HYDROLOGY PROJECT

Technical Assistance

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Training module # SWDP - 45

How to review monitoring networks

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1. Module context

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

2. Module profile

Title	:	How to review monitoring networks
Target group	:	Hydrologists, Data Processing Centre Managers
Duration	:	two sessions of 45 minutes each and 60 minutes exercise
Objectives	:	After the training the participants will be able to: Assess of data needs Review rainfall monitoring networks Review climatic networks Review hydrometric network
Key concepts	:	Stepwise approach in network design and review Data need assessment, questionnaire Measuring objectives quantification Measure of effectiveness Relative root mean square error in areal rainfall Relative root mean square interpolation error Prioritisation
Training methods	:	Lecture, exercises, softwares
Training tools required	:	Board, OHS, computers
Handouts	:	As provided in this module
Further reading and references	:	

3. Session plan

No	Activities	Time	Tools
1	***General*** • Monitoring network • Cost-effectiveness analysis • Network optimisation process • Network levels • Integration of networks • Integration of networks (2) • Steps in network design (1-4) • Steps in network design (5-9) • Steps in network design (10-11)	15 min	 OHS 1 OHS 2 OHS 3 OHS 4 OHS 5 OHS 6 OHS 7 OHS 8 OHS 9
2	***Data need assessment*** • Analysis of objectives/functions of WRM • WRM objectives and use functions • Data requirements from HIS (1) • Data requirements from HIS (2) • Data requirements from HIS (3) • Questionnaire Discussion of questionnaire	15 min	 OHS 10 OHS 11 OHS 12 OHS 13 OHS 14 OHS 15
3	***Rainfall network design and optimisation(1)*** • Measuring objectives • Measure of effectiveness • Spatial correlation function • Root mean square error of areal rainfall (1) • Root mean square error of areal rainfall (2) • Estimation error as function of Cv and N • Estimation error as function of r0 and N • Estimation error as function of d0 and N • Estimation error as function of S and N • Conclusions	15 min	 OHS 16 OHS 17 OHS 18 OHS 19 OHS 20 OHS 21 OHS 22 OHS 23 OHS 24 OHS 25
4	***Rainfall/evaporation network design and optimisation(2)*** • Example application Tel basin • Summmary of design statistics • Network requirements for S = 2,000 km2 • Network density requirements • Conclusions of network design • Minimum density requirement • Network density for rainfall • Network density for climatic variables Working with HYMOS	20 min	 OHS 26 OHS 27 OHS 28 OHS 29 OHS 30 OHS 31 OHS 32 OHS 33

5	***Hydrometric network design and optimisation*** • Data needs and data use • Measure of effectiveness • Network design considerations • Minimum hydrometric network • Networks for large and small basins • Networks for coastal areas • Further design/review considerations • Site selection consideration • WMO recommendation • Prioritisation (1) • Prioritisation (2)	25 min	 OHS 34 OHS 35 OHS 36 OHS 37 OHS 38 OHS 39 OHS 40 OHS 41 OHS 42 OHS 43 OHS 44
6	***Exercise*** • Compilation of monthly and annual rainfall series by aggregation of daily data for KHEDA basin and validate selected series • Determining of spatial rainfall structure for months June to September and for annual data • Determine the required network density if permissible error in areal rainfall estimates is 5 and 10 %	 30 min 20 min 10 min	

4. Overhead/flipchart master

5. Handout

Add copy of the main text in chapter 7, for all participants

6. Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

7. Main text

Contents

1 Introduction

A monitoring network is based upon two considerations, namely:

- the **monitoring objectives**, and
- the **physical characteristics of the systems** to be monitored.

The identification of the monitoring objectives is the first step in the design and optimisation of monitoring systems. Related to this is the identification of the potential data users and their future needs. If there is more than one objective, priorities need to be set. Identification of monitoring objectives is also important because they determine the scale of changes to be detected in the data, the kind of information to be extracted from the data and therefore the way the data are analysed.

The analysis of the data, obtained from the network, is also determined by the dynamics of the measured processes. The physical basis of the relevant processes must be known in order to be able to make preliminary guesses of the scale of the variability with respect to space and time.

To enable an optimal design of a monitoring network, a measure is required, which quantifies the effectiveness level. Which measure is adequate depends on the monitoring objectives. Often, this measure is related to statistical concepts like errors in areal estimates, interpolation error, trend detectability, etc, and can be formulated as a function of:

- sampling **variables** (what),
- sampling **locations** (where),
- sampling **frequencies** (when), and
- sampling **accuracy** (with what (technique/equipment))

These quantities also determine the cost of establishing and running of the network, like the costs related to land acquisition, station construction, equipment procurement and installation, station operation, maintenance, data processing and storage and staffing of field stations and data centres. Once the relationship between the chosen effectiveness measure and costs have been established, the optimal network can be found, in principle, by weighting the two in a **cost – effectiveness analysis**. The optimisation process is depicted in Figure 1.1

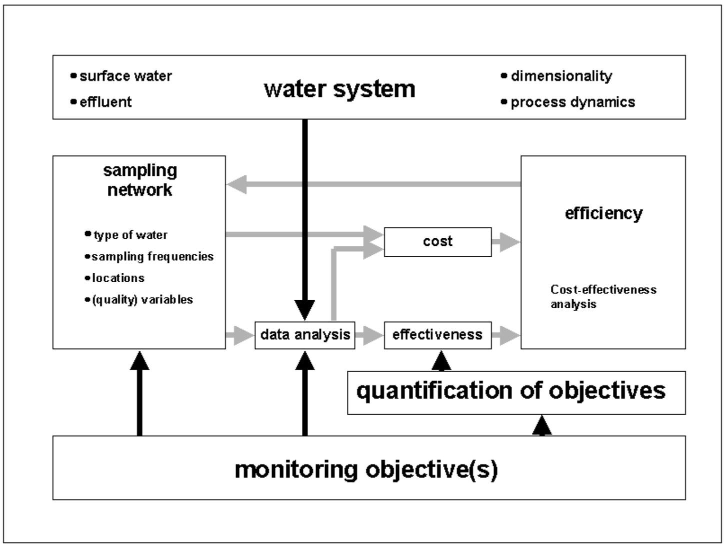


Figure 1.1: Network optimisation process

It is stressed that once the network is operational, it has to be evaluated regularly to see whether (revised) objectives still match with the produced output in a cost-effective manner. A network, therefore, is to be seen as a **dynamic system** and should never be considered as a static entity. This requires some flexibility in establishing new stations and closing down others.

2 Types of Networks

It is necessary to distinguish between the following network levels:

- **basic** or **primary** network, with a low network density, where measurements are continued for a long period of time,
- **secondary** network, with a density supplementary to basic network to meet accuracy demands, and where stations are kept operational for a shorter period of time,
- **dedicated** networks, put in place for a certain project, where the project objectives determine the network density and period of operation, and
- networks for **representative basins**, to study certain phenomena in detail.

Despite the necessary flexibility in the network layout as stipulated above, part of the network should have a permanent character, to ensure that some basic information is continually be gathered. The network used/maintained by IMD or CWC can be considered as such the primary or basic network. This network has a large coverage, though the density is limited and is in operation for a long period of time.

In addition to that network, stations may be established to better cope with the spatial variability of the observed variable. Once sufficient data have been collected from the secondary network to be able to establish relations with the primary stations, the added value of keeping the secondary station operational should be re-examined. This is particularly so if one is interested in reliable long term mean monthly, seasonal or annual values rather than in each individual value. Spatial correlation reduces the information content in a set of data from the network taken at a particular moment in time. For variables like rainfall, where any temporal correlation is fairly non-existing, one more year of data adds on much more information to the data set to compute some long-term average than one extra station does in case of non-zero spatial correlation.

The concept of representative basins is particularly useful when phenomena have to be studied in detail. The representativeness in this case particularly refers to the hydro-meteorological boundary conditions. Small basins may be selected to study e.g. the spatial and temporal variability of short duration rainfall for design purposes.

3 Integration of Networks

In the Hydrological Information System the following networks are operational:

- hydro-meteorological network of rainfall and full climatic stations
- hydrometric network,
- surface water quality network
- geo-hydrological network, and
- groundwater quality network.

These networks are operated by various State and Central agencies. To avoid duplication of work and to reduce cost the networks operated by the various agencies have to be integrated, technically and organisationally.
The hydro-meteorological network has to be considered in conjunction with the surface water and groundwater networks. The former should have sufficient spatial coverage so that all discharge stations in the hydrometric network are fully covered. This means that dependent on the objectives, rainfall-runoff computations can be made or water balances can be established. Similar water balance and resource assessment considerations apply also for the hydro-meteorological network in relation to the groundwater network.
Organisational integration of the networks implies that the networks are complimentary and that regular exchange of field data takes place to produce authenticated data of high quality. Review of the networks is also to be done in close collaboration.

4 Step 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 the Annex, 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).
6. **Review existing network:** the review covers 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.
9. **Cost-effectiveness analysis:** cost and effectiveness are compared. The steps 5 to 8 have to be repeated in full or in part if the budget is insufficient to cover the anticipated costs.
10. **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.
11. The network has to be **reviewed** after 3 years or at a shorter interval if new data needs do develop. The above listed procedure should then be executed again.

5 Data Need Assessment

Step 2 in the network design/review involves an assessment of what is really required by the users. Often, this aspect is overlooked and it is taken that the information being provided is the same, which is required by the potential users. It is obvious that user needs change from time to time and HIS would fulfil its commitment only if there is a continual review or assessment of the changing needs of the users. The assessment starts with an analysis of the objectives, functions of Water Resources Management (as related to planning and design). It is possible to make a direct link between the objectives of water resource management and use functions of the water system and the type of data that is needed from the Hydrological Information System.

Objectives, functions and activities of Water Resource Management

Based on the National Water Policy and overlying strategic national/state plans a concise objective of the water resources development in the country and in the states can be formulated. Such a specific statement on the objectives if formulated is likely to contain the elements as mentioned in the box.
These objectives of water resource management and use functions of the water system are

Objectives WRM:
- to protect human life and economic functions against flooding
- to maintain ecologically sound water-systems
- to support use functions

Use functions:
- drinking and municipal water supply
- irrigation
- fisheries
- hydropower production
- shipping
- industrial water supply
- discharge of effluents (incl. cooling water)
- recreation

linked to the type of data that is needed from the Hydrological Information System, which is outlined (as an example) in Table 5.1.

However, from an analysis point of view Table 5.1 has only an illustrative value. It will be needed to define the activities that are related to these objectives/use functions and the institutions involved. Following gives a possible classification of such activities:

- WR Policy and Strategy Development
- River-basin planning and allocation
- Water Resources Assessment
- Conservation
- Water Demand Analysis
- Demand Management (efficient use)
- Pricing of water
- Legislation and Enforcement
- Water Resources Development and Distribution
- Monitoring
- Research

This classification should be adjusted to National/State situation by looking at the priorities (following from the policies mentioned above) and the institutional setting. Furthermore it will be required to define sub-activities.

An efficient procedure to assess the data needs is through small interview teams, who explore in bilateral talks the mandates and data needs of the potential data users. In the interview teams both state surface and groundwater organisations should be represented. To guide and streamline the discussions a questionnaire has been prepared, to be filled in during visit to the data user, addressing items like:

- description of data user (name, sector, mandate, provided services, staffing and financing).
- water system use (present and future) with respect to quantity and quality, and responsibility.
- data use and requirements (parameters, type, frequency of availability, in what form, accuracy, consequences if not available, appreciation of present status of data supply.

The full questionnaire with the suggested approach to be followed by the interview team is annexed to this module. The potential data users are organised in the HDUG. A list of potential HDUG members is presented in Table 5.2

6 Rainfall Network

6.1 Measuring Objective

The major uses of rainfall data are generally for:

- water resources planning,
- design,
- management, and
- research.

Water resources planning requires generally long historical series of areal monthly, seasonal or annual data. Often one is only interested in the long-term mean value of areal rainfall. For assessment of dependable amounts of rainfall its variability is also required, either for a particular month or season in the year or for sequential months/seasons. For network design it is of importance to know which statistical parameter(s) has (have) to be estimated and with what accuracy. Given the variability in space and time this determines the number of stations required in the network and the duration of the measurements.

Objective / function	**Data requirements from HIS (examples)**
Protection: - flooding - drainage	• design studies (e.g. embankments along rivers and canals, culverts and bridges to bypass floods under roads-railways) require data on temporal and spatial distribution of extreme rainfall, on discharge extremes and river stages; • flood early warning systems require the same kind of information
Ecological sound water systems: - ecology - forestry - erosion	• assessment and habitat studies require data on the natural river stage and flow dynamics, flow velocities, variation of groundwater levels, water quality and of anthropogenic effects; • forestry/erosion require data on rainfall, evaporation, variation of river stage/groundwater levels and on quality.
Drinking water supply Municipal water supply	• resource assessment and design studies require data on water quantity and quality, e.g. temporal distribution of river flows, groundwater levels.
Agriculture - irrigation - rain-fed agriculture	• assessment and design studies (reservoirs, intakes, irrigation schemes, etc.) require data on water quantity and quality data, including extreme rainfall and river flows (spillways), historical river regime (reservoirs) and sediment transport. • for the operation planning of the system data on water demands, rainfall, river stages and flows (quantity and quality) are needed. Real-time data and forecasts are however not provided by the HIS
Fisheries	• assessment and suitability studies require data on water depth, flow velocities and water quality.
Hydropower production	• the design and operation of micro, mini and macro-hydropower systems, often in combination with water use for irrigation and flood mitigating measures require data on water quantity and quality data, including extreme rainfall and river flows (spillways), historical river regime (reservoirs) and sediment transport. • for the operation of the system data on water demands, rainfall, river stages and flows (quantity and quality) in real-time and as forecasts are needed. Such data are however not provided by the HIS
Shipping	• Design and maintenance require information on water depth, flow velocities, sedimentation (note: inland shipping is of minor importance in India).

Objective / function	Data requirements from HIS (examples)
Industrial water supply	• Availability studies (for process and cooling water) require information comparable to drinking water supply.
Discharge of effluents	• Licensing and monitoring require data on flows, various water quality parameters.
Recreation	• Assessment studies and protection require on water quality conditions, water levels and flow velocities.

Table 5.1: Data requirements from HIS

1. Governmental organisations	2. Non-governmental organisations / 3. Private sector
- State Surface Water Department - Central Water Commission - State Ground Water Department - Central Ground Water Board - Indian Meteorological Department - Irrigation Departments - State Pollution Control Board - Water Supply and Sewerage Board - Geology and Mines Department - Urban Water Supply and Drainage Board - Public Health Department - Hydropower Corporations - Thermal Power Corporations - Industries and Commerce Department - Agricultural Department - Fisheries Department - Forestry Department - Ministry of Environment and Forest - Ministry of Transport (for navigation) - Development Authorities - Roads Department - Railways Department - Drought Monitoring Cell - Tourist Board - Universities	**2. Non-governmental organisations** - Chambers of Commerce - Water Users Associations - Farmers Development Agencies - Environmental Protection Organisations - Tourist Organisations **3. Private sector** - Industries: e.g. Paper Mills, Fiber Industries, Cotton Mills, - Engineering Consultants - Contractors, etc.

Table 5.2: List of potential members of a Hydrological Data User Group

For design of structures generally statistics of short duration rainfall (e.g. quarterly, hourly or daily) have to be estimated. Rather than focussing on the average amounts, here the interest is particularly on the extremes and on the areal extent of extreme rainfall. The spatial correlation structure of short duration rainfall (minutes, hours or days) differs generally much from the same of long duration rainfall data as discussed for planning. This feature has important consequences not only for the required network density but also for the type of equipment to be used for rainfall measurement.

Management requires less historical data. Here the interest is particularly in data on a real time basis for operational purposes like reservoir operation and flood forecasting. Historical data are here required for the design of rule curves and operation strategies and for model development. The provision of real-time data is not an objective of the Hydrological Information System.

Research needs intensive data to improve the understanding of certain processes or phenomena. The research generally concentrates on small river or water resources management systems. The type of data required for research varies from study to study but is often comparable with the requirements for design.

From the above it follows that different objectives lead to different information needs and, given the variation of the spatial correlation structure of rainfall with duration, to different network densities as will be shown in the next few sub-sections, unless concessions are made towards the required accuracy.

6.2 Measure of Effectiveness

Based on the analysis presented in the previous sections the objective of the rainfall network should be to give reliable estimates of areal rainfall for areas commensurate with the hydrometric network. The latter condition stems from the need of integration of the networks. The stream gauge density in the plains is approximately one gauge per 2,000 km^2 and one per 1,000 km^2 in the hilly areas. Upstream of every stream gauging station sufficient rain gauges should be available to estimate the areal rainfall with a specified accuracy.
With respect to areal rainfall the interest is in:

- individual areal estimates, and/or
- long term mean values.

Due to the presence of spatial correlation among the point rainfall stations and (near) absence of serial correlation, (see sketch below) these objectives will lead to different networks and duration of operation. If spatial correlation would be absent then each point rainfall data in time or in space would equally contribute to the improvement of the long term mean areal rainfall estimate, provided the rainfall field is homogeneous. However, correlation reduces the effective number of data, since information in one is to some extent already included in others. Hence, due to the spatial correlation data points in time are more effective then data points in space to improve the long term areal mean. Or in other words: a less dense network operated for a longer period of time is more cost-effective than a denser network providing the same number of point rainfall data points. A reduction in the density of the network, however, adversely affects the quality of the individual areal estimates possibly to an unacceptable level. The latter is better served with a higher density, though this in turn may be sub-optimal for estimating the long term mean but is certainly not harmful.

$\longrightarrow$ number of stations N

$h_{1,1}$	$h_{1,2}$	$h_{1,3}$	……….$h_{1,N}$	year 1
$h_{2,1}$	$h_{2,2}$	$h_{2,3}$	……….$h_{2,N}$	year 2
$h_{3,1}$	$h_{3,2}$	$h_{3,3}$	……….$h_{3,N}$	year 3
$h_{n,1}$	$h_{n,2}$	$h_{n,3}$	……….$h_{n,N}$	year n

Figure 6.1:
Data matrix nxN of n years of data at N stations

(data $h_{i,1}$ to $h_{i,N}$, spatially correlated)
(data $h_{1,j}$ to $h_{n,j}$, serially not correlated)

For most hydrological purposes the objective of the rainfall network should be to provide reliable estimates of **individual** events of areal rainfall of a **particular duration**, like a duration of an hour, day, month or season. It implies that the uncertainty in each element of the areal rainfall series, estimated from point rainfall data, should not exceed a certain value.

This is particularly so for the network in use for the Hydrological Information System, where various users have to be served with different objectives. A measure for the quality of the areal rainfall data is the mean square error of the estimate. Hence, the **root mean square error in estimating the areal rainfall of a particular duration**, expressed as a percentage of the average rainfall in an area is an appropriate **measure for the effectiveness** of the network.

6.3 Network Design

To get the proper entries for this root mean square error one has to describe the spatial correlation structure of the rainfall field. For rainfall often the following exponential function applies (see also Figure 6.2):

$$r(d) = r_0 \exp(-d/d_0) \tag{6.1}$$

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

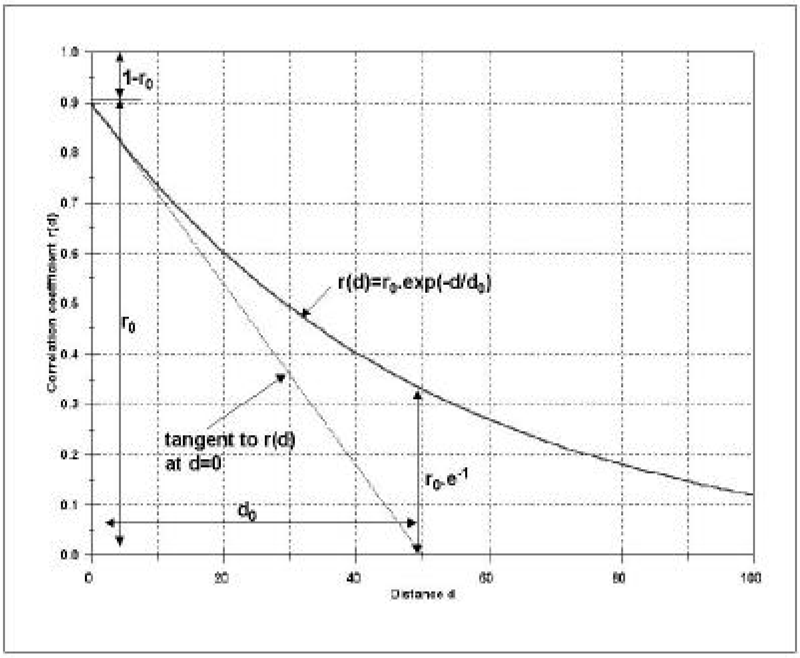


Figure 6.2: Exponential spatial corre-lation function

This model includes two parameters, r_0 and d_0, which are discussed in Module 12. The value for r_0 being less than 1 is generally attributed to measurement errors and/or microclimatic effects. The parameter d_0 increases usually with the aggregation level of the rainfall.

If the gauges are about evenly spread over the catchment then the relative root mean square error in the areal estimate reads (Kagan, 1972):

$$Z_{areal} = \frac{\sigma_e}{\overline{P}} = C_v \sqrt{\frac{1}{N}\left(1 - r_0 + \frac{0.23}{d_0}\sqrt{\frac{S}{N}}\right)} \tag{6.2}$$

with: Z_{areal} = relative root mean square error in areal rainfall estimate
σ_e = error variance of areal rainfall estimate
$\overline{P}$ = areal average rainfall

C_v = coefficient of variation of point rainfall
S = catchment area
N = number of gauging stations

The relative root mean square error is seen to be a function of:

- the coefficient of variation of the point rainfall **time** series,
- the **spatial** correlation structure of the rainfall field,
- the **size** of the basin for which an areal estimate has to be made, and
- the **number** of point rainfall data considered in estimating the areal rainfall.

By stating the permissible value of Z_{areal}, one obtains an estimate for the required minimum number of stations N in a basin with area S. Typical values for Z_{areal}, given as a percentage, are 5 or 10%. Note that when making water balances, the errors in the various components have to be judged. Errors in the river discharge are in the order of 5-10%, hence a similar error for rainfall should be acceptable. With respect to Z_{areal} some further remarks are made here:

- It should be recalled that Z is the root of the **mean** square error and, in specific cases, errors twice and even three times as high as Z are possible.
- In the above derivation a **uniformly** spaced rainfall network was assumed. If the distribution is less even, the error variance will be somewhat larger and so will Z. Then kriging is to be applied for the estimation error analysis (see Module 12).

The effects of the various parameters Cv, r_0, d_0 and S on Z_{areal} and N are shown in the Figures 6.3 to 6.6.

Figure 6.3 shows that the temporal variation of rainfall has a large impact on the required network density. Variation coefficients are high for short duration rainfall data and diminish gradually when the interval gets larger. Also pre-and post-monsoon monthly rainfall data show generally high coefficients of variation. In such cases either higher Z_{areal} -values have to be accepted or a denser network is to be applied.

Figure 6.4 illustrates the effect of inaccurate measurements (relatively low values of r_0, see equation 6.1) on the estimation error and the consequences for required density of the network. Accurate measurements pay off!!

In Figure 6.5 the effect of the characteristic correlation distance d_0 on Z_{areal} and N is given. It clearly shows, as one would expect, that a stronger spatial correlation reduces the network density requirement to reach the Z_{areal} -target. The distance d_0 generally increases with the duration, whereas C_v reduces when looking at a larger interval, but both with a similar effect on the required network density. This may be taken into consideration when deciding on the interval for which the network has to give a specified accuracy.

Figure 6.6 shows the effect of the size of the basin on the required network density. The general tendency is that for the same accuracy a smaller catchment needs a denser network than a larger one. Figure 3.6 is to be fully understood, as one may be tempted to enter for S in equation (6.2) the entire catchment area, which leads to too optimistic results. Earlier, the importance of integration of the networks was indicated. Upstream of every stream gauging station sufficient rain gauges should be available to estimate the areal rainfall with a specified accuracy. The stream gauge density in the plains is approximately one gauge per 2,000 km^2 and one per 1,000 km^2 in the hilly areas. Hence those are the catchment sizes to be considered while applying equation (6.2).

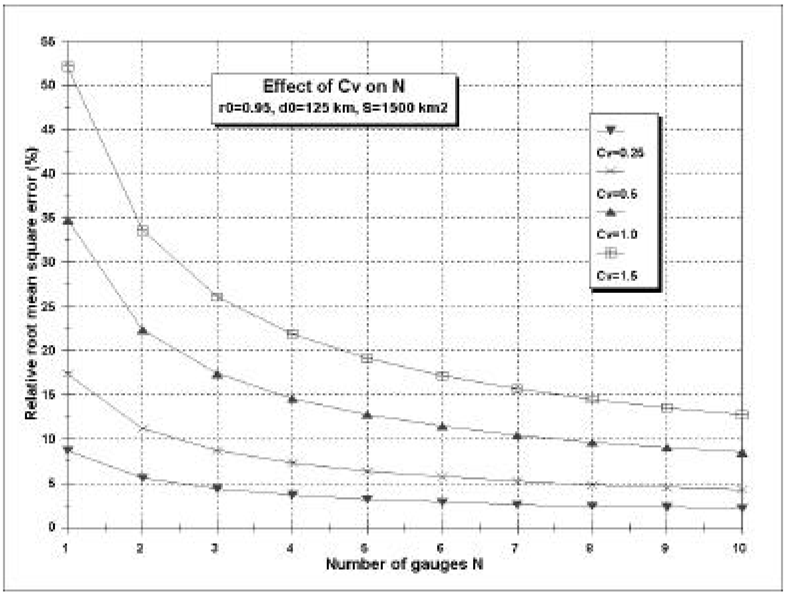


Figure 6.3: Estimation error as function of C_v and N

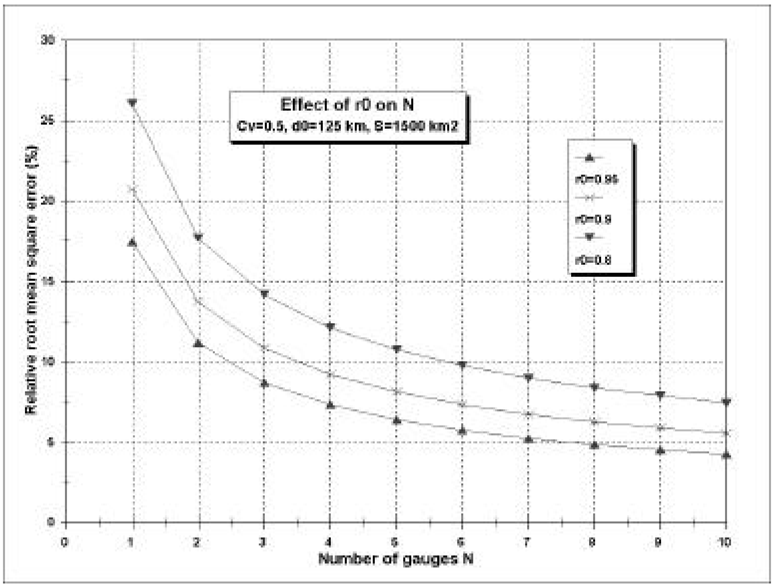


Figure 6.4: Estimation error as function of r_0 and N

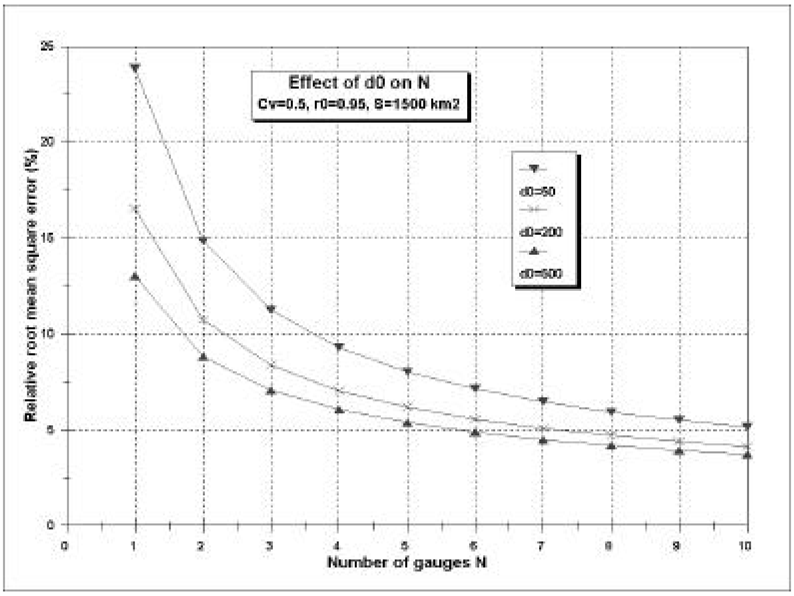


Figure 6.5: Estimation error as function of d_0 and N

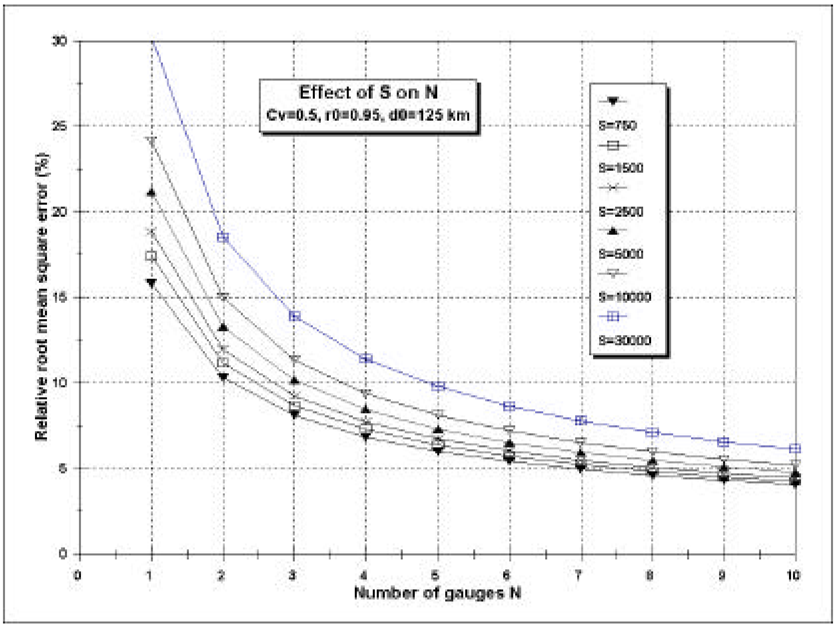


Figure 6.6: Estimation error as function of S and N

Finally, all figures show that doubling the accuracy requirement (by halving the Z_{areal} -value from 10 to 5%) can only be achieved at the cost of a much denser network. It is therefore imperative that a **cost-effectiveness analysis** is carried out before a final decision is taken.

Example 6.1 Rainfall network design in Tel basin

Considered is the south-eastern region of the Tel basin in Orissa.The area is assumed to be homogeneous with altitudes generally below 600 m, hence orographic effects are not expected. The objective is that the network should provide monthly and as an alternative seasonal or annual areal rainfall with a relative root mean square of not more than 10% on average.

Some 9 rainfall stations fairly equally spread over the area are selected. Monthly and annual point rainfall series, derived from daily observations in the period 1970-1995 are used for the analysis. The characteristics of the monthly point rainfall series are displayed in Figure 6.7. Typically, the rainfall in Tel basin is concentrated in the monsoon season, with July and August being the wettest months, both with a long-term average rainfall of approximately 400 mm. The annual rainfall in that area is 1435 mm. In the same Figure the coefficient of variation of the monthly point-rainfall series is displayed. It is observed that the C_v-values for the monsoon months are lowest, and are approximately 0.5. The C_v-values in the non-monsoon season range from 1 to 3.5. The 90% reliable C_v-values (i.e. the C_v-values which are not exceeded at 90% of the stations) are also shown. From Figure 6.7 it is observed that apart from December the variation in the C_v-values is very small. Hence the assumed homogeneity is justified. The C_v-value for the annual point-rainfall series is 0.29 (against 0.23 for the areal average series). It shows that the variation for the larger interval is about half the value of the monthly series. The C_v-statistics are summarised in Table 6.1

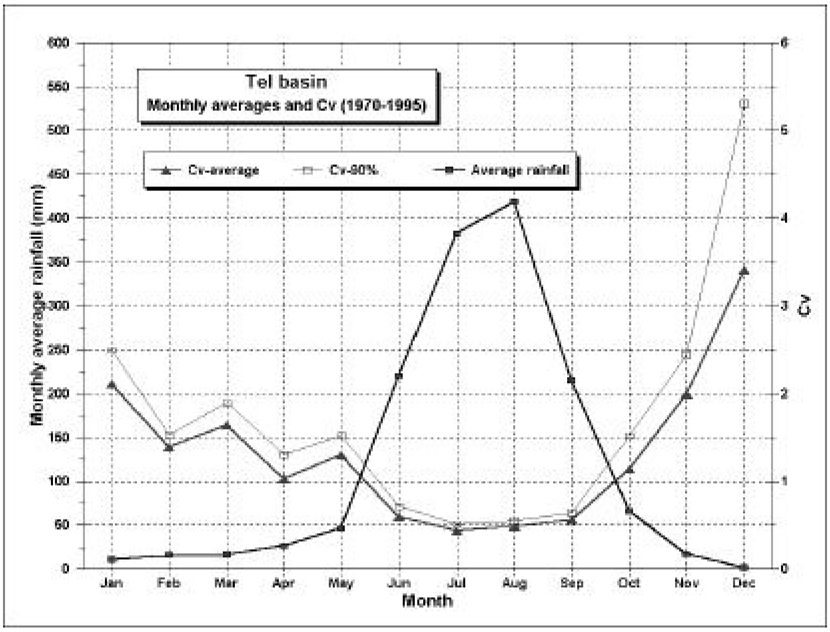


Figure 6.7:
Average monthly rainfall and C_v in Tel basin

Tel-basin	Month				Year
Design S=2000 km^2	**June**	**July**	**August**	**Sept**	
C_v-average	0.60	0.44	0.48	0.56	0.29
C_v-90%	0.71	0.51	0.55	0.64	0.33
r_0	0.975	0.85 (0.90)	0.95	0.95	0.90
d_0 (km)	140	150	125	150	200
Z_{areal}=0.1 (10%) : S/N in km^2/gauge	780	560 (800)	830	710	1670
Z_{areal} =0.05 (5%): S/N in km^2/gauge	270	150 (210)	270	220	480

Table 6.1: Summary of rainfall network design statistics and rain-gauge density requirements for different measures of effectiveness

Given that nearly all rainfall takes place in the period June to September, the analysis is concentrated only on these months as well as on the annual data. The correlation coefficients between the 9 stations for the selected months and of the annual data have been computed and to reduce the scatter have been averaged over intervals of 10 km distance. An example is shown in Figure 6.8 for the month of August.

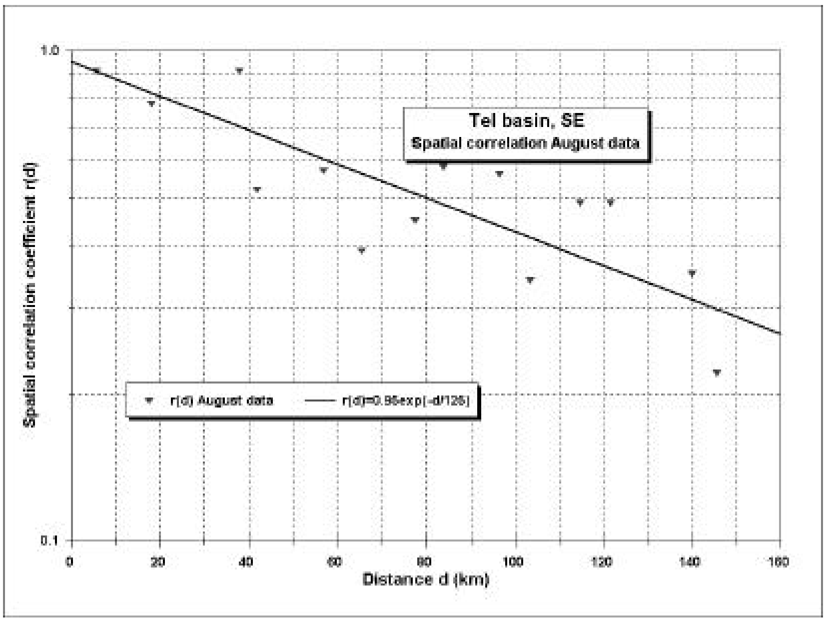


Figure 6.8:
Spatial correlation structure in Tel basin for August

The estimates for r_0 and d_0 for the monsoon months and annual data are presented in Table 6.1. July data appear to have a r_0 of 0.85, indicating large 7 measuring errors or strong microclimatic variability. The d_0 values of the monsoon monthly rainfalls are typically in the order of 125-150 km. The annual series show a larger spatial correlation, with d_0 = 200 km.
Assuming a design basin area of S = 2,000 km^2 in view of hydrometric network demands, the required network densities have been computed for each month and for the annual series meeting a Z_{areal} -value of 10%. The results are presented in Figure 6.9 and Table 6.1. It is observed that the month of July puts the largest pressure on the network. To estimate the areal rainfall in July for units of approximately 2,000 km^2 with on average an error less than 10% one gauge per 560 km2 would be required. This is primarily due to the low accuracy of the rainfall measurements in that month.

In Table 6.1 within brackets also the density requirement is indicated if the measurements of July would be improved to an error variance <10% of the series variance, (r_0=0.9). It is observed that this would reduce the required network density for that month with 30%. Hence, investment in better observation practice really pays off.

In Table 6.1 also the required network density for Z_{areal} -value of 5% is indicated. It shows that by doubling the accuracy, a network would be required, which is almost 4 times as dense. Ergo, the Z_{areal} -value has to be carefully chosen and the financial implications of different Z_{areal} -values has to be evaluated. Note that the WMO norm for plain areas is one gauge per 500 km^2, see Table 6.2. For Tel this density requirement nicely matches with the required density for monthly values if a 10% error in monthly areal rainfall estimates is considered to be acceptable.

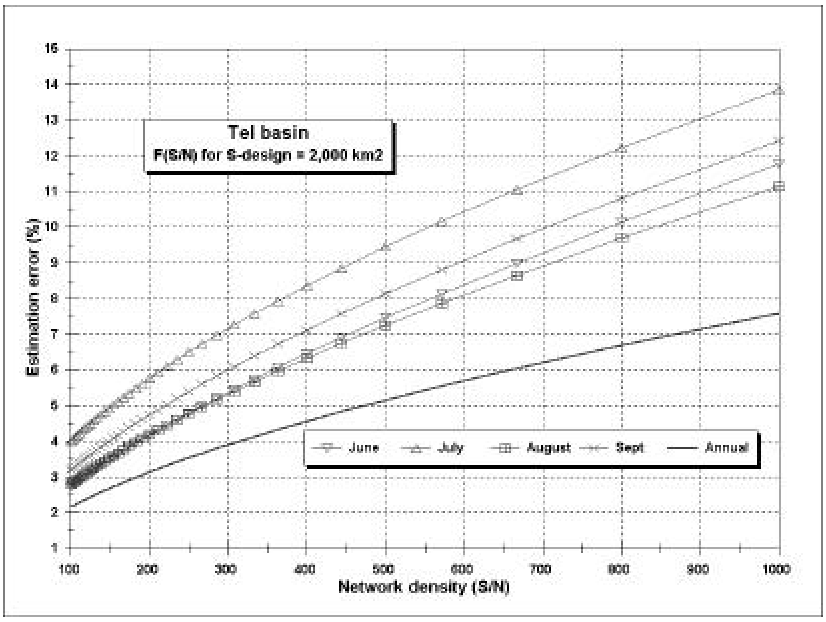


Figure 6.9: Network requirements for S = 2,000 km^2

Minimum network density

Based on world-wide experiences, WMO (1994) has presented a general guide for the required density of precipitation stations. An absolute minimum density for different physiographic units is given in Table 6.2. In their documentation no mentioning is made about the criteria applied in the preparation of this Table. According to Table 6.2 at least 10% of the network stations should be equipped with a recording raingauge.

Region	Minimum density in km^2/gauge	
	Non-recording (SRG)	Recording (ARG)
Hilly region	250	2,500
Semi-hilly region	500	5,000
Plains, high rainfall region	500	5,000
Plains, low rainfall region	900	9,000
Arid region	10,000	100,000

Table 6.2: Minimum density of precipitation stations (WMO, 1994)

Strategy

- From Example 6.1 it is deduced that WMO's minimum requirement will lead to reasonably (<10% error) accurate areal rainfall estimates for intervals of a month and larger if the Tel rainfall variability is considered representative for the rest of the country. **To start with**, the density requirements presented in Table 6.2 can be considered as adequate.
- The network required getting a sufficiently accurate areal estimate for time interval less than one month will be much denser in view of the greater variability and smaller spatial correlation. Such a dense network is likely too costly. Therefore, for short duration rainfall per climatic zone a **representative basin** should be selected in which a network is being operated with a density that fulfils the short duration rainfall requirement.

Note that in the analysis presented above errors in the areal rainfall was taken in the effectiveness measure. In some cases, like for climatic stations, the **interpolation error** between observation stations rather than the error in the areal estimate is of concern. A similar analysis, though with different formulas, can then be applied, for which reference is made to the Manual.

7 Hydrometric Network

7.1 Measurement Objectives

A hydrometric network is a system of river gauging stations in a river basin at which river stage and discharge are measured. The network provides hydrologic data needed for:

- the planning, design and management of conservation and utilisation of the waters and other natural resources of the river system
- for design and management of flood protection measures in flood prone areas

Water management requires, generally, decadal or monthly flow data, whereas for designs discharge and/or water level extremes are of importance. Navigation would be interested in exceedance durations of water levels to be able to assess the Least Available Depth. Hence, it depends on the use of the data which information is to be collected. The data should enable accurate estimation of the relevant characteristics of the hydrological regime of the river basin. In case no clarity is available one should be able to fully reproduce the entire flow regime at a number of locations along the river at such distances that the interpolation error remains sufficiently low.

7.2 Measure of Effectiveness

To enable an optimal design of the monitoring system a measure is required, which quantifies the effectiveness level. This measure depends on the monitoring objectives and can be related to an admissible error in e.g. the mean flow during a certain period, monthly flow values for water balances, extreme flows and/or river stages, etc. This error is a function of the sampling locations, sampling frequency and sampling accuracy, i.e. where, when and with what are river/reservoir stages and flows to be measured.

7.3 Network Design Consideration

In this section a number of aspects are discussed to be considered before actually designing the hydrometric network, including:

- Classification of stations,
- Minimum networks,
- Networks for large river basins,
- Networks for small river basins,
- Networks for deltas and coastal flood plains,
- Representative basins,
- Sustainability,
- Duplication avoidance, and
- Periodic re-evaluation.

Classification

Based on the network levels presented in Chapter 2 the following classification of stations is introduced:

Primary stations, maintained as key stations, principal stations or bench mark stations, where measurements are continued for a long period of time to generate representative flow series of the river system and provide general coverage of a region.

Secondary stations, which are essentially short duration stations intended to be operated only for such a length of period, which is sufficient to establish the flow characteristics of the river or stream, relative to those of a basin gauged by a primary station.

Special purpose stations usually required for the planning and design of projects or special investigations and are discontinued when their purpose is served. The purpose could vary from design, management and operation of the project to monitoring and fulfilment of legal agreements between co-basin states. The primary as well as secondary stations may also, in time serve as special purpose stations.

In designing a network all types of stations must be considered simultaneously.

Minimum networks

A minimum network should include at least one primary streamflow station in each climatological and physiographic area in a State. A river or stream which flows through more than one State should be gauged at the State boundary. At least one primary gauging station should also be established in those basins with potential for future development.

A minimum network should also include special stations. Where a project is of particular socio-economic importance to a State or Region it is essential that a gauging station is established for planning, design and possibly operational purposes. Sometimes special stations are required to fulfil a legal requirement e.g. the quantification of compensation releases or abstraction controls. Benefit - cost ratios for special stations are usually the highest and can help support the remainder of the hydrometric network.

Networks for large river basins

A **primary station** might be planned at a point on the main river where the mean discharge attains its maximum value. For rivers flowing across the plains, this site is usually in the downstream part of the river, immediately upstream of the point where the river normally divides itself into branches before joining the sea or a lake or crosses a State boundary. In the case of mountainous rivers, it is the point where water leaves the mountainous reach and enters the plain land. Subsequent stations are established at sites where significant changes in the volume of flow are noticed viz., below the confluence of a major tributary or at the outflow point of a lake etc.

If a suitable location is not available below a confluence, the sites can be located above the confluence, preferably on the tributary. While establishing sites downstream of a confluence, care should be taken to ensure that no other small stream joins the main river so as to avoid erroneous assessment of the contribution of the tributary to the main river. In the case of a large river originating in mountains, though the major contribution is from upper regions of the basin, several stations may have to be located in the downstream stretch of the river. Such stations are intended to provide an inventory of water loss from the channel by way of evaporation, infiltration, and by way of utilisation for irrigation, power generation, industrial and other domestic needs.

The distance between two stations on the same river may vary from thirty to several hundred kilometres, depending on the volume of flow. The drainage areas computed from origin up to consecutive observation sites on **a large river should preferably differ by more than 10% so that the difference in quantities of flow is significant**. The uncertainties in discharge values particularly for high flows are unlikely to be less than +/- 10%. However, every reasonable attempt should be made to minimise these uncertainties.

The above uncertainties may affect the location of stations. When tributary inflow is to be known it is generally better to gauge it directly, rather than deriving the flow from the difference of a downstream and an upstream station along the main stream. Also, a more accurate discharge record for the main stream is obtained from monitoring the feeder rivers than by a main stream station alone, however, at the expense of additional cost.

Networks for small river basins

The criteria mentioned in the previous paragraph are applicable to a river basin having a large area and well developed stream system. A different approach is to be adopted in dealing with small independent rivers, which flow directly into the sea, as in the case of west flowing rivers of Kerala and Maharashtra and some east flowing rivers of Tamil Nadu. In such cases, the first hydrological observation station might be established on a stream that is typical of the region and then further stations could be added to the network so as to widely cover the area. Streams in a particular area having meagre or lower yields should not be avoided for inclusion in the network. Absence of a station on a low flow stream may lead to the wrong conclusions on the water potential of the area as a whole, evaluated on the basis of the flow in the high flow streams. Thus, great care is to be exercised in designing the network to ensure that all distinct hydrologic areas are adequately covered. It is not possible to operate and maintain gauging stations on all the smaller watercourses in the Western Ghats, for example. Therefore, representative basins have to be selected and the data from those are used to develop techniques for estimating flows for similar ungauged sites.

Networks for deltas and coastal floodplains

Deltaic areas such as the Lower Mahanadi in Orissa where gradients are usually low and channels bifurcate, are often important as water use is productive and thus these areas need monitoring. This is particularly important, as deltas are dynamic systems i.e. they are continually changing. However, the type of network required may differ from more conventional river basins. It is often not possible due to the low gradients to locate stations with stable stage-discharge relationships i.e. variable backwater effects can occur due to tidal influences and/or changes in aquatic vegetation growth. Stage readings should be made at all principal off-takes/bifurcations or nodes in the system. These should be supplemented by current meter gaugings when required. At some sites consideration might be given to installing a slope-area method station.

Representative basins

When gauging stations are included in a network to obtain representative data from a particular physiographic zone, it is better if the chosen basins are those with water resource relatively under utilised i.e. the basins can be considered to be **close to their natural state**. The selection of representative gauging stations in basins, which are heavily utilised by dams and water abstraction and/or where significant land use changes have been made and are continuing have to be avoided.

Sustainability

Of paramount importance is **sustainability**. It is a relatively straightforward task to design a dense network of streamflow stations. However, the implementation and operation of a network is a lot more difficult. It has been found from experience that there is a tendency to adopt an idealistic approach and attempt to have as many stations as possible. There are many examples of networks throughout the world, which are no longer functioning well due to lack of financial support, skilled manpower and logistic support resources such as vehicles. It is far better to operate and maintain 10 gauging stations well than to operate and maintain 20 stations badly i.e. higher quality data from fewer stations is preferable to a lower quality of data from a greater number of stations.

Duplication avoidance

Since, generally more than one organisation is responsible for the establishment of gauging stations e.g. the State Water Departments and CWC, **it is essential that the activities are co-ordinated so they complement each other and duplication of effort is avoided**.

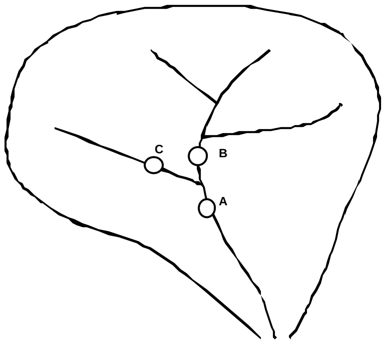
Periodic re-evaluation

Gauging station networks require **periodic re-evaluation**. The developments that take place in the basin, like construction of new irrigation/hydro-electric projects and industrialisation of

the area, may warrant addition or closure of stations. For example river reaches are often polluted due to the discharge of effluents from industry. Therefore, a need may arise to establish stations to assist with water quality monitoring and pollution assessments.
Example 7.1
Consider the basin shown in the sketch. One would like to know the flow in the main river and in its headwater rivers. What would be the best strategy if the flow at the locations are estimated at: A = 100 m3/s; B = 80 m3/s, and C = 20 m3/s. Measuring procedures are such that at each location a 10% error is made

The following options exist:

1. A = B + C
2. B = A – C
3. C = A – B



Assuming that the measurement errors made at each location are independent, it follows:

1. $\sigma_A = (8^2 + 2^2)^{1/2} = 8.25\ m^3/s$, so the relative error in the flow at A is 8.25/100 or 8%
2. $\sigma_B = (10^2 + 2^2)^{1/2} = 10.2\ m^3/s$, so the relative error in the flow at B is 10.2/80 or 13%
3. $\sigma_C = (10^2 + 8^2)^{1/2} = 12.81\ m^3/s$, so the relative error in the flow at C is 12.81/20 or 64%

From this it follows that from an accuracy point of view the best option would be to have stations at B and C even if only the flow at A is to be known. However, measuring at B and C if only A is to be known requires two stations to be kept operational, so the solution might not be cost-effective. Furthermore, the sum of B and C will be slightly less than A because due to backwater effects the stations B and C cannot be located too close to the confluence.

From the result it is also observed that estimating flows as the difference of two large values (C = A – B) will result in a very inaccurate estimate.

7.4 Network Density

The World Meteorological Organisation developed guidelines on minimum hydrological network densities. Their guidelines and potential use and limitations are presented in this section. Furthermore, prioritisation system is introduced to rank the importance of stations. Finally, comments are given on the use of statistical and mathematical optimisation techniques for hydrometric networks.

WMO recommendations

The recommendations of the WMO (World Meteorological Organisation) on the minimum density of a streamflow network for regions with different physiographic features are reproduced in Table 7.1 below.

	Type of region	Range of norms for minimum network	Range of provisional norms tolerated in[1] difficult conditions
I.	Flat regions	1,000 - 2,000	3,000 - 10,000
II.	Mountainous regions	300 - 1,000[2]	1,000 - 5,000
III.	Arid zones	5,000-20,000	------------------

NOTES:

1. Last figure in the range should be tolerated only for exceptionally difficult conditions;
2. Under very difficult conditions this may be extended up to 10000 km^2;
3. Great deserts are not included;
4. Under very difficult conditions this may be extended up to 10000 km^2.

Table 7.1: Minimum density of hydrological network according to WMO, area in km^2 for one station

It is not possible to provide specific, general guidelines on an appropriate network density. The WMO recommendations are very general guidelines which if adopted at face value in for some India's larger river basins could result in an excessively dense network. **Even though the WMO type guidelines might be used as rough rule of thumb as part of an initial network appraisal, their use in the final design of the network should be avoided**. The network density must ultimately be based on the network objectives, the temporal and spatial variability of river stages and flow and on the availability of finance, manpower and other resources.

Prioritisation system

It is suggested that in the first instance the "ideal" network size is determined. In determining the network all potential users of the data should be consulted. Each station in the "ideal" network should be prioritised. In order to do this a simple prioritisation system is useful. This prioritisation system could be a simple one such as follows:

Category	Priority	Relative Importance
A	High	Major, multi-purpose water resources development site, State boundary river, operation of major scheme, major ungauged basin, heavily polluted major water supply source
B	Medium	Medium scale water resources development project site, secondary basin, industrial development area i.e. potential water quality problems)
C	Low	Minor irrigation project site, secondary gauging station on tertiary tributary, major water course but already extensively gauged

The above categories and priorities are merely highlighted by way of example. Each State/Central organisation needs to set its own priorities based on its own policies and objectives. In prioritising sites, the following questions should be asked:

- What are the socio-economic consequences of not collecting streamflow data at the site?
- What are the alternatives to establishing a streamflow gauging station at the site under consideration?

An estimate of the number of stations within each State, Division and Sub-division which can be realistically, well maintained should be made. When deriving this estimate the following factors should be considered:

- The recurrent budget implications;
- Short and longer term manpower requirements and availability of suitably skilled personnel;
- Capacity of instrument repair, spare part provision and calibration facilities;
- Long term availability of logistic support facilities such as vehicles.

The ideal and realistic network size estimates should be compared. If necessary the size of the ideal network should then be reduced by removing the lower priority stations.

Statistical and mathematical optimisation

The streamflow network should provide information for the location indicated by the hydrological data users. At a number of locations no stations will be available. Hence the information is to be obtained from the network by e.g. interpolation. If the interpolation error in estimating a flow characteristic is too large than additional stations or a re-design should be considered. These techniques are most applicable to already well established networks, where the data have been rigorously quality controlled and are readily available in computer compatible form. However, they are less readily applied to heavily utilised, over-regulated catchments like many of the larger river basins in India. These techniques are a tool to assist with network design. They are not straightforward to apply and do not totally obviate the need for the pragmatic, common sense approach.

Annex I
Data Needs Assessment

GENERAL

Purpose

An essential feature of the Hydrological Information System is that its output is **demand driven**. This means that its output responds to the hydrological data needs of the users assembled in the Hydrological Data Users Group (HDUG). Therefore, the existing and potential data users have to be interviewed to assess their hydrological data requirements (including meteorological, surface water, groundwater and water quality data) in view of their mandate/objective. To streamline the data need assessment a questionnaire has been designed. The purpose of this questionnaire is to provide in a structured manner information on:

1. The profile of the users of hydrological data
2. The current and proposed use of water systems
3. Current hydrological data availability and requirements
4. Future hydrological data requirements

This information provides basic input for the design/review of the network, site selection, type of data collected, frequency of observation and the methods of data storage and dissemination.

Interview team

Small interview teams (IT's) are to be constituted to visit the existing and potential data user with the questionnaire. Per state the IT should include a representative of the State Surface Water Department and one of the State Groundwater Department. It is essential that the team members have thorough knowledge the Hydrological Information System and possible outputs of the system. For important (potential) data users the Head of the Data Centre should lead the IT.

Approach

The (potential) data users are approached for an interview one by one. An appointment is made with the manager/director of the data user organisation/company for a meeting with him/her and relevant staff members, who actually use or may use the data in their day to day work.

The interview comprises two visits:

1. In the first visit the IT first explains the concept of the Hydrological Information System, its objectives and possible output and subsequently explains the contents of the questionnaire and how questions have to be interpreted. It is essential to get a proper impression of their mandate/objective, and based on that, to assess possible uses of hydrological data to improve their functioning/output: the data market should be properly explored. At the end of the visit a date has to be set for the follow up visit, which should

be scheduled within one month from the first. In between the first and the follow up the (potential) data user has to complete the questionnaire.

2. In the second visit, the IT reviews with the data user the answers to the questions and checks if the questions have properly been understood and sees to it that the replies do comply with the objectives of the data user need assessment.
3. The results of the interviews should be thoroughly analysed, in two ways:
4. Have the results immediate effects for the data made available through the Data Centres, and
5. Do the results lead to adjustments in the approach of data users and possible alterations in the questionnaire.

QUESTIONNAIRE FOR HYDROLOGICAL DATA USERS

The questionnaire includes the following topics:

A. details about the organisation

particulars of organisation
services provided
personnel
financing

B. current water system

use of water system
classification of use
quantification of use
changes in use
responsibility for use

C. Current hydrological data availability and uses

Sources of data
Standards of services

D. Data requirements

Classification of data
Proposed use of data
Data parameter requirement

QUESTIONNAIRE FOR HYDROLOGICAL DATA USERS

This questionnaire is intended to collect information on hydrological data needs for the further development of the Hydrological Information System. This questionnaire serves to identify:

A. The profile of the users of hydrological data

B. The current and proposed use of water systems

C. Current hydrological data availability and requirements

D Future hydrological data requirements

STATE/CWC/CGWB:...

Date of interview:

INTERVIEWERS:

Name: Designation:

INTERVIEWEE(S):

Name: Designation:

A. DETAILS OF YOUR ORGANISATION

A1. Particulars of your organisation

i) Name of organisation..
Address...
....
....
Telephone:..
Fax:..

Sector: Governmental/Semi-governmental/Public Sector Undertaking/Private

(please delete as appropriate)

ii) If non-private, please specify to which ministry or local authority your organisation belongs:

iii) What are your organisation's responsibilities/obligations/mandates (legal mandates?) and objectives?

A2. Services Provided

i) Please provide details, supported by examples, of the type of services you provide:

ii) Who are your main customers/clients?

A3. Personnel

i) Please provide information on personnel employed by your organisation, in accordance with the following:

	Numbers of personnel			
Category	**Unskilled/ semi-skilled**	**Skilled**	**Professional (Graduate/ post graduate)**	**Total**
1. Administrative				
2. Technical				
TOTAL				

ii) Of your professional staff please indicate the numbers under each of the following categories:

Category	**Number of professional staff**
Meteorologists	
Civil Engineers	
Hydrologists	
Hydro-geologists	
Chemists	
Environmental Scientists	
Computer specialists	
Science	
Other (please specify)...........................	
TOTAL	

A4. Financing

i) What is your annual turnover?

ii) Is your organisation self-supporting? If not what is your source of revenue?

iii) Do you charge for your services?

iv) Do your charges cover all your real costs?

B CURRENT WATER SYSTEM USE

B1. Use of water system

Do you make use of a water system (not necessarily consumption only)?

i) surface water (river, lake, creek, canal)

ii) sub-surface water (spring, well, borehole)

B2. Classification of use

How do you classify your type of use (please tick where appropriate):

Classification	Please ✓
Flood control	
Domestic (domestic use, livestock watering)	
Irrigation	
Fisheries	
Forestry	
Food processing	
Industry (textiles (dyes, leather), pulp and paper, cement, petrochemical, pharmaceutical, fertiliser)	
Mining (coal, ore)	
Water transportation	
Hydroelectric power generation	
Thermal power generation	
Nuclear power generation	
Wild life and nature reserve management	
Tourism, recreation	
Other (please specify)...	

B3. Quantification of use

Please quantify the use

Amount('):

Where required('):

How much required('):

(')Please provide this information on a separate sheet (if necessary)
Timing: e.g. equally distributed around the year, peak periods, needs in low flow period
Quality: Specify the standards adopted (e.g. BIS)

Tick the important issues from the following list:

Issue	✓
Bacteriological quality	
Suspended solids	
Aesthetic items (odour, colour)	
Temperature	
Turbidity	
Salinity	
Hazardous wastes	
Acidity, corrositivity	

B4. Changes in use

Do you expect the current use to change significantly within the next 10 years? Quantify if possible.

Where required?

How much will be required?

Timing?

Quality?

B5. Responsibility for use

Are you responsible for the provision and/or discharge of water and/or the control of its water quality?

C. Current hydrological data availability and uses

C1. Sources of data

i) Does your organisation operate and/or own a (geo-)hydrological and/or meteorological network?

YES/NO?

ii) If "YES" could you please provide an inventory.

iii) Who or who else supplies your organisation with (geo-)hydrological and/or meteorological data at present? Please provide an inventory of the information needed/supplied.

iv) How, when and with what frequency and in what form do you receive this data?

How is data received? e.g. post, courier, telephone (voice and/or modem) etc.

When is data received? e.g. on request, monthly, annually etc.

Frequency of data? e.g. daily, monthly, ad-hoc etc.

Form of data? e.g. hard copy, on disk etc.

v) What charges are made, if any, to supply the data referred to above?

C2. Standards of service

i) Is your organisation satisfied with the current standards of water data services?

YES/NO?

ii) If the answer to C.2 (i) is "NO", what are your suggestions and where do you feel improvements can be made?

D Data Requirements

D1. Classification of data

How do you classify the type of data required:

- historical data[1]
- real-time data[2]

D2. Proposed uses of data

Use the following table to specify for which purpose you need the data.

Classification	Planning	Design	Management & operation
Flood control			
Domestic (domestic use, livestock watering)			
Irrigation			
Fisheries			
Forestry			
Food processing			
Industry			
Mining (coal, ore)			
Water transportation			
Hydroelectric power generation			
Thermal power generation			
Nuclear power generation			
Wild life and nature reserve management			
Tourism, recreation			
other (please specify).....................................			

[1] Historical data is data that is collected for planning and design purposes i.e. it is past data. For example the collection of a 10 year sequence of river flow data for reservoir capacity design purposes;

[2] Real time data is data that is required for day to day operational purposes e.g. river levels for flood management and warning purposes.

D3. Data parameter requirements:

Please complete Table 1 indicating the type of data you require.

TABLE 1

QUESTIONNAIRE FOR HYDROLOGICAL DATA USERS - USER DATA PARAMETER REQUIREMENTS

Data On	Type of data	Importance	Interval	Frequency	Form	Accuracy
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Meteorology	1. Rainfall					
	2. Air temperature					
	3. Air pressure					
	4. Humidity					
	5. Wind speed					
	6. Wind direction					
	7. Sunshine duration					
	8. Evaporation					
Surface water	**<u>Water quantity</u>**					
	1. Water level					
	2. Flow velocities					
	3. Stage-discharge data					
	4. Discharge					
	5. Sediment concentration					
	6. Water use					
	<u>Water quality</u>					
	1. Colour & odour					
	2. Dissolved oxygen					
	3. Electrical conductivity					
	4. pH					
	5. Water temperature					
	6. Solids dissolved/suspended					
	7. Turbidity					
	8. Alkalinity (carbonate/bicarbonate)					
	9. Chloride					
	10. Sulphate					
	11. Calcium					
	12. Magnesium					
	13. Potassium					
	14. Sodium					
	15. Nitrogen (ammonia, organic, nitrite, nitrate					

Data On	Type of data	Importance	Interval	Frequency	Form	Accuracy
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Surface water	16. Phosphate					
	17. Boron					
	18. Fluoride					
	19. Iron					
	20. Manganese					
	21. Silica					
	22. Chemical Oxygen demand					
	23. Biochemical Oxygen Demand					
	24. Coliform bacteria (total, faecal)					
	25. Trace heavy metals (arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, vanadium, zinc)					
	26. Cyanide Trace organics (phenols, petroleum, derivatives, detergents, pesticides)					
	27.					
	Other					
	1. River basin maps					
	2. Hydraulic infrastructure					
	3. Stage-discharge ratings					
	4. Sediment-discharge ratings					

Legend: (3) Importance of parameter: 0 = not required, 1 = important, 2 = indispensable/essential

(4) Required time interval of data series e.g. hour, hour, day, week, month, annual

(5) If data are required on regular basis indicate at what frequency e.g. receive on monthly basis

(6) Indicate the form in which the data is required: 1 = hard copy; 2 = computer file

(7) Specify the required accuracy of the data in absolute or relative values e.g. +/- 10 mm, +/-15%.

TABLE 1 (contd.)

QUESTIONNAIRE FOR HYDROLOGICAL DATA USERS - USER DATA PARAMETER REQUIREMENTS

Data On	Type of data	Importance	Interval	Frequency	Form	Accuracy
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Groundwater	**Water quantity**					
	1. Piezometric level					
	2. Water use					
	Water quality					
	1. Colour & odour					
	2. Electrical conductivity					
	3. pH					
	4. Water temperature					
	5. Solids dissolved/suspended					
	6. Alkalinity (carbonate/bicarbonate)					
	7. Chloride					
	8. Sulphate					
	9. Calcium					
	10. Magnesium					
	11. Potassium					
	12. Sodium					
	13. Nitrate					
	14. Phosphate					
	15. Boron					
	16. Fluoride					
	17. Iron					
	18. Manganese					
	19. Silica					
	20. Trace heavy metals (arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, vanadium, zinc)					
	21. Cyanide					

Data On	Type of data	Importance	Interval	Frequency	Form	Accurac y
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	22. Trace organics (phenols, petroleum, derivatives, detergents, pesticides)					
	Other					
	1. Geo-hydrological maps					
	2. Aquifer parameters/pump test data					
	3. Observation well data					
	4. Production well data					

Legend: (3) Importance of parameter: 0 = not required, 1 = important, 2 = indispensable/essential

(4) Required time interval of data series e.g. hour, hour, day, week, month, annual

(5) If data are required on regular basis indicate at what frequency e.g. receive on monthly basis

(6) Indicate the form in which the data is required: 1 = hard copy; 2 = computer file

(7) Specify the required accuracy of the data in absolute or relative values e.g. +/- 10 mm, +/-15%.