Alternative Approach to the Lumping of Small Dams for the Purpose of Undertaking Water Resources Modelling

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Abstract

It is perceived that some uncertainty currently exists regarding the appropriate procedure that should be followed to lump small dams for the purpose of undertaking water resources modelling. In the past, many modellers have adopted a standard approach which involves the assumption that the storage capacity of a small dam is directly related to the size of its inflows, and, by implication, that the various individual dams in a catchment would fill in equal percentage increments of its full supply volume. The purpose of this paper is to propose and alternative method that may be applied for this purpose, as well as to illustrate the differences in results obtained from the standard and proposed approaches. Furthermore, the authors wish to promote discussion on the validity of either approach, specifically insofar as they achieve the appropriate modelled behaviour of dummy dams.

Keywords: *Small Dams, Dummy Dams, Lumping of*

1. Introduction

Small dams are known to impact on the hydrological behaviour of and available water resources in a catchment. This impact occurs primarily by virtue of the storage capability provided by these dams which has the benefit of increasing the assurance of supply to water users they supply, as well as the loss of water from the system through evaporation occurring from their surface areas. It is therefore important to take these dams into account when undertaking water resource system modelling. However, unlike the major dams in a water resource system, it is generally considered to be impractical to model each small dam individually. Instead, certain defined groups of these dams are identified and the dams combined (or lumped) to form a single representative system element, generally referred to as a *dummy dam*. The process of lumping individual dams into a dummy dam must be undertaken in such a way that the impact of the dummy dam mimics the combined impact of the individual dams that it represents. Furthermore, a decision has to be taken on which specific dams would be lumped together, based on considerations such as the location of the dams in question, the location and nature of water users supplied from the dams and the desired level of complexity of the resulting system model.

In order to ensure that the impact of a dummy dam mimics the combined impact of the individual dams that it represents, it is of great importance that appropriate characteristics be applied for the dummy dam in the modelling process. For this purpose, characteristics for the dummy dam are derived from the characteristics of the individual dams and include, most importantly, its full supply capacity (FSC) and the surface area of water in the dummy dam at FSC. The FSC of the dummy dam is calculated, simply, by adding up the FSCs of the individual dams and its surface area at FSC is calculated in a similar way. Also, a relationship must be derived that represents the relationship between the volume of water in the dummy dam and the corresponding surface area. This relationship may be represented in various ways, but the most common is by means of the following simple equation:

$$\textbf{Area} = \textbf{a*Volume}^{\textbf{b}}$$

Where:

a = coefficient in the volume-surface area relationship;
b = power in the volume-surface area relationship;
Volume = volume of water in the dummy dam (million m^3);
Area = surface area of water in the dummy dam, corresponding to **Volume** (km^2).

However, it is perceived that some uncertainty currently exists regarding the appropriate procedure that should be followed to lump small dams for the purpose of deriving appropriate parameter values for the equation shown above. The purpose of this paper is to investigate two alternative methodologies that may be applied for this purpose, as well as to illustrate the differences in results obtained.

2. Standard lumping methodology

In the past, many modellers have adopted a standard approach which involves the assumption that the storage capacity of a small dam is directly related to the size of its inflows, and, by implication, that the various individual dams in a catchment would fill in equal percentage increments of their full supply volume. The popularity of this approach stems from the fact that it produces volume-surface area characteristic curves for dummy dams very similar in shape to the normal shape of a single dam.

For example, if small dam A is at 10 % of its FSC then dam B would also be at 10 % of its FSC. If the FSCs and the volume-surface area relationships for both these individual dams are known, then the actual volume of water in both dams may be calculated, as well as the corresponding surface areas. Then, if the two dams were to be lumped together to form one dummy dam, then the total volume of water in the dummy dam at 10 % of its FSC may simply be calculated by adding up the individual volumes in A and B. Similarly, the corresponding total surface area of water in the dummy dam may be calculated by adding up the individual surface areas in A and B. This calculation is then repeated at other percentages in order to provide a range of points on the volume-surface area curve of the dummy dam. Consequently, appropriate parameter values for the equation shown in **Section 1** may be derived by means of basic curve fitting techniques.

As part of a study currently being undertaken for the Department of Water Affairs and Forestry, Directorate: National Water Resource Planning, called *Updating the Hydrology and Yield Analysis in the Mokolo River Catchment*, characteristics for defined dummy dams within the Mokolo River catchment were derived based on the above standard methodology. Examples of the results are shown in **Figures 1** and **2** for the dummy dams defined in the A42A2 (Upper Sand) and A42C2 (Tweefontein) sub-quaternary catchments, respectively. The characteristics of these dummy dams are summarised in **Table 1**.

Table 1: Characteristics of dummy dams as derived using the standard lumping method

Name	FSC (million m^3)	Surface area at FSC (km^2)	Value of parameter(1)	
			a	b
A42A2 (Upper Sand)	1.198	0.643	0.5779	0.5934
A42C2 (Tweefontein)	0.073	0.055	0.2925	0.6385

Note: (1) In the equation $Area = a*Volume^b$.

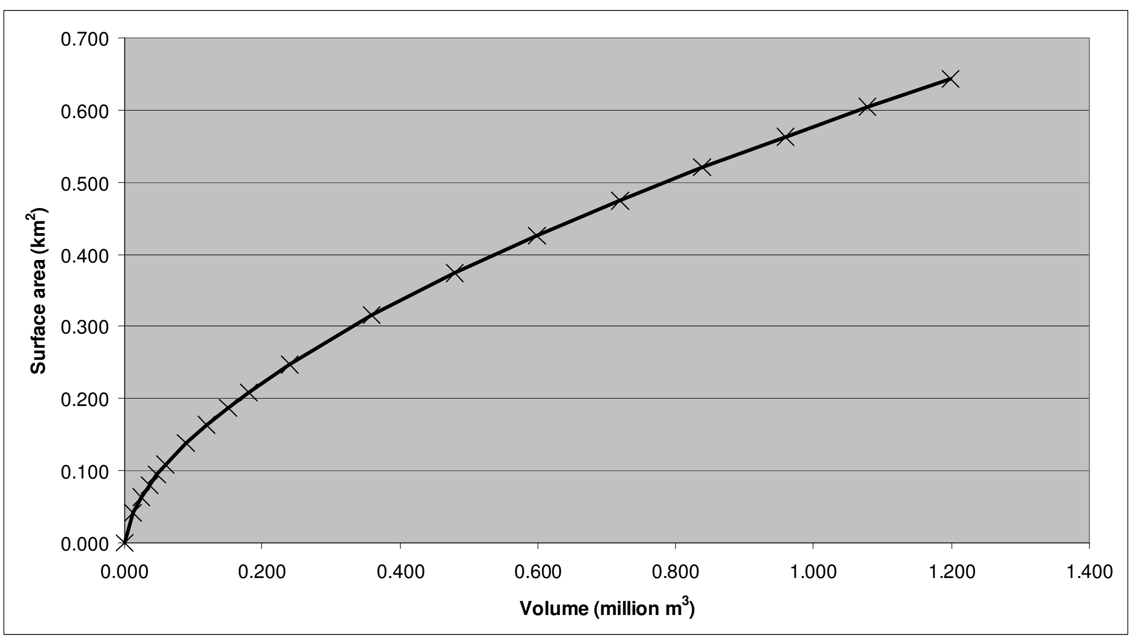

Figure 1: Volume-surface area relationship for A42A2 (Upper Sand) dummy dam, derived using the standard lumping methodology

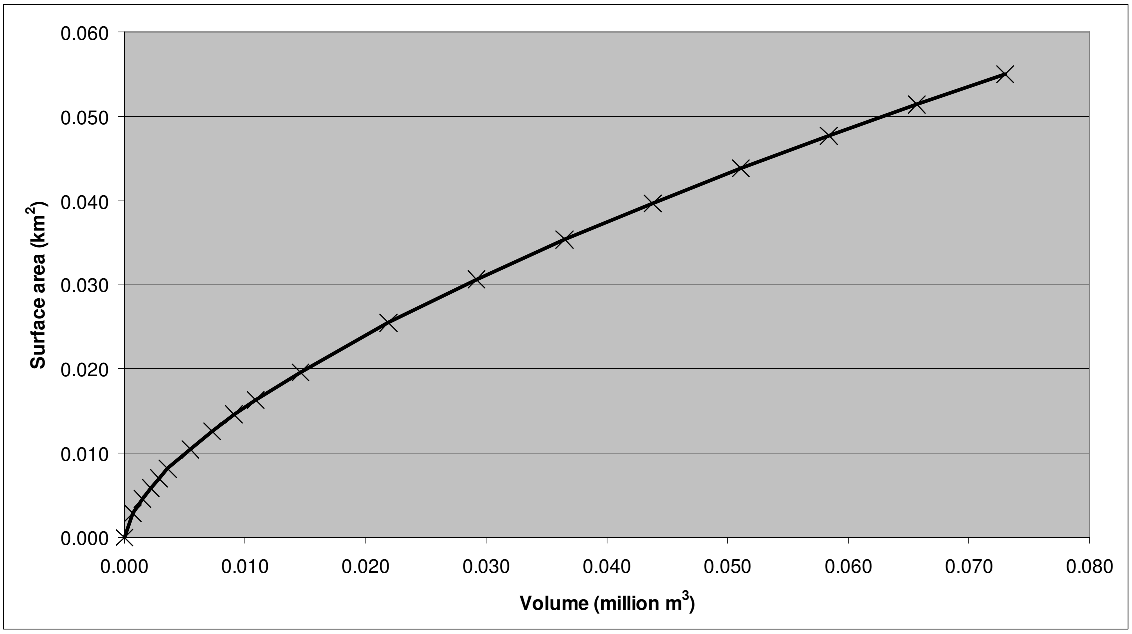

Figure 2: **Volume-surface area relationship for A42C2 (Tweefontein) dummy dam, derived using the standard lumping methodology**

3. Alternative lumping methodology

Also as part of the *Updating the Hydrology and Yield Analysis in the Mokolo River Catchment* study an alternative methodology was investigated for lumping small dams in order to derive appropriate parameter values for the equation shown in **Section 1**. It was found, however, that this alternative methodology produces volume-surface area characteristic curves for dummy dams that are very different in shape to those produced using the standard methodology discussed in **Section 2**. The alternative methodology is based on the assumption that small dams empty as a result of evaporation from their exposed water surfaces.

In order to undertake the associated calculations, a fixed evaporation rate is assumed and imposed, over a number of time steps, on all the individual dams that are to be lumped to form a specific dummy dam. The actual magnitude of the evaporation rate is not critical, and simply determines the number of time-steps that have to be undertaken until all the individual dams under consideration empty. Clearly, since a fixed rate of evaporation is used, smaller dams will empty more quickly than larger ones. The volume of evaporation for each dam and within each time step is calculated based on the surface area of water in the dam at the beginning of the time step, which is calculated from a known volume-surface area relationship for the individual dam in question. All dams are assumed to start full and the volume of water at the start of the second time step is calculated by subtracting the evaporation volume over the first time step from the volume of water in the dam at the start of the first time step. This calculation is repeated for as many time steps as are required to empty all the individual dams under consideration. Then, the total volume of water in the dummy dam, at the start of each time step, is calculated by adding up the volumes in all of the individual dams at the start of each time step. Similarly, the corresponding total surface area of water in the dummy dam is calculated by adding up the individual surface areas at the start of each time step. The result of the above calculations is a range of points on the volume-surface area curve of the dummy dam. Again, appropriate parameter values for the equation shown in **Section 1** may be derived by means of basic curve fitting techniques.

Results obtained using the alternative methodology for lumping small dams are compared with results from the standard methodology in **Figures 3** and **4** for the dummy dams defined in the A42A2 (Upper Sand) and A42C2 (Tweefontein) sub-quaternary catchments, respectively. The characteristics of these dummy dams, based on the alternative lumping method, are summarised in **Table 2**.

Table 2: Characteristics of dummy dams as derived using the alternative lumping method

Name	FSC (million m^3)	Surface area at FSC (km^2)	Value of parameter[(1)]	
			a	b
A42A2 (Upper Sand)	1.198	0.643	0.5559	0.8077
A42C2 (Tweefontein)	0.073	0.055	1.4860	1.2594

Note: (1) In the equation $Area = a*Volume^b$.

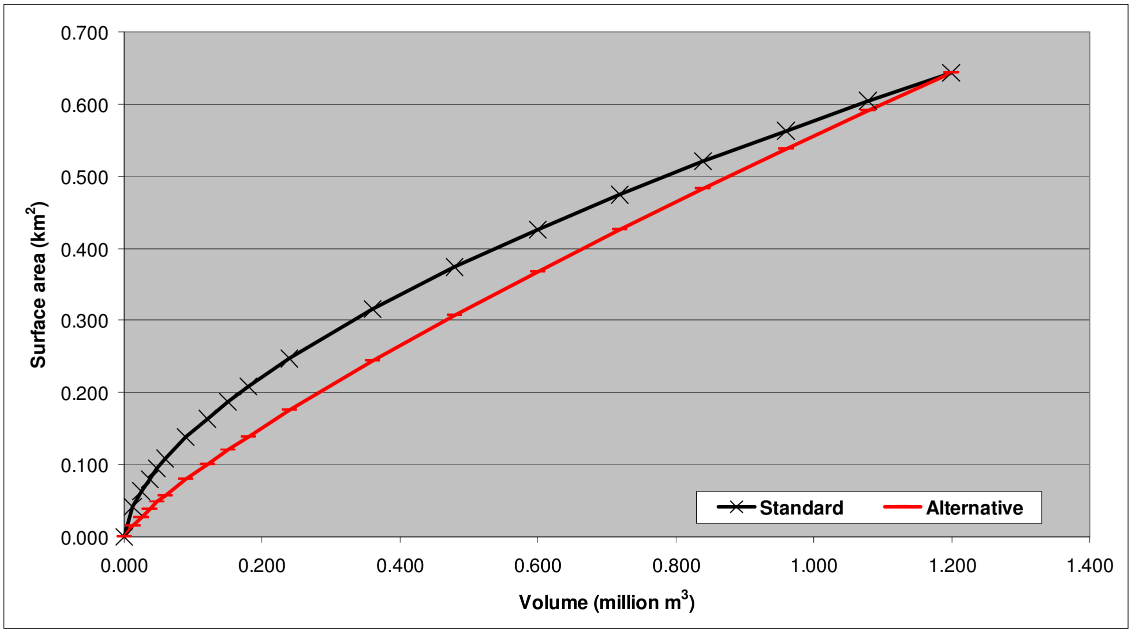

Figure 3: **Comparison of volume-surface area relationships for A42A2 (Upper Sand) dummy dam, derived using the standard and alternative lumping methodologies**

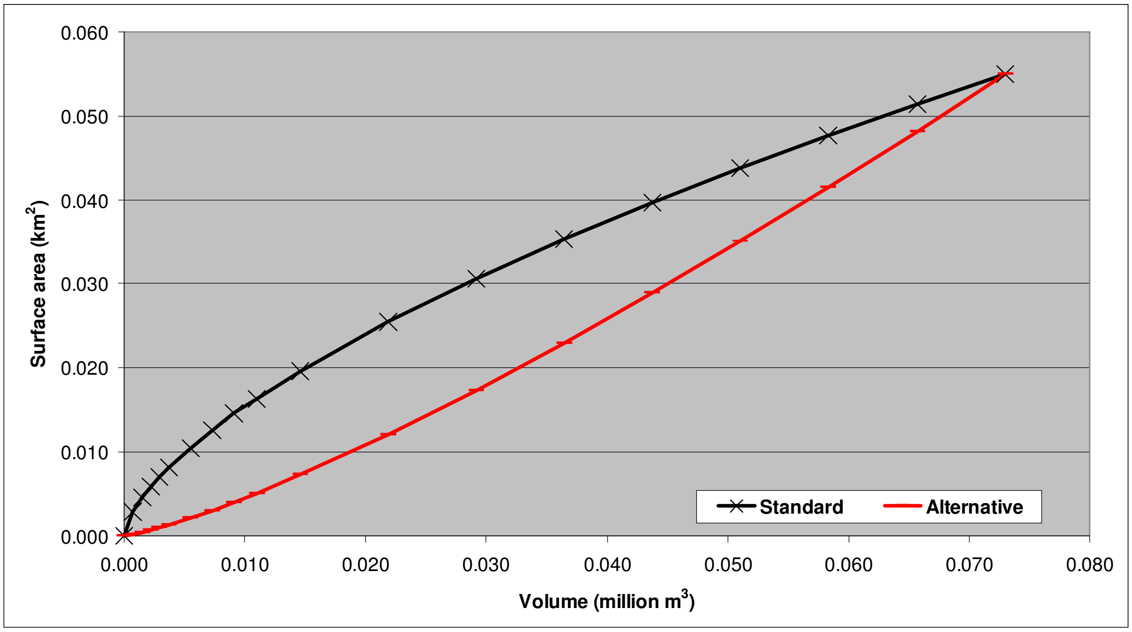

Figure 4: **Comparison of volume-surface area relationships for A42C2 (Tweefontein) dummy dam, derived using the standard and alternative lumping methodologies**

4. Discussion

As mentioned earlier, the alternative methodology for lumping small dams produces volume-surface area characteristic curves for dummy dams that are very different in shape to those produced using the standard methodology. This is clearly shown in **Figures 3** and **4** of **Section 3**. Also, it was found that, generally, curves from the alternative methodology lie below those from the standard methodology. This means that for a specific volume of water in a dummy dam, the alternative methodology would predict a smaller corresponding surface area and, therefore, when used in a water resource system model, will result in lower simulated evaporation losses.

Furthermore, it is observed that in cases like those of the A42C2 (Tweefontein) dummy dam, the alternative lumping methodology results in the power of the volume-surface area relationship (i.e. parameter *b*) to be greater than one. This means that the shape of the associated curve is concave, as opposed to the convex shape of curves normally associated with single dams.

Within the context of the above observation, it is proposed that the validity of either approach be investigated and discussed further, specifically insofar as they achieve the appropriate modelled behaviour of dummy dams.

5. References

BKS, 1989. Yield Analysis of the Hans Strijdom Dam. Report No. P A400/00/0489 compiled by BKS Incorporated as part of the *Hans Strijdom Yield Analysis* study for the Department of Water Affairs and Forestry, Directorate: Project Planning, Pretoria, South Africa. Author: McKenzie, RS.

WRP, DMM & GAA, 2006. Hydrological Analysis. Draft report compiled by WRP Consulting Engineers (Pty) Ltd, DMM Development Consultants CC and Golder Associates Africa (Pty) Ltd, in association, as part of the *Updating the Hydrology and Yield Analysis in the Mokolo River Catchment* for the Department of Water Affairs and Forestry, Directorate: National Water Resource Planning, Pretoria, South Africa. Authors: De Jager, FGB, Haasbroek, BJJ, Van Rooyen, PG, Sami, K and Coleman, TJ.