DESIGN, SIZING, CONSTRUCTION AND MAINTENANCE OF GRAVITY-FED SYSTEM IN RURAL AREAS

MODULE 3: FEASIBILITY STUDY FOR THE CONSTRUCTION OF A GRAVITY FED SYSTEM

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I. INTRODUCTION

A feasibility study allows designing roughly a project and determining whether the construction of a gravity fed system is realizable. The validation of the feasibility of gravity fed system in a village must be done on both technical and social levels.

→ **Technical validation**

In order to build a gravity fed system that can cover the needs of the population, one must make sure that the two following conditions are met:

- The quantity of water available at the spring (or springs) must be sufficient to meet the needs, i.e. the spring (s) flow over a 24 hours period must be higher or equal to the daily needs of the community.
- The topography must allow the water to flow by gravity, i.e. the slope between the highest point of the network (storage tank or spring catchments) and the last distribution point must be higher than 1% (1 m of vertical distance for 100 m of horizontal distance). If we draw a 1% slope line starting from the highest point, no part of the network must be located above this line.

→ **Social validation**

The technical validation is not enough to build a GFS, it is also necessary to make sure that the following conditions are met:

- The community must be motivated and ready to take part in the construction project,
- The construction project must answer to a need and an interest from the villagers.
- The community must be ready and able to undertake the system's operation and maintenance

II. GENERAL DATA COLLECTED AT VILLAGE LEVEL

First, field data must be collected: visit the village and the springs in order to collect all necessary information. Because of the significant number of ethnic groups, some villagers do not speak Indonesian; it is thus preferable to go to the village accompanied by a person who could be used as interpreter.
Before starting to ask questions to people, it is advisable to introduce yourself and explain the reasons of the visit. The discussions must be done with the greatest number of villagers as possible without forgetting to include the authorities of the village, such as chief of the village and elders (it is generally the latter that should be met in first). The main questions to ask must tackle the following issues:

- General data on village (authorities, population, access to the village, etc).
- Collection of data concerning health (main diseases, presence of doctors, health centres, etc).
- Collection of data concerning current water resources (type, distance, how long to reach them by walk, etc).
- Collection of data concerning the springs present around the village (it is the most difficult data to obtain and where it will be necessary to be experienced and methodical).
- Collection of data concerning participation provided by the villagers (locally available materials, number of people available for free or subsidized labour, etc).

The questions are part of a questionnaire to be filled in during discussions with the villagers. An example of questionnaire is given in annex 1.

It is also necessary to discuss with the villagers to know in which way they would participate to the construction of a gravity fed system, or to explain to them which kind of contribution is expected from them if the project is implemented. Observing the villagers reaction during the discussions is a source of indications on their motivation and their real needs.

This first visit allows deciding if the village has a real need for water, if the villagers are motivated for the project, and if the network construction is relevant. If the village is selected, it is necessary to come back to the field to deepen the information collected at the time of the first visit.

III. DATA CONCERNING SPRING

III.1. Choice of the spring

Information concerning the existing springs around the village must be obtained from the villagers. This step is the corner stone of the network construction and must be carried out thoroughly. The discussion must imperatively be held with a significant number of villagers and all information must be validated by the villagers present. It is important to underline that the villagers often do not understand the exact concept of what a spring is and they do not know how to estimate its flow. Moreover, each family, according to their activities (location of the fields, hunting area, etc…) has a good knowledge only of certain zones of the village; consequently, each person will speak in priority about the zone that he knows better and will not be able to provide proper information on some other areas.
A site visit, with villagers who know well the area of the spring to be visited, is imperative to determine the feasibility of equipping the spring initially identified by the community. The best period to visit the spring is in dry season (for exemple, for NTT province, it corresponds to the months from August to November), i.e. a period when the flows are generally low.

At the time of the site visit, it is important to identify the hydrogeological context of the area where the spring is located, and to check in priority the following points:

- Check that there is not another zone of emergence of water located above the observed spring. This first emergence could be hidden by rockfalls, a marshy zone or an uneven relief.
- Check that the emergence zone does not change during the year,
- Check that the spring is not located in a riverbed flooded during rainy season,
- Check the variations of the spring flow after an isolated rain event as well as the variations of the water turbidity. This allows estimating the vulnerability of the spring: if the variations before and after the rain are large, or the water very turbid after the rain, that means that the aquifer which supply the spring is vulnerable to external infiltrations, thus not very reliable,
- Observe the presence of vegetation around the spring; if the trees were recently chopped down, it could lead to many problems with spring in the future,
- Check that the spring provides water all year round,
- Check the water quality (taste, odor, turbidity),
- Observe if there are no possible sources of pollution above and around the spring,
- Check that the spring is not worshiped by the villagers; if it is the case, the spring location is a place of worship for community and the construction of a spring catchment will not be easily accepted.

III.3. Flow measurement

Flow measurements are essential to estimate the water production of the spring for the whole year. Strictly speaking, it is essential to have records of flow during a sufficiently long period to assess the variations in flow. In practice, owing to the fact that it is often

impossible to obtain detailed quantified information, it is necessary to collect as much as possible information from the villagers.
From measurements carried out and information obtained, we estimate the flows during the rainy and the dry seasons:

- The flow at the end of the dry season (in NTT province, it is in October/November) is the lowest flow of the year. This flow must be compared with population needs, which allows deciding if the construction of a storage tank is necessary.
- The flow in rainy season is the highest flow of the year; it is measured at the end of the rainy season. This flow allows sizing infrastructure's overflows for the spring presenting a medium or a large flow.

To measure the spring flow, the most common techniques are the weir measurement, and the chronometer & container measurment.

→ **method of chronometer and container**

This method is easy and adapted to the small flows (< 10 l/s). The necessary tools are chronometer, bucket, shovel, knife, clay and a bamboo or plastic pipe.

The step is as follows (see picture 1):

- Set a small dam with the clay to prevent the water from flowing,
- Place the pipe on the top of the small clay dam,
- Wait until the basin formed by the clay dam is filled; once the water runs out through the pipe, wait for 10 minutes, to let time for the flow to stabilize,
- Measure the time (with the chronometer) that it takes to fill the bucket; take this measurement at least 3 times

The flow is calculated in the following way: $Q = V / T$

Q = flow (liter / second),
V = bucket volume (liters),
T = bucket filling time (second).

Example:
Calculate the flow of a spring for which 4 measurement were done using a 10 liters bucket

1st measurement = 30 seconds,
2nd measurement = 32 seconds,
3rd measurement = 34 seconds,
4th measurement = 31 seconds.

Result: $T = (30 + 32 + 34 + 31) / 4 = 31.75$ seconds.
$Q = 10 / 31.75 = 0.31$ liters / seconds.

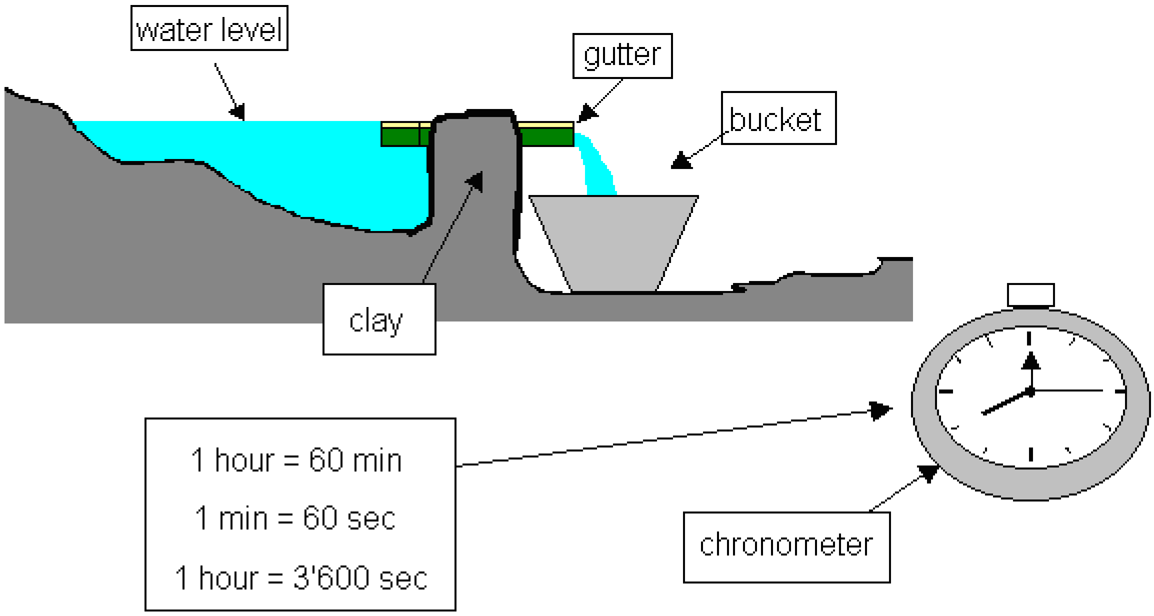
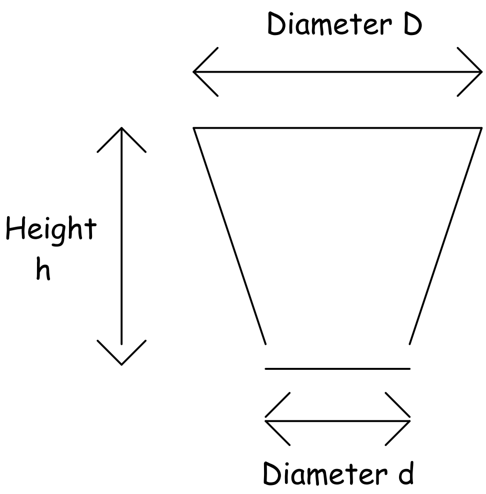


Fig.1: Chronometer and container method

To know V, it is necessary to know the volume of the bucket. If this one is not known, it is necessary to calculate it, using the following formula:



$$V = 3.14 \times h / 3 \times (R^2 + (R \times r) + r^2)$$

with $R = D / 2$ and $r = d / 2$

Example:
Which is the volume of a bucket of the following dimensions: D = 0.38 meters, d = 0.21 meters and h = 0.50 meters?

Result: R = 0.38 / 2 = 0.19 meters and r = 0.21 / 2 = 0,105 meters.
$V = 3.14 \times 0.50 / 3 \times (0{,}19^2 + (0.19 \times 0{,}105) + 0.1052) = 0.0351\ m^3$, or 35.1 liters.

When making calculations, it is necessary to pay attention to the units: volumes must be calculated with the units corresponding to the one used to measure the distances (distances in meters → volume in m^3, distances in cm → volume in cm^3, etc.).

The following table explains how to covert volume units:

m^3			dm^3			cm^3			mm^3		
Liters											
					.						

How much liters make 30 cm^3?

m^3			Dm^3			cm^3			mm^3		
							3	**0**			
Liters											
					0 .	**0**	**3**	**0**			

Answer: 0.03 liters.

How much liters make 30 m^3?

m^3			dm^3			cm^3			mm^3		
	3	**0**									
Liters											
	3	**0**	**0**	**0**	**0 .**						

Answer: 30,000 liters.

→ **Weir measurement**

A weir is a device that enables flow rate to be calculated from the height of water. The following steps should be followed (see fig 2):

- Construct a "V" shape weir out of wood or metal plates, respecting the dimensions given in fig 3: $\alpha = 60°$, total height of weir is 50cm, height of sill is 25cm.
- Install the weir perpendicularly to the direction of the flow. The blade (distance from soil to bottom of sill) must be 20cm.
- Install a ruler in the water at a distance of at least 5 x h from the weir, h being the height of water in the sill.
- Read the height of water, on both the weir and the ruler level,
- Wait until the two measured water heights stabilize and are equal
- Using the nomograph given on fig 3, you can determine the flow corresponding to the water height measured on the weir level.

In order to measure the flow using a weir, it is necessary to have a calm water flow without turbulence (laminar flow). This is why it is important to wait that the two measured heights (weir and ruler) stabilize and are equal.

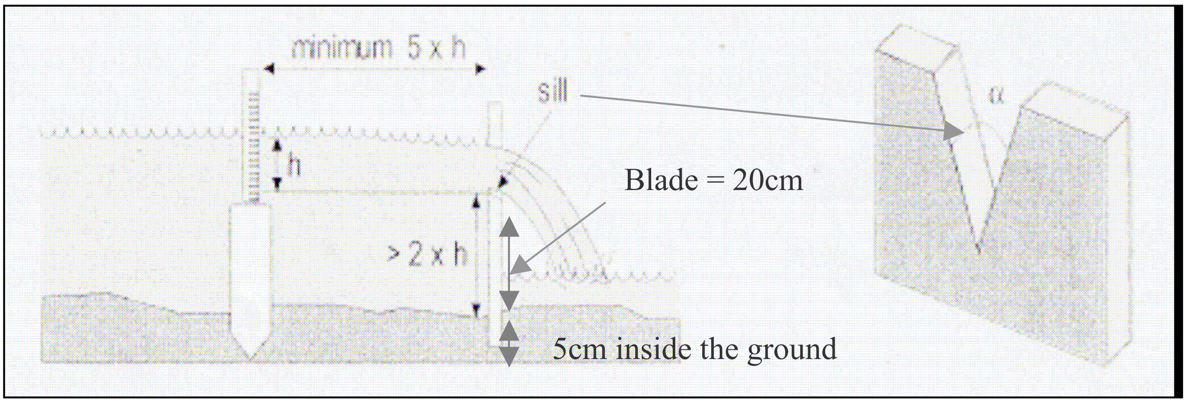


Fig.2: Scheme of the installation

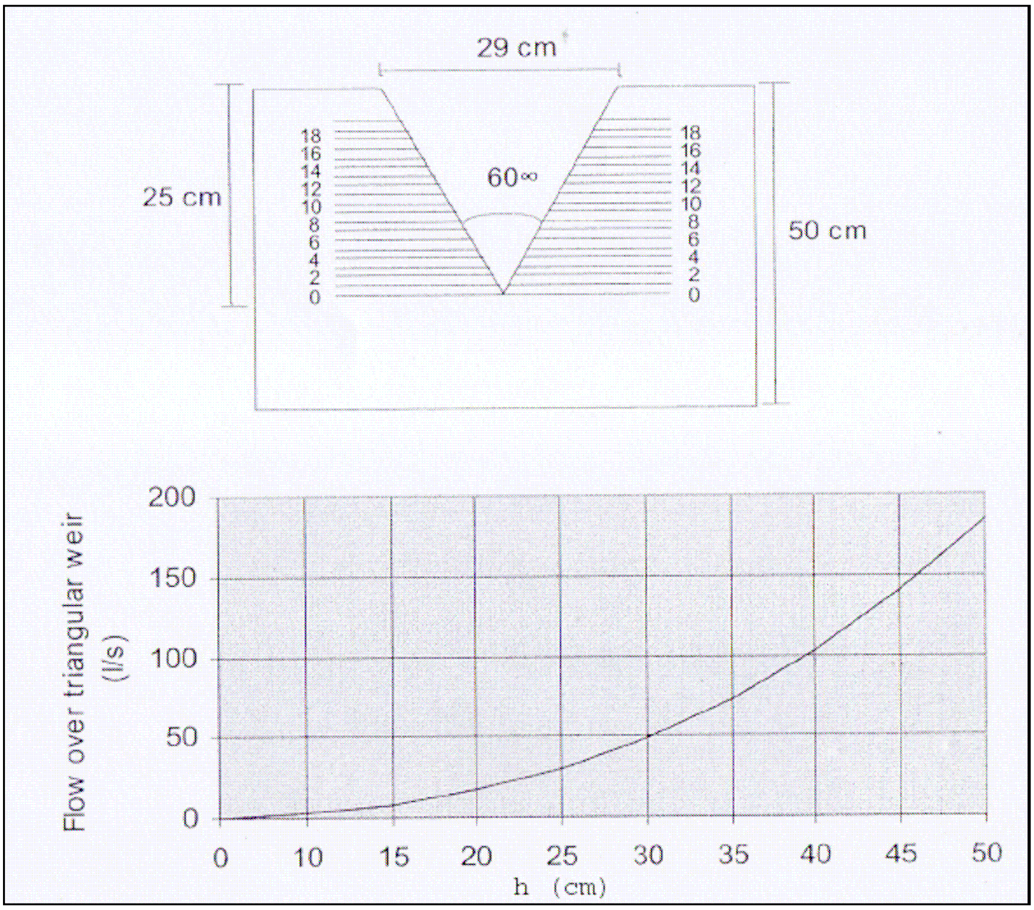


Fig 3: Nomograph of flow calculation according to h (water height in sill), for a blade = 20cm

IV. WATER REQUIREMENT

IV.1. Daily needs

The daily needs correspond to the quantity of water necessary to cover the water requirements of a given community in one day. To determine the daily needs, it is necessary to know the number of people that will use the GFS.

The water requirements must be met for a given population for a minimum duration of ten years. It is thus necessary to take into account the population increase rate and the possibility of an extraordinary population growth that can result from the construction of a water system in a village.

To size a GFS, we usually consider a yearly population increase rate of 3% (so the population increases by 3 persons per year for every 100 persons in the village each year).

The field survey enabled you to calculate the current number of people to be covered. To calculate how many people a community will have in 10 years, the following formula is used:

Population in 10 years = current population x $(t + 1)^N$

Where t = growth rate and N = number of years

By taking t = 3% and N = 10 years, we obtain:

Population in 10 years = current population x $(1 + 3 / 100)^{10}$, which means

Population in 10 years = current population x 1.34

To know the daily demand of a given population over a period of 10 years, the following steps should be followed (see table 1):

- For each population group, evaluate the corresponding unit needs in L/person/day (= column 3). Standard unit needs are given in table 2.
- For each group, calculate the number of people after 10 years: it is obtained by multiplying the current number per 1.34 (column 4 = column 2 x 1.34).
- For each group, calculate each group's total daily needs, obtained by multiplying the population number in 10 years by each unit needs (column 5 = column 4 x column 3).
- The daily demand for the community is the sum of the daily needs for each group.

Table 1: Village's daily demand calculation (T = 3% and N = 10 years)

1	2	3	4	5
Group	Current number	Unit needs (l/pers/d)	Number in ten years	Daily needs (l/d)
Inhabitants	260 people	45	350	15,750
Health center	20 consultations	10	27	270
School	100 students	15	135	2,025
Goat or Pigs	130 cattle	5l/animal/day	175	875
Total				**18,920**

It is interesting to underline that in our example, the number of cattle was taken into account. The construction of a GFS must firstly cover the water needs for the population but, when the spring flow allows it, it is always better to take into account the number of cattle present in the rural villages. Indeed, once the GFS built, the villagers often use this new water source to feed their cattle (cattle being important water consumers).

Table 2: Unit needs

	Unit needs
Domestic needs	45 l/pers/d
Health center	10 l/pers/d
Hospital	50 l/lits/d
School	15 l/student/d
Market	10 l/pers/d
Mosque / church	5 l/visitor/d
Cattle (goats, pigs)	5 -15 l/head/d

IV.2. Calculation of the hourly demand

The hourly demand corresponds to the water requirements distribution for population for a certain period, i.e. for one or several hours of the day. To calculate it, it is necessary to know the consumption coefficients over each hourly period.
Using water meters installed on the pipelines of some existing networks, ACF was able to estimate the consumption coefficients for each hour of the day. The consumption coefficients thus obtained are indicated in table 3 and can be used for all villages.
The hourly demand is obtained by multiplying the daily needs by a consumption coefficient. An example of the calculation of hourly demand is given in figure 4 and table 3.

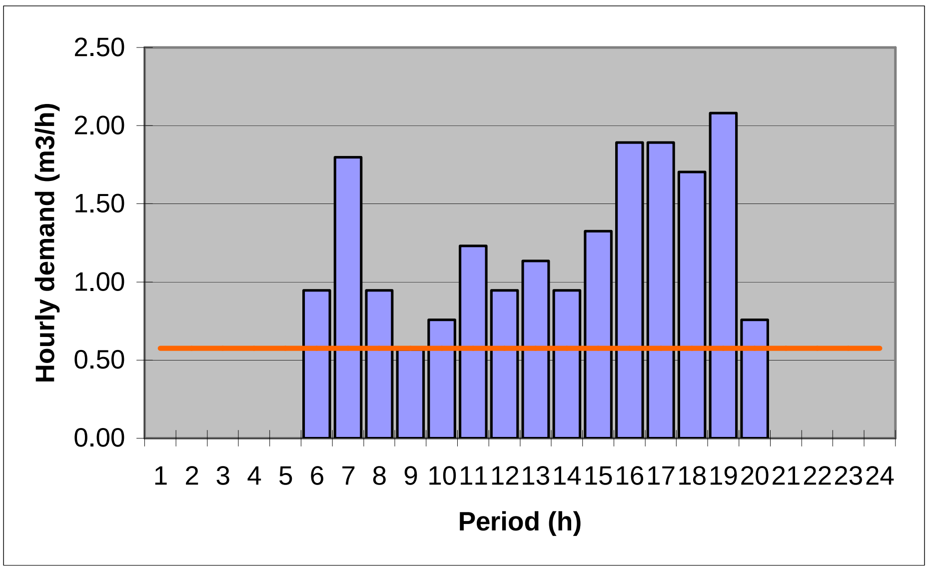


Fig.4: Chart of hourly demand (in blue) and spring flow (in red) calculated in table 3.

Table 3: Water requirements distribution and spring flow per hour for a village (the total daily needs are 18.92 m^3/day and the total spring flow 13.82 m^3/day).

Period (h)	Consumption coefficient (%)	Hourly demand (m^3)	Spring production (m^3)
1	0	0	0.58
2	0	0	0.58
3	0	0	0.58
4	0	0	0.58
5	0	0	0.58
6	5	0.95	0.58
7	9.5	1.80	0.58
8	5	0.95	0.58
9	3	0.57	0.58
10	4	0.76	0.58
11	6,5	1.23	0.58
12	5	0.95	0.58
13	6	1.14	0.58
14	5	0.95	0.58
15	7	1.32	0.58
16	10	1.89	0.58
17	10	1.89	0.58
18	9	1.70	0.58
19	11	2.08	0.58
20	4	0.76	0.58
21	0	0	0.58
22	0	0	0.58
23	0	0	0.58
24	0	0	0.58
TOTAL	**100 %**	**18.92 m^3**	**13.82 m^3**

The hour demand, compared to the spring flow, allow estimating if the GFS must be opened (no taps, no storage tank) or closed (storage tank + taps):

If needs per hour (l/h) < spring flow (l/h) → open network without tank

If needs per hour (l/h) > spring flow (l/h) → closed network with tank

In the example given in picture 4, hourly demands are larger than the spring flow: a tank will have to be built. In the example given in picture 5, all the hourly demands are lower than the spring flow: the tank construction will not be necessary.

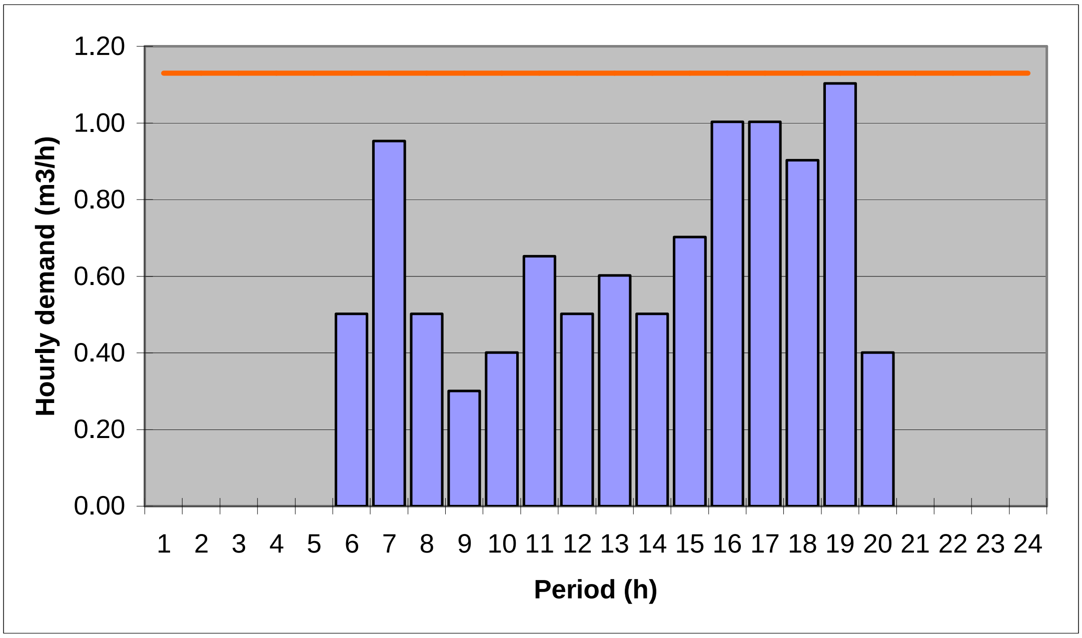


Fig.5: Example of hourly demands (in blue) and spring flow (in red) per hour.

V. LAYOUT OF THE DISTRIBUTION SCHEME

During the field survey, a sketch of the village must be made, on which the distribution zones are drawn. These zones are defined according to human criteria (origin of the populations, presence of health structure or school…) and technical criteria (accessibility, topography…). For each zone we indicate the number of people to be served (by taking into account the population increase rate over 10 years). An example is given in picture 6.

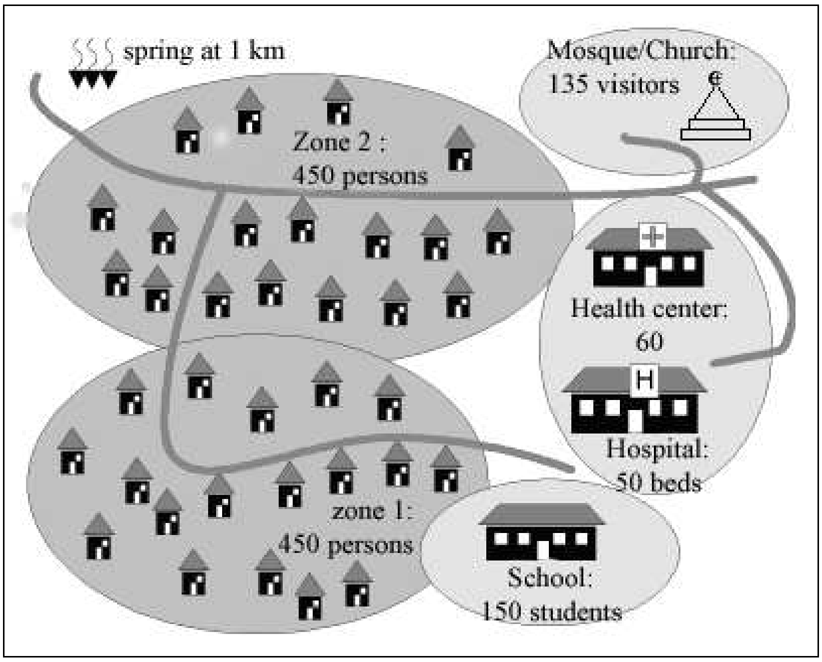


Fig.6: Example of village sketch with the various distribution zones

The number of taps and tapstands for each zone must now be estimated. For this, it is necessary to define the total water requirements for the community. These needs are expressed first in volume per day (liters/day), then in average flow on the distribution period chosen (liters/hour). The procedure for each zone is as follows:

1. Calculate the daily needs (in liter/day),
2. Determine the largest need per unit of time (in liter/second): this one is obtained by multiplying the daily need by the largest consumption coefficient of the day,
3. Knowing that the average flow of 1 tap is 0.25 l/sec, calculate the number of taps necessary (number of taps = need per unit of time (l/sec) divided by 0.25 l/sec),
4. Knowing that it is necessary to have at least 1 tap for 100 people, check if the number of taps obtained respects this criterion,
5. Determining the number of necessary tapstand according to the village area (with a maximum distance of 200 meters between two tapstands).

The results obtained for the village represented in picture 6 are indicated in table 4.

Table 4: Determination of the number of taps and tapstands for the village represented in picture 6 (the largest consumption coefficient being of 11%)

Zone	Number of users	Number in 10 years (Rate = 3%)	Unit demand (l/pers/d)	Daily needs (l/d)	The largest demand (l/s)	Number of taps (flow of each tap is 0,25 l/s)	Selected number of taps	Number of tapstands
Zone 1	335 persons	450 persons	45	20,250	0.62	3	5	3
Zone 2	335 persons	450 persons	45	20,250	0.62	3	5	3
School	110 students	150 students	15	2,250	0.07	1	2	1
Health center	45 consultations	60 consultations	10	600	0.02	1	1	1
Hospital	37 beds	50 beds	50	2,500	0.08	1	2	2
Church/mosque	100 visitors	135 visitors	5	675	0.02	1	1	1
Total				**46,525**	**1.42**	**10**	**16**	**11**

When the number of tapstands and taps is known, write the information on the village map including the layout of the pipelines. For each section of network, we calculate the maximum instantaneous flow obtained only when all the taps are opened:

Max flow = number of served taps x tap unit flow (= 0.25 l/s)

The maximum instantaneous flows calculated this way is higher than the needs. In practice, the water that will flow in the network corresponds to the maximum instantaneous flows only a few hours per day, when all the taps are opened. The rest of the time, some taps will be closed and the flows will be lower and the daily volume distributed close from the estimated needs.

The pipe layout with the maximum instantaneous flows and the number of taps obtained in table 4 is given in picture 7.

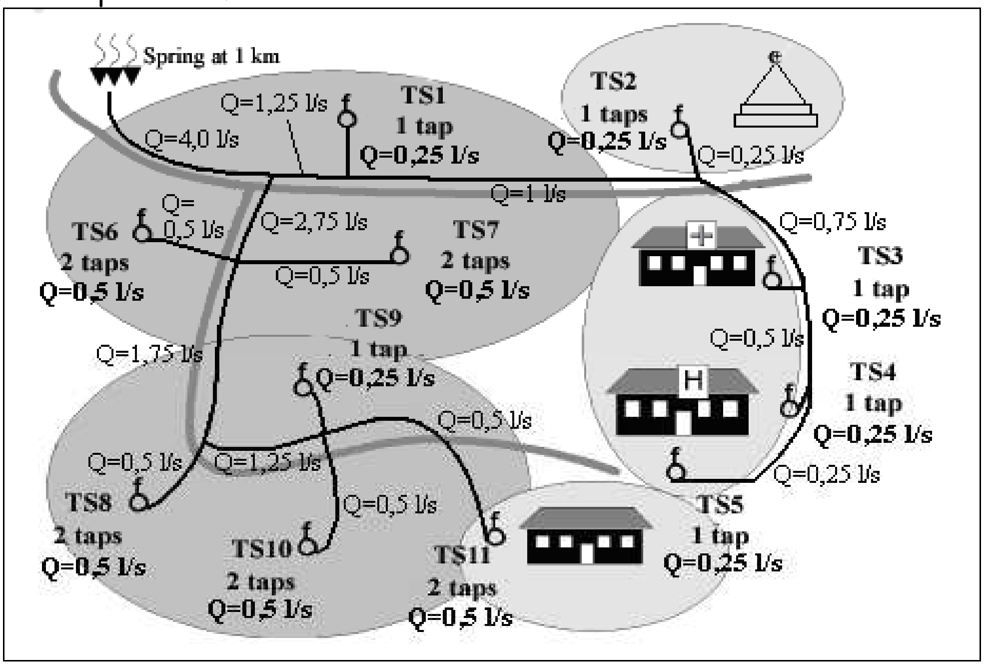


Fig.7: Pipe layout with maximal flows and number of taps.

The pipe layout obtained is approximative. The final location can be determined only during following field visits, done together with a group of villagers who know the village. To clearly define the final pipe layout, try to respect the following advices:

- Minimize the number of difficult passages (crossing of gullies or rockfall/landslide zones),
- Avoid the high points by skirting around them when it is possible (to avoid the air plugs),
- Avoid the rocky area (difficult to dig trenches),
- Prefer the accessible zones (along existing village path),
- Ask information regarding land ownership issues and get all necessary authorization from owners,
- Take into account the possibilities of draining wastewater for choosing the tapstand location (prefer a location with sufficient slope, or near a garden)
- At community level, the layout is often imposed by the constraints related to the land occupation (flooded rice plantations, houses, graveyard, etc).

Once the technical features estimated, and the layout of the pipeline made, it is important to validate it by all the villagers who will be the daily users of the network. This step often involve long discussions, since each families want the tapstand to be located as close from their own house as possible.

VI. TOPOGRAPHIC SURVEY

A topographic survey consists in measuring the ground distances and height differences between the chosen points along the adduction line (i.e., along the pipeline layout). It is possible to use several tools to carry out a topographic survey: the altimeter, the clinometer (Abney level) and the theodolite.

VI.1. Altimeter

The altimeter is a mechanical or electronics device that measures altitude. Its principle of functioning is based on the fact that the atmospheric pressure decreases when altitude increases. Easy to use (you just have to read the altitude indicated on the screen), this device has the disadvantage of not being very accurate (± 5 meters).
For the topographic survey, you have to measure the altitude of the main points of the layout (high and low points, difficult passages, and possible location of the infrastructures...). Ground distances are measured with one measurement tape. An example of survey sheet is presented in table 5.

Table 5: Example of survey sheet when using an altimeter.

Ground distance (m)	Cumulated distance (m)	Altitude (m)	Remarks
-	0	900	Spring
50	50	880	Header tank
120	170	703	River crossing
283	453	564	High hill

VI.2. Clinometer or Abney level

The clinometer is a light device easy to use in the field, and thus perfectly adapted for the topographic surveys to be done in areas presenting difficult access.
The "Abney level" is the most accurate type of clinometer (see picture 8). It consists of a tube (generally of rectangular shape with dimension of 16cm x 1,5cm x 1,5cm) whose tip is equipped with a viewfinding on the side of observer and a horizontal line on the side of the objective. A mirror, located at 45° on the side of the center of the tube on half of the section, reflects, through a hole, spirit-level located above the tube. The spirit level is connected to a graduated semi-circle, fixed on the tube side. The semi-circle is graduated to 180° (from -90° to +90°) as illustrated on figure 9. Above the graduation in degree, there is another graduation indicating percentages (from – 100% to + 100%). An arm moves along the semi-circle, with at its end a graduation indicating the minutes (-60' to +60').

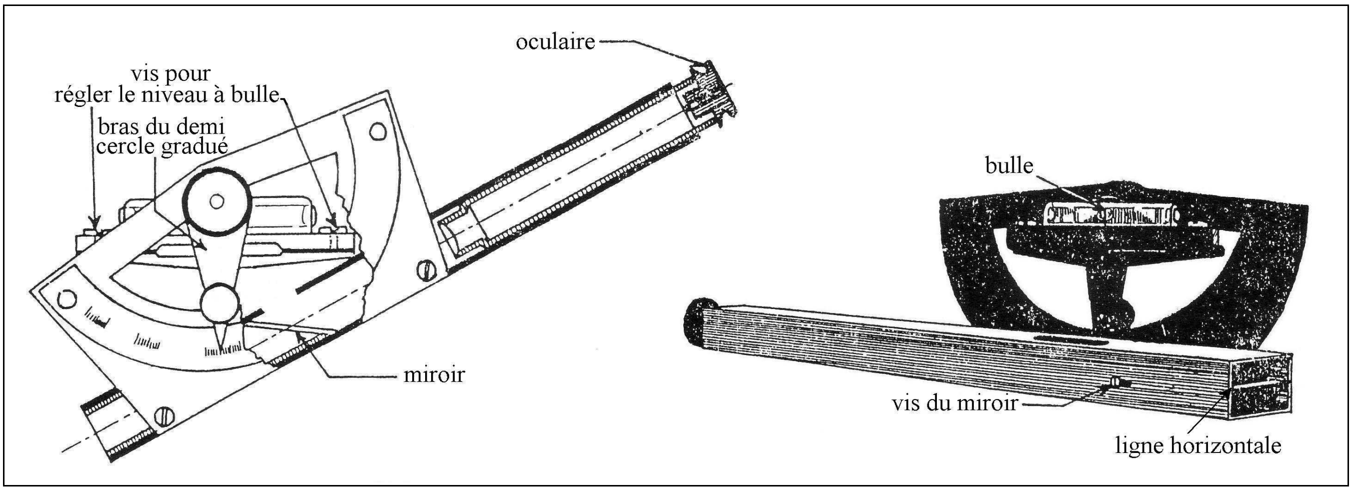


Fig.8: Abney level

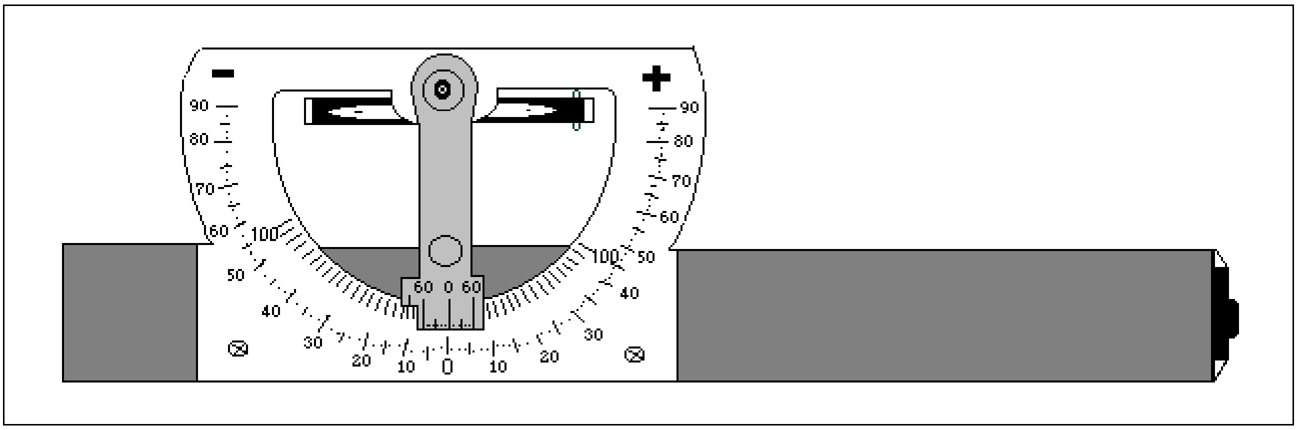


Fig.9: Detail of the semi-circle placed on the Abney level side.

The principle of the Abney level is illustrated in picture 10: it consists in measuring the angle θ formed by the horizontal line and the point we aimed at. If the ground-distance between this aimed point and the measurement apparatus (L) is known, it is easy to calculate the difference of altitude (ΔH).

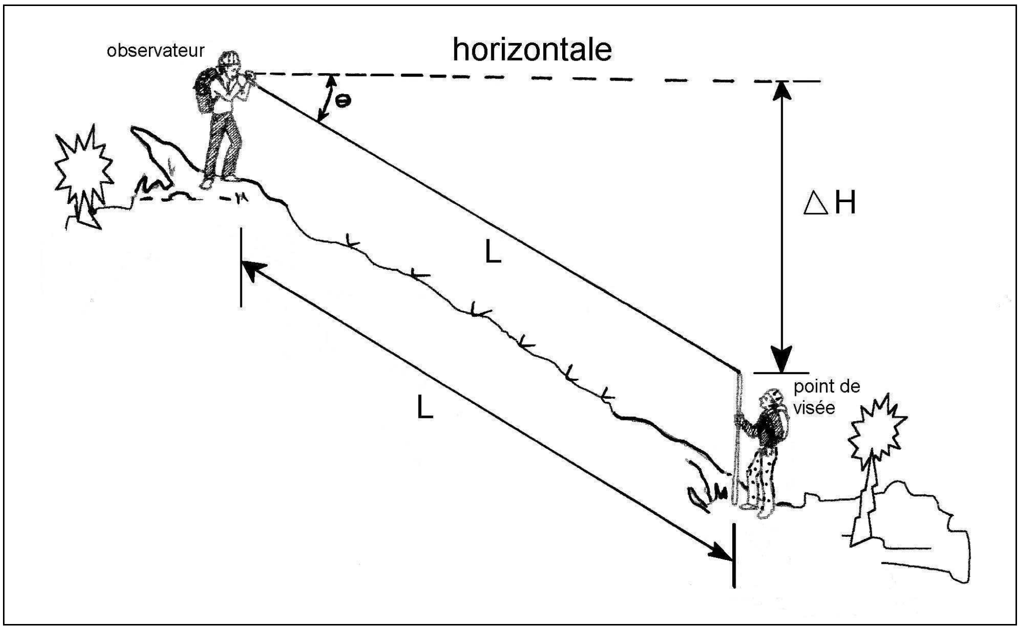
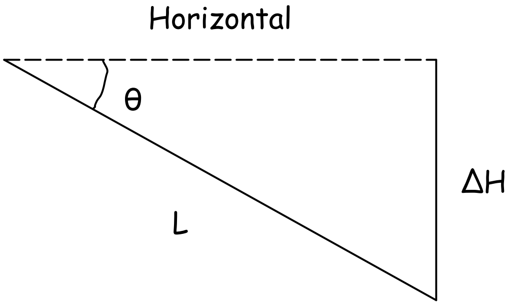


Fig.10: Principle of Abney level.

The difference of altitude (ΔH) is calculated in the following way:



θ = angle in degrees,
L = ground distance measured in meters,
ΔH = difference of altitude in meters.

$$\Delta H = L \times \sin(\theta)$$

The angle measured can be positive (when the observer is lower than the person who holds the stick) or negative (when the observer is higher than the person who holds the stick). It should be known that $\sin(-\theta) = -\sin(\theta)$.

Examples:

1. The ground distance measured is 25 meters and the angle is -16°. What is the difference of altitude?

Solution: $\theta = -16°$ and $L = 25m$

$\Delta H = 25 \times \sin(-16) = 25 \times (-\sin 16) = 25 \times (-0.2756) = -6.9$ m.

2. The ground distance measured is 32 meters and the angle of +24°. What is the difference of altitude?

Solution: $\theta = +24°$ and $L = 32m$

$\Delta H = 32 \times \sin(+24) = 32 \times (+\sin 24) = 32 \times (0.4067) = +13.0$ m.

To realize a topographic survey using an Abney level, it is necessary to have:

- 5 to 10 persons to clear the ground all along the layout (to cut the shrubs and tall grasses),
- 3 persons to carry out the topographic survey: one which measure the angle level and note the results obtained, another to measure the ground distance and hold the stick, and a third to put marks (stakes or painting) along the layout and help the two others,
- One Abney level,
- One measurement tape (to measure the ground distance),
- Machete and axes (to clean the layout ground)

Before each measurement, it is necessary to check the precision of the Abney level. To do it, we need two vertical objects placed at 7 to10 meters one to the other, and a stick. The vertical objects can be posts, trees, houses, or two other sticks. The following step should be followed (see picture 11):

- The observer should stand at the level of the first object (station A) and makes mark (= mark 1) on the object corresponding to the stick height (height to which it was aiming at),
- The observer put the level on the stick, aims at the second object with an angle of 0° and indicates to a second person standing in B where is located the second point to be aimed at. This person marks the aimed point on the second object (= mark 2),
- The observer moves with the second object (station B) and takes a stick of identical height to the one of mark 2; it puts the level on the stick, aims at the first object with a 0° angle and indicates to the second person who moved to A where is located the aimed point. this person marks the aimed point on this object (= mark 3)
- The second person makes a mark (= mark 4) exactly in the middle of the two other marks (marks 1 and 3) on the first object,
- The observer, always positioned in B, aims at the fourth mark with an angle of 0° and observes the bubble in the spirit level: if this one is correctly positioned (see picture 12 on the right-hand side), the topographic survey can be implemented. If not, it is necessary to regulate the spirit-level using the control screws.

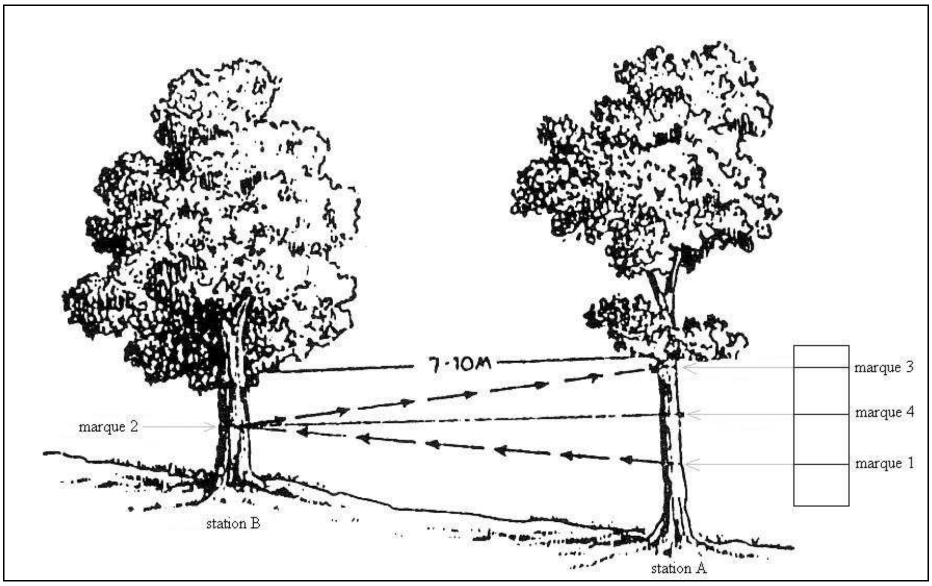


Fig.11: Verification of the Abney level accuracy.

To carry out a topographic survey with an Abney level, the following steps should be followed (see picture 12):

1. To cut two sticks of identical length (corresponding to the height H).
2. The observer position himself (position 1) with the Abney level and a stick.
3. The other person takes the second stick and position himself at a certain distance from the observer while following the planned pipeline layout (position 2). This distance is measured using the measurement tape.
4. The observer puts the Abney level on the stick and aims at the top of the stick located in position 2 (the horizontal line of the viewfinder must be exactly at the tip of the stick). The semi-circle arm of the level is turned until the bubble is located exactly in the center of the viewfinder (picture 12 right hand side). The angle obtained (α) is read on the graduated semi-circle and is noted on a card. If the observer has a problem to aim at the tip of the stick, it is necessary to paint the end of the stick with a visible color.
5. The person who holds the stick moves along the layout to position 3 and the observer moves to position 2. The distance between the two is measured using the measurement tape.
6. The observer aims at the top of the stick located in position 3 and writes down the angle measured on the sheet (β).
7. The person who holds the stick moves to position 4 and the observer with position 3. The steps described previously are repeated: reading of the angle γ then δ and so on.

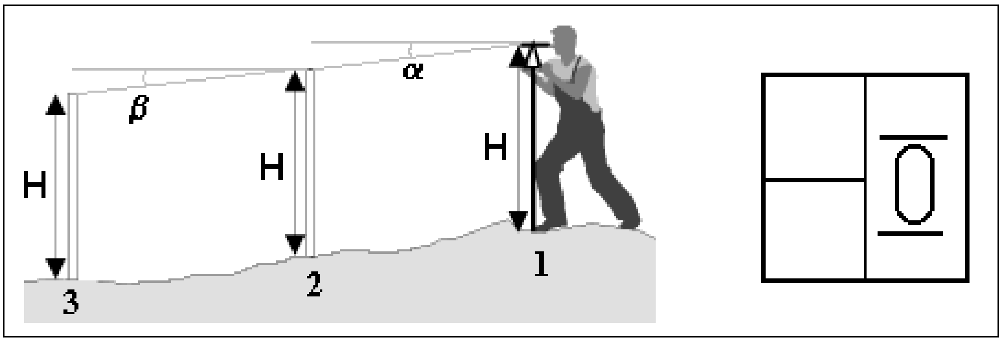


Fig.12: Topographic survey with an Abney level (image of left: measurement on the field, image of the right side: correct position of the bubble inside the viewfinder).

An example of sheet to be filled in the field is given in table 6.

Table 6: Example of measurement sheet with an Abney level.

Measure	Ground distance (m)	Cumulated distance (m)	Angle (° ‘)	Angle (°)	Difference of altitude (m)	Cumulated height (m)	Remarks
1	0	0	0	0	0	500	Spring
2	8	8	-3° 20’	-3,33	-0,46	499,54	Tree
3	25	33	-4° 50’	-4,83	-2,10	497,44	River 5 m
4	18	51	+1° 10’	+1,16	+0,36	497,80	Rock 5 m
5	30	81	+0° 30’	+0,50	+0,26	498,06	Header tank
6	26	107	-2° 40’	-2,66	-1,20	496,86	Tree

The reading of the graduated semi-circle gives us two information:

- The angle θ formed between the horizontal and an point aimed at,
- The ground slope p in % (p = difference of altitude / horizontal distance x 100).

The results obtained with the measurement of the angle θ are more precise than those obtained with the slope measurement p.
The reading of the angle on the graduated face is done in degree (°) and minute ('). Four reading examples are given in picture 13. Knowing that 1° = 60', it is thus necessary to transform the minutes into degree in order to calculate the sine of the angle.

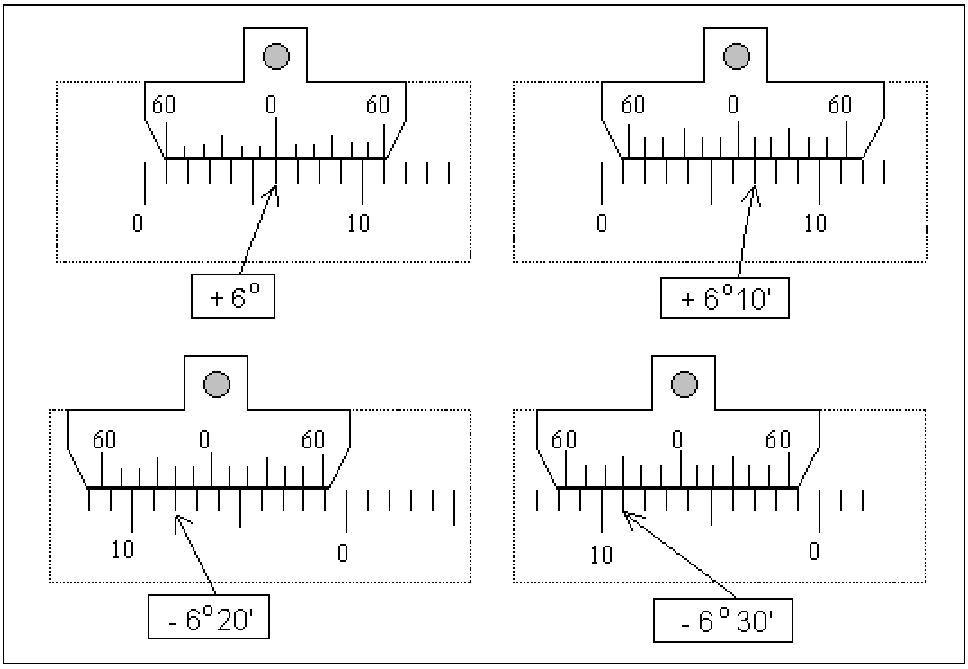


Fig.13: Reading of the graduated angle of an Abney level.

Example:
How much degree forms an angle of 2° 20'?
Solution: 20' = 20 / 60 = 0,33°, so 2° 20' = 2,33°.

Exercise:
The ground distance measured between point A and B is 25 meters and the angle measured of +16°35'. Which is the difference of altitude between the two points?
Solution: θ = +16° 35' = 16 + (35 / 60) = 16 + 0.58 = +16.58°
ΔH = 25 x sin (+16.58) = 25 x 0,285 = 7.13 m.

If a computer is not available to calculate the sine, it is possible for us to use the tables given in appendix 2.

VI.3. Theodolite

The theodolite allows carrying out extremely accurate measurement. This heavy apparatus stands on a tripod and is composed by a sight, fixed on a frame, on which the sight can make a 360° rotation (see picture 14).

To make a topographic survey using a theodolite it is necessary to have:
- 5 to 10 persons to clear the ground along the layout (to cut the shrubs and high plants),
- 3 persons to carry out the topographic survey: one to read the measurement in the sight, and write them down, another one to measure the ground distance and hold the

ruler, and a third person to put marks (stakes or paint marks) along the layout and help the two others,

- A theodolite
- Atape measure (to measure ground distances),
- a 4 to 5 meters high ruler (with graduation every 5 to 10 mm) equipped with a spirit-level,
- Knives and axes (to clean the ground along layout)

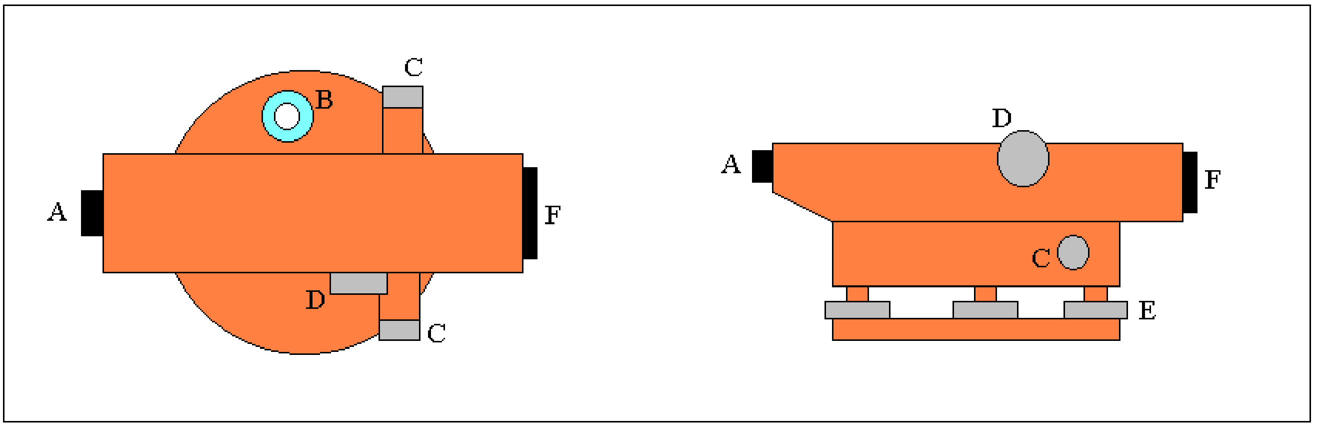


Fig.14: Theodolite. A: sight tube, B: bubble of the spirit level, C: regulating screw to adjust horizontal displacement, D: regulating screw to adjust of the image clearness, E: regulating screws to place the level on a horizontal level, F: objective.

The methodology to be used is as follows (see pictures 14 and 15):

1. Put the level standing on its tripod (N1 position).
2. Using the screws (E) and by observing the bubble of the spirit level (B), put the theodolite on a perfect horizontal level. A minimum of two adjustments are necessary to ensure the horizontality: a first one with the sight placed at an angle of 0°, and a second one with the sight placed at an angle of 90°: While rotating the sight of 360°, the bubble must always remain in the center of the circle.
3. The person who holds the ruler stands at a certain distance from the theodolite, along the planned pipeline layout (location A). Ground distance is measured using the tape measure. The ruler must be held vertically (use the ruler's spirit level).
4. The other person who remains close to the theodolite aims at the ruler with the sight, reads the obtained height measurement (R1) and write it down on a sheet.
5. The person who holds the ruler moves the ruler on the opposite side as compared to the theodolite (in location B).
6. The theodolite operator rotates the theodolite in order to aim at the ruler located in B and read the obtained height measurement (V1).
7. It is then the turn of the theodolite operator to moves (location N2) and starts again to carry out the steps described previously: reading the height measurement R2 then V2 and so on.

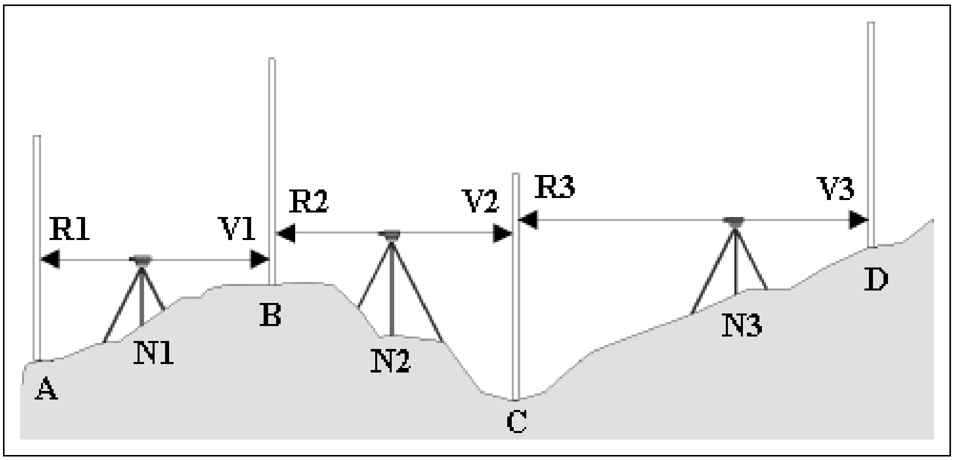


Fig.15: Topographic survey with a theodolite

An example of blank sheet to write down the measurement of the survey is given in table 7.

Table 7: Example of theodolite survey blank sheet

Location	Ground distance (m)	Cumulated ground distance (m)	Back-reading (m)	Front-reading (m)	Height difference (m)	Cumulated height difference (m)	Remark
A		0	R1			0	Spring
B	A B	AB	R2	V1	ΔH1 = R1 – V1	ΔH1	Header tank
C	BC	AB + BC	R3	V2	ΔH2 = R2 – V2	ΔH1 + ΔH2	River
D	CD	AB + BC +CD		V3	ΔH3 = R3 – V3	ΔH2 + ΔH3	Storage tank

VI.4. Which technique to use?

The advantages and disadvantages of the three different topographic survey techniques are given in table 8. The altimeter is not an extremely accurate device that can be used only for a quick topography estimation. Its main objective is to estimate if the difference of altitude between the various network elements is sufficient to allow the water to flow by gravity.
The use of the theodolite is recommended because of its extremely good accuracy. However, in the area presenting a low accessibility, the use of an Abney level is advised because of its lightness.

Table 8: Characteristics of the various topographic survey techniques

Technique	Accuracy on altitude	Advantages	Disadvantages
Altimeter	± 5 meters	- Light, - fast and easy to use.	- Not very accurate.
Clinometer or Abney level	± 0,5 meters	- Light, - accurate enough to carry out a reliable topographic survey.	- Less accurate than the theodolite
Theodolite	± 0,005 meters	- Extremely accurate	- Heavy.

VI.5. Layout of the topographic profile

The topographic measurements are plotted on a graph that allows visualizing the ground topography followed by the pipeline. To do this, once all the measurements were taken with the theodolite, we plot each difference of altitude and corresponding ground measurement on an X and Y graph for which the center is 0. A profile example is given in picture 17.

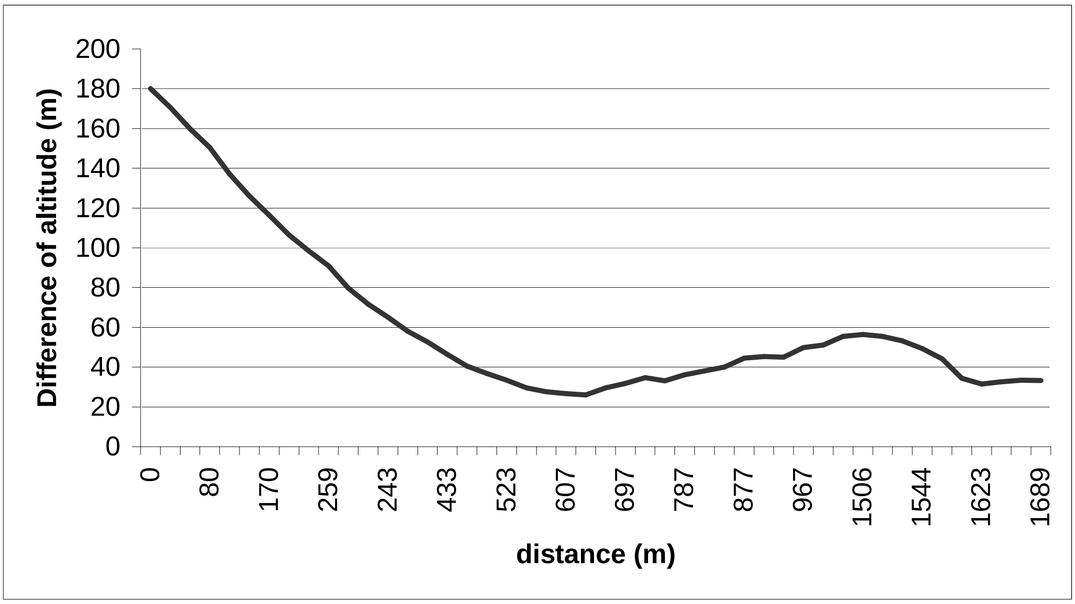


Fig.17: Topographic profile.

It is interesting to match each profile with a top view map allowing visualizing the main network infrastructures and the junctions with the other lines. An example is given in picture 18.

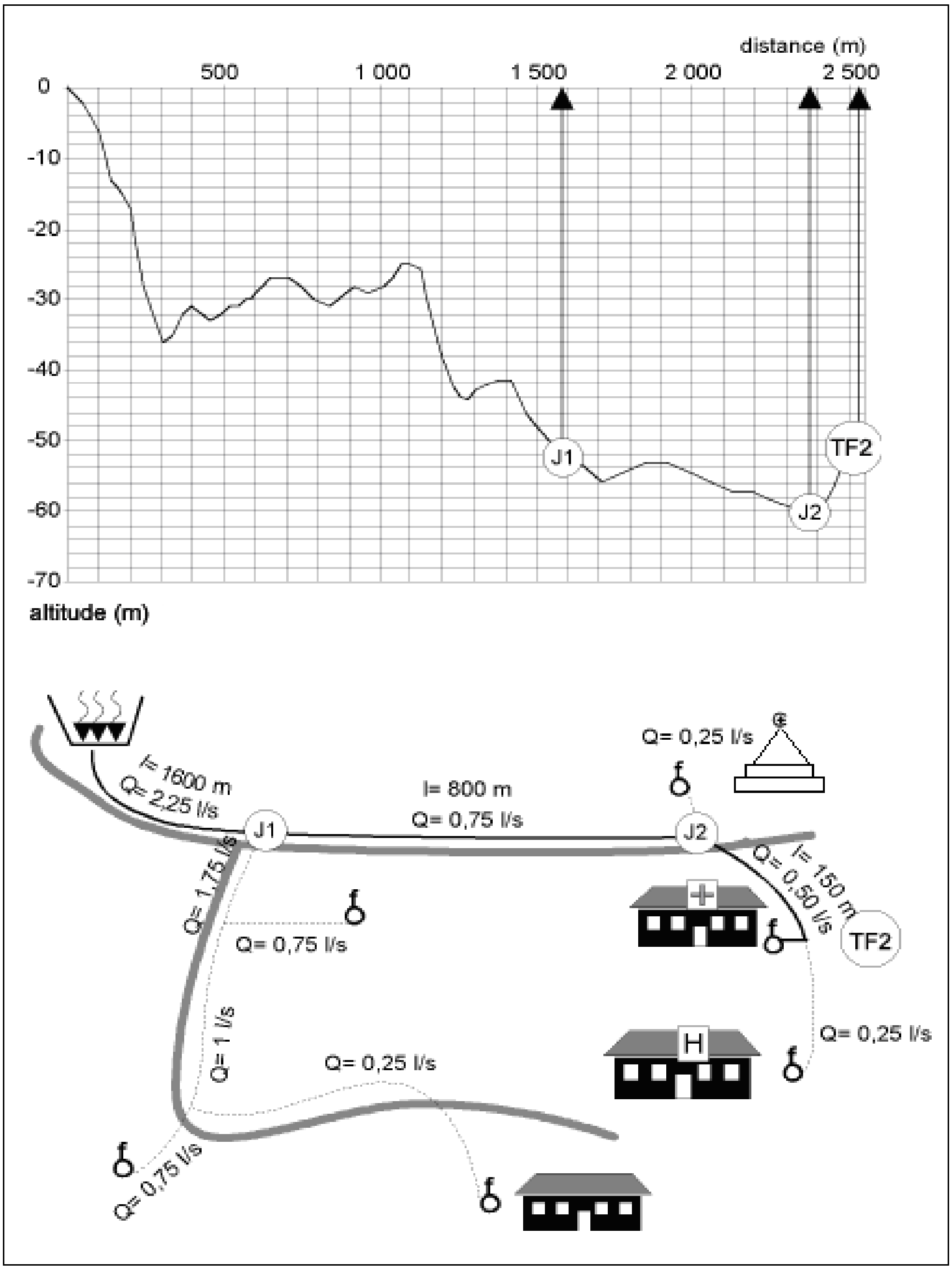


Fig.18: Topographic profile with associated map.

The topographic profile and the information given by the map will allow sizing the Gravity Fed System.

V. APPENDIXES

APPENDIX 1: VILLAGERS QUESTIONNAIRE

Date			
Filled by			
Province		District	
Village Survey date		Reference	

Village authorities	
Name	Position
	Chief of the village
	Chief assistant or secretary
	Village volunteer 1
	Village volunteer 2

Demographic data			
Population		Number of houses	
Number of children < 5 years		Ethnic group	
Number of families		No of families who plan to leave the village	
Number of women		No of families who plan to settle in the village	

Cattle (total number)			
Buffaloes		Pigs	
Cows		Chickens	

General village data	
General impression of the village (poor, clean, wealthy...)	
Priority needs for the village according to the villagers	1. 2. 3.

Assistance already provided or planned for the village (school, road,…)	
Government	
ONG	
Other	

Village accessibility			
	Road (unloading place)	River (unloading place)	Walking time from unloading place
Dry season			
Rainy season			

Health		
Main diseases (malaria, diarrhoea…)	1. 2. 3.	
Number of deaths in the last few years (N-1 / N-2 / N-3)		/ /
Causes of the deaths	Number	%
1.	/ /	/ /
2.	/ /	/ /
3.	/ /	/ /
4.	/ /	/ /
5.	/ /	/ /

Water			
Where do the villagers fetch their water?			
Type (spring, well, river…)	Distance (walking times)	Period of the year (dry season, rainy season)	Remark/description
1.			
2.			
3.			

Are there other water points around the village?			
Type (spring, well, river…)	Distance (walk-times)	Period of the year (dry season, rain season)	Remark/description
A.			
B.			
C.			
D.			
E.			
F.			
G.			

When you work in the fields, where do you take water?	
While hunting / find food in the forest, where do you take water?	

Data on possibility of future infrastructure construction		
Materials available	Place (specify the distance / walking times)	Quality (technician observation)
Sand	1. 2. 3.	1. 2. 3.
Gravel	1. 2. 3.	1. 2. 3.

How many people would be available for the labour?	

In the following page, to make a sketch of the village including springs, rivers and well by specifying the corresponding number or letter (reuse the numbering according to the list given previously by the villagers).

N.B.: the map is very important; the investigator must check with the villagers that no water resource was forgotten in the list made previously by the villagers.

APPENDIX 2: TABLES FOR SINE, COSINE AND TANGEN

Angle	Sin	Cos	Tan	Cot	
0°	0	1	0	1	90°
0° 30’	.0087	.99996	.0087	114.6	89° 30’
1°	.0175	.99985	.0175	57.29	89°
1° 30’	.0262	.99966	.0262	38.19	88° 30’
2°	.0349	.99939	.0349	28.64	88°
2° 30’	.0436	.99905	.0437	22.90	87° 30’
3°	.0523	.99863	.0524	19.08	87°
3° 30’	.0610	.99813	.0612	16.35	86° 30’
4°	.0698	.99756	.0699	14.30	86°
4° 30’	.0785	.99692	.0787	12.71	85° 30’
5°	.0872	.99619	.0875	11.43	85°
5° 30’	.0958	.99540	.0963	10.39	84° 30’
6°	.1045	.99452	.1051	9.514	84°
6° 30’	.1132	.99357	.1139	8.777	83° 30’
7°	.1219	.99255	.1228	8.114	83°
7° 30’	.1305	.99144	.1317	7.596	82° 30’
8°	.1392	.99027	.1405	7.115	82°
8° 30’	.1478	.98902	.1495	6.691	81° 30’
9°	.1564	.98769	.1584	6.314	81°
9° 30’	.1650	.98629	.1673	5.976	80° 30’
10°	.1736	.98481	.1763	5.671	80°
10° 30’	.1822	.98325	.1853	5.396	79° 30’
11°	.1908	.98163	.1944	5.145	79°
11° 30’	.1994	.97992	.2035	4.915	78° 30’
12°	.2079	.97815	.2126	4.705	78°
12° 30’	.2164	.97630	.2217	4.511	77° 30’
13°	.2250	.97437	.2309	4.331	77°
13° 30’	.2334	.97237	.2401	4.165	76° 30’
14°	.2419	.97030	.2493	4.011	76°
14° 30’	.2504	.96815	.2586	3.867	75° 30’
15°	.2588	.96593	.2679	3.732	75°
15° 30’	.2672	.96363	.2773	3.606	74° 30’
16°	.2756	.96126	.2867	3.487	74°
16° 30’	.2840	.95882	.2962	3.376	73° 30’
17°	.2924	.95630	.3057	3.271	73°
17° 30’	.3007	.95372	.3153	3.172	72° 30’
18°	.3090	.95106	.3249	3.078	72°
18° 30’	.3173	.94832	.3346	2.989	71° 30’
19°	.3256	.94552	.3443	2.904	71°
19° 30’	.3338	.94264	.3541	2.824	70° 30’
20°	.2420	.93969	.3640	2.747	70°
20° 30’	.3502	.93667	.3739	2.675	69° 30’
21°	.3584	.93358	.3839	2.605	69°
21° 30’	.3665	.93042	.3939	2.539	68° 30’
22°	.3746	.92718	.4040	2.475	68°
22° 30’	.3827	.92388	.4142	2.414	67° 30’
	Cos	Sin	Cot	Tan	Angle

Angle	Sin	Cos	Tan	Cot	
23°	.3907	.92050	.4245	2.356	67°
23° 30’	.3987	.91706	.4348	2.300	66° 30’
24°	.4067	.91355	.4452	2.246	66°
24° 30’	.4147	.90996	.4557	2.194	65° 30’
25°	.4226	.90631	.4663	2.145	65°
25° 30’	.4305	.90259	.4770	2.097	64° 30’
26°	.4384	.89879	.4877	2.050	64°
26° 30’	.4462	.89493	.4986	2.006	63° 30’
27°	.4540	.89101	.5095	1.963	63°
27° 30’	.4617	.88701	.5206	1.921	62° 30’
28°	.4695	.88295	.5317	1.881	62°
28° 30’	.4772	.87882	.5430	1.842	61° 30’
29°	.4848	.87462	.5543	1.804	61°
29° 30’	.4942	.87063	.5658	1.767	60° 30’
30°	.5000	.86603	.5774	1.732	60°
30° 30’	.5075	.86163	.5890	1.698	59° 30’
31°	.5150	.85717	.6009	1.664	59°
31° 30’	.5225	.85264	.6128	1.632	58° 30’
32°	.5299	.84805	.6249	1.600	58°
32° 30’	.5373	.84339	.6371	1.570	57° 30’
33°	.5446	.83867	.6494	1.540	57°
33° 30’	.5519	.83389	.6619	1.511	56° 30’
34°	.5592	.82904	.6745	1.483	56°
34° 30’	.5664	.82413	.6873	1.455	55° 30’
35°	.5736	.81915	.7002	1.428	55°
35° 30’	.5807	.81412	.7133	1.402	54° 30’
36°	.5878	.80902	.7265	1.376	54°
36° 30’	.5948	.80386	.7400	1.351	53° 30’
37°	.6018	.79864	.7536	1.327	53°
37° 30’	.6088	.79335	.7673	1.303	52° 30’
38°	.6157	.78801	.7813	1.280	52°
38° 30’	.6225	.78261	.7954	1.257	51° 30’
39°	.6293	.77715	.8098	1.235	51°
39° 30’	.6361	.77162	.8243	1.213	50° 30’
40°	.6428	.76604	.8391	1.192	50°
40° 30’	.6494	.76041	.8541	1.171	49° 30’
41°	.6561	.75471	.8693	1.150	49°
41° 30’	.6626	.74896	.8847	1.130	48° 30’
42°	.6691	.74314	.9004	1.111	48°
42° 30’	.6756	.73728	.9163	1.091	47° 30’
43°	.6820	.73135	.9325	1.072	47°
43° 30’	.6884	.72537	.9490	1.054	46° 30’
44°	.6947	.71934	.9657	1.036	46°
44° 30’	.7009	.71325	.9827	1.018	45° 30’
	.7071	.70711	1	1.000	45°
	Sin	Cos	Cot	Tan	Angle

Angle	Sine
0 ð	0
0.ð10	0.0029
0.ð20	0.0058
0.ð30	0.0087
0.ð40	0.0117
0.ð50	0.0146
1 ð	0.0175
1.ð10	0.0204
1.ð20	0.0232
1.ð30	0.0262
1.ð40	0.0291
1.ð50	0.0320
2.ð	0.0349
2.ð10	0.0379
2.ð20	0.0407
2.ð30	0.0436
2.ð40	0.0466
2.ð50	0.0495
3.ð	0.0523
3.ð10	0.0552
3.ð20	0.0581
3.ð30	0.0610
3.ð40	0.0640
3.ð50	0.0669
4.ð	0.0698
4.ð10	0.0727
4.ð20	0.0756
4.ð30	0.0785
4.ð40	0.0814
4.ð50	0.0843
5.ð	0.0871
5.ð10	0.0901
5.ð20	0.0930
5.ð30	0.0958
5.ð40	0.0988
5.ð50	0.1016
6.ð	0.1045
6ð10	0.1074
6ð20	0.1103
6ð30	0.1132
6ð40	0.1161
6ð50	0.1190
7.ð	0.1219
7.ð10	0.1248
7.ð20	0.1277
7.ð30	0.1205
7.ð40	0.1334
7.ð50	0.1363

Angle	Sine
8.ð	0.1392
8.ð10	0.1421
8.ð20	0.1449
8.ð30	0.1478
8.ð40	0.1507
8.ð50	0.1536
9.ð	0.1564
9.ð10	0.1593
9.ð20	0.1622
9.ð30	0.1650
9.ð40	0.1691
9.ð50	0.1708
10.ð	0.1736
10.ð10	0.1765
10.ð20	0.1794
10.ð30	0.1822
10.ð40	0.1851
10.ð50	0.1880
11.ð	0.1908
11.ð10	0.1937
11.ð20	0.1965
11.ð30	0.1994
11.ð40	0.2022
11.ð50	0.2051
12.ð	0.2079
12.ð10	0.2108
12.ð20	0.2136
12.ð30	0.2164
12.ð40	0.2193
12.ð50	0.2221
13.ð	0.2250
13.ð10	0.2278
13.ð20	0.2306
13.ð30	0.2334
13.ð40	0.2363
13.ð50	0.2391
14.ð	0.2419
14.ð10	0.2447
14.ð20	0.2476
14.ð30	0.2504
14.ð40	0.2532
14.ð50	0.2560
15.ð	0.2588
15.ð10	0.2616
15.ð20	0.2644
15.ð30	0.2672
15.ð40	0.2770
15.ð50	0.2728

Angle	Sine
16.ð	0.2756
16.ð10	0.2784
16.ð20	0.2812
16.ð30	0.2840
16.ð40	0.2868
16.ð50	0.2896
17.ð	0.2924
17.ð10	0.2952
17.ð20	0.2979
17.ð30	0..3007
17.ð40	0.3035
17.ð50	0.3062
18.ð	0.3090
18.ð10	0.3118
18.ð20	0.3145
18.ð30	0.3173
18.ð40	0.3201
18.ð50	0.3228
19.ð	0.3256
19.ð10	0.3283
19.ð20	0.3311
19.ð30	0.3338
19.ð40	0.3365
19.ð50	0.3393
20.ð	0.3420
20.ð10	0.3448
20.ð20	0.3475
20.ð30	0.3502
20.ð40	0.3529
20.ð50	0.3557
21.ð	0.3584
21.ð10	0.3611
21.ð20	0.3638
21.ð30	0.3665
21.ð40	0.3692
21.ð50	0.3719
22.ð	0.3746
22.ð10	0.3773
22.ð20	0.3800
22.ð30	0.3827
22.ð40	0.3854
22.ð50	0.3880
23.ð	0.3907
23.ð10	0.3934
23.ð20	0.3961
23.ð30	0.3987
23.ð40	0.4014
23.ð50	0.4041

Angle	Sine
24.ð	0.4067
24.ð10	0.4094
24.ð20	0.4120
24.ð30	0.4147
24.ð40	0.4173
24.ð50	0.4200
25.ð	0.4226
25.ð10	0.4253
25.ð20	0.4278
25.ð30	0.4305
25.ð40	0.4331
25.ð50	0.4357
26.ð	0.4384
26.ð10	0.4410
26.ð20	0.4436
26.ð30	0.4462
26.ð40	0.4488
26.ð50	0.4514
27.ð	0.4540
27.ð10	0.4566
27.ð20	0.4592
27.ð30	0.519
27.ð40	0.4643
27.ð50	0.4690
28.ð	0.4695
28.ð10	0.4720
28.ð20	0.4746
28.ð30	0.4772
28.ð40	0.4800
28.ð50	0.4823
29.ð	0.4848
29.ð10	0.4874
29.ð20	0.4899
29.ð30	0.4924
29.ð40	0.4950
29.ð50	0.4975
30.ð	0.5000
30.ð10	0.5025
30.ð20	0.5050
30.ð30	0.5075
30.ð40	0.5100
30.ð50	0.5125
31.ð	0.5150
31.ð10	0.5175
31.ð20	0.5200
31..ð30	0.5225
31.ð40	0.5250
31.ð50	0.5275