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Monitoring the hydrological regime in tropical islands: Cuban experience in managing the hydrological network

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Abstract This work presents the Cuban experience in the organization and operation of the hydrological network, as well as some results reached in the utilization of the basic data. The work presents the way in which the Hydrological Service of Cuba has achieved a harmonious development of its hydrological network.

Monitoreo del régimen hidrológico en las islas tropicales: experiencia cubana en la operación de las redes hidrológicas

Resumen Este artículo expone la experiencia cubana en la organización y operación de las redes hidrológicas, así como algunos de los resultados de la ulterior utilización de los datos básicos. Se presenta la forma en que el Servicio Hidrológico de Cuba ha logrado un desarrollo estable en las redes.

THE HYDROLOGICAL NETWORK IN CUBA: ORIGIN AND EVOLUTION

The origin of the hydrological network in Cuba is intimately linked with the intensive development of the sugar cane industry and the early introduction of the railway in the nineteenth century. This gave rise to a raingauge network that, though wrongly distributed and without an adequate design, almost encompassed all the flatlands in the country. The first commissioned institution for water resources management was founded in 1961 and since then the network evolution has been based on scientific criteria.

The high development of the hydraulic infrastructure has transformed the natural reference framework of the hydrological processes and, consequently, many ideas about the hydrological network. An example of this is the reduction of the number of natural reaches of rivers suitable for use as hydrometric stations. This has required inclusion in the network of a number of dams as stations that, through the water balance, estimate the river runoff volumes. Also, assimilation of Cuba's small islands for tourist activity has required hydrologists to develop new criteria about the hydrological network in these territories.

NETWORK DESIGN AND CLASSIFICATION OF THE HYDROLOGICAL STATIONS

The network design in Cuba is an integrated system that includes: raingauging stations, weather stations, river stations, groundwater stations and water quality stations. Table 1 shows the hydrological network statistics. The design answers the

Table 1 The Cuban Hydrological Network (1995).

Network type	Basic network	Special network	Total	Density (km^2 per station)
Pluviometers	2116	689	805	40
Recording rain-gauge	120	190	310	358
Climatic stations	76			1460
River stations:		-	126	890
conventional	64			
water balance	62			
Groundwater stations	1942	457	399	-
Water quality stations	2009	-	-	-

questions: (a) what is to be measured? (b) where to measure? (c) when to measure? and (d) how accurately is it to be measured?

According to Moss (1991), the design is based on the following concepts: (a) institutional set-up, (b) purpose of the network, (c) objective of the network, (d) established priorities, (e) assessment of the existing network, (f) network design, (g) optimize operation, (h) cost-benefit analysis, (i) implementation and (j) review of network.

The hydrological stations are classified as: (a) principal stations, (b) secondary stations and (c) special stations (WMO, 1984).

HYDROLOGICAL NETWORK OPERATION

Network operation comprises, between its principal objectives, the constant improvement of its design, checking the quality of data observation procedures and analysis, and generalization of the data. To achieve this an integrated work programme exists: (a) plan of inspection and maintenance of stations, (b) work plan for the observations in all stations, (c) specific programme for extreme events, (d) procedures for the primary processing of the data, (e) procedures for the generalization of the information, and (f) procedures for evaluating the network operation.

All stations possess a work programme that establishes a common period of operation within the hydrological network.

ORGANIZATIONAL AND TECHNICAL BASE FOR THE HYDROLOGICAL NETWORK

The organizational base for the network operation is the hydraulic administrative structure of the country, which permits a systematic interaction between its levels: Hydraulic Zone, Hydraulic Complex and Provincial and National Offices of the Hydrological Service.

The Hydraulic Complex is an administrative unit that, in the infrastructure base, controls the operation of the superficial and the underground basins, the hydrological network and the hydraulic works that, within a territorial unit, maintain a mutually functional relationship the water users (Planos *et al.*, 1995).

Raingauge network

This network is observed by voluntary personnel (2000 observers) who do not receive any pay for their labour. The observers of the recording raingauges receive a monthly reward for observation and care of the equipment.

A characteristic of the raingauge network is that approximately 74% of its stations send data monthly by mail to the Hydrological Office of the Hydraulic Complexes, employing for this an exempted mail card. The pluviometers, as well as the graduated scales employed for the measurements, are manufactured by the Hydrological Service. The observers' voluntary work, the use of exempted mail cards and the central manufacturing of some equipment, reduce the hydrological network operation costs.

The field attention to the pluviometers is carried out quarterly; this term can be shortened if the observer reports some anomaly on the mail card, or if the card is not received during two consecutive months. For the recording raingauges, the attention required is more specialized and is therefore monthly. Because the pluviograph operation is more expensive, and to reduce the cost of attention to recording raingauges (and to give a greater safety to this equipment), the recording raingauge installation has been made at river and climatic stations, dams and other facilities of the Cuban National Water Resource Institute.

All pluviometers of the hydrological network have a requirement that, from the first day of operation, all incidents that could have importance in studying the quality of the rain data are collected, e.g. changes, existence/elimination of interference, interruptions, observer changes, rule changes, inspection results, among other useful aspects. Changes in the hydrological network (new installations, decreases and movements) are regulated strictly by a formal document. Any change in the network always requires the approval of the National Office of the Hydrological Service.

Annually, the Provincial Office of the Hydrological Service makes an inspection of the pluviometers. The National Office of Hydrological Service effects sampling inspections to the hydrological network, with the participation of personnel from provincial entities and of the corresponding Hydraulic Complex.

Climatic Stations Network (CSN)

The CSN is designed to obtain data for evaporation from a free water surface. This data is used for the dam and basin water balances. The CSN stations are supplied with the necessary equipment and are operated by the Hydraulic Complexes under the specifications of the Hydrological Service. Observations are carried out by specially trained personnel who, unless in the isolated stations (currently 18 of the 76 existing), share other technical tasks in the dam or river stations. This type of hydrological station requires special attention, because of the assorted equipment that it contains. The stability in the operation of this hydrological network has been high, since it has been watched by personnel who live in its surroundings.

River stations network

These stations are grouped into two categories: (a) conventional river stations, and (b) dams where the water balance is accomplished. The network density, 890 km^2 per station, is low (Buján & Lora, 1995), compared with the minimal density criterion established by the WMO (140–300 km^2 per station) (WMO, 1984). This low density is a consequence of: (a) the insular character of the Cuban territory, with small basins and short rivers, many of them ephemeral, and river reaches lacking good hydraulic conditions for measurement, and (b) the existence of more than 200 dams built in the principal basins.

The stations are provided with convenient facilities for measurement (scales, limnigraph and cable-ways for measuring high discharges). The stations are operated by professional observers who live nearby. In the stations located in inaccessible places, customary practice has been to build housing for the personnel of the station and their families.

In the hydrometric network area-velocity measurements prevail and therefore, in most of them, the hydrometric current meter is employed. The low water levels are monitored by fording and the high water levels with the cable-way.

The possibility of locating stations in river reaches with good hydraulic conditions is scarce, given the short river courses. Rivers flow through flat zones and usually, during heavy rainfall, the riverbeds overflow. The stations are located in reaches with different types of hydraulic regimes, so that measurement and calculation methods must be employed with a considerable degree of suitability.

The number of stations with stable and simple water level-discharge relationships is small and this compels having an excellent measurement plan to guarantee the discharge analysis, making the operation of the stations costly. The operation cost of these stations is increased by the need to measure the river levels constantly through automatic equipment, because in summer the high discharges occur suddenly and, frequently, at night.

Dams in hydrological water balance replace the stations already closed and are equivalent to these stations with respect to monthly and annual runoff data. Dams in hydrological water balance provide the only alternative for increasing the hydrological network, due to the great number of existing regulated basins in the country. The resulting data from the hydrological water balance are not so accurate as the measurements from conventional stations. However, with respect to estimating monthly and annual volumes of superficial runoff, as well as its distribution over the year, they provide valuable data.

Groundwater network

Aquifers open to the sea and karstic aquifers are common in the country. Also, in the extended part of the Cuban territory, the water supply is mainly derived from aquifers. Thus groundwater control is an important task for the Hydrological Service.

Because of the geological complexity of Cuba, the hydrogeological network design is based on the spatial relationships between geological and geomorphological structures, groundwater characteristics, and rain distribution. In karstic territories the

preferential connection between the karstic structures is taken into account. Then the hydrogeological network design is specific for each aquifer.

This network is extended, principally, in the more significant aquifers of the country. The principal objective of this network is monitoring of aquifer water table levels; information that is used to evaluate the aquifer stage in relation to its exploitation and the groundwater quality. The information that is collected from a special network is controlled by the Hydrogeological National Office. The groundwater quality data are checked by mathematical modelling and spatial technical data analysis.

Water quality network

Water quality is strictly controlled by formal regulations. Different laboratory techniques are applied according to water use. A national laboratory network specializing in water quality analysis covers the whole country.

SYSTEMATIC PROCESSING OF THE HYDROLOGICAL DATA

There are three processing levels of the data: (a) primary processing, (b) analysis of the data quality, and (c) rectification of errors in the hydrological information. The primary processing is accomplished in the Hydrology Offices of the Hydraulic Complexes; the objective of this work is to certify the accuracy of the basic information. The analysis of the data quality is accomplished monthly in the Provincial Office of the Hydrological Service, using conventional statistical and hydrological methods.

DAILY INFORMATIVE HYDROLOGICAL NETWORK OF RAIN (DIHNR)

The DIHNR constitutes a special hydrological network that compliments the need to have daily rainfall data (Fig. 1). This network has been in operation since 1973. Bulletins destined for government authorities, institutions, the press and the population are generated from the data supplied by this network. The equipment that composes this network is located at sites connected with the national telegraphic network.

CONTROL OF DAM OPERATION

Operationally, the water abstraction from the dams is regulated according to special rules that use the exploitation graphic illustrated in Fig. 2. Using information of on the natural water supply to a dam, and the distribution of monthly runoff, the dam water level is controlled such that water supply is guaranteed without any risk of dam drainage. The exploitation graphic details the annual plan of water supply and indicates when it is possible to increase the water supply and make use of water during drought.

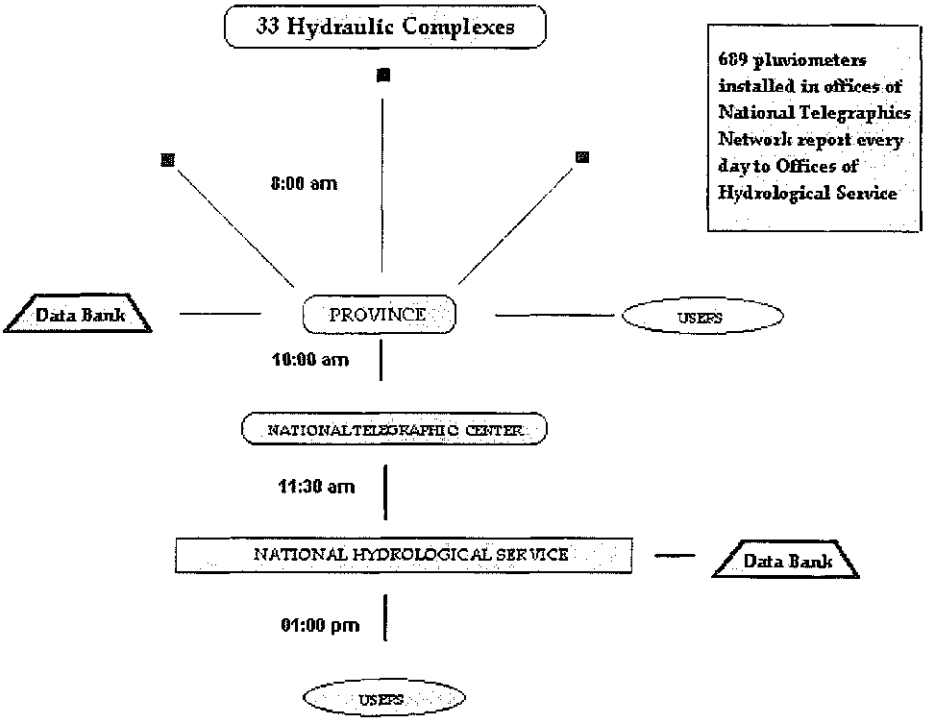

Fig. 1 Flow chart of the daily information network.

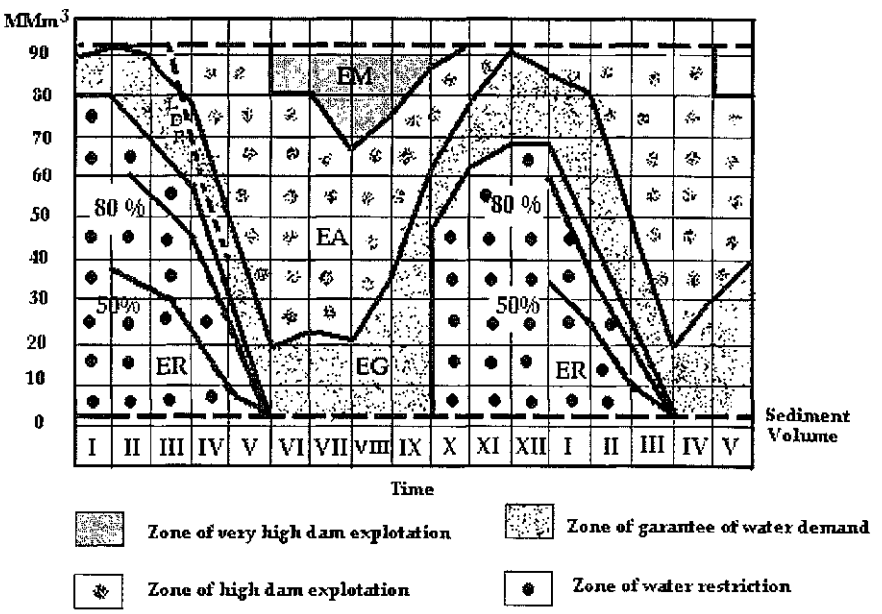

Fig. 2 Graphic for daily control of dam operation.

The main features of the exploitation graphic are:

- *EM area*: maximum supply; it is possible to increase the water supply up the plan and open the drainage valve.
- *EA area*: high supply; it is possible to increase the water supply up the plan.
- *EG area*: the supply should not exceed the plan. Depending on the dam water level, the current period in the hydrological year and the actual hydrological conditions, there may be some flexibility in the dam operation.
- *ER area*: minimum supply; the water supply depends on the dam water level, the current period in the hydrological year and the actual hydrological conditions.

TRAINING PROGRAMME FOR HYDROLOGICAL OBSERVERS

There is a training programme for the qualification of the personnel running the hydrometric network. To contribute to the training programme, technical books are published.

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