

Small Reservoir Capacity Estimation

Authors

Munamati, M., Department of Soil Science and Agricultural Engineering, University Zimbabwe, Zimbabwe

Senzanje, A., School of Bioresources Engineering & Environmental Hydrology, University of KwaZulu Natal, South Africa

Sawunyama, T., Institute of Water Research, Rhodes University, South Africa

Mhizha, A, Department of Civil Engineering, University of Zimbabwe, Zimbabwe

Rodrigues, L. N., Weschenfelder, R., Passo, D. P., da Silva, A. N., Embrapa Ceras, Platalina DF, Brazil

Liebe, J., Center for Development Research, University of Bonn, Germany

Scope: questions/ challenges the tool addresses

The storage capacity of many small reservoirs in the Limpopo Basin and other semi-arid areas has not been measured, possibly because the tools currently used for such measurement are labor-intensive, costly and time-consuming. This tool allows the estimation of reservoir storage capacity as a function of the surface area, which may be observed with satellites.

Target group of the tool

Water resource managers, policy makers, water agencies and researchers

Requirements for tool application

This tool is most suitable for technical people, who have computer skills (GIS) and some mathematical background. Community members can help identify local reservoirs and can provide valuable support services. Equipment and materials include: theodolite, stadia rod and chain, 1:50000 maps, tripod, level, tape measure (50m), notebooks, GPS, vehicle, and a boat.

Tool: description and application

- Remote sensing is used to identify small reservoirs. The surface area of each is calculated from satellite images. (See mapping reservoirs tool – Reservoirs Inventory Mapping by Jens Liebe, Center for Development Research, University of Bonn, Germany, Nick van de Giesen, Delft University of Technology, the Netherlands, and Frank Ohene Annor, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana in section IIa II. a) Reservoir ensembles measurements.)
- A sub-set of reservoirs is selected. For each reservoir in the sub-set, the surface area is estimated from field surveys, and storage capacity is estimated using information on reservoir surface area, depth and shape. Depth is measured using a stadia rod (5 m), see figure below. The spacing between measurements should not be more than 20 m to allow creation of contours from which the shape of the reservoir is derived. (See reservoir

bathymetry tool - Bathymetric survey by depth-sonar and lake sediment coring by Beeker sampler to identify sediment budgets and siltation rates of small reservoirs by A.C. Brunner, Center for Development Research, University of Bonn, Germany in section IIb Hydrology and Physical Measures of Performance)

- For reservoirs in the sub-set, estimated surface area is used as an input into the triangulated irregular network (TIN) model. This model splits up the reservoir surface into triangular elements.
- Arcview 3.2 GIS package with Spatial Analyst, plus Surface Areas from elevation Grid extension is used to automate surface area calculations and to provide surface area statistics.
- Comparisons are made between estimates of surface area from field surveys and estimates of surface area from remote sensing. A linear regression analysis is carried out to establish the relationship between surface area and storage capacities.

The modelling equation is developed as shown below in figure 1.

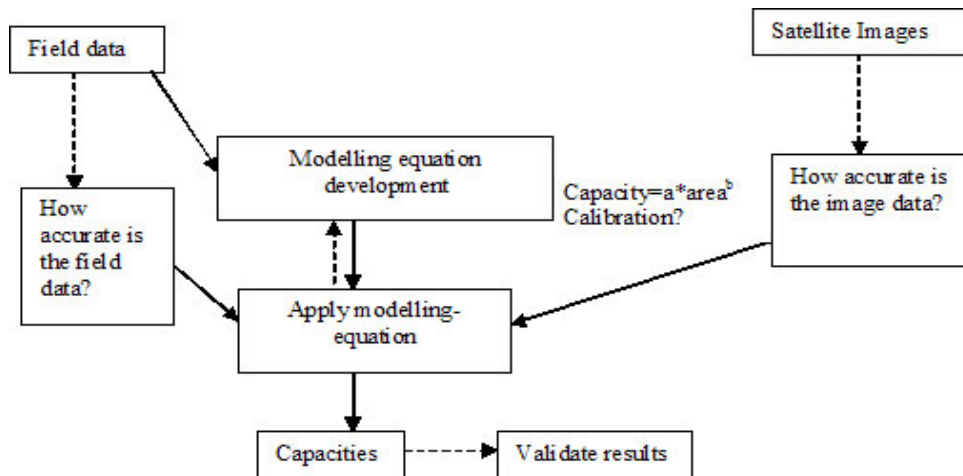


Figure 1: Development of modelling equation

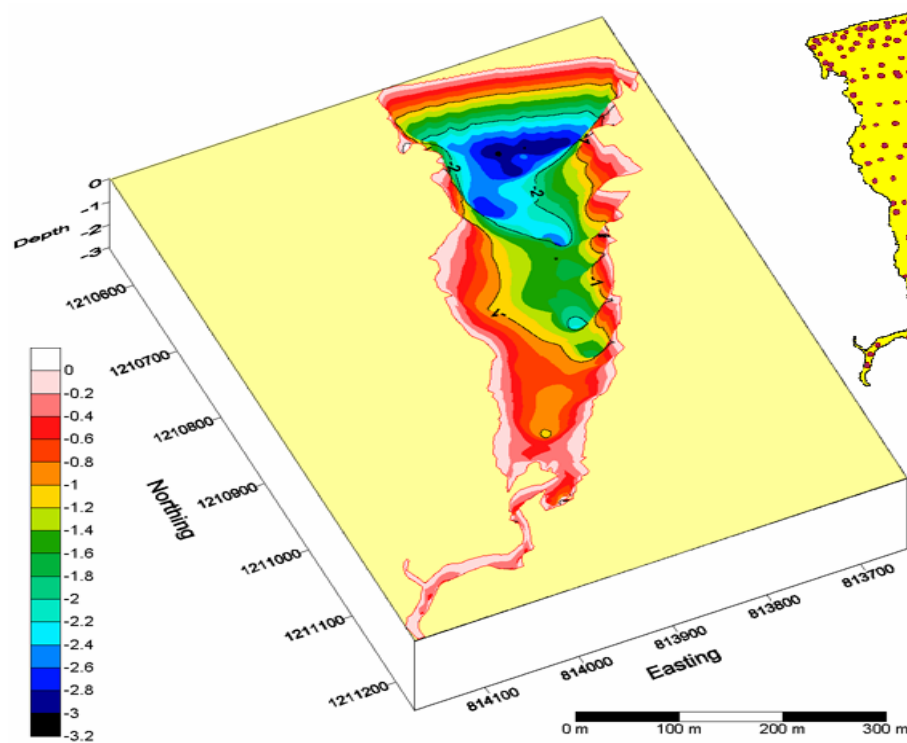


Figure 2: 3-D model of reservoir and distribution of measurements (Liebe, 2002)

The distribution of depth measurements (inset in Figure 2) shows a high density in close range to the dam wall (top end), where the deepest point of a reservoir is expected. The remaining part of the reservoir was covered with evenly distributed measurements (Referenced with UTM coordinates. Orientation changed).

Within a geomorphologically homogenous region, one may expect a good correlation between the surface area, which may be determined through satellite observations, and the stored volume. Such a relation depends on the general shape of the slopes (convex, through straight, to concave). For straight slope, one would expect the reservoir to have the shape of half a pyramid, with the dam forming the base of the (half) pyramid. For straight slopes, one would expect the volume to depend on the area to the power of one and a half:

$$Volume = constant \times Area^{1.5}$$

In reality, slopes tend to be convex, resulting in powers in the above relation of less than one and a half. For several parts of the world, the empirically correct relations have been established (see below). Once the volumes and areas of a number of reservoirs (20 to 60) have been established for a geomorphologically homogenous region, the correct relation between areas and volumes can be established by plotting the log of the areas against the log of the volumes in, for example, Excel. The slope of the line fitted through these points is the *exponent* (1.5 for straight slopes) and the *offset* is the constant. The correlation coefficient (R) is a measure of how good the correlation holds. For the Upper East Region of Ghana, an $R^2 > 0.98$ was found, implying that more than 98% of the variation in volume can be explained by measured areas (Liebe et al., 2005, Figure 3).

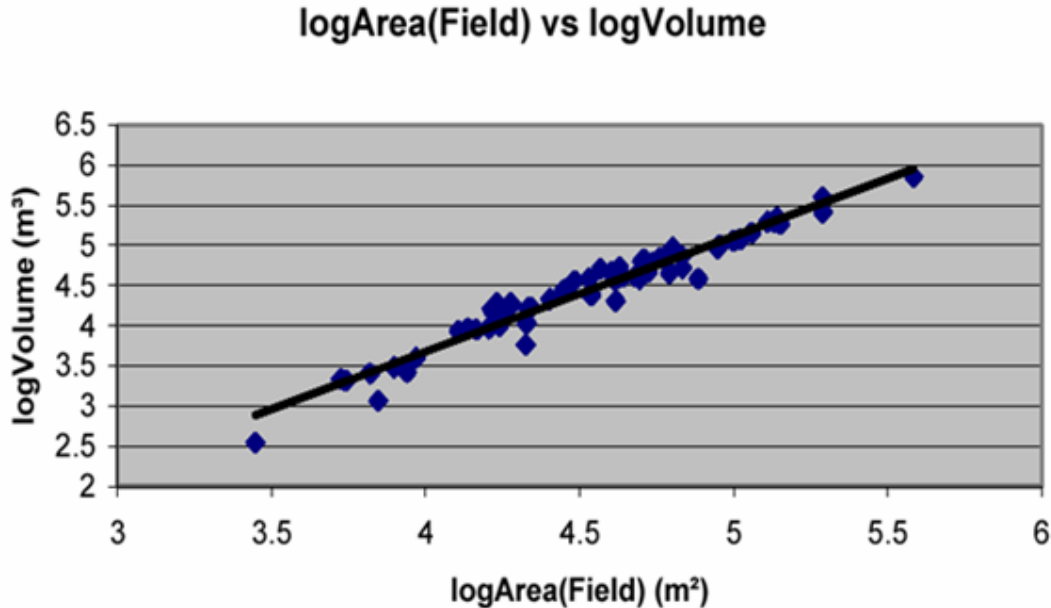


Figure 3: Establishing the relation between area (A) and volume (V) by plotting $\log(A)$ versus $\log(V)$. The slope is equal to *exponent* in $V = \text{constant} \times A^{\text{exponent}}$, and the offset is equal to $\log(\text{constant})$. Example from Liebe et al. (2005).

In the Limpopo Basin, Lower Mzingwane sub-catchment, this tool established that there is a power relationship between remotely sensed surface areas (m^2) and storage capacities of reservoirs (m^3), given as:

$$\text{Volume} = 0.023083 \times \text{Area}^{1.3272}$$

with 95% variation of the storage capacity being explained by surface areas (Sawunyama, et. al., 2006).

In the Upper East region of the Volta Basin in Ghana the area volume equation is:

$$\text{Volume} = 0.00857 \times \text{Area}^{1.43}$$

The area volume equation is based on a comprehensive survey of 61 of a total of 156 reservoirs that are larger than 1 ha, and explains 97.5% of the observed variance (Liebe 2002, Liebe et al. 2005).

In the Rio Preto sub-basin of the Sao Francisco River Basin, the volume (m^3) area (m^2) relationship is:

$$\text{Volume} = 0.2643 \times \text{Area}^{1.1632}$$

With an R^2 of 92.1%, thus surface area adequately explaining the variance in observed volume (Rodrigues, et. al., 2007).

In the Bandama River Basin in North Cote d'Ivoire, the volume (m^3) area (m^2) relationship developed was (Guordin, et. al., 2007):

$$Volume = 0.00405 \times Area^{1.4953}$$

The above volume-area relationships from different basins point to the fact that the approach used is robust and repeatable, and that the proposed tool can be used with confidence.

When a relationship between storage capacity and surface area is established for small reservoirs in a region, it can be used for the following purposes:

- Assess the economic value of water, based on water demand for different kinds of crops
- Conduct environmental modelling: estimates of storage volumes and surface areas can help, for instance, to improve and regionalize runoff, climate and land use information
- Evaluate potential reservoir sites where excess runoff can be captured without affecting downstream water uses
- Model the filling and depletion of reservoirs for different rainfall and evaporation conditions (Liebe 2002).

Lessons learned

There is a correlation between remotely sensed surface areas, and surface areas obtained from field surveys, hence reservoir storage capacity can be estimated using remote sensing information and modelled equations. In addition, remote sensing can help detect small reservoirs and adequately measure their surface areas. In this study, there were occasions in which remotely sensed surface area did not coincide with surface area estimated by field surveys. This may be caused by erroneous classification, for example, when areas with floating vegetation are classified as wetlands while similar areas with submerged vegetation are classified as water. Another explanation is that a relatively coarse spatial resolution (30m) was used. Thus, it is recommended that a resolution of 10m or less be used to detect small reservoirs (although higher resolution comes at a greater expense).

Limitations of the tool

While the power relationship tool can be used for estimating storage capacities of small reservoirs, the equations do not apply to very deep valley cross-sections.

References

- Crapper, P.F. 1980. Errors incurred in estimating an area of uniform land cover using Landsat, *Photogrammetric Engineering and Remote Sensing*, Journal 46:1295-1301.
- Gourdin F., Cecchi Philippe, Corbin Daniel, Etienne Jackie, Koné S., Casenave Alain. In : Cecchi Philippe (ed.), Lévêque Christian (préf.), Aubertin Catherine (préf.). *L'eau en partage : les petits barrages de Côte d'Ivoire*. Paris : IRD, 2007, p. 75-95. (Latitudes 23).
- Liebe, J. 2002. Estimation of water storage capacity and evaporation losses of small reservoirs in the Upper East Region of Ghana, Diploma Thesis, Geography Department, Bonn University.
- Liebe, J., N. van de Giesen, and M. Andreini, 2005. Estimation of small reservoir storage capacities in a semi-arid environment. A case study in the Upper East Region of Ghana. *Physics and Chemistry of the Earth 30* (2005), 448–454.

RODRIGUES, L. N. ; SANA, Edson Eyji ; AZEVEDO, Juscelino Antônio de ; SILVA, Euzebio Medrado da .
Distribuição espacial e área máxima do espelho d'água de pequenas barragens de terra na Bacia do Rio Preto.
Espaço e Geografia (UnB), v. 10, p. 101-122, 2007.

Sawunyama, T., Senzanje, A., Mhizha, A., 2006. Estimation of small reservoir storage capacities in Limpopo river basin using geographical information systems (GIS) and remotely sensed surface areas: Case of Mzingwane catchment. *Physics and Chemistry of the Earth* 31, 995-1002.

Sithole, P., Senzanje, A., 2006. A socio-economic study on small reservoir use, management and institutional issues in Avoca communal Lands, Insiza District, Gwanda, Limpopo Basin, Zimbabwe. Unpublished, Small Reservoirs Project Report, CPWF PN46, Accra, Ghana.

Contacts and Links

Munamati, M¹, Senzanje, A², Sawunyama, T³, Mhizha, A⁴, Rodriguez, L⁵, Liebe, J⁶

¹ *Department of Soil Science and Agricultural Engineering, University Zimbabwe, Zimbabwe Email: muchiemunamati@yahoo.com, mismuchie@gmail.com*

² *School of Bioresources Engineering & Environmental Hydrology, University of KwaZulu Natal, South Africa. Email: Senzanje@gmail.com, senzanje@ukzn.ac.za*

³ *Institute of Water Research, Rhodes University, South Africa, Email: tendai@iwr.ru.ac.za*

⁴ *Department of Civil Engineering, University of Zimbabwe, Zimbabwe. Email: mhizha@eng.uz.ac.zw*

⁵ *Embrapa Cerrados, Planaltina, DF. Brazil. Email: lineu@cpac.embrapa.br*

⁶ *Center for Development Research, University of Bonn. Germany. E-mail: jliebe@uni-bonn.de*

Website: www.smallreservoirs.org