2. TOPOGRAPHY

2.1 SITE IDENTIFICATION

The development of a high head hydropower project usually starts with the identification of the site. At the beginning of the works stand topographical map studies to find a suitable location and layout of the development. Depending on the region to be investigated, the more detailed the map, the more useful is the determination of possible identification sites.

For the assessment of the hydropower potential of any region, various basic physical parameters are required, namely: discharge, head available and geologic setup.

The discharges are established on basis of available information about the hydrologic regime, which can be directly determined from gauging stations or through the application of mathematical models. However, the available discharges may need to take into account existing water rights, which may vary depending on the degree of development of the area, population density, extent, magnitude and pattern of irrigation requirements, etc.

On the other hand, it is always desirable to have comprehensive topographic coverage of the area under investigation. However, topographic maps only allow a rough estimation of the available head. Typically, depending on the scale of the maps, contours are shown at certain vertical distances. For example, maps on scale 1:50,000 are very common in many countries, having contours every 20 to 40 meters.

Fig. 2.1: Contour lines of topographic sheet in mountainous area

Geologic maps provide in most cases regional information, which depending on the level of detail may provide information about the overall tectonic setup, geologic formations and their characteristics, etc.

The above mentioned hydrologic, topographic and geologic information may provide a basis to carry out desk works for the preliminary identification of promising sites. However, these have to be confirmed in the field. Therefore, the purpose of the field visit can be summarized as follows:

- Critically assess the possibility of having a hydropower development with the characteristics and layout proposed through the deskwork.
- To establish/confirm the gross head by means of altimeters or Global Positioning System (GPS)
- To find topographically and geologically adequate locations for all structures required for the hydropower project
- To investigate the access possibilities to all structural components of the project

In case the field yields a confirmation of reasonable development possibilities, further studies can be carried out. When maps of adequate scale are available, a preliminary design can be undertaken. However, when the topographical information is not satisfactory in terms of accuracy and level of detail, survey works have to be undertaken.

2.2 DATA COLLECTION

2.2.1 GEODESY

2.2.1.1 BASIC GEODETIC SURVEY

Bases for the cartographic representation of the surface of the earth coordinate systems, which describe the site and size of the selected area. The reference of the ground surface to the map projection is given by the marking of control stations in the area, which are geometrically defined by an indicating number of coordinates according to a local net.

There are hardly areas on the earth, for which a coordinate net does not exist. Often the same areas are covered by different local nets, which have been established by different groups, most frequently without coordination with each other, for construction, administration duties, cartographic projects, military aims, etc. It is regrettable that these nets are not always kept in good condition after completion of the projects, so that their integration for further use is not always possible.

Most often each civil engineering project has to provide its own survey net. Local nets, even of high precision, can be produced by known and tested geodetic survey techniques with the help of experienced personnel.

Normally mountainous regions are not easily accessible. In some cases it is necessary to make long detours to reach places being not far apart. Depending on the topography, in some cases, the far-sight is excellent, while, in other cases, especially in valleys, only short-range orientation is possible.

These conditions influence the selection and design of nets of control stations. Because of this, it is not possible to recommend a specific measuring procedure can be recommended for mountainous areas, better is the combination of different procedures.

Before the time of satellite navigation, impassable areas could only be worked out with measurement techniques based on astronomical positioning and barometric measurement of heights. Modern measuring techniques have nowadays replaced both procedures. Therefore, it should not be forgotten if 'old' nets of control stations have to be examined in order to use them for present-day tasks.
The following steps are essential to create a local net of control stations:

1. Creation of a basic net by combining triangulation and optical distance measurement.

2. GPS-measurements for a highly exact definition of the relative position of the control stations.
3. Gyro measurements for the orientation of the local network. This step is very important for the excavation of tunnels.
4. Computation of the point coordinates from all measurements in a combined adjustment processing.
5. Permanent control measurements to prove the stability of the reference points.

Common survey procedures have always been used for the production of basic and micro networks. Modern electronic parts and computer-aided procedures further rationalize the surveys. So today the use of electronic theodolites with an integrated distance measuring device -so called total stations- is standard. The total stations are equipped with standard interface plugs provided for an electronic data flow to adapted computers. With the use of these kinds of instruments survey works for setting up networks of control stations can be done efficiently.

The common geodetic survey methods are generally important for additional measurements and for applications for which the result of survey is needed without delay at the site.

In contrast to photogrammetry, geodetic survey is a point-by-point measuring method, which is able to determine relatively few, but therefore very exact coordinates of points in a unit of time.

Tachometry needs a reflector at the target for point determination. Therefore it is not always an economic tool in areas, which are difficult to pass. It is possible, to connect a total station like a digitizer to a cartographic computer program, so that one can see measured points and lines immediately after measurement at the screen of a portable computer. This technique requires very well trained and experienced personnel.

Intersectional procedures are especially useful in mountainous regions, because coordinates of points can be determined "without contact". The identification of targets is not always easy. As help, two total stations can be operated at the same time by radio contact, which will reduce working time and will minimize the potential quota of errors.

2.2.1.2 POSITIONING

2.2.1.2.1 ASTRONOMICAL POSITIONING

The astronomical determination of the latitude and longitude of a point on the surface of the earth is a conventional procedure. It needs extraterrestrial references. The geographical latitude is calculated from measurements of the angle of elevation to known stars. The geographical longitude can be computed from measurements of time with calibrated watches. If the definition in geographical coordinates is not sufficient, these have to be transformed into a local system of coordinates. At best case, the error of position will be about some 10 m.

2.2.1.2.2 BAROMETRICAL ALTIMETER MEASURING

The fact that air pressure drops with increasing height from orthometric elevation is the physical basis of the barometrical measuring. The pressure drop per unit of height is not linear, but decreases down with increasing height. The air pressure also depends on meteorological air pressure variations, on the geographical latitude and, on a small scale, on the humidity. Therefore, in measuring the air pressure only differences in elevations can be determined.

If this procedure is limited by the measurement of elevation differences below 1000 m.a.s.l, errors up to 10 m may be expected. Measurements in higher elevations can be even larger.

2.2.1.2.3 DETERMINATION OF AZIMUTH WITH GYRO

Highly exact measurements of the azimuth are necessary if several local nets have to be combined. A typical use occurs in the construction of tunnels, when the reference nets at the tunnel entrance and exit cannot be combined with each other by direct measurements.
Local nets can also be directed by astronomical direction measurements. The disadvantage of this procedure is the fact that weather can obscure the chosen celestial targets. The correct direction can only be determined after large-scale conversions of the data with astronomical tables and time measurement, which are difficult to obtain especially in the dark. The advantage of the determination of the azimuth lies in its high exactness by observing stars.

Foucault (1819 -1868) was not the first to be guided by the wish to determine the northern direction on the earth by using a method which does not need extraterrestrial targets. The magnetic compass used in navigation and in the early days of geodesy was in the beginning sufficient for certain mapping purposes. The demand for accuracy in modern engineering tasks cannot be obtained by these methods.

In the early 19th century works started for developing the gyrocompass. The first gyro suited for survey was built by Schuler (1921) for the Anschütz Company. With this instrument (weight: 350 kg, measuring duration: 6 h) the azimuth could be determined to ± 6 mgon. In doing so the gyro oscillations ("Schulermittel") were evaluated.

Especially the mining industry gave important impulses for the further development of the gyro technology. The DMT-Gyromat is the most modern survey gyro. It has an average weight of 10 kg. It determines the azimuth fully automatically after a measuring time of 7 minutes achieving an exactness of <± 1 mgon.

The measurement, which has to take place in an already established net of control points, is undertaken in the following steps:

1. Centering the gyro on the network
2. Approximate alignment northwards
3. Aiming of a target
4. Starting the gyro
5. After a short time (max. 7 min.) the azimuth is shown on the gyro´s display

The north finding process is fully automatic. The measured north direction is transferred to the alidade of the theodolite automatically. After finishing the measurement, the azimuth can be directly read by aiming at the desired target.

Particular advantages of using gyros are:
- Automatic, highly accurate measurement of azimuth
- No knowledge in astronomical theory and observation methods is needed
- Measurements are almost weather independent

Main areas for gyro measurements are:
- Geodetic indication of direction in tunnel and canal construction
- Relative and absolute geodetic network orientation
- Positioning for GPS networks
- Control of underground drilling machines
- Setting of reference lines for inertial navigation systems
- North alignment of motion simulators

- Determination of anomalies in the magnetic field of the earth
- Determination of atmospheric effects of refraction.

To orientate a net of control stations a few gyro measurements on selected traverse legs are sufficient. The azimuths are brought together with all other measuring data to a combined adjusted computation of coordinates.

Like any other geodetic measurement the gyro measurement has also to be controlled. This can be done either by control measurements with a second gyro and/or by calibration of the instrument on a calibration line. The azimuth of the calibration line is being determined astronomically.

2.2.1.2.4 GLOBAL POSITIONING SYSTEM (GPS)

The Department of Defense of the United States of America demanded in the beginning of the 70th century the development of a navigational system for a worldwide exact determination of position. A user equipped in such a manner - it does not matter if stationary or with low or high dynamics - shall receive extremely exact information about his three-dimensional position, his velocity and also about the time everywhere on or near the earth. The system has to provide always this information independently of weather conditions.

This so called "Global Positioning System" (GPS) was conceived and implemented through the simultaneous development of 3 segments.

The *space segment*, which in its final phase should comprise 24 navigation satellites. Out of these, 18 satellites are necessary for a full coverage of the earth, the other 6 ones shall serve as reserve. By now, all satellites are in their orbits. Each satellite carries a beacon giving out coding bursts of radio signals and a broadcasting time. These signals are used for high precision survey measurements. The orbits of the satellites have been set in such a manner, that always a minimum of 4 satellites can be received simultaneously at any point on the earth. This constellation fulfills the demand, that a moving user of the GPS can receive, without delay and break, information about his three dimensional position.

The *control segment* shall supervise the satellites and compute the exact orbits. These tasks are carried out by 5 ground stations, which are positioned near the equator at an equal distance around the earth.

All GPS receivers together represent the *user segment*. For survey purposes there are small, lightweight antennas available with accurately defined phase center. GPS measurements are being related to a global terrestrial coordinate system. In the same system are also defined the ephemeris data of the satellites.
The global terrestrial coordinate system is defined as follows:

1. The origin of coordinates is the central point of the earth.
2. The earth axis of rotation is the z-axis.
3. The x-axis penetrates the equator at the Greenwich degree of latitude.
4. The y-axis is originated by the rotation of the x-axis counterclockwise of 90 degrees.

This system of coordinates is supported geocentrically and takes part in the rotation of the earth. Based on this, the World Geodetic System 1984 (WGS 84) was defined for the description of the ephemeris of GPS satellites with regard to further parameters. It cannot be compared with well-known geodetic systems of coordinates. The GPS coordinates defined in the WGS 84 system have to be afterwards converted into a user defined systems of coordinates.

Nowadays, setting up of nets of control stations and their control is impossible without GPS. By this procedure, high accuracy, especially over a long distance, can be reached which other survey methods cannot provide. It is also an advantage that the data collection can be made automatically and to a very large extent independently of the weather. Therefore, the work at the site is restricted to set up control stations and the measurement of the antenna eccentricity. The control stations can be out of sight from each other and can be as far away from each other as necessary.

The practical use can confront the user with different sources of errors. The errors can be caused by:

- The space segment (e.g. orbit of the satellites, disturbances of satellites)
- Interferences (e.g. atmospherical disturbances of the measuring signal)
- The user segment (e.g. disturbances of the receiver, reflections or shading of the measuring signal by unfavorable choice of the place of measurement).

Without a nearer description of the errors one can conclude that through suitable design of the measuring procedures and by a selection of suitable post processing software, for most practical cases the error budget can be kept lowest. In any case, an exhaustive planning of the measurement and also an exact selection of the measuring time is an essential presumption for a successful GPS campaign.

Out of geometrical reasons GPS measurements have to be made with at least 4 satellites simultaneously. Additionally, to obtain exact results these 4 satellites have to be distributed equally over the horizon. The accuracy as given below applies only for most favorable satellite constellations.

According to use, 5 GPS survey modes can be distinguished. All procedures provide space vectors from measurements of the difference according to WGS 84. Therefore all procedures always need a continuously tracking reference station and at least 1 roving receiver. By an appropriate combination of the space vectors between reference station and roving receiver the coordinates of the GPS control points can be computed (tri-lateration), which are then transferred in a simultaneous adjustment process into a user defined coordinate system.

With this principal measuring arrangement, errors in measuring based on irregularities of satellite orbits can be balanced.

The five GPS modes are:
Rapid Static needs a permanently stationed reference station and several roving receivers moving from point to point. This mode can be used for any job where many points have to be surveyed quickly. It is suitable for measurements of baselines up to about 15 km with short observation times. The accuracy is about ± 10mm + 1ppm baseline. A minimum of 4 satellites must be available during the whole survey campaign.

Static is the classical method for baseline measurement with highest accuracy. It needs permanently stationed receivers on chosen net points during one observation window. This mode is recommended for the survey of base networks. It needs relatively long observation times but it is more accurate and more economical than traditional geodetic methods. For advanced solutions a minimum of 3 receivers have to be available. The accuracy is about ± 5 mm + 1 ppm baseline.

Stop and Go is the quickest way to survey detail points with an accuracy of about ± 20 mm + 1 ppm baseline. This mode needs a temporary reference station, which tracks continuously, and a roving receiver. The roving receiver stops for a few minutes time on point 1. After data registration it is moved, maintaining lock on satellites, to point 2, stops for a few minutes time... and so on. Stop an Go should be used only in open areas when surveying points are close together and when there is the opportunity to repeat measurements when blunders may occur.

Reoccupation is similar to rapid static with the difference that one has to reoccupy a point after at least one hour. That makes this mode insensitive against critical satellite constellations.

True Kinematic is the mode for the location of dynamic systems (e.g. hydrographic survey, registration of exposure points during aerial photo flights). This mode needs like all others a continuously tracking reference station on the ground. The starting point of the vehicle has to be observed for a few minutes time for rapid static fix. Then the continuous movement of the vehicle can be recorded with measurements at selected time intervals. Accuracies for this mode are reported of about ±10 cm rms.

For first order surveys static mode is recommended. This is the most exact method, but at the same time the most time-consuming method in comparison to other GPS modes. Because it is often difficult to transport instruments in mountainous regions one has to take into consideration that sometimes only one GPS reference per phase of satellite (=per day) can be measured. One also has to take into consideration the additional need of time for the exploration of the survey site. The choice of suitable GPS control points for undisturbed receiving of the satellite signal is also connected with this.

Accurate and efficient GPS works can be done with at least 3 receivers. The costs of equipment and computer software can be amortized quickly when appropriately used.

Recently different manufacturers have offered so-called GPS hand held antennas in connection with a programmable pocket calculator for the post processing software. These small GPS receivers are used for example on small sporting boats and have proved their worth for navigational use. These small GPS receivers can be used in the same way as mentioned above (5 GPS modes), but one is confronted with a reduced accuracy. If several hand held antennas are used simultaneously and if the satellite constellation is very good, positioning results of some 10 meters can be reached. Although they are not well suited for measuring purposes, the surveying parties should in any case be equipped with hand held receivers, if they are in the position to explore the terrain on foot. Positioning "to find the way back" or "to find the site again" can be made very well with these modern instruments.

Fig. 2.2: **GPS measurement at the Karakorum Mountain Range**

2.2.2 PHOTOGRAMMETRY

In international literature, "photogrammetry" is mentioned first in 1867 by Meydenbauer, the founder of the first archive of metric photos of monuments and architecture. The most common use of photogrammetric techniques is to recognize and identify an object by its photographic image and to derive its size and its position in space from the photographs. Further technological developments today give us the possibility to get images of objects by recording them with special sensors even outside the normal visual range of the film and camera.

The best up-to-date definition of "photogrammetry" is given by the American Society of Photogrammetry:

> *Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena.*

Today, the best known application of photogrammetry is to produce topographic maps of the earth from photographs and other images based on measurements by means of optical instruments and analytic computations.

The world of photogrammetry can be divided into several categories according to the types and position of sensors and the process of getting information from the images.

Here photogrammetry is explained according to the technologies to obtain information from photographic images. In this case, depending on the position of the camera, we can distinguish two categories:

- The terrestrial photogrammetry where the camera is placed on the ground and the optical axis is nearly horizontal
- The aerial photogrammetry where the camera is mounted in an airplane and the optical axis is vertical.

2.2.2.1 EQUIPMENT

2.2.2.1.1 CAMERAS

Cameras for photogrammetric use must fulfill certain conditions. Photogrammetric cameras, so called metric cameras, differ from normal cameras in such a way that their Interior Orientation must be known. The Interior Orientation defines those parameters which are necessary for the reconstruction of optical image formation. These parameters are the focal length, the principal point and the distortion. Parameters as such are being defined by calibration. Additionally the construction of the camera must ensure that the focal plane is absolutely plain, that means that all light rays passing through the lens come to a focus in one plane. Metric cameras ensure by their construction that the once calibrated parameters of the Interior Orientation are constant over a long period of time.

The principal parts of a typical aerial camera for metric images in the format 225 mm x 225 mm are:

The *body* contains the electronic and mechanic components for the camera control.

The *lens cone assembly* is mounted into the body. Lens cone assembly consists of lens, frame and shutter. If a lens with a different focal length is used this part can be exchanged completely. The frame defines the focal plane. It provides for auxiliary information on the film at each exposure (flight height, time and date, navigation signs, film numbers, fiducial marks). An exchangeable electronic shutter and filter can be mounted into the passage of light.

The *film magazine* houses - of course - two film rolls for exposed and unexposed film, the drive mechanism, and the film flattening device (typical a vacuum system). Some magazines can be equipped with an image motion compensation. These are constructional features providing film movement during exposure at such a rate to compensate for the movement of the photographic images. The image motion compensation allows advanced photographic techniques e.g. photos from high speed aircrafts or photos at low altitudes or photos with slow speed high definition film.

The complete aerial camera equipment has a weight of about 250 - 300 kg

Terrestrial metric cameras are offered for all common film formats. For photos of mountainous areas all metric cameras can be used but the format of the film should not be smaller than 70 mm. Well suited for terrestrial photos in mountainous areas is the Rolleimetric camera system. It combines the advantages of a series-produced professional camera system with the possibilities of photogrammetric evaluations. This light-weight equipment (≤ 20 kg) can easily be transported by one person across difficult terrain.

If the camera is mounted on a theodolite further advantages come out of the design of photogrammetric surveys.

2.2.2.1.2 FILMS

The photo industry offers different emulsions for all photogrammetric purposes. In most cases a black and white film is sufficient. By its manifold possibilities in exposure and processing the most economical and safest solution for successful missions is given. Colour films are provided as positive or negative material. They demand excellent weather conditions during exposure, but supply with additional information of natural colors.

For special use infrared films are necessary. Black and white infrared films easily penetrate mist and fog. They are also suitable for representation of water bodies. These films have a very high contrast and a relatively poor definition, which may causes loss of information. Color infrared (or false color) films are mainly used for photo interpretation works in areas with vegetation and are therefore very popular for environmental protection studies. This kind of film helps to visualize diseased vegetation and water pollution.

2.2.2.1.3 ANALYTICAL PLOTTERS

Analytical plotters are used to determine geometric information from metric images. They can be described as computer aided measuring machines. Metric images are adapted on 2 carriages, which are moveable in 2 directions. By an ocular system a spatial view is possible on stereoscopic metric images.

A computer program solves mathematically the relationship between photographic image coordinates measured in the two dimensional photographic reference system and the 3D object coordinates. Interface routines make it possible to communicate with cartographic software, so that analytical plotters can be used as 3D digitizers for the on-line evaluation of photos.

With modern accessories it is even possible to reflect the evaluated line map back into the ray path of the analytical plotter, so that the operator can at the same time look upon the stereo model of the object and the cartographic result.

2.2.2.1.4 SURVEY AIRCRAFT

In principle any aircraft can be used for aerial photos. There is no typical survey aircraft. The actual relevant task decides which aircraft is best suited.

Basically a survey aircraft has to provide for the space for pilot and navigator, and for more extensive missions also space for the camera operator. This as well as the heavy camera equipment should also be considered, so that at least a 6 seater is convenient.

For the use in high mountain areas additional requirements are necessary. A pressure cabin and pressurized turbo prop engines are obligatory. For safety reasons twin engine aircrafts are preferable. An aircraft with these features can be used at altitudes up to 10000 m. Higher altitudes require pure jet aircraft.

2.2.2.2 TERRESTRIAL PHOTOGRAMMETRY

Since its invention the photography has been used for measuring purposes. Because of the original technique with long exposure time and unwieldy devices terrestrial - photogrammetric applications were to the fore. Soon there were reports about the use of this method during exploring expeditions and for the documentation of monuments.

Instead of the theodolite the terrestrial photogrammetry uses a metric camera. There also existed application of both, the theodolite and metric camera, so called phototheodolites. Both types of cameras were used for taking single pictures.

To determine the coordinates of object points their corresponding image points were measured with comparators and converted into object-coordinates. The object-coordinates computed in this way agree in quality with those obtained by the geodetic procedure of intersection, and are also used in the following processes of data acquisition.

Since the beginning of photogrammetry in the last century, this method was applied for the survey of landscapes and buildings. Modern camera and software developments have created with this kind of photogrammetry an efficient tool for highly-precise remote measuring of marked points.

For cartographic purposes this procedure has the disadvantage that many points have to be measured in many single photos. These measuring data have to be compiled in an extra procedure into graphical data. Additionally, there are difficulties to identify the same point in different photos. Therefore, the stereophotogrammetry is better suited for cartographic evaluation.

In the stereophotogrammetric procedure the photos are taken from two standpoints, so that in the following process a spatial (stereoscopic) view can be evaluated. In this case the dimensioning of the baseline between the two-camera standpoints has a special meaning. It depends from the spatial eyesight of man and from the geometry of the camera stand points according to the exposed object.

The geometric evaluation of the metric photos is being made by computer aided measuring machines - the analytical plotter. By the complete analytic formulation of the process of data analysis almost all photos can be evaluated.

Since the development of the first instrument for analysis of terrestrial stereo photos in the year 1911 the meaning of the terrestrial photogrammetry, which lies in large scale mapping of mountain regions has stayed the same. In the European countries of the Alps, terrestrial photogrammetry is firmly integrated in the procedure of producing and updating of official maps.

2.2.2.3 AERIAL PHOTOGRAMMETRY

Each photo flight is to be planned exactly. The planning of such a flight provides the crew with all needed information to photograph a given area with the desired coverage. The main use of the metric images should be defined beforehand. Different use results in different requirements to the flight design, e.g. for interpretations, for orthophotos, for mapping special conditions have to be regarded respectively.

The most important initial values for the flight design are photo scale and focal length.

Focal length: In aerial cameras one can distinguish between wide angle-, standard angle- and telephoto lenses. If photomaps have to be produced or interpretations are demanded, longer focal lengths are preferable because the perspective distortion is smaller. If line maps are to be produced it is better to use a wide-angle lens to take aerial photos. In doing so the highest accuracy for measurements of heights can be obtained.
Photo scale: The correct choice for the photo scale depends very much on the demanded evaluations. For photomaps the scale should not be enlarged more than 5 times than the scale of the aerial photos. Bigger enlargements are technically possible, but then the photographic quality of the photos is not sufficient for a good result. For analytic evaluation e.g. for measurement of digital terrain models or for line maps, an enlargement factor up to 1:10 between photo and map is possible.

The exact keeping of a desired photo scale imposes on the aircraft crew in high mountain areas a high amount of flying ability. The photo scale is defined as the proportion of focal length and flight height above ground. The exact determination of the flight height is not unproblematic in a terrain with large altitude differences. It is e.g. possible that the same distances between flight lines can lead to a loss of the side lap above changing ground, although the flight height is the same. It often cannot be avoided to have a flight design with different distances between flight lines and different flight heights. In any case a suitable terrain height has to be determined as a reference elevation.

It is difficult to describe the further procedure universally valid. It is rather necessary to determine the heading of flight in any special case as dependent on the object and the task.

A further important parameter for planning of the photo flight is the forward overlap. In mountainous regions a high overlap should be chosen, e.g. 90%. For stereoscopic evaluation normally a photo pair with 60% overlap is sufficient, but especially when using wide angle photos it can happen that parts of the photographed area are not visible because of big differences in height (dead angle, shadows). Many photos made in a short succession (=high overlap) provide a larger choice of possible stereoscopic photo pairs for evaluation.

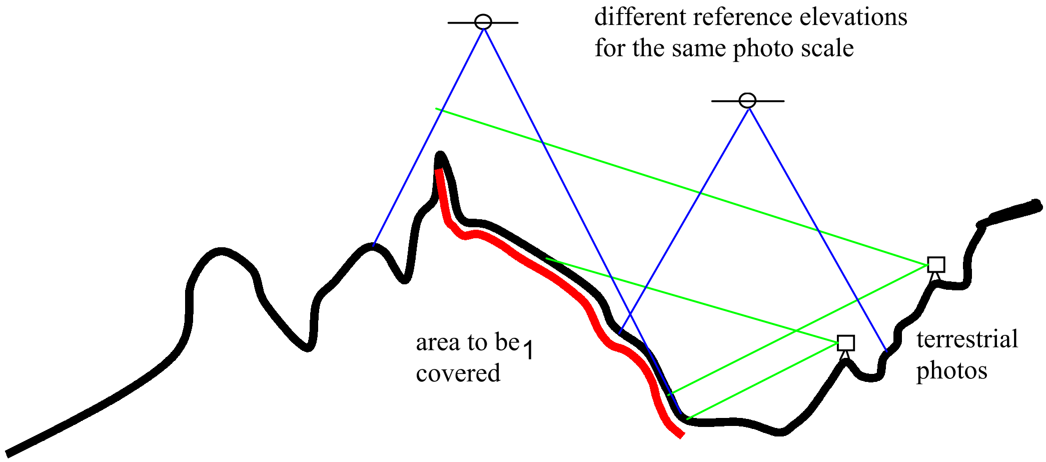

Fig. 2.3: **Photogrammetry in high mountainous areas**

2.2.2.4 PHOTOGRAMMETRIC PRODUCTS

2.2.2.4.1 PHOTOMOSAIC

Especially for big projects the handling of aerial photos has to be supported by a photomosaic. The photomosaic serves as a better overall view and helps to identify the photos. Contact copies of the aerial photos are laid on touch for the photomosaic. The photos are equipped with a clearly readable title. The title should contain date, scale, and the photo number. In the end this original mosaic is being reduced to a useable format by reprography and can afterwards be copied. Along with this mosaic all participating groups can select easily and order the photos they want.

2.2.2.4.2 PHOTOS

Single photos include many possibilities for use because of the multitude of the represented information and because of the reproduction of the terrain-conditions at the moment of exposure.

By stereoscopic examinations the planning engineer has a distinct perspective of the terrain. Interpretations and judgements for selection of project areas can be done with competence.

Important information about geological formations, morphology, vegetation, water bodies, buildings, settlements, impairments caused by environmental influences can be obtained through the interpretation of aerial photos.

Handy to identify objects and control points and to interpret characteristics of the terrain are enlargements in a format of between 24x24 cm^2 and 50x50 cm^2. The smaller format offers advantages at the stereoscopic viewing, the bigger one can be used as a first basis for mapping.

If the photos are covered with a transparent sheet, the interesting photo parts can easily be marked. Preliminary layout and planning of hydropower projects can be done with help of this technique.

Different transparent sheets can be laid one on top of the other as layers. These can allow the integration of different information through combinations as desired or necessary. Already by these simple methods the basis for a geographic information system can be laid.
For the description of level parts of terrain and if the geometrical information is second-rate, rectifications have to be used. For the description of mountain regions they do not obtain special advantages towards the cheaper enlargements.

2.2.2.4.3 ORTHOPHOTOS

The central perspective reproduction of objects by photos has for geometrical tasks the disadvantage, that photos are not of a homogenous scale. Same sized objects are represented in the foreground bigger than in the background. In the photogrammetrical process of evaluation, the size of objects can be represented in two dimensions correctly by the transfer of the central perspective into a parallel perspective line map. The third dimension has to be represented by constructed information, as there are for example contour lines. The result of photogrammetrical evaluation is always an interpretation of the visible photo information.

At the orthophoto map a parallel-perspective representation of the photo is being generated by a differential transformation from the central perspective photo. A digital model of terrain, which can be produced by stereophotogrammetrical evaluation, gives the basis for this.

For the transformation one single photo is being digitized by scanner and disassembled in as many as required picture elements (pixels). With help of computer software, each pixel is then transferred to its place in the model of terrain, whereby its projection into the map is done.

By further procedures of digital image processing in addition certain parts can be emphasized or suppressed. Assemblies out of some photos are possible. The preliminary result is the exposure of the transformed raster image on film.

Production of orthophoto maps costs about 30 - 50% of conventional line-maps.

On the basis of the digital model of terrain necessary for the production of orthophotos, additional information can be produced such as contour lines, profile lines, etc., which are then linked with the image information.

In further working steps hybrid maps can be realized as a combination out of photographic, geometric and semantic information and can be cared for and worked upon in so called information systems by computer.

2.2.2.4.4 DIGITAL MODELS OF OBJECTS AND SURFACES

In a digital model the surface is defined by a certain number of points. The X, Y and Z coordinates of each point are measured with an analytical plotter. There are computer programs, which support this process of measuring. The better and more exact the surface has to be described the bigger will be the number of the points to be measured. For exact representation of the shape of the ground (> 1:2000) some hundred points per square kilometer have to be measured.

The measured points are transferred as primary data to special computer programs. These programs solve surface functions from adjacent points. Based on this further evaluations can be made such as are computation of contour lines, profile constructions, deformation analyses, computations of volume and surface, steps of declivity, maps of water flow direction etc.

If the result of planning is given digitally, it is also possible to visualize the planned object in combination with the digital model of the terrain as computer animation. With large-scale projects such visualizations often helped to get knowledge about purpose and future prospects.

2.2.2.4.5 MAPPING

The presentation of the actual conditions in an understandable and visualized form is the main task of the mapping process. Civil engineering projects in mountainous areas have their own requirements on the mapping process:

- Large-scale maps are mainly required.

- The maps often contain additional information which are normally not included in topographical maps.
- The maps have to be produced quickly and cheaply.
- Actualization and revising have to be possible on the job.
- The mapping concept should be independent of the scale to a very high degree, so that the geometric information, which is valid for one scale is transferable to another one.

Modern mapping techniques can fulfill these requirements if all working steps can be made computer aided. The representation of mountainous regions in readable maps is considered particularly difficult in cartography, because a combination of different procedures is necessary for a sensible reproduction of characteristic mountain prospects.

For example, pure contour line presentations of mountainous areas often lead to an unreadable jumble of lines. The production of skeleton lines and shadow shades for a realistic reproduction of mountain bodies is very work intensive and is also tightly connected to a map scale.

A low-cost solution is the combination of a digital orthophoto with planimetric line maps to a hybrid cartographic concept. Proper software can operate this hybrid information in such a form that according to use either the photographic or the line information can be emphasized. Such a technique can be realized in certain parts also independently from the scale.

Some advantages of hybrid cartographic systems are:
- A hybrid cartographic system as a combination of picture-like information with line drawings is superior to all other concepts, especially for planning tasks in areas with reduced cartographic preconditions
- First results for interpretation purposes with still reduced geometric accuracy can be produced quickly and with favorable terms, without being forced to set foot on the territory that is to be examined.
- The feedback got from interdisciplinary working methods leads object-related optimized visualizing techniques, which are freed from unproductive ballast.
- The complete electronic data storage makes it possible to work with a computer network not bound to local places.

Based on this, various mapping products can be offered for engineering projects:

1. If there are absolutely no cartographic fundamentals or if only - as most usually - maps are available in small scales like 1:250000, then for a first presentation and general idea, scenes resulting from satellites can be produced. For this purpose the following satellite systems are suitable: Spot, Sojus Karta and the metric camera missions of Space lab. This data material is exceptionally suitable for maps up to a scale of 1:25 000. If the existing satellite scenes for the desired map segment are not available the required scenes can be ordered from Spot and Sojus Karta with a time of preparation of approximately 6 - 8 months. The satellites then are maneuvered into the necessary photo positions. The geodetic ground control for geometric orientation of the satellite scenes is appropriately produced by GPS supported surveys. Maps resulting out of these data are extremely useful for the localization of proper construction sites. It is often sufficient to use the stereoscopic view of the satellite scenes. They are also very helpful for field works.

2. In a next step of data processing vertical and/or oblique photos from survey aircraft can be used. Those photos can be practically evaluated for all desired map scales. Additional terrestrial photos guarantee the complete representation of the site. Based on this, maps can be produced when they are actually needed. Further information can be added without further fieldwork.

3. By digital storing of all cartographic information special representations can be produced. e.g. for representation of location lines (utility lines, communication lines and other) often combinations of ground plan and sections on one map sheet are required. Reliefs of terrain e.g. for visibility tests can be realized on the basis of a digital terrain model with different perspectives.

2.2.3 GENERAL SURVEY WORKS

High head development is usually closely connected to remote areas in mountainous regions. Since available topographical maps are not accurate enough for hydropower development, comprehensive survey works are needed at the identified site and its locations for structures. Mainly three different survey methods can be distinguished:

- conventional survey by triangulation and optical distance measurement
- photogrammetry
  - aerial, with optical axis vertical
    - satellite
    - air plane
    - helicopter
  - terrestrial, with optical axis parallel or inclined
- Global Positioning System (GPS)

To achieve accurate results with the conventional method the coordinates of at least two measurement points have to be known. Since fixed points are hardly available in remote high mountains, this method might not be applicable.

In case of photography the horizontal position and altitude of at least one point should be known. Of course, the more coordinates of objects on the photo are known, the more reliable is the determination of coordinates of other points. Moreover especially aerial photography is very expensive. In mountainous area, a reduced line spacing between the airplanes should be ensured, to cover also the area of steep slopes.

In recent years with increasing use of technology the processing of satellite images becomes more and more important in survey works. The technology has reached a standard, allowing the resolution of i.e. Landsat images having a square grid of 30 m length. Of course, this cannot be utilized for detailed survey works, but might be useful for the location of structures, as problematic geological formations may be identified. Similar to other aerial photographs, survey coordinates of objects must be known for a reliable use of so called georeferenced images. Following sketch illustrates the problem in determination of correct altitudes and positioning for high mountain areas.

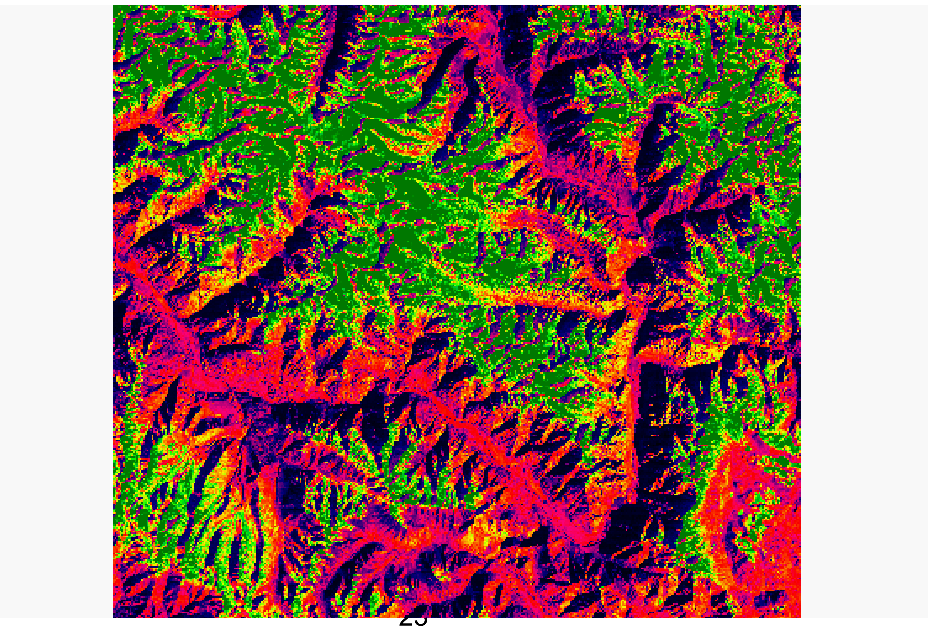

Fig. 2.4: **Channel 3 of Landsat TM image of Himal Pradesh**

Global Positioning System can be considered as an appropriate tool in survey works in context with high head hydropower developments. The position of the actual measurement point is determined with help of the satellites in the area of field measurements. The position and altitude of the point is given in a world coordinate system, which can be converted to local coordinates systems. GPS can also be combined with all other mentioned survey methods. It can be considered as an ideal survey tool in remote area. Once two measuring points are determined with GPS, survey can be carried as usual with conventional techniques as tachymeter etc. A local net of control stations can be established either in a global coordinate system or in local coordinates system.
It has to be mentioned also in this context, that in high mountain areas GPS should not stand “in a shadow” of a mountain because this endangers the measuring communication between the satellite and the GPS units. Experience is needed to take into account all requirements while measuring.

2.2.4 HYDROGRAPHIC SURVEY

For any hydraulic/hydrological calculations of the river or a proposed reservoir, the geometry can be considered as the most decisive parameter. For this reason the geometry of the river and the valley have to be measured accurately in the horizontal and vertical dimension. By using the measuring techniques and instruments mentioned above, a position next to the river can be determined.

For hydraulic calculations of a river the cross-section and the longitudinal section are needed. While the cross-section determines the area of flow, the longitudinal section gives the slope of the bed. The longitudinal section is also determined by a sequence of measured cross-sections. Since three dimensional effects are of importance in case of mountainous rivers, the course of the river in the important reaches should be measured. If possible, the typical mountain structures, such as step-pools shall be reported.

The principle of measuring the cross sectional profiles for a given discharge consists in measuring the water depths at different equidistant verticals of the river. The number of verticals depends on the size of the river. Sufficient points shall be measured to describe the shape of the river. The cross-section should be measured right-angled to the flow direction and the coordinates of the reference points at each side of the bank should be known. A leveling of the water level has to be conducted to determine the elevation of the cross section points.

The simplest method of measuring the cross sectional profile is to take the depth of the water with a stick. The survey coordinates of each measurement point must be clear in the outline. Usually a tag line is used for smaller water bodies. Plane tables, theodolites and GPS are used to survey larger areas. The distance to any point in a cross section is measured from an initial point of the bank. It is also very important to keep a record of water levels in order to be able to refer the survey data to the same datum.

Since the velocities in mountain torrents are sometimes very high and can exceed 5 m/s locally, measurements should preferably be carried out during low flow. Usually the water depth has to be measured for discharge measurements. Having this in mind, locations with easily accessible bridges are favorable places for measuring.

A regular measurement of cross-sections at the same locations should be intended to record possible changes in the geomorphology of the river.

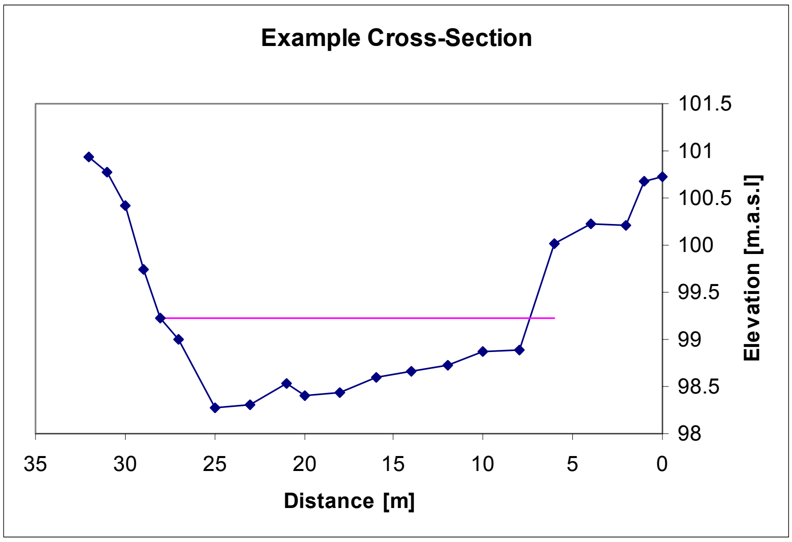

Fig. 2.5: Cross-Section of Mountain River with equidistant measured points

Furthermore today echo-sounding systems are used in hydrographic survey. This technique is only applicable in big rivers with less steep slopes. It may be used for the survey in medium head hydropower projects.

In case a storage layout is considered for the preliminary layout of the hydropower project, the intended dimensions of the reservoir have to be measured to determine the storage capacity. For this reason, tachymeter measurement points are taken in the valley. Based on this data a contour line of the planned reservoir will be established giving the contours of each for example 10 m.

2.2.5 SPECIAL SURVEY WORKS

2.2.5.1 TUNNEL SURVEY

Normally tunnels are excavated from both sides to meet exactly in the middle. Also, there might be given certain reasons to excavate auxiliary tunnels from which the actual tunnel can be excavated from the middle to the adits.

The survey engineer bears a great part of the responsibility for the success of such works. He has to take care of a survey system for which the far-reaching control is only possible at the closing of the works.

It is sensible to cover the survey design by simulation computations. E.g. from graphic results of different net configurations data can be digitized. These data can be combined simultaneously to the planned network with the available software. Hence precious hints may be obtained about the error budget of the chosen survey methods.

When the direction for the tunnel excavation is given various marginal notes for the best gyro operation still have to be cleared, as there are: excavations from one or two sides, straight or bent tunneling, tunnel length, average length of the polygon sides and other. The design of measurement must be outlined and adapted anew for each new tunnel, so that here only common recommendations can be given.

Short tunnels up to a length of about 5-km can be excavated from one side. Geodesy does not present any difficulties in supervising these excavations.

The excavation of long tunnels, which often must be driven from both sides, gives a different situation. Here the combination of various modern measuring techniques gives the necessary requirements for a successful tunnel survey.

Previous to all other works, a local geodetic network of control stations in front of every tunnel adit has to be installed. To keep the error budget as low as possible, it is an empiric fact that the net should have a diameter similar to the length of the tunnel. Near the tunnel adits a micro network is additionally installed. The points of this net are the control points for the tunnel survey. This micro network is also used for the construction survey for the buildings close to the tunnel entrances.

To achieve a breakthrough with defined accuracy, the control stations of both nets have to be fixed in a homogeneous system of coordinates.

GPS measurements are very well suited for the integrated definition of such nets, especially when a sight connection is obscured by topography. It is not necessary to survey all control stations by GPS. A more economical approach is reached by a purposive selection of well-distributed control stations to which all the other control stations can be transformed. When selecting the GPS control stations one has to give special attention to the fact that the space vectors which are measured between the control stations define in their wholeness a well defined geometric figure, which provides a system of coordinates.

The traverse is used for the actual survey of the tunnel. Angles and distances are measured with first order instruments. To keep the misclosure within planned limits, various error influences have to be taken into consideration like measurements of angles, lengths of traverse legs, and elevations; lateral refraction; length and curvature of the tunnel; tunnel design and excavation method; and higher geodesy (geoid undulation).

Various descriptions of misclosures of tunnel breakthroughs can be found in the literature. To sum up it can be said, that with gyro orientated traverses misclosures ≤ 20 mm per km of tunnel length can be achieved.

From the beginning of tunnel excavation further control measurements can be made additionally to the geodetic necessary ones. Here the advantages of photogrammetric procedures can be used with added force such as are: short measuring times at site, purposive data evaluation for the actual use, documentation of the actual condition for the purpose of proof, repetition of evaluation under new aspects.

If the out-crops of layers and deposits which always change during excavating are recorded stereophotogrammetrically the viewer gets a realistic impression of the given conditions. By use of accordingly modified photogrammetric procedures, tectonic rock parameters (dip, strike-line, fault plane, fissure a.o.) can be defined. The state of tunnel laggings and possible tunnel movements caused by rock pressure can also be proved by photogrammetric deformation analysis.

Many mining companies use these procedures to ensure safety of operation especially to find out possible subsidences of rock, for forecast of tectonic strains and stresses, for survey of cores of bore-holes, for determination of permeability of water flow and other monitoring procedures.

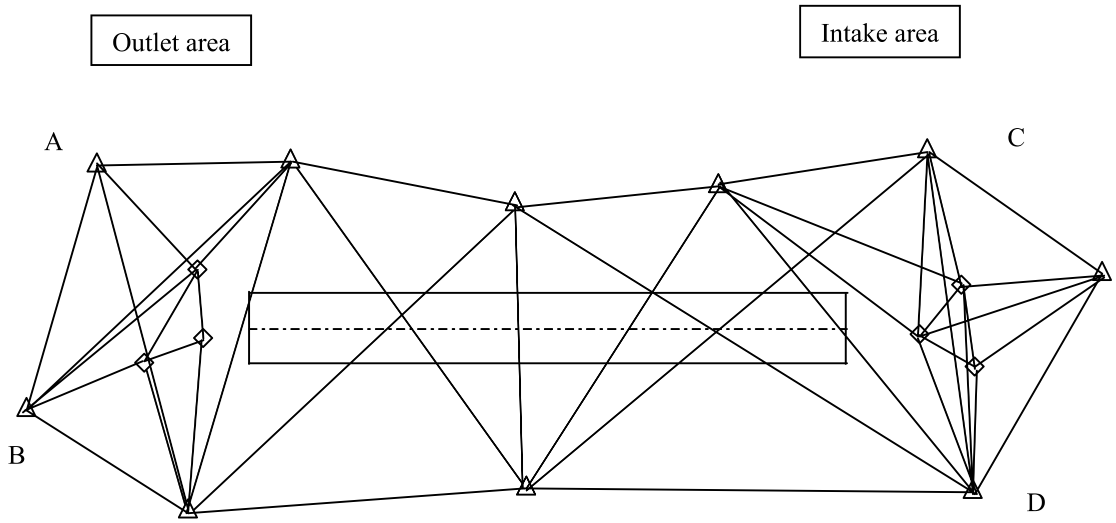

Fig. 2.6: Geodetic basic Triangulation/ Trilateration network and micro networks [1]

2.2.5.2 SURVEY DURING CONSTRUCTION AND AFTER COMPLETION

Though this kind of surveying is not directly connected to the steps for implementation of hydropower projects, it is an important part in the monitoring during the construction phase and provides information about measurements after completion of the project.

Surveying is needed for the permanent control of construction progress to avoid any problems due to inaccurate working. During construction structures have to have the same position in nature as planned, otherwise problems in operation might occur.

After the completion of the project, the establishment of benchmarks is needed to control any kind of movement in horizontal or vertical direction. This is of absolute priority for structures as dams etc. New measuring devices have been developed in during the last decades. Especially in young mountain areas, such as Himalayas, movements can occur due to seismic events and tectonic activities.

2.2.6 FIELD INVESTIGATIONS

Especially in high head hydropower development survey has to be carried out in some remote area. For this reason the benchmark of the national geodetic grid at a nearby location (if available and proved reliable) has to be selected as the main horizontal and vertical control station for the project. After this, reference points have to be established, which should be done with help of GPS survey equipment. Thus a primary GPS network consists of the control station and the different reference points. The reference points should be established next to the location of the main structures, such as powerhouse, weir, intake, tunnel entry and exit etc.

During work with GPS it is necessary that a minimum of four satellites is available during the collection of GPS data. The observation should be long enough to gain reliable co-ordinates and elevations of the control measurement.

After the GPS network is established, a detailed topographic survey is carried out from the reference points using Total Stations. Modern Total Station record the data on memory cards. The data can then be downloaded to a computer, where the data processing and error checking is carried out. The data processing is discussed in the next paragraph

2.3 DATA PROCESSING

2.3.1 GPS DATA

All the GPS data processing is carried out by using the software supplied by the manufacturers. Since GPS data are in the WGS84 format, data have to be converted to the local map co-ordinates. The necessary steps are briefly described below:

- Collection of GPS data at the site using the GPS receivers
- Downloading of data to computers using appropriate software
- Post-processing of data from the known and unknown station using a baseline processor. All internal computations within the software take place in the WGS84 system. The output contains co-ordinate data for each point in WGS84 format
- Determination of transformation parameters (from WGS 84 to local coordinate system)
- Conversion of WGS 84 co-ordinates into local map-coordinates on basis of the transformation parameters. Correction of any mistakes takes place before conversion.
- Conversion of all points to local grid system including horizontal and vertical adjustments

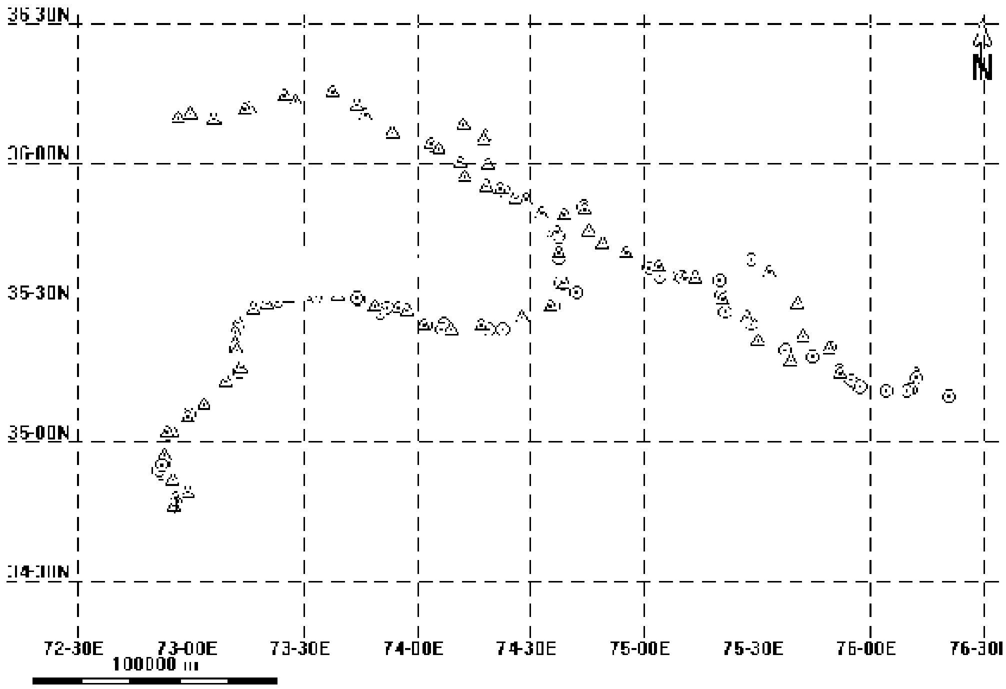

Fig. 2.7: GPS Net along Upper Indus River and Main Tributaries

2.3.2 TOTAL STATION DATA

The data processing of total station data first involves the downloading of the field data into the computers through an interface. Each survey data file is then transferred into the program database. The next step is the checking of each file in terms of future code errors and coordinate/elevation errors. Once any existing errors are removed, the files are processed for feature codes, which help to build up a plot of the surveyed area. These plot files are then transferred to CAD software for final setting and plotting.

2.3.3 CONTOUR DEVELOPMENT AND MAPPING

The converted Total Station data are further processed with CAD software. Today there are special applications with digital terrain modeling software for production of contours. One DTM software is MOSS (Modeling of Surface Systems), which is the world industry standard for formation of digital terrain models. Once contours at the required interval had been developed on MOSS, they can be fed to a CAD software in form of contours. The information can be used for the production of a map, showing both the topographic details and features as well as contours.

2.3.4 HYDROGRAPHIC SURVEY

The survey of the cross-section of the river at different locations along the proposed high head development is important for hydraulic and hydrologic calculations. The measured points can be processed in form of drawings showing longitudinal profiles and cross-sections at relevant locations i.e. dam site, powerhouse, tailrace, etc. Both types of information can also be processed in form of tables, giving the distance from a reference point of the bank to the measuring vertical and the corresponding water depth at that point.

2.4 APPLICATION

With help of the processed topographical digital maps, detailed information is available for the layout and design works for the development of high head hydropower. With this information, the design of structures can be made according to site conditions. Geometric dimensions of the layout can be planned in detail.

Moreover the designed structures can be developed within a CAD environment to ensure a proper presentation of planned design. Locations of different components of high head developments, such as headworks and appurtenant structures, alignment and dimensions of penstocks and tunnels etc. can be implemented into the topographic maps.

Survey works with high accuracy are especially needed to ensure proper alignment and design of proposed tunnels. Errors in measurement will have a dramatic impact on the success and the costs of the project.

With the exact hydrographic survey at important locations, such as weir, intake etc. a preliminary as well as detailed design of the structures and especially its dimensions and elevations can be elaborated. Furthermore hydrographic surveys can be used for numerical and physical modeling purposes. Together with the streamflow data and information concerning bed material, both types of models can be calibrated and different layouts can be studied before detailed engineering design.

List of Figures