the assigned sequence of values $C\{j,u_t\}$), for each of the S time series generated, within each step of the proposed optimization algorithm (namely a Genetic Algorithm; [25]), and for each "individual" uniquely defined by the choice of a N-tuple of values of the "utilization coefficient" $C\{j,u_t\}$ related to the generic sub-period "j" ($j = 1,2,...,N$) and to the generic user "u_t" ($u_t = 1,2,...,m$);
4. ordering, in ascending order, of the values thus obtained and estimation of the probability of exceeding the assigned value of B_S;
5. estimation of the maximum annual benefit "B", for the assigned exceedance probability and for the assigned method of distribution among the various users of the volume "E", in the various sub-periods of the year;
6. identification of the maximum benefit that can be obtained with the assigned exceedance probability, B_{max}, as the laws of use of the outflows vary (and, therefore, as the values of the "coefficients of use" $C\{j,u_t\}$ relative to the generic sub-period "j" ($j = 1,2,...,N$) and to the generic user "u_t" ($u_t = 1,2,...,m$) vary, and, therefore, as the "individuals" of the "Population" generated at each step of the GA;
7. iteration of the procedure outlined in points 4) to 7) using an optimization technique based on a GA, so as to progressively increase the value of the maximum benefit that can be obtained;
8. identification of the optimal utilization law for the correct management of the reservoir and the water resources that flow into it starting from the values of the utilization coefficients used to obtain B_{max}.

For each scenario of outflows and sediments arriving at the reservoir, a prefixed number P of so-called "adjustment possibility curves" (E-W) were been constructed. In particular, E is the annual supply guaranteed by the reservoir, and W the useful volume to be kept available inside the reservoir in order to allow the supply of the annual volume E. The E-W curves are able to solve both "design problems" and "verification problems". As a matter of fact, they provide the volume E annually deliverable from the reservoir, as a function of the useful volume W within the reservoir and for assigned values of the "utilization coefficient" $C\{j,u_t\}$ relative to the generic sub-period j ($j = 1,2,...,N$) and the generic user u_t ($u_t = 1,2,...,m$). In particular, for each step of the iterative optimization procedure, P “outflow regulation possibility curves” were been created. Each curve is generated by creating P “individuals”, characterized, in turn, by a specific set of values of the utilization coefficients C{j,u_t} relative to the different users to be served, and by a specific set of ratios (E{annual_user}/E{total_annual}) between the annual supply provided to each user and the total annual supply guaranteed by the reservoir, equal to the sum of the different values relative to the individual users. For the identification of the values of B_s and B_{max}, the benefits that can be derived from the supply of water for these uses are added to those related to the use of the volumes upstream of the dam, and to the reduction of the costs arising from any overflow from the stretches of riverbed downstream of the dam.

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