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DHV CONSULTANTS & DELFT HYDRAULICS with HALCROW, TAHAL, CES, ORG & JPS

VOLUME 3
HYDRO-METEOROLOGY

FIELD MANUAL - PART I

NETWORK DESIGN AND SITE SELECTION

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GENERAL

The Field Manual for Hydro-meteorology, comprises the procedures to be carried out to ensure proper execution of rainfall and climatological network design, operation and maintenance. The operational procedures are tuned to the task descriptions prepared for each Hydrological Information System (HIS) function. The task description for each HIS-function is presented in Volume 1, Field Manual, Hydrological Information System.

It is essential, that the procedures, described in the Manual, are closely followed to create uniformity in the field operations, which is the first step to arrive at comparable hydro-meteorological data of high quality. Further, reference is made to the other volumes of the manual where hydrometry, sediment transport measurements and water quality sampling and analysis is described. It is stressed that hydro-meteorology cannot be seen in isolation; in the HIS integration of networks and of activities is a must.

This Volume of the Field Manual consists of 5 parts:

- Part I deals with the steps to be taken for network design and optimisation. The procedures refer to network design/review based on measures of effectiveness for estimating areal values of rainfall and potential evapotranspiration, and interpolation. Furthermore, site selection procedures are included.
- Part II comprises operation and routine maintenance of rainfall stations with SRG (non-recording rain gauge).
- Part III comprises operation and routine maintenance of rainfall stations with ARG or TBR (recording rain gauge) and SRG (non-recording rain gauge).
- Part IV comprises operation and routine maintenance of full climatic station (FCS).
- Part V covers the field inspections and audits as well as maintenance and calibration.

In the Parts II to IV for each of the stations the day to day activities are spelled out, with reference to a HIS-function. The procedures as listed out in this manual are in concurrence with the procedures adopted by IMD to operate its network, who in turn follow closely the WMO-recommended procedures.

1 NETWORK OPTIMISATION

Steps in network design

The sequence of steps to be carried out for network review and redesign include:

1. **Institutional set-up**: review of mandates, roles and aims of the organisations involved in the operation of the HIS. Where required communication links should be improved to ensure co-ordination/integration of data collection networks.
2. **Data need identification**: with the aid of the questionnaire ‘Data needs assessment’ presented in Part III of Volume I, Field Manual, Hydrological Information System, the existing and potential future data users have to be approached to review their data needs.
3. **Objectives of the network**: based on the outcome of Step 2 a Hydrological Information Need (HIN) document is to be prepared, which lists out a set of objectives in terms of required network output. The consequences of not meeting the target are to be indicated.
4. **Prioritisation**: a priority ranking among the set of objectives is to be made in case of budget constraints.
5. **Network density**: based on the objectives the required network density is determined using an effectiveness measure, taking in view the spatial (and temporal) correlation structure of the variable(s), see below.
6. **Review existing network**: the review covers the existing network density versus the required one as worked out in Step 5, spreading of the stations in conjunction with the hydrometric and groundwater network, available equipment and its adequacy for collecting the required information, and adequacy of operational procedures and possible improvements. Deficiencies have to be reported upon.
7. **Site and equipment selection**: if the existing network is inadequate to meet the information demands additional sites have to be selected as well as the appropriate equipment.
8. **Cost estimation**: costs involved in developing, operating and maintaining the existing and new sites as well as the data centres have to be estimated and a cost-effectiveness analysis has to be carried out. The Steps 5 to 8 have to be repeated in full or in part if the budget is insufficient to cover the anticipated costs.
9. **Implementation**: once the network design is approved the network is to be implemented in a planned manner where execution of civil works, equipment procurement and installation and staff recruitment and training is properly tuned to each other. The use of HIDAP is a necessity.
10. **Network review**: the network has to be reviewed again after 3 years or at a shorter interval if new data needs do develop. The above listed procedure should then be executed again.

Step 5 in detail

If the relative root mean square error of areal rainfall/potential evaporation estimates Z_{areal} is taken as the measure of effectiveness of the network, then the following steps are involved in the computational process:

Based on the objectives of the network to be designed or reviewed:

1. Select the smallest duration or time interval Δt^* for which areal rainfall/potential evaporation estimates have to be made, and define the maximum acceptable value for Z_{areal} for a particular season in the year.
2. Collect the rainfall/evaporation data of all stations in the region under study, including the stations nearby the region with the same climatological conditions to create a data set as large as possible, and show the locations on a map, scale 1:250,000. Obviously, the condition for the time interval of the data is: $\Delta t \leq \Delta t^*$.

3. Make sure that the rainfall/potential evaporation data have been thoroughly validated. If not, the procedure presented in the Data Processing Manual for validation of rainfall/climatological data have to be applied. It is strongly advised not to fill in missing data as this will generally affect the variability of the point processes and increase the correlation between the series and will lead to an inadequate network. If series are too short, these should be left out of the analysis.
4. Aggregate the series to interval Δt^* and derive the basic statistics of the point rainfall/potential evaporation time series, i.e. mean, standard deviation and coefficient of variation per month or any other suitable homogeneous period in the year.
5. Based on topography, movement of weather systems and computed statistics divide the region under study in homogeneous areas. Apply statistical tests on the mean and the standard deviation to confirm the homogeneity. Compute per homogeneous area the point average and 90% reliable Cv value. If homogeneity cannot be achieved, then before the actual analysis is made the data are made homogeneous by application of a suitable transformation (normalisation, standardisation, detrending, etc.).
6. Review the period for which the maximum acceptable value of Z_{areal} should be applicable based on the outcome of Step 5, also in view of the possible variation of Cv through the year. E.g., the analysis may concentrate only on the monsoon season, and/or any other selected season.
7. Compute the correlation coefficient between the point rainfall/potential evaporation time series for the same periods in the year for which the basic statistics have been determined in Step 5 and plot the data per homogeneous area for each period against distance between the stations. The correlation coefficients should be based only on **non-zero** data.
8. If the scatter in the correlation coefficient versus distance plots is too large, group the coefficients in distance intervals and plot the average correlation coefficient versus average distance instead for each interval.
9. Eliminate outliers from the correlation-distance plots and fit a straight line through the data points using a semi-log scale or apply regression on ln(r(d)) versus distance. Estimate the parameters r_0 and $d_0$in the relation:

$$r(d) = r_0 \exp(-d/d_0) \qquad (2.1)$$

where:
- r(d) = correlation coefficient as a function of distance
- d = distance
- r_0 = correlation coefficient at d=0
- d_0 = characteristic correlation distance: $r(d_0)=r_0e^{-1}=0.368r_0$

10. Determine the relative root mean square error as a function of the number of gauging sites N for a design area S (to be derived from the hydrometric network) for each period in the year to which the data apply. Compute for each period the required gauge density for a series of values for Z_{areal}. The computation is carried out by using the following formula:

$$Z_{areal} = Cv\sqrt{\frac{1}{N}\left(1 - r_0 + \frac{0.23}{d_0}\sqrt{\frac{S}{N}}\right)} \qquad (2.2)$$

where:
- Cv = coefficient of (time) variation of the point process
- S = design basin area
- N = number of rainfall or climatological stations in S

11. Apply a sensitivity analysis on the assumed design conditions and parameter values. Test the computed Z_{areal} -values with block-kriging available in HYMOS.
12. Investigate the option to differentiate in the required network density to meet various objectives. Particularly for design purposes with respect to rainfall, where the time variation and areal extent of short duration rainfall is required a dense network with recorders will be required. In such cases a cost-effective solution is to have in a few representative basins a dense network, fulfilling the demands for design, whereas the network covering the whole region should have a density meeting the objectives for planning and management, say based on accuracy's for decadal, monthly or seasonal data.

13. Make an estimate of the costs involved in development and operation of the network commensurate with the range of values for Z_{areal} (see Steps 10 and 11), including the cost additional data processing activities and make a trade off between Z_{areal} and cost.
14. Analyse the consequences of not meeting the Z_{areal} -target.
15. Prepare a document in which the preferred network layout with a few variants is given inclusive of the financial consequences of all options.

Note

If instead of Z_{areal} the objective is to meet an interpolation error target Z_{int}, instead of the formula for Z_{areal} the following expression has to be applied

$$Z_{int} = Cv\sqrt{1/3(1-r_0) + 0.52\frac{r_0}{d_0}\sqrt{\frac{S}{N}}} \qquad (2.3)$$

with Cv, r_0, d_0, S, N defined as above. Further, the procedure runs exactly as above.

2 SITE SELECTION

2.1 GENERAL

The following types of hydro-meteorological stations are available in HIS:

1 **SRG-station**, a rainfall station equipped with a standard or non-recording rain gauge,
2 **ARG station**, a rainfall station with a recording (and also a non-recording) rain gauge, and
3 **FCS station**, a full climatic station, where the following climatic variables are being observed:
  - for direct evaporation measurements: pan-evaporation,
  - for evaporation estimation:
    - sunshine duration
    - air temperature
    - humidity
    - wind speed and direction, and
    - atmospheric pressure (also used for groundwater studies).

Several factors are to be taken into consideration, while making a proper choice for the site for setting up the observatory station to ensure long term reliable data.

The following aspects are to be considered:

- technical
- environmental
- logistical
- security
- legal, and
- financial.

The above aspects are discussed in the following sections. In addition, practicalities, necessary for a proper execution of the site survey, are dealt with.

2.2 TECHNICAL ASPECTS

Technical aspects include:

- what variable is to be measured where and with what accuracy and frequency
- integration with surface water and/or groundwater quantity and quality networks

Prior to the site visit the preferred location from a technical point of view has to be determined. This requires two steps:

- First, approximate positioning of the station on the map to obtain maximum reduction of estimation errors, in relation with the variable of concern and observation interval to be used, and subsequently
- Integration of the site in, or tuning of it to, the hydrometric and/or groundwater network.

Network review

Since, everywhere networks are in operation, first the existing network should be reviewed for its suitability. To assess the suitability in view of the required accuracy as derived from the user requirements, a contour plot is made of the estimation errors produced by the present network using point kriging and block kriging. Errors in interpolation between stations and/or estimation of areal averages have been discussed in the previous chapter. If the estimation errors are too large, the network has to be adjusted by repositioning of existing stations and/or creating new stations.

Siting of new stations

New sites are located where maximum reduction of the standard error, visualised by kriging, is accomplished. To check the effectiveness of the new location, point kriging is redone with the new site(s) included and the interpolation or areal average estimation error, whichever is relevant, is evaluated anew. This process is repeated a few times till the estimation error is maximally reduced.

Network integration

These new locations are subsequently compared with the hydrometric and/or groundwater network. Efficiency requires, that where possible, hydro-meteorological sites are to be combined with hydrometric sites in view of staffing costs, security and logistics. Similar benefits apply for groundwater by integrating hydro-meteorological sites in recharge study areas.

Agencies outside the HIS are also operating hydro-meteorological stations. If their stations fit into the HIS network and their equipment and operational performance meet the HIS standards then discussions should be initiated with those agencies to get access to their data on a regular basis. A prerequisite is that these stations have been inspected by IMD and are brought up to the mark. The use of data of other agencies applies particularly to the hilly areas, where hydro-meteorological networks are in operation with the Electricity Boards.

2.3 ENVIRONMENTAL ASPECTS

When siting a rainfall or climatic stations the following environmental aspects have to be considered:

- availability of suitable levelled ground
- exposure conditions
- future expansion near the site
- no water logging

Rainfall stations

The main purpose of establishing a rainfall station is to obtain representative samples of the rainfall over a basin. Particularly wind affects the rainfall measurements, while further losses due to evaporation and splashing play a role. To eliminate or reduce wind effects, the site should be chosen such that:

- the wind speed at the level of the rain gauge is as low as possible, but in such a way that the surrounding does not affect the rain catch, and/or
- a horizontal air flow over the gauge orifice is occurring.

Ideally, the protection against the force of wind should come from all directions by objects of uniform height. Trees, shrub, etc. of nearly uniform height are ideal to protect the gauging site from wind, provided that the angle from the top of the gauge, to the top of the encircling objects and the horizontal is between 30^o and 45^o. This implies, that if the height of the surrounding objects above the gauge orifice is H then the distance L between the surrounding objects and the gauge should be within the limits: $H \leq L \leq 2H$.

Windbreaks of a single row of trees should be avoided, as they tend to increase the turbulence. Similarly, uneven protections create a disturbed wind field over the gauge orifice. If single obstacles affect the wind field around the gauge the distance between obstacle and gauge should be: $L \geq 4H$. One should make sure that there are no plans in the near future to build any structure in close proximity.

Slopes also affect the wind field. Sites on a slope or with the ground sloping sharply away in one direction (particularly in the direction of the wind) are to be avoided.

The gauge should be on level ground above flood level and free from water logging. Further, the site should have the same ground cover as the natural cover obtained in the surroundings. Surroundings covered with short grass are ideal. A hard ground such as concrete gives rise to excessive splashing and should be avoided. The plot required for an SRG is 5m x 5m, whereas an ARG station needs 10m x 5m.

Full climatic stations

Since a FCS also accommodates rain gauges, the environmental conditions discussed above for rainfall stations apply here as well. The sunshine recorder should at no instant be sheltered from solar radiation. Very essential in case of a full climatic stations is that the area, on which the station is to be built, is representative for a surrounding area of about 5,000 km^2. Sites were abrupt climatic differences are noticed due to swamps, mountains, river gorges and lakes should be avoided, unless the data should be representative for such an area. Some general indications of climatic changes are indicated below:

vegetation: transition from dry to irrigated areas results in lower temperature, higher humidity and decreased evaporation; very distinct in dry windy climates (advection)

topography: elevation differences not only largely affects precipitation (>800 m) but also minimum temperature, wind speed and wind direction

rivers: relatively small effect, possibly confined to some 100 m, except for large rivers and river deltas

lakes: depends on the size of the lake, but rapid changes are generally confined to 1 to 2 km

sea: will vary greatly, but rapid changes occur normally over the first 2 km, with gradual changes for the next 10 to 15 km. It affects mostly wind, humidity and temperature

altitude: depends strongly on local climatic conditions, but normally with increasing altitude temperature and evaporation decrease, while rainfall and wind tend to increase

mountains: downwind effect up to distances 50 times their height; the affected upwind area is much smaller.

For agricultural purposes the station should be within a cultivated area with a crop cover as large as possible upwind. There should be no road in close proximity. Depressions should be avoided, as the temperature in depressions is frequently higher during the day and cooler in the night.

A full climatic station requires a level plot of land of the size 18m x 15 m, preferably with green grass cover. To get a proper assessment of the potential evapotranspiration, the site should be in the centre of an open space of at least 50 x 50 m, which is covered by grass or a short crop. If needed and feasible the grass cover of the station should be irrigated and clipped frequently to fulfil the environmental conditions of the definition of potential evapotranspiration.

2.4 LOGISTICAL ASPECTS

Logistical aspects comprise:

- accessibility
- communication
- staffing

Accessibility

The measurement site should be easily accessible even under adverse weather conditions. Hence, while inspecting a location, the surrounding of the site should also be evaluated. Either the existing road or path gives access at all time, or civil works are required to make the site accessible. In the latter case the costs of such works have to be considered in the final selection.

Communication

Proper communication means should be available in the vicinity of the station to ensure that the data from the station can be transferred without difficulty at regular intervals to the nearest sub-divisional office for entry into the computer.

Staffing

Availability of qualified persons near the site to operate the station throughout the year is another aspect to be considered. Schoolteachers prove often to be reliable observers and their attendance is also guaranteed, apart from the holiday season. Availability of qualified staff makes the combination of a hydro-meteorological station with a hydrometric site very attractive, because at the latter site staff will always be present. Hence, at no additional cost but extra training, the staff of the hydrometric station can look after the rainfall or climatic station.

2.5 SECURITY ASPECTS

Security aspects concerns:

- security of instruments
- away from residential areas and play grounds

Stations should be located at safe places to avoid damage or theft of instruments. The locations should therefore be chosen away from residential areas and playgrounds. Though, proper fencing is a prerequisite around a station, it will not prevent unauthorised persons and animals to enter the site. Hence in addition, particularly an FCS site also requires a watchman to guard over the instruments. Furthermore, (wild) animal tracks must be avoided as they may ravage the site entirely.

2.6 LEGAL ASPECTS

Legal aspects include:

- land acquisition
- right of passage

The land on which a station is to be established should be state property. If the otherwise ideal site is on private land, it should be realised that the land acquisition process may require about one year. This is therefore a major aspect in the final judgement on the suitability of the location for establishing a station.

Beside acquisition of land also free passage to the plot of land under all weather conditions has to be taken into consideration.

2.7 FINANCIAL ASPECTS

The financial aspects have to be considered when comparing suitability of sites and for selecting a site. For each location the following cost factors have to be considered:

- land acquisition inclusive of cost of the acquisition process
- civil works, like access to the site, clearance of obstacles, levelling of the site, foundation for equipment fencing, staff quarters and station maintenance
- equipment procurement, calibration and maintenance,
- data collection, transfer and processing, and
- staff fees, travel expenses and training cost.

A proper distinction should be made between investment costs and running costs to make a fair comparison between alternatives possible.

2.8 SITE VISIT PRACTICALITIES

The site selection has to be carried out in collaboration with an IMD Inspector, to ensure full professional input in the selection process. During the site visit the aspects dealt with in the previous sections have to be discussed with the IMD Inspector. While visiting the field for site selection the following items should be available:

- a map of the area,
- a copy of the Master Plan if constructions are likely in the near future,
- a 50 or 100 metre measuring tape,
- a compass, and
- marking white powder.

Before marking the plot, the Inspector should measure the distances to the nearest obstacles like trees, and assess the height of the obstacles and ensure that the distance between the observatory boundary and the obstructions fits with the requirement. For marking the plot, the dimensions are preferably 5 x 5, 5 x10 for an SRG and ARG station respectively and 18 x 15 metres for a FCS-site.

The Inspector should prepare a sketch of the site indicating close-by buildings, trees and other obstructions and their distances from the boundary of the proposed enclosure. The geographical North should be marked. He/she should also make recommendations like trimming of the trees, clearance of bushes if exposure conditions need improvement or if levelling of plot is needed.