HYDROLOGICAL DATA ACQUISITION SYSTEMS

G. G. S. Pegram
Department of Civil Engineering, University of Natal, Durban, South Africa

S. Van Biljon
Department of Water Affairs and Forestry, Pretoria, South Africa

J. M. Jordaan
Arcadia, Pretoria, South Africa

Keywords: Hydrology, water distribution, hydrologic cycle, rain gauge data, water data acquisition, HYCOS, WHYCOS, METEOSAT

Contents

Summary

This chapter describes some of the systems used to collect and disseminate data on hydrological processes such as rainfall, stream flow, and extreme weather phenomena. Rainfall data are collected by means of rain gauges and radar observations. The progress of storm systems may be forecast by means of stochastic models on a daily or seasonal basis. Hydrological data are collected by means of a number of technologies ranging from observing gauges, installed at flow measuring points, to automatic data recorders and remote sensing. Transmission of data from international hydrological data collection systems is done by telephone communication, radio, and satellite. The application of a hydrological cycle observing system operated in southern Africa is described. This was applied to flood monitoring during the passage of the tropical *Cyclone Eline* across southern Mozambique and South Africa, with the associated human tragedies caused by the extreme floods in 2000.

1. Introduction

Hydrology is the scientific study and gathering of information regarding the presence and availability of water in all its forms on earth. It includes water distribution in both space and time on the globe, and the processing, storage, and retrieval of hydrological data. The aim and purpose of the analyses of hydrological information is to be able to benefit humanity at a future time with respect to water supply, flood protection, waterpower, and coastal defense projects.

The collection of hydrological data must be based on sound theoretical principles, well coordinated, and subjected to strict quality control and error estimation and correction techniques. The detailed ways of obtaining and recording hydrological data by means of hydraulic measuring flumes and calibrated weirs are described elsewhere in the present theme and form the basis of good practice (see *Flow Measuring Techniques*).

2. The Hydrologic Cycle

The hydrologic cycle considers all water on Earth to form part of an interconnected process of storage, evaporation, precipitation, surface runoff and underground transport, absorption by plant roots, transpiration from vegetative cover, consumptive usage by humans and animals, wastewater disposal, and return to storage—continuously repeated for periods ranging from days to centuries. The driver behind this eternal cycle is solar energy and the restoring force is gravity.

The analysis of the behavior of water in the global continuum, both on land and at sea, has become a scientific pursuit in its own right and is approached from both theoretical and practical points of view as described elsewhere (see *Hydroinformatics*).

3. Hydrological Data Collection

The earliest data collection systematically carried out involved the measuring of rainfall and evaporation from free-water surfaces, the gauging of lake levels and measurement of stream flow, and the assessment of underground water storage and potential yields. Snow and ice accumulations were also surveyed to obtain estimates of spring snowmelt, and changes in the levels of enclosed water bodies, estuaries, and oceans were monitored. The following sections cover brief surveys of the principal data collection systems that are involved in the gathering and analysis of hydrological information.

3.1. Rainfall Data

Rainfall data is obtained by means of three types of instruments: rain gauges, radar, and satellite technology.

- *Rain gauges* measure the accumulated point rainfall depth over periods at selected stations by means of direct interception into graduated collector vessels (hourly, daily, monthly, and so on). These are attended by observers or may be of the autographic recording type.

- *Radar* measures the returned electromagnetic power (backscatter) from radio-frequency signals sent out into storm-cloud accumulations, and the rainfall intensity is inferred instantaneously over areas of up to 200 km in diameter.
- *Satellite technology* measures the emitted radiation (thermal) and infers the rainfall intensity rate at any instant over entire regions such as continents (e.g., Meteosat, Tiros).

By comparing these different measurements, the characteristics of point rainfall intensity and area rainfall, both instantaneous and accumulated values, can be derived and the differences emphasized; for example, rain gauging would complement the other methods by providing local calibration of more diffused data. The other methods, however, can give more instantaneous peak-value indications than rain gauges operating over a time period and needing frequent site visits, i.e. they provide real-time information rather than archival data. This is invaluable in preparing evacuation routines in the face of approaching storms such as hurricanes, typhoons, tropical cyclones, and tornadoes.

3.2. Rainfall Data Formats

Rainfall data coming from the systems described above differ from each other in important respects.

- *Rain gauges* yield time-series accumulations over seconds, hours, days, months, and years. These time series can be viewed as realizations of *pulsed processes* over time occurring at an infinitesimally small area (a point). These time series can be collected and brought together into multisite data series and treated as *multivariate time series*.
- *Radar* and *satellite technology* yield various products, but the most useful contribution to hydrology is an estimate of the *rainfall rate at ground level*. The data therefore are estimates of the instantaneous realization of a process happening over an area during a time period. The data can be viewed as *instantaneous samples***,** averaged in two-dimensional space from a *random field process* taken over small areas of about 1 km^2.

3.3. Uses of Rain Gauge Data

The uses made of data from rain gauges can be differentiated according to the time intervals over which the data are collected or averaged, namely as follows:

- *Annual Data* are used for drought studies considering wet and dry years and for the study of pseudocyclicity of climate variations. Annual data generally show a low serial correlation of 0.1 plus or minus 0.05.
- *Monthly Data* may be used for “patching” stream flow data by means of catchment and stochastic models. Notably, the serial correlation of “deseasonalized” data is about 0.15 plus or minus 0.05.
- *Daily Data* are used for driving catchment models for estimating water resources, flood forecasting, and soil moisture accounting for agriculture.
- *Hourly Data* are used for design storm analyses, flash-flood forecasting by means of catchment models, and for modeling erosivity.

The problem with data from rain gauging is that this form of data collection is diminishing; therefore, there are often gaps and errors and a general lack of high-resolution information. There are large intrinsic errors, and spatial estimates over short time duration are not good.

3.4. Rain Gauge Data Models

These models are dictated by the type of data, e.g., annually, monthly, and so on.

- *Annual Data* are nearly *normally distributed*, usually without zero values, yet annual series have *low predictability*.
- *Monthly Data* are difficult to model in arid regions, many months having zero rainfall; in humid regions models are successful. It is unusual to use models to simulate monthly rainfall; they tend to be used directly in catchment runoff models. Problems are encountered with supplying missing data, but the most successful method to date is a linear regression combination with an EM algorithm.
- *Daily Data* represent the bulk of the available raw data sets and are divided into either *univariate* or *multivariate* sets.
  - *Univariate* daily data are characterized by intermittency and low correlation between amounts gauged on successive days. The wet-dry process is modeled as a two-state Markov chain. The wet-period process amounts are independently distributed as mixed exponential, log-normal, gamma, and other distributions. In an application, the univariate model has been interpolated over half a million 1-arc-min squares in South Africa, using co-kriging techniques.
  - *Multivariate* daily data are difficult to specify as a multisite two-state Markov chain. There are maps of average behavior at individual sites, which are not based on joint distribution behavior, used for yielding areal estimates. Areal reduction factors relate the extreme statistics of daily data at a typical gauged site to obtain extreme statistics over an area, and this is used particularly for flood studies relating to dams and bridges. Methods of areal integration vary from unsophisticated averaging to surface fitting to highly sophisticated *kriging* techniques.
- *Hourly Data* may be obtained by means of special gauges incorporating tipping buckets or drop-counters. Timing of pulses is recorded, usually accumulated over short intervals of 5 min and then aggregated over an hour. There are various models of continuous processes used for assimilation and disaggregation of daily data records.

3.5. Uses of and Problems with Radar Data

Radar gives detailed spatial information over a large area in real time at a high frequency. Problems with radar data are the following:

- The quality of the data decreases with the radius of the coverage: good up to a 50-km radius, reasonable between a 50-km and 70-km radius, and questionable between a 70-km and 100-km radius.
- There are limitations due to the height of the base-scan above the ground, partial beam filling, and bright band ground clutter, together with anomalous propagation due density variations in the atmosphere.

For flood forecasting purposes, it is as valuable to know where it is raining and where not, as it is to know how much it is raining. Therefore, radar information is a valuable real-time indicator of imminent flooding danger.

3.6. Radar Data Models

There are two kinds of modeling of radar data, namely *spatial* models and *space-time* models.

- *Spatial models* fall into two broad types, Mandelbrot's fractals and Gaussian random fields. The first are models of fractal noise, which include the alpha model—a multiplicative cascade model. Such models are intrinsically nonstationary. The second are models characterized by being stationary. Both types of model use a small parameter set and both address the nature of the spatial dependence in a rainfall field that is typified by a linear-log spectrum. This concentrates power at low frequencies with enough remaining at high frequencies to give a choppy, semi-intermittent clustering appearance to the modeled field, typifying what the radar data look like.
- *Space-time models*. The correlation of random rainfall fields in time can be characterized by the *spectrum* (or equivalently the *correlogram*) if the process is stationary. There is evidence indicating that rain fields appearing to be nonstationary locally have a correlation distance less than 30 km for most types of rainfall. In this case, transformed Gaussian random field models are suitable for describing the space-time behavior of the rainfall. One of the advantages of these linear models is that the serial dependence structure can be expressed conveniently in difference-equation form. This has considerable advantages for short-term *stochastic forecasting* (see *Probabilistic Methods and Stochastic Hydrology*).

-
-
-

Bibliography

Biswas A.K. *History of Hydrology*, 336 pp. Amsterdam: North Holland. [A standard textbook on the subject].

Gray D.M. (1973). *Handbook on the Principles of Hydrology*. US: Water Information Center. [An introductory treatise].

<medhycos.com> [A regional database for gauging hydrological systems in the Mediterranean that was established at IRD.]

Rodda J.C., Pieyns S.A., Sehmi S. and Matthews G. (1993). Toward a World Hydrological Cycle Observing System. *Hydrological Sciences Journal* **38** (5). [A proposal for a worldwide network of key hydrological stations linked by satellite to a quality control database, forming the World Hydrological Cycle Observing System, WHYCOS.]

UNCED (1992). *Agenda 21*, Chapter 18, 321 pp. Rio de Janeiro: United Nations Conference on Environment and Development (UNCED). [An approach for reconciling water resources development with environmental protection. Considered to be a recognized guideline for the future.]

Van Biljon S., Houghton-Carr H. and Booysen G. (2000). SADC-HYCOS: An Opportunity for Diversified Monitoring and Information. *International Conference on Mozambique Floods.* Maputo, Mozambique: SADC (Southern African Development Community). [A detailed description of the HYCOS system and its use for the implementation of flood-warning measures in southern Mozambique during the disastrous floods of February 2000 from the tropical *Cyclone Eline*.]

<www.sadchyco.pwv.gov.za/sadc> [Information on the Southern African Development Community regional HYCOS project.]

Biographical Sketches

Geoffrey Pegram is Professor of Hydraulic Engineering in the Department of Civil Engineering at the University of Natal in Durban, South Africa. His Bachelor's and Master's degrees in Engineering were obtained at the University of Natal, and his doctorate was awarded by the University of Lancaster Mathematics Department for work on probability theory as applied to storage.

His expertise lies in hydraulic and hydrologic modeling, stochastic hydrology, and radar rainfall modeling. Apart from rain fields and rainfall modeling, his research interests include river flood hydraulics, flood protection and forecasting, and large reservoir system reliability. He has published in stochastic hydrology, water resources, and hydraulics and has an interest in space-time modeling of rain fields measured by weather radar.

He is the representative of the International Association of Hydrological Sciences (IAHS) on the International Commission on Remote Sensing and Data Transmission (ICRSDT). He is a member of the South African National Committee of the IAHS (SANCIAHS) for 2000 to 2003.

S. Van Biljon is director of Hydrology of the Department of Water Affairs and Forestry, Pretoria, South Africa. He has a B.Sc. (Hons.) degree, is a specialist in hydrological investigations, and has developed his career around practical solutions for data collection on stream flow for the Department of Water Affairs and Forestry and on the interpretation of hydrological data.

He has presented and published several technical papers at international conferences, implemented the SA HYCOS project, and contributed toward the implementation of the SADC-HYCOS project. He is a member of the WHYCOS International Advisory Group of WMO and active in the promotion of WHYCOS principles.

He serves on various steering committees for hydrological and meteorological research. He is active on operational activities for monitoring the surface water resources of South Africa, flood forecasting and recording, and water resources assessment.

J.M. Jordaan is a retired professor of civil engineering and a professional engineer in civil engineering hydraulics. He graduated from the University of the Witwatersrand (B.Sc. Eng.) and obtained the degrees M.S. (U. Wisconsin), Civil Engineer (MIT), and Sc.D. (MIT). He has lectured at the Universities of Hawaii, Delaware, and Pretoria.

His professional career included hydraulic and coastal engineering research with the Council for Scientific and Industrial Research in Pretoria, South Africa, and the US Naval Civil Engineering Laboratory, Port Hueneme California, US.

He specialized in hydraulic engineering practice for a period of 28 years with the Department of Water Affairs in South Africa and Namibia and was active as technical assessor for the proposed Misicuni Multiple-Purpose Hydroelectric and Water Project, Cochabamba, Bolivia, South America.