# 3. HYDROLOGY

## 3.1. GENERAL

The main purpose of hydrologic investigations is the determination of design parameters for hydroelectric projects under consideration. These comprise basically:

- available discharges for power generation
- floods
- transported sediments by water

As it is known, the discharges cannot be measured directly in a continuos way. Therefore continuos water level readings are transformed to discharges by discharge measurements and the development of rating curves. Floods are decisive for the layout and the design of the hydropower project. They are calculated by hydrologic procedures, which will be explained in the next paragraph of ”Data Processing”. Beneath the water data, sediments are important i.e. with respect to estimation of useful life of seasonal reservoirs and to design of structures.

The following paragraphs contain initially, a description of collection and processing of hydrological data. The processing and estimation of design parameters are shown in the next chapter. Before data collection is described, first the use of hydrologic data as part of hydropower implementation is illustrated in the next two paragraphs.

### 3.1.1. DISCHARGES

Before details are discussed concerning the data collection in the field, some more information on the type, source, processing and purpose of data shall be given. This is to illustrate the intention of collecting data.
Two types of information can be distinguished for discharges:

- normal flow series
- water rights
    - irrigation
    - water supply
    - any other

Especially the issue of water rights is very critical in development of hydropower projects in rural areas and areas of different provinces. The resource water can be considered as the decisive resource for irrigation purposes and water supply. Both have to be ensured during development of hydropower to avoid any socio-economical impact on life.

The discharges can be obtained from gauging stations, if available, or design data. Discharges concerning water rights have to be determined from the local authority, by taking data about the population, and the area of cultivated land. Additionally it is recommended to carry out measurements of discharges in irrigation and water supply canals during different seasons to gain information about actual irrigation practices.

With help of above mentioned discharge data processing can be started, which will be discussed in detail in the next chapter. The flow duration curve can be calculated for the selection of discharge range and determination of design discharge, the available discharge for power generation can be obtained by subtracting water rights discharges. Thereby water rights are taken into account and adapted hydropower projects can be developed.

In this respect two cases have to be distinguished:

- canals

- rivers

The maximum water discharge of a canal is determined and cannot be changed, the discharge of a river is highly variable through different natural conditions, such as ice- and snowmelt, monsoon etc. The following sketch gives an overview over the type and source of discharge data and its purpose for canals.

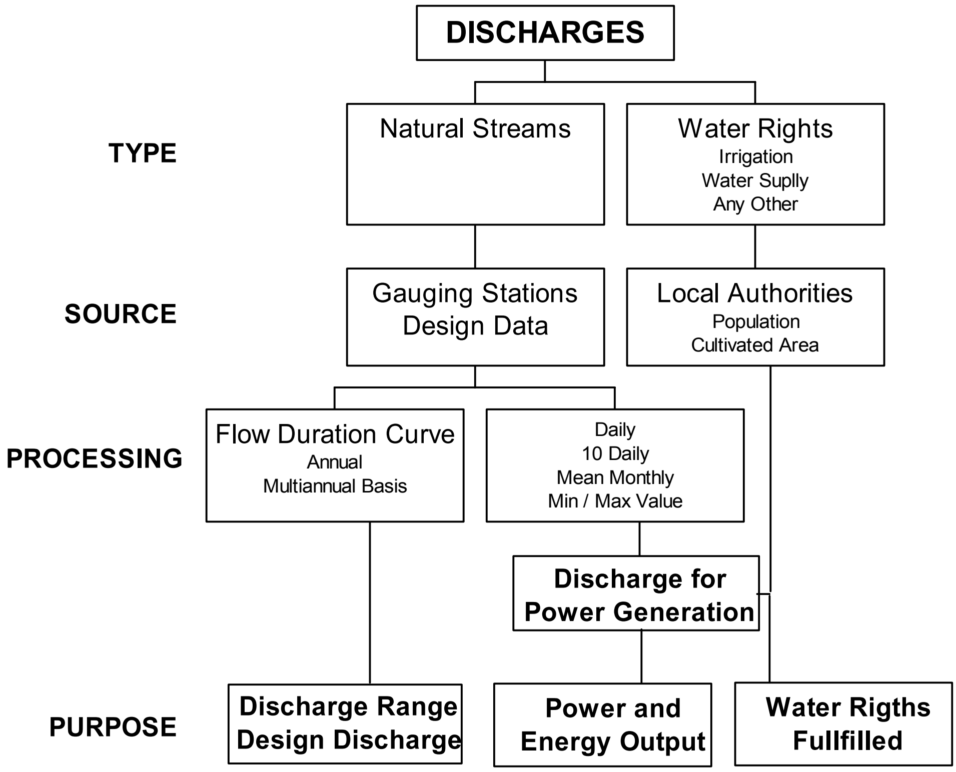


**Fig. 3.1: Type, source, processing, and purpose of discharge data for canals**

Additionally to the parameters shown in the sketch above, at rivers floods have to be considered, which have an enormous impact on the design of hydraulic structures and relief structures of the hydropower development. The chosen return period is also important for the sizing of the structures, which will be explained in detail in the following paragraphs.

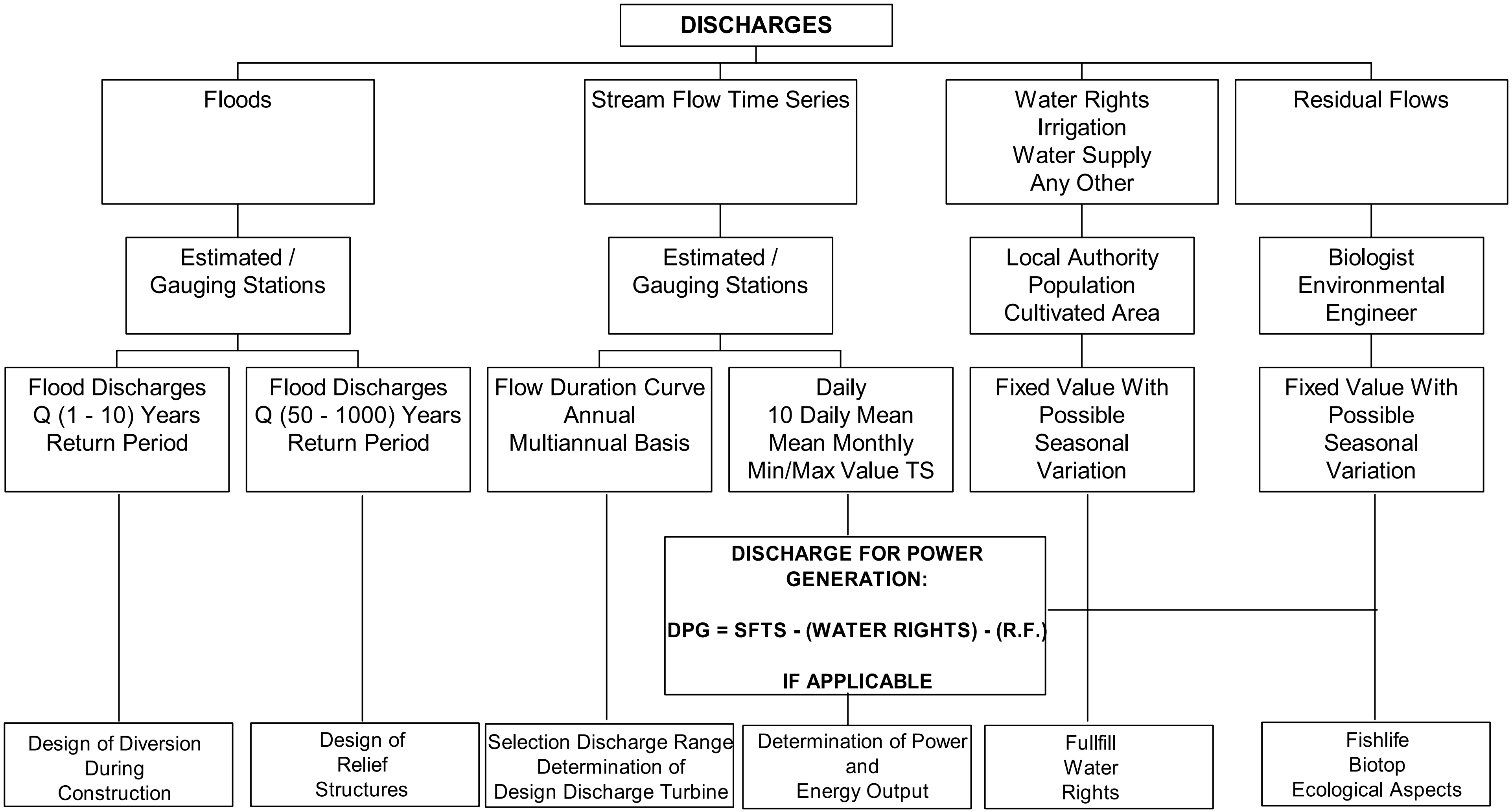


**Fig. 3.2: Type, source, processing, and purpose of discharges for rivers**

### 3.1.2. WATER LEVELS

For hydropower projects the water levels of following types are of special interest:

- headwater levels
- tailwater levels

Both types of data are obtained from gauging readings and design. Through detailed processing of water levels, rating curve, minimum and maximum water levels can be determined. Thereby the available head for hydropower can be generated and a proposal can be calculated for the power and energy output in the application. In case of the use of Kaplan turbines for low heads the setting of the tailwater levels are interested for the setting of the turbine. An overview over the complete procedure in case of canals is given in the following sketch.

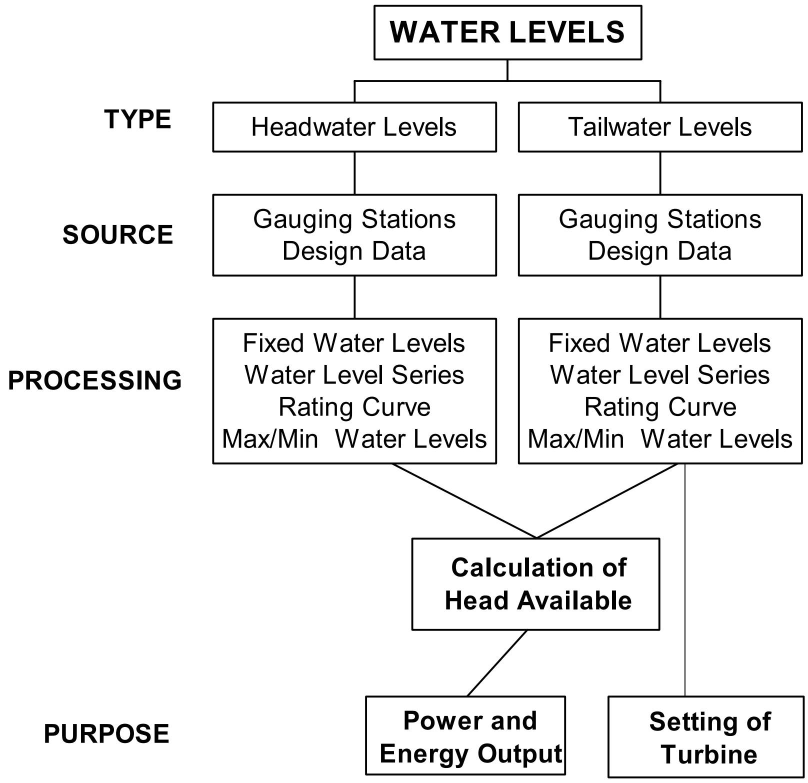


**Fig. 3.3: Type, source, processing, and purpose of data for canals**

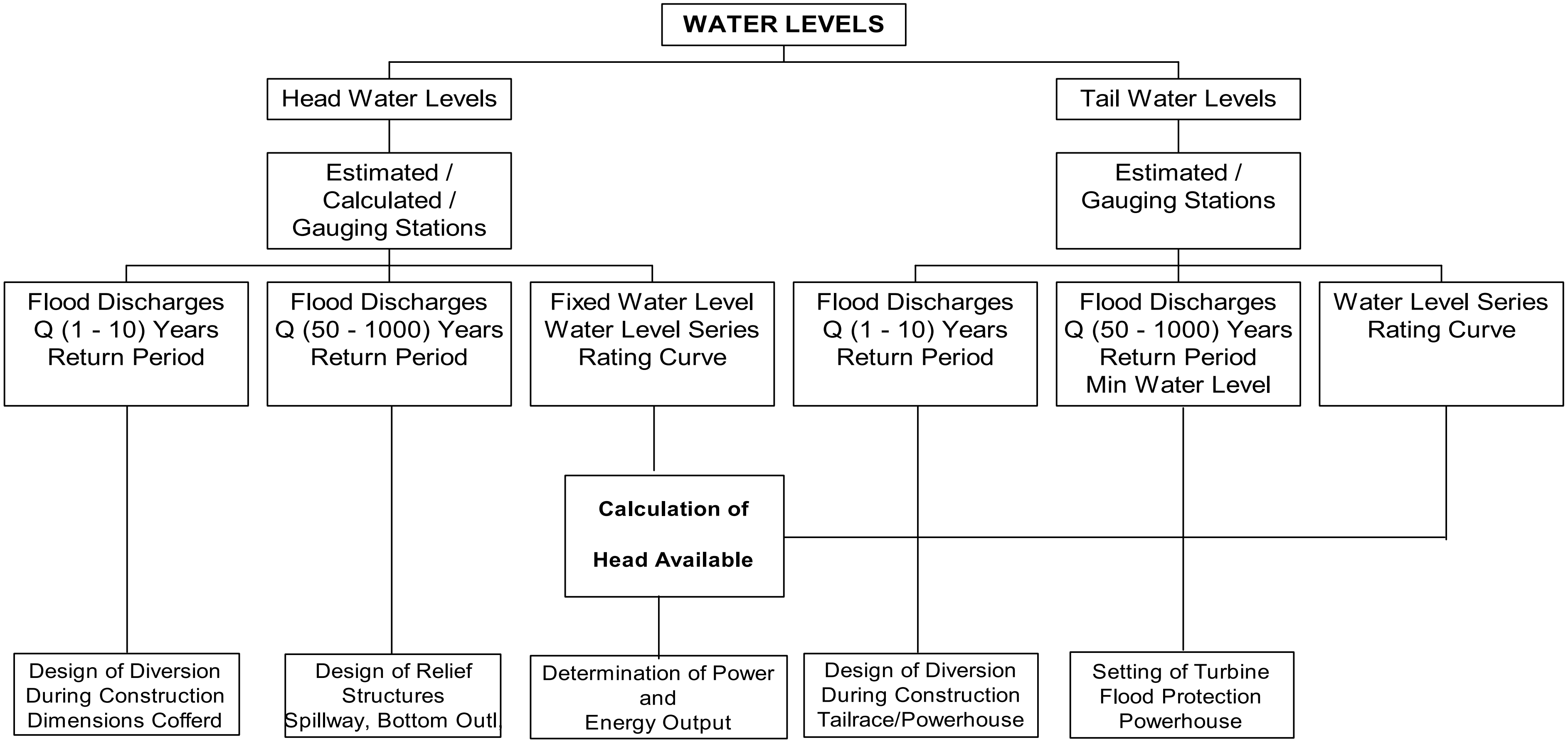


**Fig. 3.4**: **Type, source, processing, and purpose of water levels for rivers**

## 3.2. DATA COLLECTION

Collection of hydrologic data comprises the observation of the rivers in the field, the measurement of its state, the processing of the data and its presentation in a comprehensive form.

Usually discharge data is available in case of low head hydropower developments in form of gauging stations with discharge measurements. At great rivers gauging stations have been introduced in the past to gain quantitative information about the state of rivers. However it might also be possible, that only sporadic measurements are carried out in smaller rivers in rural areas.

### 3.2.1. SPORADIC MEASUREMENTS

Sporadic measurements have been made for various purposes, but basically comprise low flow measurements. Staff gauges have not been installed and only the measured discharges with indication of site and date are reported. In some areas where no other data is available, these records constitute the only source of information.

For a proper interpretation and use, sporadic discharge measurements need to be correlated with records of gauging stations. This is due to the fact that low flow measurements do not necessarily imply that the minimum expected discharges have been recorded with the sporadic measurement.

### 3.2.2. GAUGING STATIONS

#### 3.2.2.1. STAFF GAUGES

Gauging stations, independently of the technique adopted, require the installation of staff gauges to monitor the water levels. Readings of the staff gauges constitute the reference level for any measurement or additional equipment installed at the station.

Staff gauges have to be properly fixed in order to avoid their destruction during floods. An additional reference point out of the reach of the floods level has to be provided. This reference point is provided in order to continue the water level record from the same reference level when the gauges have been washed away.

When recording instruments are not installed, records of water levels are *discrete* and require the appointment of personnel for this specific job. Readings are made with different frequency according to the time of the year, location of the gauging station from nearest population center, etc. An example of staff gauging readings can be seen in Figure 3-1 in the appendix.

#### 3.2.2.2. WATER LEVEL RECORDERS

Recording at gauging stations may be *continuous*, installing instruments that record the water levels on graph paper.

Water level recorder consists basically of a drum, a pen holding device and the sensor. The graph chart is placed on the drum, which moves at a velocity determined by the scale of the graph chart. Normally, adjustment of the velocity of the drum is possible for longer or shorter period of record. The sensor transmits mechanically or electronically the water level to the pen holding device, which writes the water levels on the paper chart. An example of a gauging station is given in the appendix in Figure 3-2.

Three types of sensors are the most popular in use today, float, pressure and sonic. In the table below some of the pros and cons of the three types of sensors are depicted:

**Table 3.1: Different water level recorders**

| ITEM | TYPE OF SENSOR | | |
|---|---|---|---|
| | FLOAT | PRESSURE | SONIC |
| Stilling Well | Required | Not required | Required |
| Power Supply | Not required | Required | Required |
| Maintenance | Laborious | Simple | Laborious |
| Repair | Simple | By manufacturer | By Manufacturer |
| Heavy sediment load | Frequent maintenance | No special maintenance | Frequent maintenance |
| Freezing Water | Not suitable | Suitable | Not Suitable |

In case freezing water conditions are expected at the site, it is recommended to use pressure sensors. If not, other measuring devices are also possible. In general it should be mentioned in this context, that the simpler a measuring device is, less parts can be out of order.

#### 3.2.2.3. DATA LOGGERS

Data loggers provide the facility of storing the data on magnetic media. The loggers can be attached to the water level recorder or directly connected to the sensor. The data is stored either in the loggers memory or on memory cards. Form of storage of data is important especially in rough environment. If the data is stored in the logger's memory, the data have to be retrieved in the field. The operation of retrieving data may last from fractions of an hour to hours, depending on the amount of data to be retrieved. Memory cards have the advantage that they can be replaced by a new memory card and the data can be retrieved in the office.

Data loggers provide a convenient way of storing data and processing hydrological data is simplified when data stored on magnetic media is available. However, matching of data from loggers with the gauge readings have to be checked. Data loggers storing data on memory cards provide the most convenient way to acquire, retrieve and process data. Consequently, the equipment acquired for the new stations is of this type.

### 3.2.3. FLOW MEASUREMENTS

Besides recorded water levels, streamflow measurements are regularly taken at gauging stations to allow development of rating curves. The protocol of one measurement can be seen in Figure 3-3.

Although desirable, rating curves derived strictly on basis of available streamflow measurements, do not always cover the whole range of recorded water levels. In this case, extrapolation of the rating curves is required. To extrapolate the rating curve the most common method in use is the "Slope-Conveyance" method. To extrapolate rating curves by the "Slope-Conveyance" method at least one cross section of the river at the place of the gauges is required.

Other problems arise with the estimation of discharge values when the river bed varies throughout the year at the gauging site. In Pakistan the technique of "shifting" the rating curve has been used during the last 2 decades. The method was developed by the US Geological Survey to estimate river discharges when the stage-discharge relationship does not remain constant.

For estimation of mean daily flows the method of shifting the rating curves is available as an option in the software of the hydrological data bank. The principle of shift is explained in the next two figures, it means:

- Shift is the correction applied to the stage of a discharge measurement to bring the measurement to the standard curve.
- Shifts vary with time and fluctuations of stream flow.

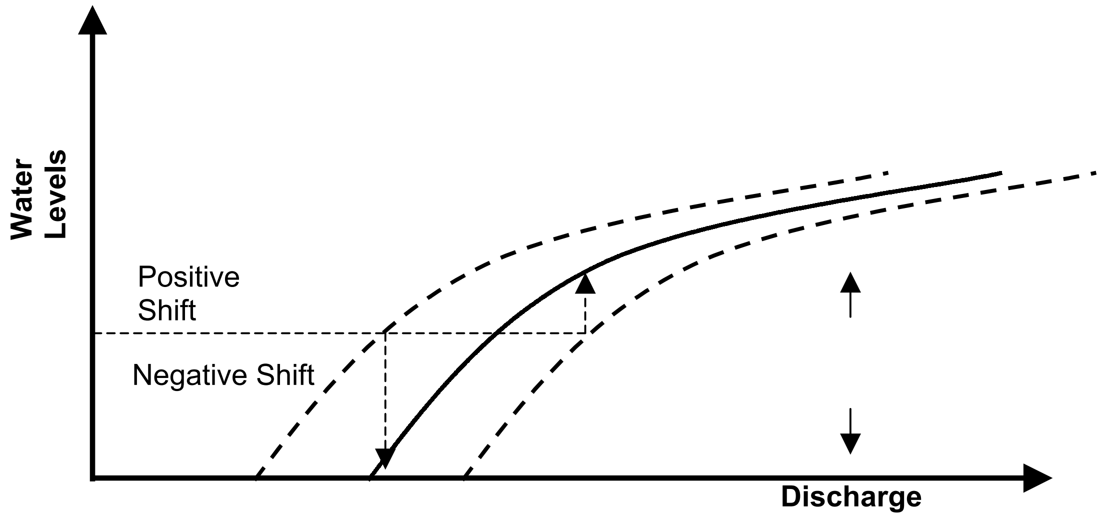


**Fig. 3.5: Shifting of stage-discharge rating curve**

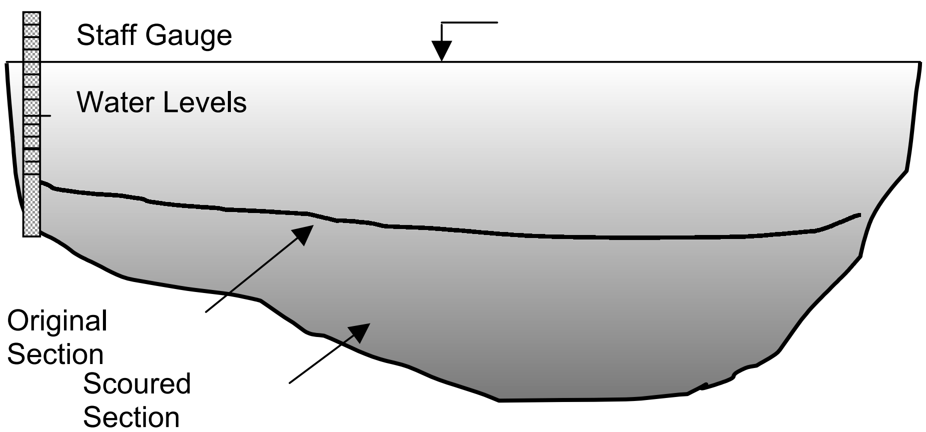


**Fig. 3.6: Application of Shifting at scoured cross sections**

### 3.2.4. FIELD INVESTIGATIONS

Some basic considerations concerning field measurements of discharge in plain rivers should be given here. Plain rivers, especially in Asia are characterized by large widths. Due to this, discharge measurements are sometimes difficult to carry out. For this reason usually suspended bridges are used for the establishment of gauging stations and the location of discharge measurements.

The other possibility to measure discharges is to use boats with appropriate equipment, such as anchors and cranes. It should be ensured, that the boats measure along a cross section that is right angled to the flow direction. Therefore river reaches with straight alignment are recommended for this purpose. The staff should be installed on a location, where flow conditions are calm and the sensor of the automated gauge cannot be destroyed by the flow of the river.

Due to high flow velocities during floods, discharge measurements are sometimes impossible to carry out. In the consequence, seldom discharge measurements are available for floods to extend the adaptation of the rating curve with reliable data for estimated floods. Some discharge measurement protocols are enclosed in the appendix as practical examples from the field.

### 3.2.5. SEDIMENT SAMPLING

This topic is treated in detail in the next chapter.

### 3.2.6. WATER QUALITY

The purpose is to determine the physical, chemical and biological characteristics of the water bodies.

Some parameters (i.e. temperature and turbidity) can be easily determined in the field while others require sophisticated laboratory facilities (i.e. biological analyses).

### 3.2.7. HYDROLOGIC DATA FOR LOW HEADS IN PAKISTAN

For low head hydropower calculation purpose downstream daily discharges are very important. Therefore daily discharges covering 20 years are considered sufficient for the planning of a hydropower project.

The special situation concerning hydrological data in Pakistan at great rivers as Indus should be mentioned in this context. The construction of Tarbela Dam on the Indus River has modified the natural flow pattern of the river. During the flood season in summer the high flows are stored in the reservoir and released according to the irrigation water budgeting during the rest of the year. The storage capacity of the Tarbela reservoir is only 10% of the annual flow volume at the barrage and consequently, it can regulate natural river flows only to a limited extent. Kalbagh Dam is proposed for construction to further regulate the river flows. The reservoir that it creates will initially have a live storage of about 9.400 million $m^3$.

These circumstances show, that the upstream water conditions have to be considered in low head hydropower development, regulation and operation of upstream structures have to be investigated in detail, especially concerning an analysis of historical data and the developed forecast for the future.
Moreover it is important to emphasize, that the existing barrages at the Indus River have been

built as pure irrigation projects, and therefore the released water volumes for irrigation have to be considered during design. This has an impact on the availability of flows for low head hydropower generation.

## 3.3. DATA PROCESSING

Processing of hydrological data from data entry to the final yearbook is performed by a series of programs that have been integrated into the hydrological data bank. Following paragraphs actually describe the performance of the series of programs contained in the data bank.

### 3.3.1. WATER LEVELS

#### 3.3.1.1. STAFF GAUGES

Processing of water levels from staff gauges comprises the type and review of the gauge readings taken by the gauge reader. The data are typed in a screen specially designed for this purpose. The data is automatically scrutinized to avoid typing mistakes that people commit frequently while typing. After typing one year, a graph showing gauge height against time is shown to locate possible typing mistakes that are not possible to catch during the typing process.

#### 3.3.1.2. WATER LEVEL RECORDERS

Processing of graphs from water level recorders comprises the digitization of the graph. That means that the graph has to be converted into pairs of points gauge height-time.

Digitization by reading gauge height and time from the graph is possible, but it takes too long time and consequently it is inefficient. Provision is made in the data bank to digitize the graph through a digitizer. A series of pairs of values of gauge height and time are obtained from the digitization procedure. These pairs of values have to be adjusted according to the gauge reading and interpolated to obtain 24 hours readings at the exact hour.

Water levels obtained from the digitization process have to be compared with the gauge heights taken by the gauge reader to guarantee that the data have been correctly retrieved. Differences between the digitized values and the gauge readings can be mainly due to:

- Improper installation of recording paper in the water level recorder
- Loss of calibration of the recording instruments
- Freezing of the stream
- Improper initialization of the digitizer
- Inconsistent/incorrect gauge readings

Loss of calibration of the pressure sensors is due to temperature changes as well as long-term drift. These changes are very small and can be easily corrected. Frequent visits to the stations is the best way to avoid these and other problems.

#### 3.3.1.3. DATA LOGGERS

Water levels stored on magnetic media are read from the memory cards with a special device connected to a computer and through a computer program specially prepared for this purpose.

The data comprises time, water levels and battery charge. The file obtained from the memory card has to be converted into the format used for calculation of flows. Later on, the file undergoes the same comparison with the gauge readings as explained for the digitized data. Automatic water level recorders are more precise than the records of a gauge reader. While the automatic type shows the small fluctuations in a day. The gauge reading shows only a linear line. However it has to be mentioned in this context, that this phenomenon is not so strong for rivers in the plains. Due to the considerable magnitude of rivers, discharge fluctuations during a day will only have small water level changes in consequence.

### 3.3.2. DERIVATION OF RATING CURVES

Rating curves relating the water levels to the discharge are obtained from the discharge measurements. To determine the rating curve of a gauging station, a mathematical function is fitted to the pairs of values gauge height-discharges given by the flow measurements. There are various procedures to fit the rating curve:

- Manually using linear or log-log paper
- Numerically using the method of least-squares

The manual procedures were used in the past. They are time consuming, requiring plotting of each point by hand. Curve fitting is also done manually, which is not always a straightforward procedure when the data is highly dispersed. The results are to some extent subjective and subject to controversy.

Advances in the field of computer hardware and software have facilitated the development of efficient tools, which allow considerable time saving in the analysis of hydrologic data. Nowadays, numerical methods are normally used to fit the rating curves. Independently of the type of equation adopted, due to its simplicity the method of least-squares is frequently applied.

The flow measurements have to be critically analyzed before fitting the rating curve. Outliers may have to be removed to avoid distortions in the analysis. This is especially important when the method of least-squares is applied.

When the flow measurements do not adequately cover the range of gauge readings, extrapolation of the rating curve is required for which various methods are available. The so-called slope-conveyance method is used in most practical applications. To apply the method a series of flow measurements and a cross section at gauging point are necessary. Other information like description of the riverbed and pictures of the site are useful.

The method is based on application of the Manning-Strickler formula for steady state flow in open channels. The geometric characteristics of the section (area and wetted perimeter) used in the formula are obtained from the available cross section. Hydraulic parameters (hydraulic gradient and roughness) are estimated and extrapolated from the values obtained from available flow measurements. Estimation of flows for the higher water levels is then possible applying the Manning-Strickler formula.

A mathematical function describing the rating curve is adjusted to the flow measurements and to the estimated flows at higher stages. The rating curve is then adjusted to the flow measurements and to the estimated flows at higher stages.

It has to be stressed that a reliable estimation of floods highly depends on the extrapolation of the rating curves. This is especially important in rivers draining small catchment areas, where floods last for a short period of time. In this case flow measurements at the time of the floods are very unlikely. For a reliable estimation of floods frequent discharge measurements during the flood season are required. Furthermore, a comprehensive method for extrapolation of the rating curves is required to ensure an accurate estimation of floods.

An example of fitting and extrapolation of a rating curve is given in Figure 3-4 for Jinnah Hydropower Project for the years 1977 and 1982. The downstream rating curve for Chashma HPP is illustrated in Figure 3-5.

### 3.3.3. ESTIMATION OF FLOWS

Estimation of flows can be undertaken after water levels are known and rating curves have been fitted. Obviously, the work can be done more easily with help of computers, especially when specific software for the task is available.

Mean daily flows basically weighted averages of the flow estimates of each day, which are estimated according to the available information of water levels.

In some cases gauge reading from a fixed point is not possible because changes in the river cross-section may occur due to scouring and sedimentation. To estimate the discharge of such rivers, shifting of the rating curve may be applied. However, to ensure an accurate estimation of flows frequent flow measurements are required. The method of shifting the rating curve was developed by the US Geological Survey and is included as an option in the hydrologic data bank.

Maximum instantaneous discharges are also estimated. Without shifting the maximum instantaneous discharge coincides with the maximum gauge height. When shifting of the rating curve is applied, the maximum instantaneous discharge has to be traced from the various daily maximum instantaneous discharges.

The procedure to estimate maximum instantaneous discharges is extremely laborious and time consuming if no computerized procedure is applied. Calculation of maximum instantaneous discharge when the curve is shifted is automatically performed with the available computer software.

### 3.3.4. COMPARISON OF DISCHARGES UP AND DOWNSTREAM

Once the daily flows have been calculated, comparison of estimated flows of stations located on the same river may be undertaken. Provided that no water diversion or losses between the stations occurs, the discharges calculated upstream have to be smaller or equal to the ones measured downstream. If the stations are located on tributaries and on the main stream, estimated discharges calculated for the tributaries are added up and compared with the estimated discharges at the point downstream of the confluence.

If the calculated discharges upstream of the confluence happen to be larger than the calculated discharges downstream, the records for this period have to be thoroughly reviewed and corrected. Mots likely the problem lies in the extrapolation of the rating curve. Comparing the records for each month of the year can easily check this.

Comparison of discharges up and downstream is a complex task and once a station is changed the whole process of comparison up and downstream has to be reviewed.

### 3.3.5. PREPARATION FOR PUBLISHING

Before the preparation of a yearbook can be started, a uniform system of units (metric or British) has to be agreed upon for all parameters to be included in the publication.

Once the conversion of daily flows and sediment and quality data of all stations has been completed, the information undergoes a final processing in order to present the data in a comprehensive form.

Following information is included in the table summarizing the flows of the year:

- Salient features of the stations (code, name, location, elevation, river, basin, catchment area, installation date, year of the data).
- Summary of daily flows of the year.
- Summary of monthly flows (given in $m^3/s$, $lt/(s\text{-}km^2$, mm, maf).
- Summary of extreme flows during the year (daily maximum and minimum, and instantaneous maximum discharge during the year).

Following information is included in the table summarizing the available sediment data:

- Date of the sample.
- Discharge while taking the sample.
- Temperature of water if available.
- Total parts per million (ppm) by weight.
- Percentages of sand, silt and clay

Following information is included in the table summarizing the water quality data:

- Concentration in milli equivalent per liter of following elements:

Ca, Mg, Na, K, $CO_3$, $HCO_3$, Cl, $SO_4$, $NO_3$ and F.

- Total cations and anions.
- Concentration in parts per million of: $SiO_2$, Fe, B, dissolved solids by evaporation
- electric conductivity at 25 $^o$ C.
- PH.
- Residual $CO_3$ in me/l.
- Sodium Adsorption Ratio (SAR).

If sediment and water quality data are available for the same station, two tables (one for sediment samples and one for water quality data) containing the data of the available samples are recommended. The tables presenting sediment and water quality data are presented after the summary of flows of each station.

A front page, preface text, staff involved in the preparation of the yearbook, table of contents, explanatory text, summary of stations and maps showing the location of the stations are prepared.

Once the above mentioned items have been prepared and after final review, the yearbook is ready for printing and reproduction.

### 3.3.6. HYDROLOGICAL DATA BANK DBHYDRO

The hydrological data bank presented here has been developed by GTZ during the last years and summarizes a series of programs and methodologies that have been used in many countries, including Pakistan.

Development of the hydrological data bank has been necessarily a dynamic process in order to be able to adapt its concepts to a technologically changing environment. Technological improvements in hardware include for hydrological purposes, more powerful computers, data loggers and memory cards. Similarly, more sophisticated software for handling of data and programs is now available to enhance the capabilities of the processing tools. Both aspects have been and continue to be revised with the final aim of improving the collection, processing, publication and storage of hydrological data. The concept behind the hydrological data bank is to facilitate the collection, processing, publication and storing of hydrological data in a user friendly environment to speed up the availability of data and to improve its quality.

## 3.4. APPLICATION

### 3.4.1. DESIGN PARAMETERS

The analysis and synthesis of discharge data implies the determination of flows in terms of their magnitude, seasonal distributions and multi-annual variations. Discharge records constitute a fundamental input in the identification and evaluation of potential sites for hydropower development.

Hydrological stations are frequently not at the same place as the potential sites to be investigated. Therefore, hydrological parameters estimated for the sites of the gauging stations have to be adjusted, interpolated, extrapolated and synthesized as required to estimate the design parameters at the site of the potential power development.

Usually 10 day mean and mean monthly flows are calculated from the period of historical data. The following paragraphs are referred to the estimation of flows from available records.

#### 3.4.1.1. MEAN ANNUAL FLOW

The most stable hydrologic parameter is the mean annual flow. It constitutes always the first parameter to be investigated.

The mean annual flow can only be calculated from stations with at least one complete year of record. Although, taking into consideration the variability of the hydrologic regime, longer records are always required to achieve reliable estimates.

The next Figure shows the relationship between mean annual flow and record length at various gauging stations. As expected, the mean annual flow varies significantly during the initial years of operation and becomes more stable after some time.

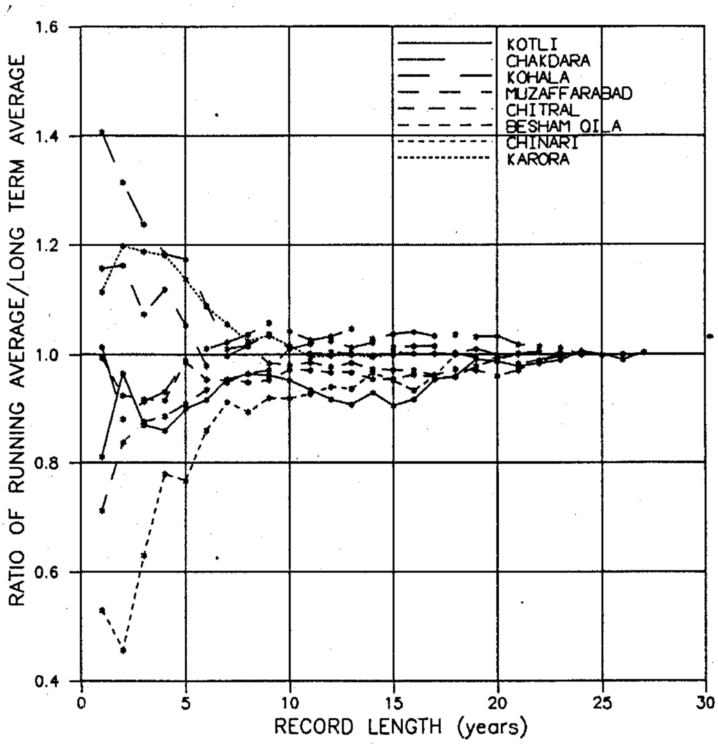


**Fig. 3.7: Variation of the mean annual flow with the record length**

### 3.4.1.2. MEAN MONTHLY FLOWS

Mean monthly flows are the mean values of the mean daily flows recorded during each particular month. Mean monthly flows are used to determine the degree of variability of the flows throughout the year of a particular river.

### 3.4.1.3. TEN DAY MEAN FLOWS

Ten day mean flows are the mean values of ten mean daily flows recorded during the time period. Compared to mean monthly flows, the resolution of ten daily flows is better and can be used for a more appropriate design of low head hydropower developments.

### 3.4.1.4. FLOW DURATION CURVES

Flow duration curves show the percentage of time that flow is equaled or exceeded. A duration curve is generally constructed by counting the number of days with flows in various class intervals. The selection of the time unit of the class intervals depends on the purpose of the curve. If a project for diversion without storage is under study, the time unit should be the day, so that absolute minimum flows will be indicated. For reservoir design, lesser number of intervals (100 to 200) may be sufficient depending upon reservoir size in relation to inflow.

The main drawback of the flow duration curve as a design tool is that it does not present the flows in their chronological sequence of occurrence. It is not possible to tell whether the lowest flows occurred in consecutive days or scattered throughout the record.

For low head developments usually daily discharges data is processed to analyze the availability of flows. Flow duration curves are plotted with five year intervals. These curves give information about the allowable proportion of flows that can be diverted through the powerhouse for turbine generation. Figures 3-6 up to 3-10 show the flow duration curves of Jinnah HPP.

The flow duration curve of a low head development in a canal is different from a river and shown in Figure 3-11 with the example of Rohri HPP. The flow duration curves for each year from 1974 to 1987 have been prepared from frequency analysis. The figure shows the flow duration curves for each year using daily data. The curves show the increasing behavior of flow diverted into the canal. The curves 1987 and 1974 show maximum and minimum availability of flows respectively. In view of power generation, higher availability of flows is preferred but it is also not advisable to base only on one year availability, i.e. 1987. Therefore a comparative study is recommended in such a case. Figure 3-12 shows the flow duration curve for the period between 1977 and 1981.

The main defect of the flow duration curve as a design tool is that it does not present flow in natural sequence. It is not possible to tell whether the lowest flows occurred in consecutive days or scattered throughout the record.

### 3.4.1.5. MONTHLY SERIES OF STREAM FLOWS

Monthly series of flows are useful when evaluating hydroelectric projects that include seasonal reservoirs. Monthly series of flows comprise the series of monthly values calculated from the daily flows. If the available record is long enough, analysis can be performed directly from the observed series. However, if the available record is short, completion and/or extension of the recorded series can be undertaken as explained in later.

### 3.4.1.6. LOW FLOWS

In order to analyze droughts in a proper manner, it is necessary to consider the magnitude and duration of the droughts. For this purpose, the lowest flows in given period during each year are considered. The minimum discharge is defined as the average minimum discharge for the period of time within a year. The period of time is generally taken as one or several days.

A frequency analysis is performed on the series of minimum flows for the period or for the various periods of time, to determine magnitude, duration and recurrence of the droughts.

### 3.4.1.7. FLOODS

Estimations of floods for different return periods are required to establish dimensions and costs of river diversions during construction and of permanent relief structures (bottom outlets, spillways, etc.).

The phenomena which every year give origin to floods in general comprise:

- Precipitation, as in case of storms and tropical cyclones. In the subcontinent, high precipitation intensities during monsoon are the cause for the largest recorded floods.
- Ice and snowmelt during spring and summer months.

## 3.5. METHODS FOR ESTIMATION OF DESIGN PARAMETERS

### 3.5.1. FLOWS

In case of low head hydropower developments usually water levels are recorded by the methods described above. By use of derived rating curves, the flows are transformed into discharges, which can be further processed for the calculation of generated power and estimation of floods.

### 3.5.2. MONTHLY SERIES OF STREAM FLOWS

Time series (in this case monthly series of flows) can be observed or synthetic. Observed series of monthly flows are calculated from the available daily flows. Synthetic series of monthly flows are generated on basis of other stations or on basis of the statistical parameters of the observed series. If the available series of monthly flows is long enough, the studies can be performed on basis of the available data. If the series is not long enough, completion of the series can be undertaken on basis of others stations with longer and concurrent periods of record. To undertake a confident completion of time series, good correlation coefficients have to be obtained between the two time series.

Synthetic flows can be generated from the statistical parameters of the observed series of data when the series of data is not long enough and no station is available for completion of the data. Synthetic flow series are expected to preserve the statistical properties of the series of observed flows. Synthetically generated data provide other possibilities of analysis, as compared with analysis based only on recorded series of flows. However, completion or extension of the time series based on the recorded data of other stations normally provides a more adequate basis for analysis, especially concerning the critical period of the series.

The program HEC-4 developed by the Hydrologic Engineering Center of the US Army Corps of Engineers has been extensively used for completion and generation of flows. The program analyzes monthly streamflows at a number of interrelated stations to determine their statistical characteristics and generates a sequence of synthetic streamflows of any desired length preserving the basic characteristics of the original series. The program reconstitutes missing streamflows on the basis of concurrent flows observed at other locations. It also has the capability to use a generalized simulation model for generating monthly streamflows at ungauged locations based on regional studies.

Time series analysis is required for the design of water resources projects, especially those which foresee seasonal reservoirs. There are many methods to estimate the required capacity of a reservoir. However, with the modern computational facilities, simulation of reservoirs with existing or generated monthly series of flows is part of normal practice. Other time discretization may also be adopted (i.e. 10-daily or weekly), especially in case of multi purpose reservoirs.

The simulation of reservoir operation is based on the solution of the continuity equation for each time step over the total simulation period. The mathematical models used simulate the operation of the reservoir assuming the existing or generated monthly flows as inflows into the reservoir. Evaporation from the free surface of the reservoir is calculated and subtracted as water loses. Releases from the reservoir are simulated according to the requirements for energy generation, irrigation, etc. Finally, to ensure conservation of mass, surpluses are accounted as spill water.

### 3.5.3. ANALYSIS OF LOW FLOWS

As already discussed, analysis of low flows is required in order to determine the magnitude, duration and recurrence of droughts. For this purpose, the series of minimum flows for various duration have to be determined from the daily series of flows. One value is normally determined for each duration and recorded year. After the series of minimum flows has been obtained, a frequency analysis is performed to determine the lowest flows for different return periods as necessary. Extreme value distributions, such as Gumbel and Pearson Type III have been found to provide satisfactory results.

### 3.5.4. ESTIMATION OF FLOODS BY PROBABILITY ANALYSIS

Estimation of floods for different return periods are required to establish dimensions and costs of river diversions during construction and of permanent relief structures (bottom outlets, spillways, etc).

The phenomena which every year give origin to floods in general comprise:

- Intensive precipitation, as in case of storms, tropical cyclones and typhoons.
- Ice and snow melt
- Tropical cyclones in Central America, typhoons in the Far East and monsoon rains in the Indian subcontinent have caused the largest recorded floods.
- In Europe combinations of intensive rains, ice and snowmelt have been the cause of flooding.

Main parameters determining the hydrologic regime are precipitation and temperature. The figure shows that total annual precipitation determines the total runoff, while the distribution of both rainfall and temperature determines the pattern of flows throughout the year.

Depending on the location of the proposed site different influences have to be investigated in detail. In the plains of Pakistan it can be said, that the monsoon in the summer cause season flood, which is further aggravated by the snow melt. Based on the analysis of existing data the design parameters are estimated with the application of probability methods.

There are mainly three different methods to estimate floods. Since it can be assumed, that gauge readings and discharge measurements are available in rivers for low head developments, only the classical method of probabilistic analysis will be explained in the next paragraph.

- Empirical or semi-empirical formulae.
- Probability analysis.
- Precipitation - runoff models.

Determination of design floods can be made on basis of analysis of maximum instantaneous flows for each year of record. The classical analysis considers the fitting of an extreme value distribution to the annual floods. In most cases, the symmetrical Gaussian normal distribution is not suitable to describe the distribution of floods because it does not regard the asymmetry (skewness) of the observed series. Therefore, the distributions used in flood analysis are the following:

- Pearson Type 3
- Log Pearson 3
- Gumbel

- Log Gumbel
- Gamma
- Log Gamma
- Normal (Gauss)
- Log Normal

In most cases, the symmetrical Gaussian normal distribution is not suitable to assess the return periods of floods because it does not regard the asymmetry (skewness) of the observed series.

Since the distribution function of the infinite number of all random events-in this case all possible annual maximum discharges- is not known, we stand in need of approaching the true distribution function on the basis of a sample and by application of various methods.

In practice, the statistical parameters of the true distribution, the so called moments have to be estimated from the sample; such moments are the arithmetic mean, the variance and the skewness:
mean:

$$\overline{Q} = \frac{1}{n} \sum^{n} Q_i \tag{3.1}$$

variance:

$$\overline{Q} = \frac{1}{n} \sum^{n} Q_i \tag{3.2}$$

Coefficient of variation:

$$C_V = \frac{S}{\overline{Q}} \tag{3.3}$$

Coefficient of skewness:

$$C_S = \frac{n \sum_{i=1}^{n} (Q_i - \overline{Q})^3}{(n-1)(n-2)\ S^3} \tag{3.4}$$

where,
$Q_i$ = annual maximum discharge in the year i within the n-year observation period.

It should be strongly emphasized that in some cases the deviation of results obtained by the application of different distributions may be of considerable magnitude. Therefore a characterization of the design flood simply by its exceedance frequency may be very elusive. Therefore it is necessary that, if a flood discharge is characterized on probability basis, besides its exceedance frequency (or recurrence interval) also the distribution should be given.

### 3.5.4.1. DIRECT ESTIMATION FROM THE RECORDS

If the period of record of the station is long enough, floods for different return periods can be calculated directly from the records with confidence. An example of the estimation of floods directly from the records is given on Figure 3-13 as estimated for Jhelum River at Mangla. TABLE 3-5 gives a summary of flood peaks at Jinnah Barrage. It shows the exact data of the highest discharge of each year between 1972 and 1996. Based on this record, the plotting position method can be applied to determine the exceedence frequency of floods and to determine the characteristic design discharges for decisive structures, i.e. the flood with a return period of hundred years etc.

### 3.5.4.2. EXTENSION OF FLOOD RECORDS

As already discussed, short records is one of the problems normally faced when determining hydrologic design parameters. In this regard, estimation of design floods with confidence requires observation of floods during a long period, which normally is not available at the sites of the projects. Consequently, the available information, including the information of other stations located nearby the point of interest should be analyzed in detail to obtain the most reliable estimation of floods.

When analyzing the flood information available within the Jhelum river in Pakistan, two methods have been applied to improve the frequency curves and consequently the estimation of floods:

- Comparison with a long-term record station. The statistical parameters of the logarithms of the series of recorded floods (mean, standard deviation and skewness coefficient) are adjusted on basis of a regression analysis with a long-term record. The floods for various periods of return are determined from the adjusted statistical parameters using the log Pearson 3 distribution.
- Adjustment of frequency curve by a high outlier. The statistical parameters of the logarithms of the series of recorded floods without the outlier are adjusted assigning a weighting factor to the outlier that depends on the years of record and the period for which the outlier is the maximum. The floods for various periods of return are determined from the adjusted statistical parameters using the log Pearson 3 distribution.

The graph is given in the appendix in Figure 3-14.