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SATELLITE DATA TRANSMISSION AND HYDROLOGICAL FORECASTING IN THE FIGHT AGAINST ONCHOCERCIASIS IN WEST AFRICA

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ABSTRACT

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Onchocerciasis, or river blindness, is an endemic disease which causes great hardship in west Africa. Within the World Health Organization's Onchocerciasis Control Program (WHO/OCP), reliable data on the discharge of the watercourses have been obtained by using remote satellite transmission. These data are necessary to calculate how much insecticide should be introduced into the rivers. A description of the equipment and its use is followed by an initial report covering the functioning of the equipment, its efficiency and the economies attained. The improvement in the resulting treatment and the reduction in the running costs of the programme are discussed. Software for forecasting the discharge over different time intervals was developed by ORSTOM at the request of the OCP. The different functions of this software (PERLES) are described. In conclusion, the advantages of remote transmission techniques for operational hydrology in general are discussed (flood warning systems, hydrological networks, etc.).

INTRODUCTION

Onchocerciasis, or river blindness, is a disease transmitted to man by small flies, simulium (*Simulium damnosum*) which inject filaria into the body when they bite – these filaria eventually cause blindness.

This disease is endemic in west Africa, and particularly in the Sudanese savanna region. The infested areas are usually abandoned, when often these are the most fertile, because they are adjacent to the rivers. The larvae of the Onchocerciasis vector develop in water in areas of rapids or where the flow is fast, allowing good oxygenation. Owing to the lack of any suitable medicine for mass treatment, the aim of the OCP is to destroy the simulium larvae by treating the rivers with insecticides.

In 1974, the World Health Organization (WHO) launched the Onchocerciasis

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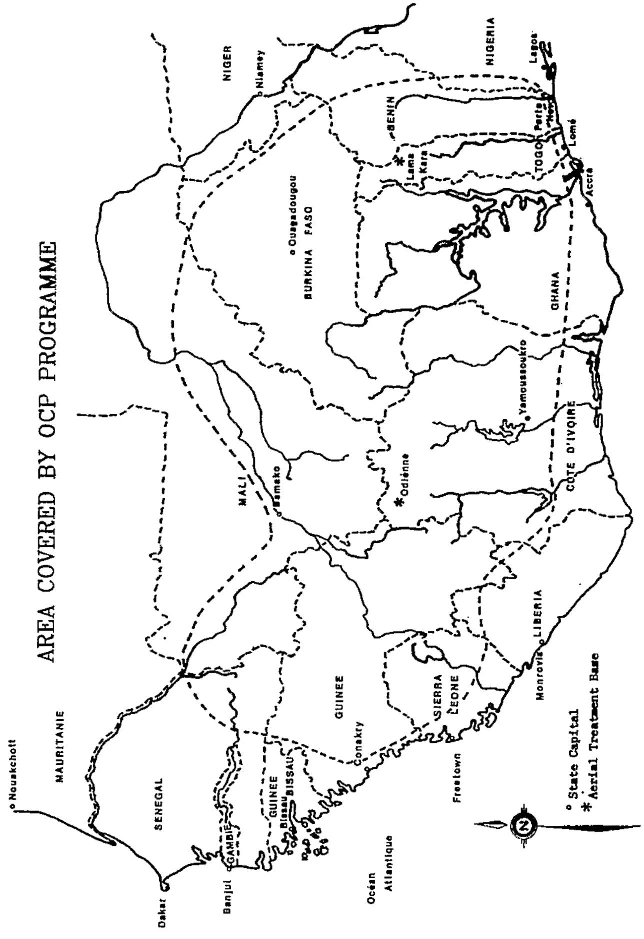

Fig. 1. Map of the area covered by the WHO/OCP.

Control Program (OCP), a comprehensive programme to control Onchocerciasis in west Africa. This programme currently covers all or parts of several African countries (Benin, Togo, Ghana, Côte d'Ivoire, Burkina Faso, Mali and Guinea) and is due to be extended towards the west (Sierra Leone and West Senegal, Fig. 1).

After an initial survey of the infested areas, WHO used Abat, an insecticide whose properties (area of spread, effectiveness in dilution, cost, etc.) do not require exact hydrological data, making the use of the insecticide relatively simple. During their weekly inspection, the WHO/OCP teams recorded the water levels from the river gauges at the hydrometric stations. At the end of the week these levels were given to the treatment base who calculated the quantity of insecticide to be used and gave cards with the weekly treatments to the aeroplane and helicopter pilots responsible for the spraying. The quantities given were not precise, especially in the rainy season, but the margin of error tolerated by the insecticide was such that an exact hydrological study was not considered necessary. However, certain disadvantages in the procedure considerably reduced the effectiveness of the treatment:

(1) Data were not always available because access roads to the hydrometric stations became impassable in the rainy season or because the treatment areas were too far from the WHO/OCP bases.

(2) When the discharge in the reaches varied too much from that taken as the basis for the calculation of insecticide doses, treatment of the larvae was ineffective. In the rainy season, the discharge of certain rivers can often double in a few hours.

(3) The reliability of the water level data were very limited for several reasons: approximate readings, numerous stages in the transmission of the information before the dosage was calculated, doubts about the accuracy of the gauges themselves.

Since 1985, because of cases of resistance to the insecticide, WHO/OCP has had to use new products, which are less tolerant (limited spread, risk of intoxication, significant differences in effectiveness when diluted, as well as being higher in cost). Given the problem of effectiveness and cost, it became necessary to have more accurate information about the discharge of each reach at the time of treatment and, therefore, to have more exact and reliable hydrological data. It was therefore decided to install a remote satellite transmission network, to transmit the water levels recorded at different points in the OCP treatment area.

THE REMOTE TRANSMISSION SYSTEM USED IN OCP

The advantages of remote transmission

The use of new insecticides which require more precise application means that the effectiveness of the treatment is dependent on a good fit between the discharge measurement and the dose of insecticide. To achieve maximum effectiveness, therefore, means that those responsible for the aerial treatment of the reaches must work in real time.

Given the size of the area covered by WHO/OCP, the satellite transmission of the data collected by automatic recorders seems to be one of the best ways of achieving this objective (Pouyaud and Le Barbe, 1987).

The technique offers several advantages:

— guaranteed access to data in all seasons;
— transmission of the water levels almost in real-time because of the number of times the satellite passes daily;
— more reliable data than that from the river gauges, which has to be transcribed a number of times – each one a source of error;
— quick and easy centralization of the data through the reception centres at the aerial operation bases (currently two, in Odienne, Côte d'Ivoire and Lama Kara in Togo) whose function is to collect the information relayed by the satellites.

Equipment and methodology

Description of the equipment

In close collaboration with the ORSTOM Hydrology Laboratory, the company Elsyde France has developed a hydrological platform called CHLOE. This platform consists of a system for measuring water level using a pressure sensor and an electronic box containing a clock and a system for recording data on a removable solid state memory. The system is powered by a solar panel and a battery. In collaboration with ORSTOM and Elsyde France, the company CEIS-Espace has added an ARGOS card which transmits the data to the reception centres, at the aerial treatment bases, via satellite.

Methodology

The remote transmission out-station is installed near a watercourse. If it is not at a station of the national hydrometric network, it is necessary to determine its calibration curve. The pressure sensor (SPI) is installed at the same location as the staff gauge so that it is covered by water even at the lowest water level. The electronic box is placed above the highest water level and at any distance from the SPI, the sensor and electronic box being linked by a cable (Fig. 2).

At regular intervals, the pressure is measured, corrected by temperature and the level of water calculated. The SPI can also be interrogated at any time outside of the programmed measuring times.

The interval between measurements is half an hour. The measurements are recorded on solid state memory (together with the time and date) if the level varies by more than ± 1 cm between readings; the solid state memories last for approximately one year and can be erased and reused. This locally-logged information can be analysed independently of that sent via satellite, by micro-computer, using software developed at ORSTOM (Raous, 1987).

Fig. 2. The hydrological platform, with its solar panel, linked to the pressure sensor, on the Dion River, Diamaradou, Guinea. (Photograph by Michel Gautier, ORSTOM.)

Every 220 seconds, the ARGOS card transmits values of the previous 15 half hour's readings. If one of the satellites in the ARGOS system passes over the out-station at that moment, it relays the message to a reception station.

The reception station (SRDA) collects and handles the messages as they arrive. Developed by CEIS-Espace, the station uses an IBM-AT computer (or XT-286 or MS-DOS compatible) and can service a network of up to 100 remote out-stations. The SRDA software creates new files every time the satellite passes. The station checks the messages received, correcting transmission errors if necessary, using an error correction code. These files, when sorted, can be printed out, either automatically for some parameters or manually, by the computer operator, for others. The station puts out a certain number of 'alerts' concerned with the internal functioning of the platforms or with the minimum or maximum water level thresholds fixed by the operator (Pouyaud, 1987).

Current report

The network of out-stations

The stream velocity required for the development of simulium larvae occurs mainly in watercourses of medium width or in headwaters, where water movement is greatest. The network of hydrological platforms, equipped with satellite transmission facilities is, therefore, more dense in the headwaters of the Niger, the Sassandra, the Bandama, the Comoe and the Black Volta rivers. Currently, apart from the sixty WHO/OCP out-stations, the network contains a dozen out-stations from the Hydro-Niger network and two others managed by the Black Volta Basin Agency.

Performance report

The hydrological platforms are of recent innovation and are likely to be developed further. After two rainy seasons, and despite some problems with the power supply, solid state memories and electronic cards, performance generally has been good. Because of the difficulties encountered, modifications have been made to improve reliability. For example, after having used the out-stations for a few months, priority has been given to the transmission of the message instead of the storage on solid state memory. This way, if there is any problem with the solid state memory, the message will not be recorded while the transmission will remain effective.

Improvement in the efficiency of treatment and in the reduction of costs

Before the new method of treatment was introduced, the pilots sprayed the watercourses with doses of insecticide calculated from the gauge readings of the previous week. In the rainy season it was often impossible to obtain the correct dosage of insecticide because of the large rate and magnitude of the discharge variation. As exact hydrological data are now available, the doses can be calculated with a precision rarely achieved before. Apart from the improvement in the efficiency of treatment, there has also been a significant reduction in cost, for which the following reasons can be given: (i) a better calculation of the doses of insecticide, and thus a reduction in costly overdoses; (ii) more efficient treatment, which allows for breaks in treatment of a week or more; and (iii) suspension of treatment if flood levels are too high.

To improve efficiency further, WHO/OCP asked ORSTOM to develop software to predict the discharge in each of the reaches to be treated, based on data transmitted by satellite.

SOFTWARE TO PREDICT DISCHARGES

Aims

The software (PERLES) which is now installed in the microcomputers at the OCP aerial operations base in Odienne, was developed to improve the efficiency of the system. Several factors influenced its development:

(1) The software had to be user-friendly, as it would be used by the OCP operators who are neither trained in computers nor hydrology. PERLES, therefore, consists of a series of menus, which are simple to use, and which allow access to different sections of the software or the selection of one of the numerous functions.

(2) PERLES had to be able to predict discharges for all the reaches under treatment for different time spans. To achieve this, different forecasting models are used, which estimate the discharge every 3, 6 and 12 h in the rainy season, when variations in discharge can occur very rapidly. In the dry seasons the watercourses recede and the predictions are made at 1, 3, 5 and 8 days.

(3) Such a software, which uses not only the data transmitted by satellite, but also those from staff gauges, needed to include data base management. Therefore, PERLES handles and stores the readings, as well as the calibration curves, from all the staff gauges and out-stations.

Software structure

PERLES is in two parts: the first is in the receiving station, the second in a

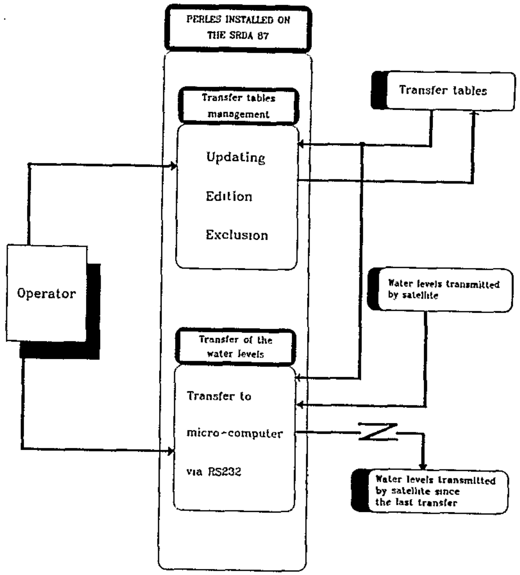

Fig. 3. Flow diagram of the PERLES software at the data reception station.

microcomputer linked to the station, which is used for all the forecasting calculations and management operations.

Receiving station software

The software at the receiving station collects, organizes and manages the transfer of the water level measurements received via satellite to the microcomputer (Fig. 3).

The transfer is facilitated by transfer tables, which contain the numbers of the out-stations to be dealt with. When the data are transferred, the date is recorded for each out-station before the calculation stage. By this means, only the levels recorded since the date of the last transfer are entered, satisfying the criteria that the whole operation (transfer of data, calculation and availability of predictions) must not take more than 15 min.

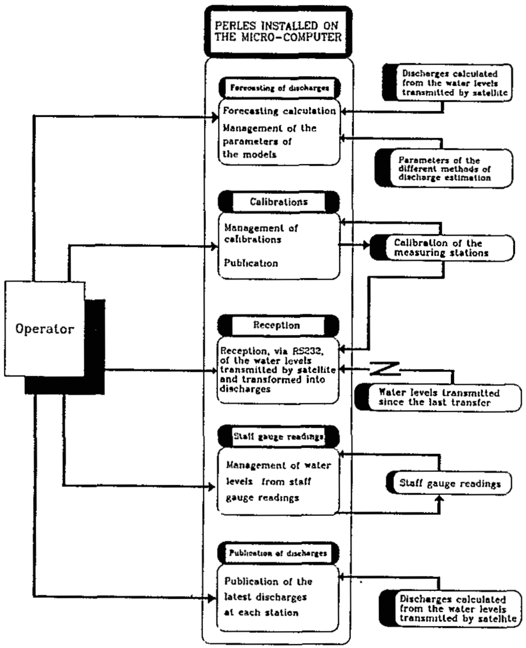

Fig. 4. Flow diagram of the PERLES software in the microcomputer used for forecasting calculations.

The microcomputer

The second part of the PERLES software is installed in the microcomputer used for calculations (Fig. 4). It has several functions which can be divided into two groups.

Access to the first group of functions is open to any PERLES operator. It consists of: data reception, management of the calibrations of the reference stations and of the hydrometric data base, calculation and publication of the discharges and the corresponding doses of insecticide for each reach treated. All these operations are carried out by selecting options from the different menus.

The second group of functions is only accessible to the hydrologist who builds the models used to make the predictions. Parameters are defined for each reach concerned. These parameters include not only the coefficients of the models used but also the priority coefficients attributed to them.

The software ranks the methods of forecasting for each reach by priority. There are five methods: a propagation model based on the Hayami method (Ven Te Chow, 1959; Quivey and Keefer, 1974), an auto-regression model, a correlation model between the remote transmission out-station and the staff gauge, OCP's own empirical method and the recession model. Each of these methods requires specific information to enable its use. For each reach we have, therefore, defined a preferential order of use of these forecasting techniques. If the method which is best adapted and the most precise cannot be used (e.g. for lack of necessary data), the next one is used and so on. This procedure enables the discharge through a reach to be estimated in approximately 90% of cases.

The methods used

The diffused flood wave model. The diffused flood wave model is used first whenever possible. It consists of ignoring the terms of inertia in the Barre de Saint Venant equations. The spread of the floods obeys the following equation:

$$\delta Q/\delta t + C\,\delta Q/\delta x - D\,\delta^2 Q/\delta x^2 = 0 \tag{1}$$

where:
Q = discharge
C = speed of the flood wave
D = diffusion coefficient of the flood wave
x = abscissa
t = time.

If C and D can be considered invariables, the solution to the equation is expressed in the form of a convolution product as Hayami proved (Ven Te Chow, 1959):

$$Q_x(t) = \int_0^t Q_0(u)\,K_x(t-u)\,\mathrm{d}u \tag{2}$$

where K is the core of the convolution:

$$K_x(t) = \{x/[2t^{3/2}\sqrt{(\pi D)}]\} \exp\{-(x-Ct)/[2\sqrt{(Dt)}]^2\} \qquad (3)$$

As a general rule, in the rivers treated by OCP, the speeds of the flood spread are very different depending on the type of river bed. Certain alterations have therefore been made to the method. For instance, the values of C and D which cannot be considered constant are recalculated in each case. This allows a core of convolution, appropriate to each flood, to be used (Bader et al., 1988; Le Barbe and Bader, 1988).

The auto-regression models. The auto-regression models are used for the reaches equipped with satellite transmission. The equations are determined with the help of a progressive regression method, 'Stepwise' (Draper and Smith, 1981). The usual form is:

$$Q(t_0 + H) = A_0 + A_1 Q(t_0) + A_2 Q(t_0 - 1) + \ldots + A_{n+1} Q(t_0 - n) \qquad (4)$$

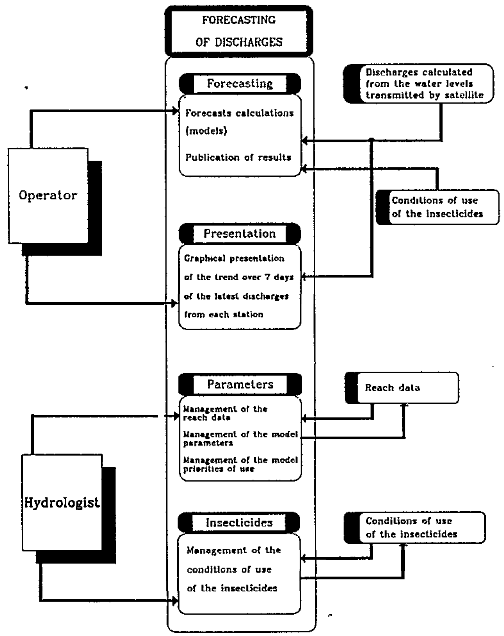

Fig. 5. Flow diagram of the forecasting part of the PERLES software.

where:
$Q(t)$ = discharge at time t
t_0 = date of forecasting
H = time span of the forecasting (3, 6 or 12 h)
$A_0, \ldots, A_{n+1}$ = coefficients of the equation.

Correlation between out-station and gauge. The correlations between the out-stations and the gauges, allow improvement in the estimates of discharge for the reaches where the staff gauge is only read weekly.

The empirical correlation model. The empirical correlation model, sometimes used as a last resort, correlates the discharge of different watercourses in the determination of the discharge of a given reach. This correlation results from years of observation and the local OCP staff's excellent knowledge of the area.

The recession model. The recession model used in the dry season, a period during which the rainfall in the area treated is non-existent or light, is a decreasing exponential function, the equation of which is:

$$Q(t_0 + H) = Q(t_0) \exp(-\alpha H) \qquad (5)$$

where:
Q = discharge at time t
t_0 = date of forecasting
H = time span (1, 3, 5 or 8 days)
α = recession coefficient.

These models form the heart of the forecasting part of the software. The complete flow diagram is presented in Fig. 5.

The values of calculated discharges can be used as inputs to other software. This particular software, however, aims to improve the organization of flying hours and refuelling points for both aircraft fuel and insecticide.

CONCLUSION AND FUTURE PROSPECTS

The PERLES software is not only a user-friendly tool for the forecasting of discharges and the calculation of insecticide doses, but also a staff gauge data base manager.

Its modular organization (see Figs. 3, 4 and 5) allows the selection of many options, notably of different forecasting models, as appropriate.

The use of this software results in great time-saving, because for a medium-sized area of treatment (e.g. 10 out-stations and 60 reaches) it takes less than 15 min from the transfer of the data from the reception station to the availability of the results. This timing fits in well with that required for the daily briefing of pilots and the start of treatment.

Furthermore, the hydrographic network equipment comprising the satellite transmission stations, has enabled us to progress from a system with a reaction time that is weekly to one where the calculations can be made in near real time.

The linking of PERLES with the ARGOS system has allowed further improvement of the device by enabling predictions to be made covering different time intervals. A good fit is therefore obtained between the doses of insecticide and the discharge. The system has, therefore, led to a significant improvement in the OCP programme in that: (i) it avoids underdosage, which causes failure and also risks eventually producing strains of Simulium resistant to the insecticides; (ii) it avoids overdosage, which can have a damaging effect on the environment and is unnecessarily costly; (iii) it increases the success rate and also allows occasional suspension of treatment in some reaches, which in itself reduces cost.

OCP is satisfied with these initial results and intends to complete its network of out-stations as it extends the programme towards the west; eventually there should be up to 100 remote transmitting out-stations in the network.

Outside of the OCP, satellite transmission also offers numerous prospects for hydrology. It should, for example, be extremely useful in flood warning systems in large catchments and its advantage for the management of a national hydrological network is obvious. By transmitting certain parameters relating to their own operation such systems can check on themselves, to a certain extent, reducing network running costs by reducing the number of maintenance visits and targetting them better (Pouyaud, 1988).

These advantages make satellite transmission particularly attractive to developing countries, where sometimes access roads to out-stations are impassable or where local staff may not be available.

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PARAMETER IDENTIFICATION OF SOLUTE TRANSPORT MODELS FOR UNSATURATED SOILS

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ABSTRACT

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In models of unsaturated flow and solute transport, parametric relationships may be used to define material properties, namely the soil moisture characteristic, unsaturated conductivity function and the hydrodynamic dispersion relationship. The application of optimisation methods to identify parameter values from experimental data of time-varying vertical profiles of moisture content and solute concentration is investigated for a sandy soil. Multiple local optima are identified for both flow and solute transport relationships, but these alternative parameter sets are shown to be generally robust in prediction within the range of observed system states, which suggests some utility for this approach to parameter identification. Other possible forms of dispersion relationship are investigated, and several different formulations produce identical performance. This indicates that the dispersion relationship is ambiguous and hence the interpretation of analytical form from this type of experimental data may not be possible.

INTRODUCTION

The need to predict the movement of chemicals such as pesticides, fertilisers and toxic and hazardous wastes through soils to groundwater has led to considerable recent interest in the phenomena associated with mass transport through unsaturated soils.

An approach to this problem based on continuum mechanics has the advantage, in principle, that prediction is based on conventionally defined material properties (plus appropriate specification of initial and boundary conditions). Although a number of analytical solutions of the resulting partial differential equations have been developed to describe one-dimensional solute transport (e.g. Brenner, 1962; Van Genuchten, 1981; Mironenko and Pachepskii, 1983) these solutions are applicable only to specific cases where simplifying assumptions can be made. In general, numerical solutions are required (Bresler, 1973; Gureghian et al., 1979).

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