BIBLIOGRAPHIE

BATTISTI C., Gli studi limnologici italiani nel 1898. *Riv. Geogr. Ital.* Firenze, 1898.
DONA' FERDINANDO, Il clima nelle conche dai laghi d Levico e di Caldonazzo. *Soc. Tipografica Mareggiani*, 1952.
MARINELLI O., Area e profondità dei principali laghi italiani. *Riv. Geograf. Ital.* Firenze 1894-95.
MORANDINI G., Considerazioni generali sulla distribuzione dei laghi nella Venezia Tridentina. *Boll. pesca, pisc. e idrob.* Roma 1933.
MORANDINI G., Caratteri generali e condizioni morfometriche dei laghi di Caldonazzo e di Levico. *Soc. Tipograf. Mareggiani*, Bologna 1952.
MORANDINI G., Ricerche limnologische sugli alti laghi alpini della Venezia Tridentina. Secondo contributo. *Boll. pesca, pisc. e idrob.* Roma 1949.
MORANDINI G. et SCHENK I., Condizioni termiche dei laghi di Caldonazzo e di Levico. *Soc. Tipograf. Mareggiani*, Bologna 1952.
MORONI, Cenni topografici sul Lago di Caldonazzo. Padova 1836.
TRENER G. B. et MORANDINI G., Gli alto laghi alpini della Venezia Tridentina. Primo contributo. *Suppl. al Boll. pesca, pisc. e idrob.* Roma 1936.
SERVIZIO IDROGRAFICO ITALIANO, Annali idrologici. Ist. Poligrafico dello Stato Roma.



# THE ESTIMATION OF BANK STORAGE FROM INFLOW-OUTFLOW STUDIES

D. R. DAWDY

U.S. Geological Survey, Menlo Park, California

ABSTRACT

The question of the design of storage projects which consider storage changes related to movement of water into and out of aquifers bordering the reservoir pool largely is unresolved and is infrequently treated in the literature. A method is presented for estimating bank storage by correlation of records of inflow and outflow of a reservoir. Records are corrected for evaporation from the lake surface. Residual bank storage inflow and outflow is shown to be related to the stage of the reservoir.

RÉSUMÉ

*Estimation de l'emmagasinement dans les berges d'un réservoir, basée sur l'étude des volumes d'eau pénétrant dans le réservoir et en sortant.*

La question de la prise en compte, lors de l'établissement de projets d'emmagasinement, des mouvements d'eau provenant des nappes aquifères bordant le réservoir ou y pénétrant n'est guère résolue et elle est rarement évoquée dans la littérature. Une méthode d'évaluation de cet emmagasinement souterrain est présentée, se basant sur la comparaison des volumes entrant dans le réservoir et en sortant. Les relevés sont corrigés pour tenir compte de l'évaporation de la surface d'eau. Il est montré que l'emmagasinement ou la restitution d'eau dans les berges est influencé par le niveau de l'eau du réservoir.

The question of the operation of storage projects which consider storage changes related to movement of water into and out of aquifers bordering the reservoir pool largely is unresolved and is infrequently treated in the literature. A method is presented for estimating bank storage by correlation of records of inflow and outflow of a reservoir. Records are corrected for evaporation from the lake surface. Residual bank storage inflow and outflow are shown to be related to both change in contents and stage of the reservoir.

In the compilation of stream-flow records for California[1], the surface streamflow records for the U S. Geological Survey gaging station on the Merced River at Exchequer were used to estimate missing record for the station at Bagby (see Figure 1). Lake McClure, capacity 280, 900 acre-feet, lies between the two stations, and the records for Exchequer, the downstream station, were corrected for change in storage of the lake and for evaporation. The plot of runoff at Bagby against Exchequer (adjusted) showed excessive scatter, particularly for the lower flows (Figure 2). Both ratings were well-defined, and the evaporation adjustments were minor, relative to the scatter. Therefore, it was assumed the scatter was the effect of bank storage in Lake McClure.

The direction of scatter on figure 2 was dependent upon the direction of the change in contents of Lake McClure. Those months where the change in storage was greater than 50 percent of the flow at Bagby and negligible runoff occurred from the drainage area between the two gages, were used as a basis for determining bank storage. A 45° regression of equal flow was assumed, because the scatter was so great the true relation between the flows at Bagby and Exchequer was unknown. The deviations

[1]U.S. Geological Survey 1960 Water Supply Paper 1315-A "Compilation of Records of Surface Waters of the United States through September 1950.

from the regression were related to change in contents in the reservoir, in a manner similar to Langbein[1], but there was excessive scatter.

In order to reduce the scatter, the deviation for each month was divided by the change in stage of the reservoir during the month. The value obtained was acre-feet of bank storage per foot of change in stage of the reservoir. This incremental storage was plotted against the change in contents for the reservoir during the month. (Figure 3)

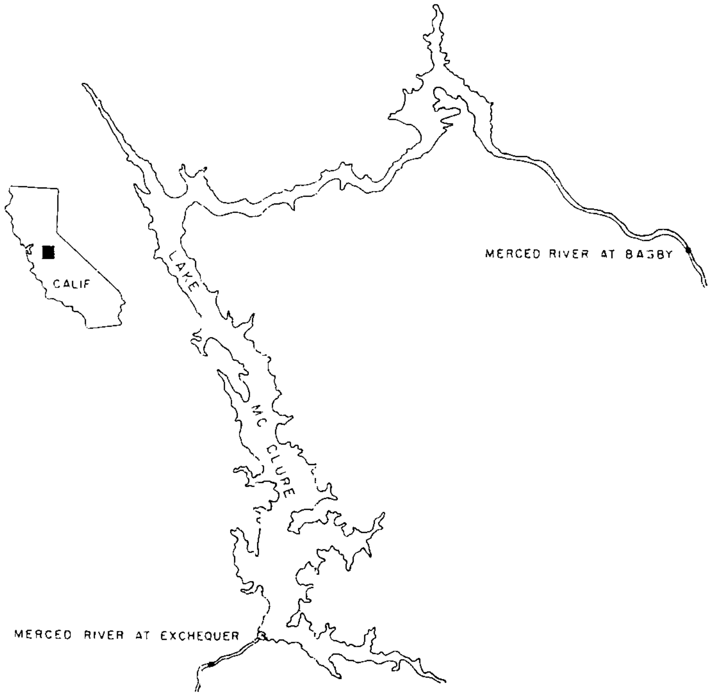


Fig. 1 — Location map of the study area.

Different corrections could be applied for rising and falling stages in the reservoir. The bank storage was greater when the reservoir was filling than when it was emptying. This could be owing to more water going into bank storage than returns from bank storage, with the difference between the two curves representing losses to groundwater.

From the shapes of the bank storage curves, one might expect the reservoir perimeter to consist of an impervious layer up to a gage-height of 500 ft., a layer of fairly homogeneously pervious material between 500 and 600 ft., with impervious outcrops above 600 ft. From about 700 ft. and above, the perimeter seems to be completely impervious. It is believed the pervious materials probably are mainly flood plain

[1]Langbein, W. B., 1960, Water Budget, Chapter J in *U.S. Geological Survey Professional Paper* 295, "Comprehensive Survey of Sedimentation in Lake Mead, 1948-49."



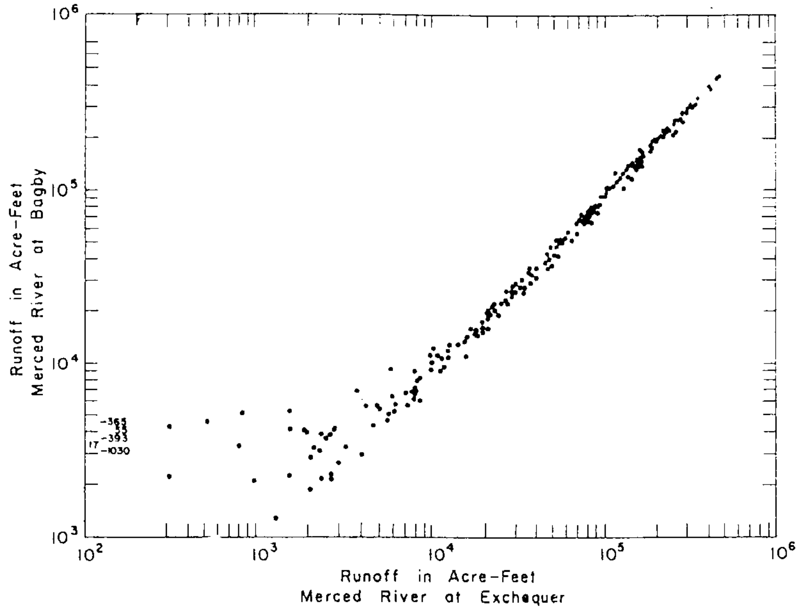


Fig. 2 — Comparison of streamflow of Merced River at Bagby and at Exchequer, adjusted for storage in and evaporation from Lake McClure.

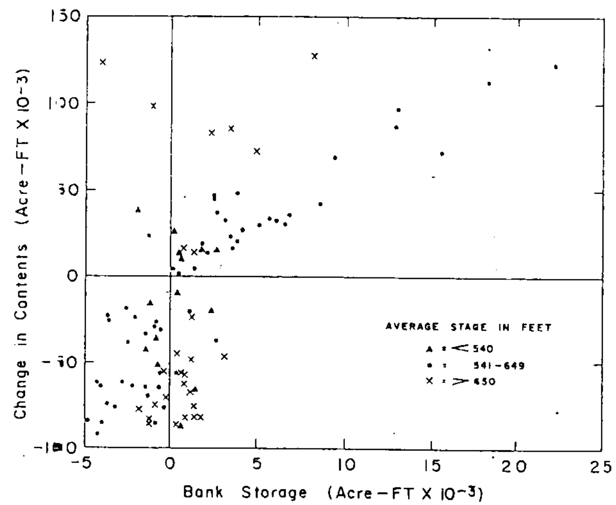


Fig. 3 — Relation of bank storage to monthly change in contents and average stage in Lake McClure.

deposits of the Merced River. This would require an alluvium 50 to 100 feet in thickness deposited in a bedrock valley, a common occurrence in the Sierra Nevada of California.

Adjustments for bank storage on the basis of Figure 3 were used to adjust the Exchequer record, and a new plot was made with the Bagby record (Figure 4). The scatter has been reduced considerably, and the pattern of scatter apparently no longer is related to the operation of the reservoir.

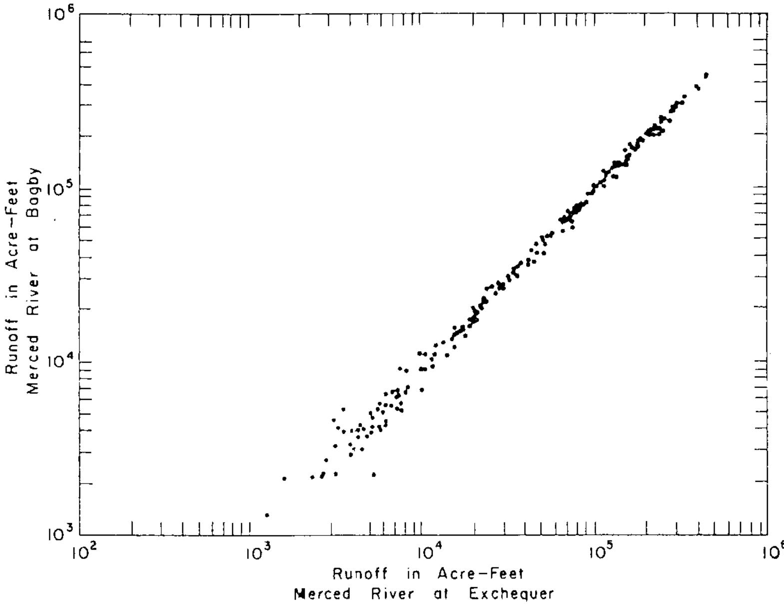


Fig. 4 — Comparison of streamflow values of Figure 2 adjusted for bank storage.

Figure 3 indicates two departures from the results of Langbein at Lake Mead. First, all water going into bank storage is not recoverable. Second, a family of curves rather than a single relation applies. This is shown in Figure 3, where the data are plotted to Langbein's ordinates. There is a break in the relation at the origin. For data in the optimum bank storage region of 575-625 feet, incremental bank storage equals about 15% of the incremental reservoir storage, but only about 1/3 of the bank storage is recoverable. For both very high stages (>650 ft.) and very low stages (<540 ft.) incremental bank storage may be on the order of 5% or less of the incremental reservoir storage, and practically none of this bank storage is recoverable.

Because the discharge into groundwater is approximated by the average gain in storage curve, and the area of the reservoir can be obtained from the capacity table, the rate of inflow into the bank storage aquifer can be computed, and is shown in Table 1.

The inflow figures in Table 1 are based on the assumption of a circular plan view for the aquifer, and on the surface area of the reservoir. Therefore, the values are only semi-quantitative but are relatively comparable because a similar scale factor adjustment probably applies to all flow values.



TABLE 1

*Computation of inflow to bank storage*

| Stage (ft.) | Area (acres) | Radius of lake (ft.) | Area of wetted surface per ft. of stage (sq. ft.) | Flux per month per foot of stage (acre-ft.) | Flux per day per foot of stage (1,000 gal.) | Flux (Gal. per day per sq. ft.) |
|---|---|---|---|---|---|---|
| 520 | 400 | 2,350 | 14,800 | 40 | 436 | 29.5 |
| 540 | 550 | 2,750 | 17,300 | 75 | 818 | 47.3 |
| 560 | 700 | 3,100 | 19,500 | 110 | 1,200 | 61.5 |
| 580 | 900 | 3,500 | 22,000 | 140 | 1,530 | 69.5 |
| 600 | 1100 | 3,900 | 24,400 | 150 | 1,630 | 66.7 |
| 620 | 1300 | 4,200 | 26,400 | 145 | 1,580 | 59,8 |

This analysis shows that inflow-outflow studies may be used to determine amounts of bank storage. The additional easily recoverable volume in bank storage can be computed as a function of stage of the reservoir. Inflow to bank storage and recoverable bank storage actually may be budgeted for in reservoir operations.