Chapter 9

INFILTRATION IN THE UPPER RÍO CHAGRES BASIN, PANAMA:

The Soil Conservation Service "Curve Numbers"

Lucas E. Calvo[1], Fred L. Ogden[2], and Jan M.H. Hendrickx[3]
[1]Universidad Tecnológica de Panama, [2]University of Connecticut, [3]New Mexico Institute of Technology

Abstract: Annual runoff hydrographs recorded by the Panama Canal Authority in the upper Río Chagres basin indicate several peculiar features. First, the annual hydrograph is strikingly seasonal, with very few signs of direct runoff and a continuous decay in base flow during the dry season. Secondly, there are signs of anomalously high runoff production efficiencies early in the wet season. Thirdly, the base flow from the catchment exhibits up to three different "quasi-stable" base flow discharges as the wet season progresses. This study examined runoff generation in the upper Río Chagres basin using the US Department of Agriculture, Natural Resources Conservation Service '*Curve Number*' *(CN)* methodology. Specifically, variation curve of the *CN* was analyzed using rainfall and runoff observations from the basin. Results indicate significant influence of seasonality on the *CN*. Furthermore, there are significant inter-seasonal changes in the *CN* that invalidate the applicability of the *CN* approach in this tropical watershed.

Keywords: Panama; Río Chagres; rainfall-runoff; hydrograph analysis

1. THE UPPER RÍO CHAGRES BASIN

The upper Río Chagres basin is one of the most important hydrologic catchments in Panama. Runoff from this basin represents a significant fraction of the water used to transit ships through the Panama Canal. Furthermore, this catchment provides drinking water for a large fraction of the population of Panama City. The basin is located on the eastern edge of the Panama Canal Watershed, as shown in Figure 1 (Panama Canal Commission, 1994).

According to Robinson (1985): …"A large portion of the basin is covered with thick, tropical rainforest. The terrain found along the river is probably the most rugged found in the entire Panama Canal Watershed. Landslides are seen in many places and indicate that even with thick foliage, erosion does occur. High hills with 45 degree slopes are common and the divide elevation rises up to 2500 ft (760 m) near the headwaters."

Rainfall and streamflow have been continuously recorded since 1933 at the Chico gage, located at the outlet of the upper Río Chagres basin, which has a drainage area of 411 km^2. A second gage, located in the downstream reaches of one of the major Río Chagres tributaries - the Río Piedras - has been recording rainfall and river stages since 1985. However a stage-discharge relation for the Piedras gage was not developed until after December, 2000 (Ogden, 2003, see CD accompanying this volume). Beginning in 1998, additional five rain gaging stations were installed in or near the boundary of the catchment at places called: Candelaria, Esperanza, Limpio, Río Piedras and Vista Mares. Figure 1 shows also the location of these stations inside the upper Río Chagres basin.

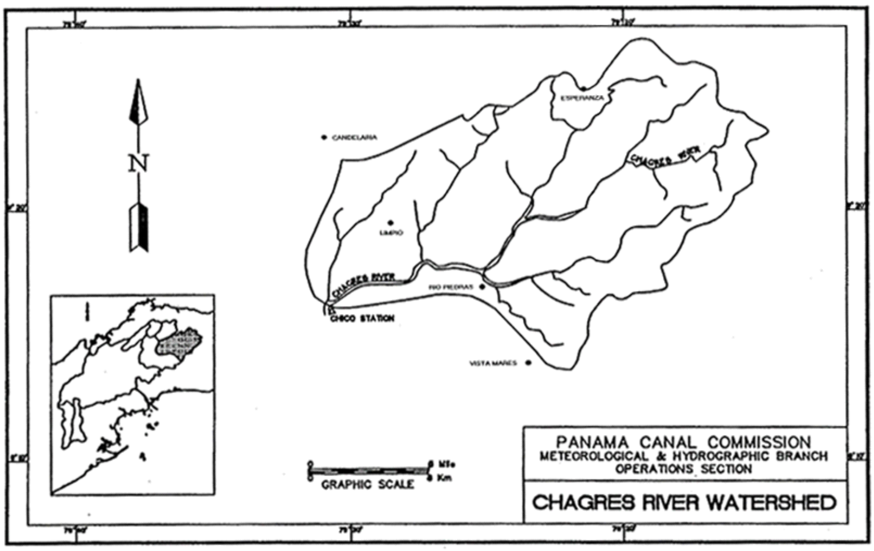

Figure 1. The upper Río Chagres basin, showing major rivers and streams.

2. DETERMINATION OF CURVE NUMBERS

Design rainfall runoff hydrology and environmental impact analysis draws heavily on the *'Curve Number' Method'* (USDA-SCS, 1972). The centerpiece of the method is the *'Curve Number'* coefficient (or *CN*), a measure of a watershed's hydrologic response potential, and usually selected from handbooks based on soils, cover, and land use. It can be shown that, when used to calculate rainfall excess and synthesis of composite hydrographs, the *CN* value is the most influential factor that determines flood peaks and volume,

The *CN* concept has been around for a considerable length of time (Ponce and Hawkins, 1996). The longevity of the approach lies in its simplicity. It has been re-interpreted several times (Steenhuis *et al.,* 1995), and has been the subject of much discussion. Limited comparisons elsewhere have suggested significant departures between handbook and data-defined *CN*s. In addition, the primary reference for the *CN* method, National Engineering Handbook#4, suggests that the soils-based table values are only guides, and that local values should be used if possible. A joint workgroup was formed by the US Department of Agriculture to review the *CN* procedure in terms of current field measurements. As a result of this workgroup much of the National Engineering Handbook has been rewritten to improve consistency and clarity (Hjelmfelt *et al.,* 2000). Furthermore, an asymptotic method was developed for determining *Curve Numbers* from rainfall-runoff data.

One of the principal modifications done by the group was to remove reference to the antecedent moisture conditions (AMC). Variability is incorporated by considering *CN* as a random variable and the AMC-I and AMC-III conditions as bounds on the distribution.

The equation utilized by the Soil Conservation Service for direct runoff estimation is:

$$Q = \frac{\left(P - 0.2S\right)^2}{\left(P + 0.8S\right)} \tag{1}$$

for $P > 0.2S$, where *Q* and *P* are the direct runoff and rainfall depths, and S is a storage index, all in inches. *CN* is a transformation of *S*, or:

$$CN = \frac{1000}{S + 10} \tag{2}$$

The runoff equation can be solved via the quadratic formula to yield:

$$S = 5\left(P + 2Q - \sqrt{4Q^2 + 5PQ}\right) \tag{3}$$

If values for Q and P are available from local watersheds, then S and CN can be calculated for every event with $0 < Q < P$. CN may vary from 0 to 100, although CNs are typically in the range of 55-95.

The above procedure works well using "ordered" P and Q data (Hawkins, 1993). That is, when P and Q are matched by rank order. This unnatural pairing matches the frequency of each, in keeping with the dominant usage of the method. That is, to estimate the (for example) 100-yr runoff from the100-yr rainfall. When this is done, often times a strong secondary relationship remains between the CN and P. For most cases, this relationship is well described by the function:

$$CN = CN_\infty + (100 - CN_\infty)e^{-kP} \tag{4}$$

where CN_∞ and k are coefficients to be determined. A least squares procedure for fitting the above equation can be developed. As CN_∞ is the asymptotic stable value approached as P grows larger, it is more appropriate for large events, such as design storms, and thus CN_∞ is taken as the defining CN for the watershed.

3. DETERMINATION OF CURVE NUMBERS FOR THE UPPER RÍO CHAGRES BASIN

A total of 31 storm events were selected for which precipitation and discharge were recorded from 1998 to 2000 in the upper Río Chagres basin (Table 1). Within this period at least five rain gauges were working in the basin. Discharge measurements were used from the Chico gage, at the basin outlet.

The Thiessen Polygon Method was used to estimate the average rainfall depth, P, in the basin. For the 1998 and 1999 storms, data were available from six rain gage stations; for 2000 no data were available for the Limpio gage. After constructing the polygons and measuring the areas, the weights shown in Table 2 were obtained. Care should be taken in the determination of P to include only those precipitation intervals that corresponds in fact to the analyzed event.

The total direct runoff, Q, is obtained by separating the baseflow from the total hydrographs measured on Chico gage. Baseflow was separated by a