The anatomy of a flash flood in the Hartbeespoort catchment

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Abstract

As in many other semi-arid regions, rainfall in northern South Africa is erratic in both space and time. In response to such rainfall, runoff in the Hartbeespoort catchment tends to be flashy, particularly runoff arising from rain falling on paved surfaces in the northern suburbs of Johannesburg.

A specific flash flood was monitored from the originating storm down to the dissipation of the underflow in the lake. The storm was fairly typical of the region. Owing to low pondage in the channel, the velocities of the surge and current were almost equal and the hydrograph at the lower end of the channel could be derived by a simple model from those higher up. Two distinct silt loads were generated by the flood, the first probably containing larger particles eroded from around the channel and the second containing smaller particles eroded from the ground upon which the rain had fallen. The second silt load appeared to aggregate a large proportion of the chemicals dissolved in the river and to lead to a density current which produced anomalies in the normal current and temperature profiles. The underflowing flood-water displaced the water resident in the drowned river channel well down into the lake, but entrained sufficient upper-level water during its passage to warm it to a temperature which prevented it from reaching the deepest parts of the lake.

Introduction

Rain tends to fall erratically over arid and semi-arid regions (Christian and Parsons, 1959; Macmahon, 1979), including the northern part of South Africa. In winter, the region lies in the dry zone between the tropical convection zone and the temperate/ cyclonic zone, while in summer it lies within the tropical convection zone itself. Rain in summer falls predominantly in the form of scattered thunderstorms, generally lasting around an hour, travelling in a swathe less than 20 km wide and often persisting, at any particular spot, for less than 15 min (Alexander, undated). Because of the strength and scattered nature of the rainfall, the resulting river flow tends to be flashy. Since rain falls mainly in late afternoon (Preston Whyte and Tyson, 1988), as much as 16 h may elapse before the cold runoff is heated significantly by radiation. Thus river water debouching into lakes is expected to dive under warmer resident water (Hutchinson, 1957).

Lake Hartbeespoort is situated in the highveld region of northern South Africa, some 250 km south of the tropic of Capricorn (Fig. 1 A). At full supply, its surface lies 1 162 m above mean sea level (m a.m.s.l.). The lake forms the sink to a catchment (Fig. 1A) shaped like an irregular semi-circle. Mean annual rainfall over the catchment is estimated by Pitman (1986) to be 685 mm per year. Streams originating from rainfall flow from the southern perimeter to the terminal impoundment at the centre of the semi-circle in the north, subject to a straight-line gradient of approximately 1:70.

The mean annual runoff from the total catchment is estimated by Pitman (1986) to be 163 x $10^6 m^3$. The section of the catchment drained by the Magalies River, although large in area, yields less than 10% of this (Robarts et a1, 1982), since the main volume of precipitation over this section appears to be transpired by the vegetation covering it (Van Riet, 1987). The subcatchment over which most runoff occurs includes the headwaters of the Jukskei River and Braamfontein Spruit, and covers an area of some 500 km^2. This subcatchment contains a large proportion of the 12% urban cover of the total catchment, within which the pavements (61 km^2 in 1984, according to Pitman, 1986) roofs and culverts are expected to give rise to rapid and high runoff (NIWR, 1985).

The lake capacity, at full supply level, is 195 x $10^6 m^3$, under a surface area of around 20.3 km^2, giving a mean depth of 9.5 m. The local geology determines its cruciform shape, with the main body stretching from east to west and confined between two east-west ridges. The gorge in which the dam-wall lies follows the same NE-SW fault as the Crocodile River (Fig. IB).

In order to examine the effects of influx on the lake, the development of an isolated flash flood in a river channel and its debouchement is described. This medium-severity flood occurred in March 1984, after a three-week rainless period, and during a three-year drought.

Hydrology

Intensities of rainstorms which give rise to floods can be estimated in three dimensions with weather radar, subject to interpretation of the effects of factors such as temperature inversions, water vapour pressure gradients and ground clutter. They can alternatively by assessed with rain gauges, subject to difficulties involved in building three-dimensional pictures from often unevenly distributed point-sources in uneven terrain. They can thirdly be assessed in integrated form with flow meters in the runoff channels, subject to effects of factors such as capture, transpiration and seepage (Mimikou and Baltas, 1996).

The time of concentration of runoff at the lowest point in the catchment under a rainstorm can be calculated in terms of the Bransby-Williams equation (Alexander, undated):

$$t_c = k_b(L_s^{1.2} /(H_s^{0.2} A_c^{0.1})) \quad (1)$$

where:

t_c = the time it takes for precipitation falling on the hydraulically most remote point of the rainstorm to reach the lowest point
L_s = length of main river or reach
H_s = height difference from remote point to outlet
A_c = area of catchment
k_b = constant.

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