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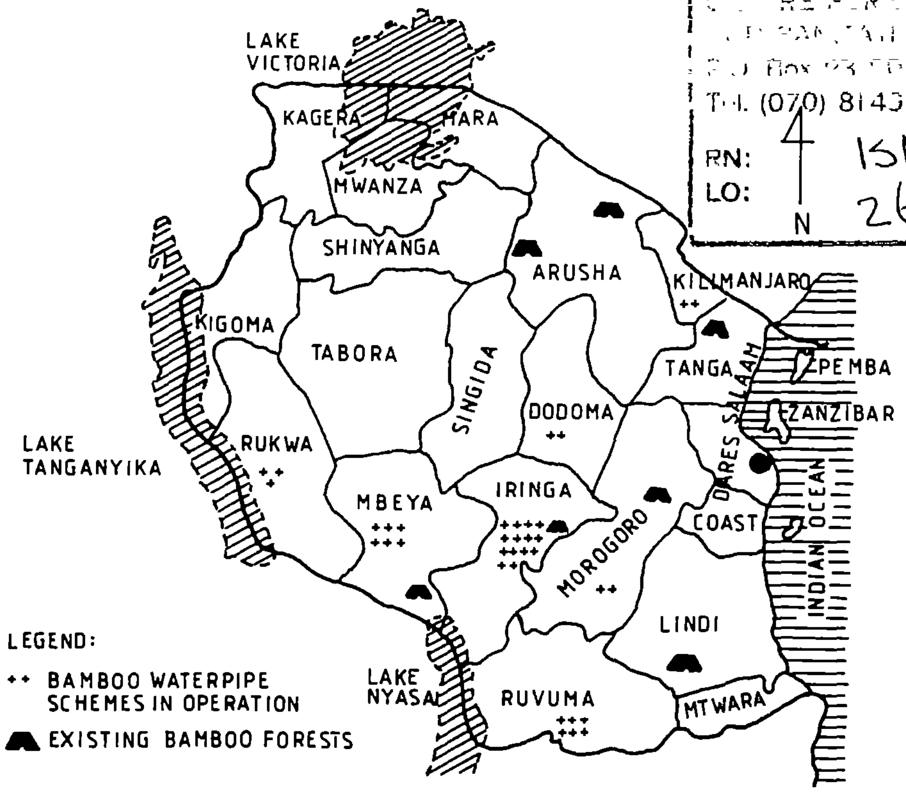
Bamboo as an Alternative Pipe Material for Rural Water Supply in Tanzania



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BAMBOO AS AN ALTERNATIVE PIPE MATERIAL FOR RURAL WATER SUPPLY IN TANZANIA

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ABSTRACT

Bamboo pipes have been traditionally used as water conduits in many parts of the world. They are cheap to use, maintain and easy to construct especially where the material is locally available. In Tanzania, bamboo pipes have been used since early 1970's. Over 300 km of bamboo pipelines supply water for more than 150 000 Tanzanians.

The principal objective of this study was to observe the appropriateness of using bamboo pipes as water supply conduits with respect to specific engineering behaviour as compared to conventional pipes. Present construction methodology, operation and maintenance procedures for operating schemes and the cost aspect of the technology were investigated.

The study was based on an intensive literature review and laboratory investigations on the hydraulic properties of bamboo pipes. The roughness coefficients of the Manning (n) and Hazen-Williams (C) equations have been determined and the pressure withstanding ability of the pipes investigated.

Average values of the roughness coefficients n and C were observed to vary 0.016 - 0.013 and 80 - 95 respectively. Factors like internode removal, non-uniformity or irregularity of the pipe diameter and the roughness of the inside of the bamboo culm wall were observed to affect the roughness coefficients. Also most of the values of the friction factor ( ) plotted against the Reynolds number (Re) on the Moody diagram were in the rough turbulent zone. This justified the use of exponential formulae where the friction factor is a function of relative roughness.

The observed maximum water pressures of bamboo pipes were 350 - 800 kPa. It was observed that bamboo pipes can withstand high instantaneous pressures under laboratory conditions opposite to their low ability under field conditions. Factors influencing this pressure performance could not be depicted clearly and poor correlation was observed under nodal distances and the culm wall thickness.

1 INTRODUCTION

Lack of conventional pipe materials, unstable economic situation in the country and other problems like poor infrastructure, are the major hindrances in the implementation of rural water supply in Tanzania. Conventional pipes need huge amounts of foreign currency even if the pipes are manufactured locally. Under these circumstances bamboo pipes are realized as an alternative solution.

In early 1970's Tanzania started investigations on the use of locally available materials, wood and bamboo, as water conduits. Investigations were a pioneer work, but they did not add much peoples interest; indeed, the only motivating force was that people needed water and due to their limited resources, alternative means at lower costs had to be found.

For centuries the bamboo played an important role in the daily life of people in many tropical countries. Recently a growing interest in the peculiar plants, the bamboos, with their rapid rate of growth and multipurpose use has been generated. This 'poor man's timber' or sometimes referred to as 'miracle grass' can simultaneously be used in agriculture, construction, energy source, paper industry, piping, furniture, handicrafts, etc. Its socio-economic importance for the rural population and the use of modern technologies to manufacture these products is realized.

Lipangile (1984) confirmed that the use of bamboo pipes in the small communities of the rural areas is quite feasible, cheap and easy to implement. The outstanding advantage of bamboo pipes over the conventional ones is that bamboos are abundant in rural areas. They are easy to harvest, transport and store, and a bamboo piping system is cheap to construct and maintain. The construction process though labour intensive is best carried out at the village level with the exception of the design work.

Bamboo pipes are limited to high pressures which makes them inferior to conventional pipes. They need careful maintenance and sophisticated chemical treatment to prevent them against termite and fungal attack.

Unfortunately, although bamboo pipes have been used traditionally as water pipes in many parts of the world, scientific information regarding their behaviour as engineering material is very insufficient. Bamboo pipes in conveying water raise the following questions on design, construction, operation and maintenance of the schemes:

- What are the factors affecting the hydraulic properties of bamboo pipes?
- What is the influence of different parameters on the pressure performance of bamboo pipes?
- What are the present design and construction techniques, as well as operation and maintenance procedures?
- How are the operating schemes performing?
- What are the cost differences between bamboo and conventional pipes?
- What are the general advantages and disadvantages of using bamboo?

In this study the effect of various parameters on the hydraulic properties of the bamboo pipes as well as their pressure withstanding ability were investigated under laboratory conditions. An attempt was made to establish parameters that influence pressure performance of bamboo pipes. In general, the friction factors, roughness coefficients and bursting pressure of bamboo pipes were investigated. Also the performance of existing schemes and the comparative costs of bamboo and polythene pipes were investigated.

2 BAMBOO AS AN ALTERNATIVE PIPE MATERIAL

2.1 Species of bamboo

Bamboo is the tallest and thinnest type of monocotyledon belonging to the family of the Gramine grasses. It is a perennial plant which grows in different parts of tropical and sub-tropical regions in the world. The largest abundance is recorded in South-East Asia. Sharma (1980) reported that there are 75 genera and 1 250 species of bamboos which are widely distributed ranging from the coastal belt up to an altitude of 3 700 m depending on the specie.

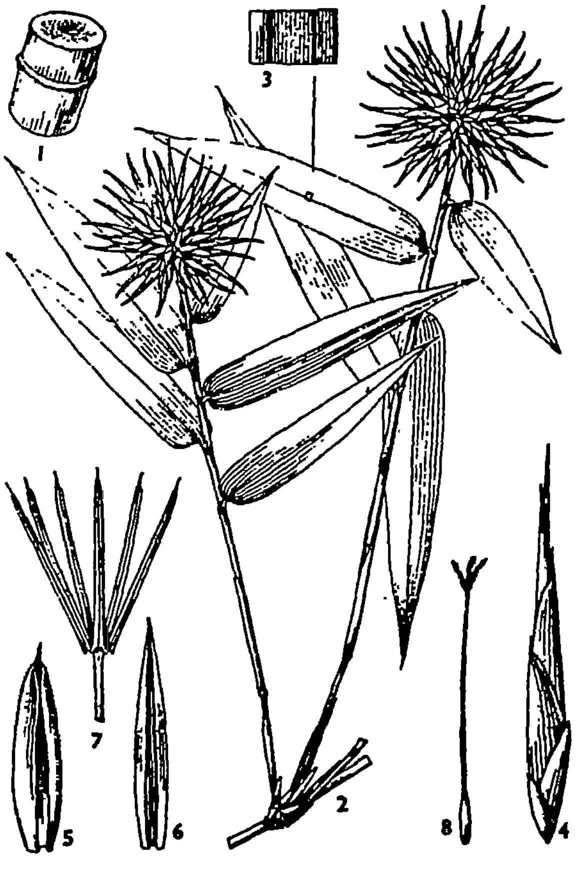
2.1.1 Tanzanian species

There are two main species of bamboo in Tanzania (Johan 1979): Arundinaria Alpina (A. Alpina) and Bambusa Vulgaris (B. Vulgaris). A. Alpina, also called the Green African Mountain Bamboo, is an indigenous species which grows between altitudes 2 500 - 3 400 m. Unlike most other species it does not grow in clumps, but appears in forests. One hectare can contain more than 5 000 stems and where conditions are favourable it will take 3 - 4 years for a bamboo to grow to full maturity. The lowest part of the stem is straight up to about 7 m with internal diameter of 60 - 70 mm. At its full maturity, this species reaches a height of 18 m with an internal diameter of 50 - 85 mm. The distance between nodes is about 700 mm. Figure 1 shows A. Alpina from Rungwe Mountains in Mbeya district, Southern Tanzania.

Figure 1. A. Alpina bamboo species from Rungwe Mountain, Mbeya, Tanzania (van der Heuvel 1983).

Comparatively, B. Vulgaris, a green stripped, yellow coloured bamboo has the ability to withstand high pressures. Whereas the green bamboo has shorter distances between nodes of 250 - 300 mm with larger diameters up to 150 mm, A. Alpina has nodal distances of about 700 mm and its density in the forest is about 10 000 - 1 500 stems/hectare.

Tanzania forest officials estimated the total coverage of bamboo forests in Kigoma and Kibondo districts and in Lindi Region to be 700 km^2. According to Clayton (1970, cited by van der Heuvel 1983), the flora of tropical East Africa known as Oxytenanthera Abyssinica is a species growing in dense clumps with 3 - 10 m high culms. Similar to this species is Oxytenanthera Macrothyrsus found in Dar es Salaam and Kisarawe along the coast. Other species include Oxytenanthera Braunii found in Iringa Region and Oreobambos Buchwaldii found in East Usambara mountains and Rungwe district. Figures 2 and 3 show some of these species.



Legend:
1. piece of culm taken 6 m above ground level
2. leafy branchlets with inflorescences
3. part of under-side of leaf blades showing tessellate venation
4. spikelet
5. lemma
6. pales
7. androcium
8. gynoecium

Figure 2. Oxytenanthera Abyssinica (Clayton 1970, cited by van der Heuvel 1983).

Legend:
1. **leaf branchlet**
2. **leaves**
3. **part of dorsal surface of blade showing tessellate venation**

4a. flowering branchlet
4b. flowering branchlet

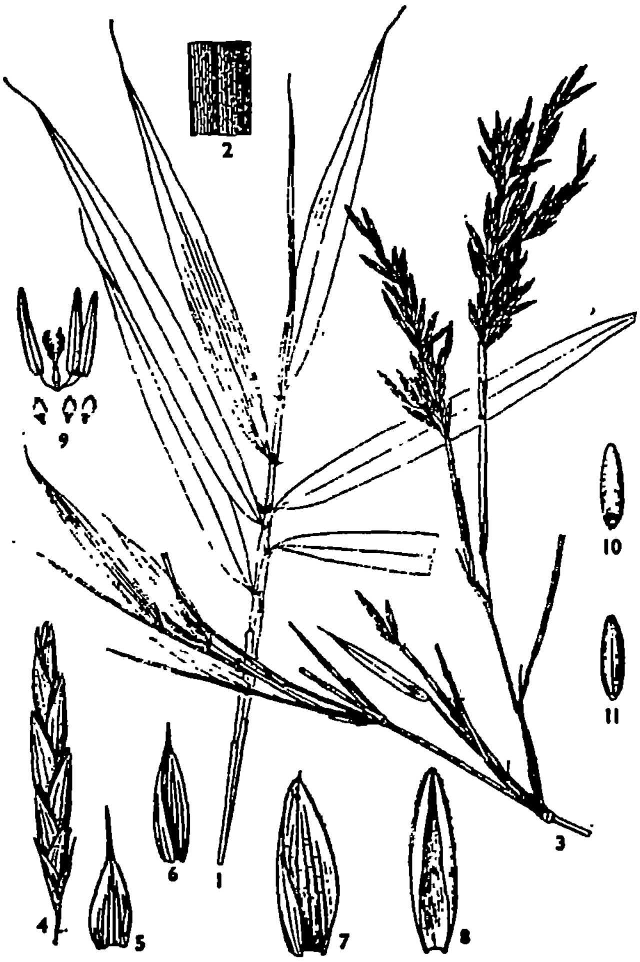
5. **spikelet cluster**
6. **bract**
7. **spikelet cluster**

Figure 3. Oreobambos Buchwaldii (Clayton 1970, cited by van der Heuvel 1983, modified by the author).

2.1.2 Growth process of bamboo

Bamboo planting is propagated by the seed or offshoots and in some cases by cutting or layers. Due to scarcity of seeds, the vegetative method is usually preferred though it has the disadvantage of resulting into clumps which flower along with the parent clump rendering to short life span of the offsprings. Research is to be done on bamboo propagation including studies on possible hormonal treatment (Gaur 1985).

Bamboo culms attain their maximum size in about a year. At this time, however, they lack strength. Full maturity is attained after three years. Mature bamboo culms are tall and thick with 15 - 30 m height, 200 - 250 mm external diameter and thickness of up to 30 mm. New culms shoot up like rhizomes from the periphery of the clump. Figure 4 shows typical shoot-outs of the A. Alpina species.



Legend:
1. leafy shoot
2. part of the underside of leaf-blade showing tessellate venation
3. flowering shoot
4. spikelet
5. lower glume
6. upper glume
7. lemma
8. palea
9. flower with lodicules dissected free
10. caryopsis, dorsal view
11. caryopsis, ventral view

Figure 4. A. Alpina (Clayton 1970, cited by van der Heuvel 1983).

The phenomenon of bamboo flowering still puzzles bamboo scientists. It is infrequent and gregarious in most of bamboo species. In some cases, all bamboo culms of the same species flower at the same time irrespective of the age or location. Records show that bamboos flower at the age of 30 - 60 years and such flowerings are followed by the culm death which can happen on large scale.

2.2 Physical and chemical characteristics of bamboos

Bamboos vary a lot in their natural appearance from small thin species to species with 300 mm thick stems which can reach a height of 30 m. All are however characterized by hollow stems having solid nodes (with partition walls) at intermediate distances. Culms with shorter intervals between nodes are strong and durable (Jacobs and Lindburg 1978).

2.2.1 Bamboo culm structure

Many researchers have studied the structure of the bamboo culm. Liese (1986) has observed that between internodes, cells are axially oriented and in the nodes they are traversely interconnected with branching vessels. The inter-branching at the nodes eventually solidifies into a partition wall. The high tensile strength of the bamboo culm is thus attributed to the different orientations of the underlying fibral layers.

The main chemical constituents of the culm are cellulose, peritosans and lignin whose distribution in the plant varies between different species. Cellulose is the major constituent. Other compounds occurring are small quantities of resins, salts, tannins and wax.

As the culm grows, the proportions of these constituents vary, and on reaching full maturity the lignification process ceases. Studies (Chen Youde 1985, cited by Lipangile 1990) have shown that with increase in culm age, contents of cellulose decrease.

2.2.2 Physical dimensions

Experiments to determine variations in bore size along the bamboo stem revealed that the portion of the bamboo starting from 1 m to 5 m was of uniform bore size and thickness (Msimbe 1984). Table 1 shows the variation of the average bore size and the difference in diameter at the pipe ends.

Table 1. Variations in average bore size and diameter of A, Alpina species (Msimbe 1984).

Average bore size	mm	38	50	63	75
Difference in diameter	mm	3	1	1	0

Most of the physical dimensions vary with species and from stem to stem of the same species. It is rare to find bamboo species with similar dimensions and in fact small or bigger variations are predominant. Table 2 shows typical variations of the physical dimensions of the A. Alpina species as observed in this study.

Table 2. Physical dimensions of various bamboo pipes for the A. Alpina.

Internal diameter mm	External diameter mm	Wall thickness mm	Uniform length m
60	75	15	3.97
58	75	17	3.96
52	76	24	3.72
61	77	16	3.85
62	77	15	4.00
54	74	20	3.83
65	81	16	4.20
56	74	18	3.83
58	76	18	3.85
56	75	19	3.98
59	76	17	3.96
63	79	16	3.98
59	79	20	4.04
54	71	17	4.00

2.2.3 Strength characteristics

Each species of bamboo has its own strength characteristics (United Nations 1972). For the use of bamboo as a water pipe it is a disadvantage that the shearing strength of the bamboo culm is low compared to that of wood. This is because the fibres of wood form rays while those of bamboo are merely glued together by pectin.

Iringili and Mahungu (1979) experimented pressures which bamboo can withstand and revealed that the material is capable of standing very high instantaneous pressures. For the green bamboo values up to 600 kPa were observed and for the yellow bamboo up to 1 000 kPa. However, the pressure withstanding capability differs very much from stem to stem and maximum values drop considerably when the stem is exposed to high pressures for long times. No parameters could be established which correlated or predicted the pressure withstanding capability. It was also concluded that working pressure for green bamboo should not exceed 150 kPa and for yellow bamboo 200 - 300 kPa.

According to Lipangile and Landman (1976), when bamboo pipes are reinforced by putting wire around it, there is a significant impact on the pressure withstanding ability in case of the green bamboo, whereas it was less clear for the yellow bamboo. This is probably because the surface of yellow bamboo is harder and smoother than that of green bamboo. Tightening of wires around the yellow bamboo by hand devices were more difficult resulting in a less effective contact between the wire and the surface. When green bamboo pipes are reinforced, their pressure ability increases with decreased reinforcement spacing. Table 3 shows some of the strength properties of bamboos.

Table 3. Strength properties of bamboos (Bajaj et al 1970, cited by Lipangile 1990).

Strength properties	Unit	Value
Specific gravity	kg/m^3	575 - 655
Average weight	kg/m	0.625
Static bending		
- fibre stress at elastic limit	kg/cm^2	390 - 100
- modulus of rapture	kg/cm^2	610 - 1 600
- modulus of elasticity	kg/cm^2	1.5 - 2x10^5
Ultimate crushing stress	kg/cm^2	520 - 720
Average tensile stress at yield point	kg/cm^2	1 400 - 2 800
Ultimate compressive stress	kg/cm^2	794 - 864
Safe working stress in tension	kg/cm^2	160 - 350
Safe working stress in compression	kg/cm^2	105
Safe working stress in shear	kg/cm^2	115 - 180

2.3 Hydraulic properties of bamboo pipes

The use of bamboo as piping material has some limitations: the friction factor and the water hammer bearing capacity of the pipe. Whereas the former factor has a large bearing on the pressure losses, the latter signifies the extent to which the pipe can bear pressure without bursting upon valve closure (Jacobs and Lindburg 1978).

According to Suhan (1979) the discharge-pressure measurements showed bigger variations of the friction factor (λ) as determined by Darcy-Weisbach equation with Reynolds number (Re). Most of the results depicted the rough turbulence conditions as was indicated on the Moody diagram.

Suhan (1979) also concluded in his experiment that values of Manning roughness coefficient (n) and Hazen-Williams (C) coefficient varied 0.013 - 0.016 and 75 - 90 respectively. The lower n-values indicate good node removal and higher ones poor node removal from the inside of bamboo pipes. Suhan (1979) further concluded that if the quality of the node removal is not known, it is advisable to use the values given for poorly removed nodes. Jacobs and Lindburg (1978) defined good removal of nodes as leaving a difference (s) of 1 mm between radii at node contraction and away from it.

3 EXPERIMENTAL INVESTIGATIONS ON HYDRAULIC PROPERTIES OF BAMBOO PIPES

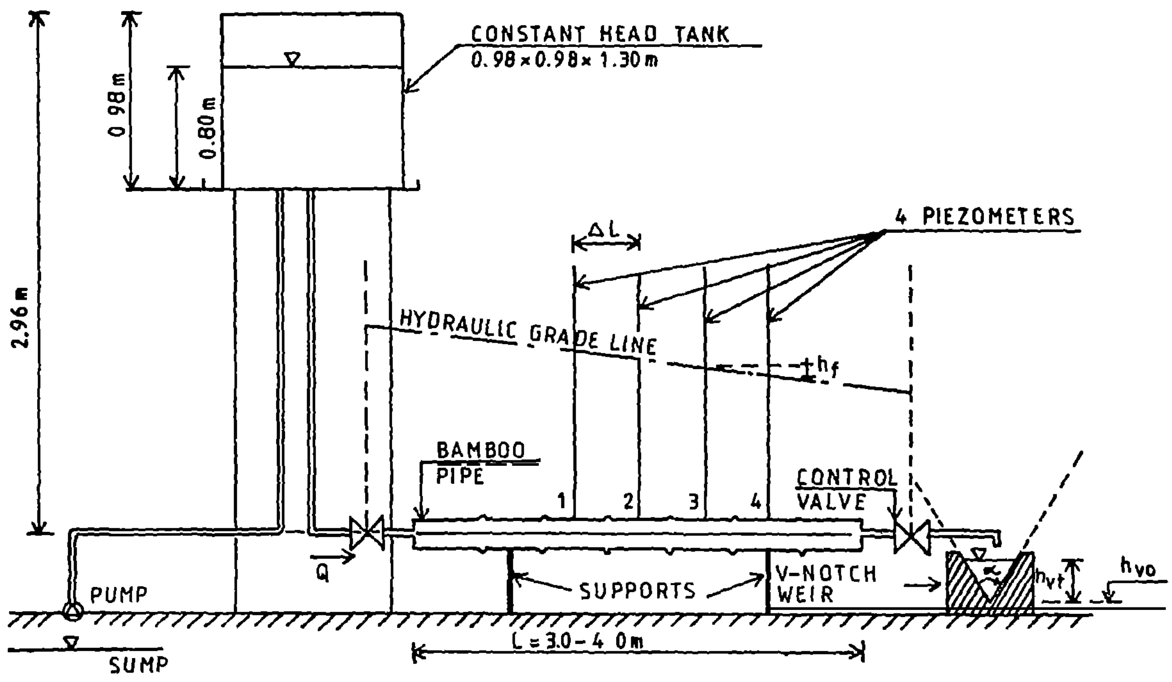
3.1 Pipe friction investigations

3.1.1 Methodology

The experiments on the friction factors and roughness coefficients were performed at the Hydraulics Laboratory at the University of Dar es Salaam during November - December 1989. Samples of bamboo pipes were obtained from Iringa and supplied by the Wood/Bamboo Department of the Ministry of Water.

Test equipment

The tested sections (3.7 - 4.2 m long bamboo pipes) were connected individually through PVC couplings to a constant head tank. Each pipe was laid horizontally with gate valves at both ends enabling to achieve a wide range of pressure and discharge. Figure 5 shows the experimental set-up.



Legend:
Q = volumetric flow rate in the pipe
L = interval between two piezometers
h_{vo} = reading of V-notch weir for $Q = Q$
h_{vt} = reading of V-notch weir for $Q = Qt$
α = V-notch apex angle = 60°
h_f = friction loss

Figure 5. Pipe friction experimental set-up.

The apparatus was designed to enable the measurements of the discharge and the pressure at various points along the pipe. Principally, the set-up is used to determine experimentally the friction coefficients of the tested pipes. These coefficients are the function of the following parameters: the diameter (D) (measured directly), the discharge (in/or directly measured at V-notch), water viscosity (function of temperature) and slope of the hydraulic grade line. The latter was obtained through pressure measurements of four equidistant piezometers.

Pipes

Fourteen pipes of diameters 51 - 65 mm and wall thickness of 15 - 24 mm were tested. Five pipes (pipes number 1, 3, 4, 5 and 6) were unlined, while nine were lined inside with tar.

Discharge

The discharge (Q) was 1.2 - 3.1 l/s.

Velocity

The velocities (v) reached during the tests were 0.42 - 1.10 m/s.

Gradients

The friction gradients (I) were 0.001 - 0.150.

3.1.2 Measures

Pipe diameter

Prior to mounting the pipe, its internal and external diameters were measured by series of caliper-square measurements.

Pressure

The pressure along the pipe was measured with four piezometers installed in the middle of the pipe, with a distance of 0.60 m between each other.

Discharge

The discharge was measured using a V-notch weir. The notch used had an apex angle of $\alpha = 60^o$ and a coefficient of discharge Cd = 0.565.

A rating curve was established so that the discharge could be measured directly. Figure 6 shows the rating curve for a 60^o V-notch weir. From the rating curve it is easy to set a certain depth (H) for a particular discharge (Q).

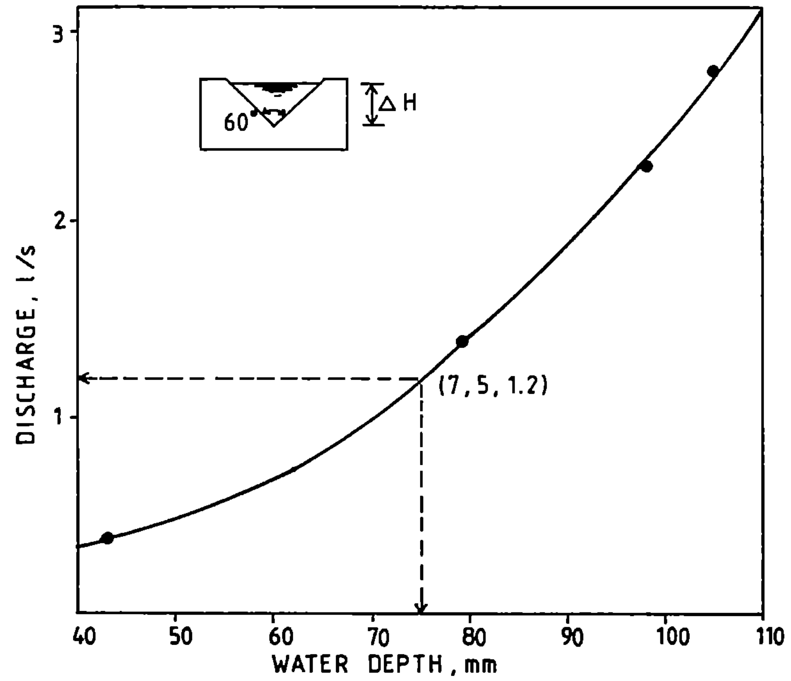


Figure 6. Rating curve for a 60^o V-notch weir.

3.1.3 Experiment procedure

The experiment involved starting the pump while all valves were open. A stable hydraulic grade line was established by suitable adjustment of the gate valves. Steady conditions had to be established especially at V-notch. Measurements for the piezometer heights (h1, h2, h3, h4) and the water depth at V-notch (hv) had to be taken and the results entered on a data sheet.

Then, proceeded again several times with other stable hydraulic grade lines (by changing the valve settings). After several readings, the pipe was disconnected, and measurements for inside and outside diameter, length and water temperature were recorded. Lastly, the average values of Manning roughness coefficient (n) and Hazen-Williams (C) were calculated and the values of Reynolds number (Re) were plotted on a Moody diagram against the friction factor (λ).

3.2 Pressure test methodology

Pressure tests of bamboo pipes were carried out at Mgama Research plot situated 30 km from Iringa Town. The plot was developed earlier for the purpose of conducting research activities related to wood and bamboo technology. The tests were carried out during the first week of January, 1990.

Pipes

Under this experiment 12 reinforced pipes with diameters 53 - 67 mm were tested. Four pipes were green (A. Alpina) and eight yellow (B. Vulgaris).

Research equipment

The tested bamboo section was laid horizontally and connected directly to the pump. With the assumption that high pressure values will be obtained, high head pump with a head (H) of 100 m was used. Pressure readings were recorded with bourdon gauges of capacities 1 500 - 1 600 kPa. Figure 7 shows the set-up of the experiment.

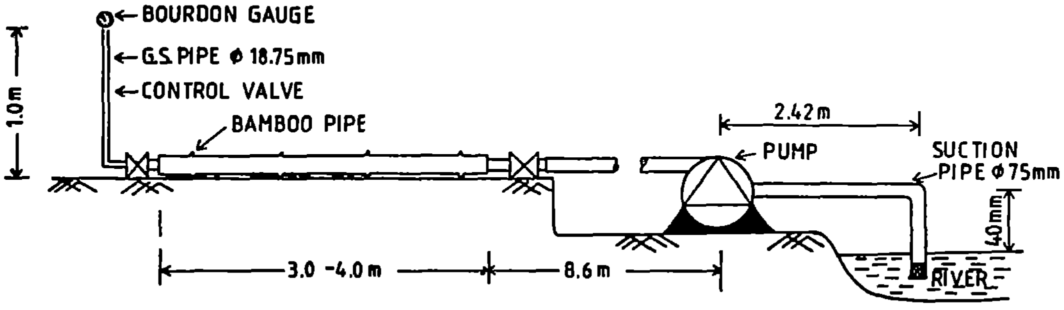


Figure 7. Pressure test experimental set-up.

Experiment procedure

The pump was started with all valves open. Then, the outlet valve was closed slowly while carefully observing the pressure gauge. The valve was continuously closed until the pipe bursted and the reading on the gauge was taken recording the bursting pressure of the pipe. All physical dimensions, like diameters of the pipe, length and internodal distances were recorded. The procedure was similar for all pipes.

3.3 Pipe friction results and discussion

3.3.1 Theoretical considerations

Pipe friction results in losses of pressure head, as evidenced by the gradient of the hydraulic grade line. Several equations have been developed to describe pipe friction. They all involve the use of friction factors or roughness coefficients, which are the characteristics of the pipe material and diameter (Hosia 1988). For the purpose of data processing, the following equations were used:

a) Darcy-Weisbach equation

According to Darcy-Weisbach equation, the head loss between two points of a pipe separated by a distance is given by

$$hf = \lambda \times \frac{L}{D} \times \frac{v^2}{2g} \tag{1}$$

where
hf = head loss between two points (m)
λ = friction factor
L = distance between two points (m)
D = pipe diameter (m)
v = water velocity (m/s)
g = 9.81 m/s^2

The friction factor (λ) depends on the velocity (v), the pipe diameter (D), the viscosity of the liquid (i.e. on the Reynolds number Re = vD/ν) and characteristics of wall roughness. Since λ is not a constant other formulae are preferred in engineering practice (Hosia 1988).

b) Manning formula

Among the various formulae to correlate the mean velocity (v) with the slope of the energy grade line (I) and with the mean hydraulic radius (R), the one which have been most frequently used for the flows both in open channels and in closed conduits is the Manning equation:

$$v = \frac{1}{n} \times I^{1/2} \times R^{2/3} \tag{2}$$

where
v = mean velocity (m/s)
n = roughness coefficient (s/m$^{1/3}$)
I = hydraulic gradient
R = D/4, the hydraulic radius (m)

Manning roughness coefficient can be related to the friction factor :

$$n = \sqrt{\frac{\lambda}{8g}} \times R^{1/6} \tag{3}$$

The application of the Manning formula is recommended for flows in rough turbulent zone of the Moody diagram, i.e. when the friction is independent from the Reynold number.

c) Hazen-Williams formula

Another widely used experimental formula is the Hazen-Williams formula, recommended for the flow in the transition zone:

$$v = 0.354\ C\ D^{0.63}\ I^{0.54} \tag{4}$$

where v = mean velocity (m/s)
C = roughness coefficient
D = pipe diameter (m)
I = hydraulic gradient

3.3.2 Results of experiments

The friction factor (λ), Manning and Hazen-Williams roughness coefficients (n) and (C) respectively, and the Reynolds number (Re) have been determined for a series of 148 tests performed on 14 different pipes. Table 4 is a summary of the test results. Detailed results are shown in Appendix 1.

Table 4. Summary of results of pipe friction experiments.

Pipe no.	No. of values observed	Manning's					Hazen-William's				
		nmax	nmin	nmax-nmin	$\bar{n}$	Sn	cmax	cmin	cmax-cmin	c	Sc
1*)	36	0.0214	0.0123	0.0091	0.0169*)	0.0020	98	55	43	69	10.9
2	10	0.0141	0.0088	0.0053	0.012	0.0010	137	79	58	103	14.4
3*)	20	0.0197	0.0101	0.0096	0.015*)	0.0030	116	55	61	81	23.0
4*)	32	0.0178	0.0113	0.0070	0.015*)	0.0020	108	64	44	79	12.2
5*)	29	0.0432	0.0127	(0.0305)	(0.0265)*)	0.0008	98	29	69	(49)	17.4
6*)	12	0.0298	0.0102	(0.0196)	0.0170*)	0.0007	115	36	79	76	25.2
7	22	0.0176	0.0123	0.0053	0.0151	0.0002	97	65	32	92	12.3
8	15	0.0152	0.0113	0.0039	0.0122	0.0001	100	90	10	94	5.7
9	26	0.0204	0.0106	0.0098	0.0126	0.0002	110	57	53	98	10.4
10	36	0.0299	0.0138	(0.0161)	(0.0223)	0.0005	87	36	51	(53)	13.2
11	16	0.0129	0.0118	0.0011	0.0123	0.0004	102	89	13	94	3.2
12	27	0.0196	0.0109	0.0087	0.0139	0.0002	107	60	47	97	12.3
13	25	0.0161	0.0113	0.0048	0.0134	0.0013	108	70	38	97	9.7
14	9	0.0157	0.0137	0.0020	0.0152	0.0006	85	70	15	82	4.4

Note: *) unlined pipes
Values with large variations have not been considered and appear in brackets.

The average values of pipes 1, 3, 4, 5 and 6 (unlined pipes) are n = 0.01626 s/m$^{1/3}$ and C = 81.4. Pipes 2, 7, 8, 9, 10, 11, 12, 13 and 14 (lined with tar internally) have the average values n = 0.0139 s/m$^{1/3}$ and C = 95.8.

Values in brackets (Table 4) indicating large variations of the results were a result of experimental shortcomings from one side or irregularities in the physical dimensions of the tested pipe sections. Otherwise, this is a true picture of bamboo pipes which cannot be similar to other conventional pipes.

The values of the friction factor have been plotted against Reynolds number on the Moody diagram for some of the values of the performed tests (Figure 8).

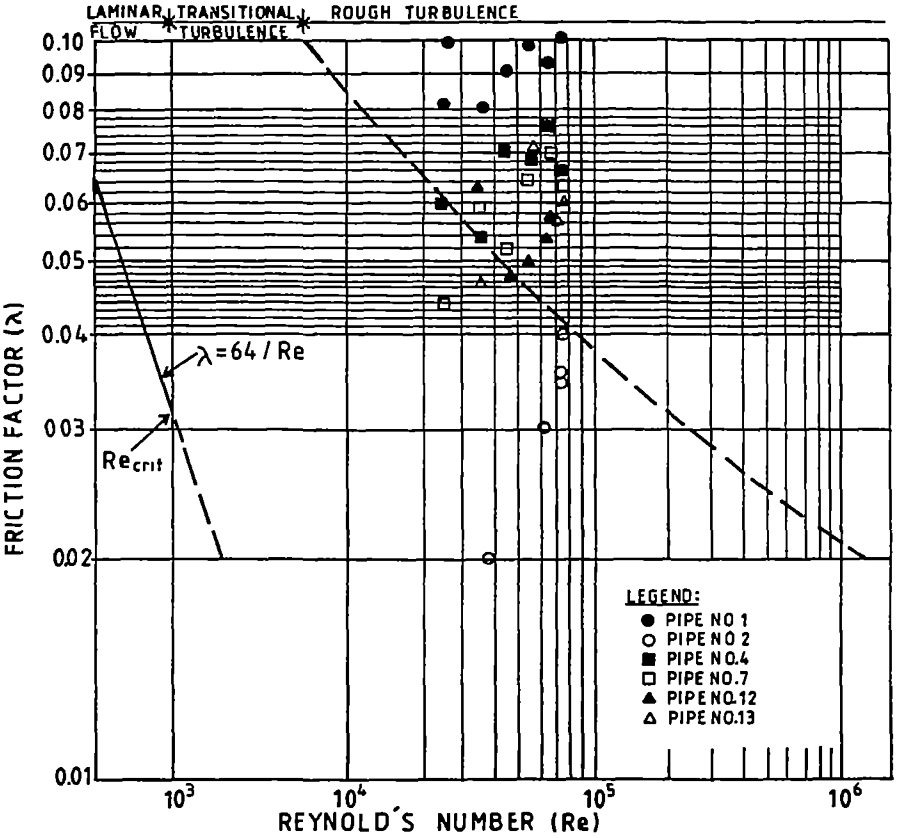


Figure 8. Friction factor (λ) of some bamboo pipes on Moody diagram.

Figure 8 shows that most of the values are in the rough zone of the Moody diagram, therefore the use of exponential formulae, where the friction factor is a function of the relative roughness, is justified.

Maximum discharge

A maximum discharge of Q_{max} = 3.1 l/s was achieved. This discharge was limited by the capacity of the constant head tank. The corresponding velocity was 1.5 m/s. The capacities of the V-notch and piezometers did not allow other measurements beyond these conditions.

3.3.3 Factors influencing pipe friction

Several factors affect the friction factor and coefficient of friction as observed from the results. Factors like non-uniformity of the pipe (diameter), irregularity of the internodes and the bamboo culm wall roughness affect the friction factors and the corresponding coefficients of friction.

Internodes

The internodes are the major irregularity on the pipe internal surface which otherwise is smooth and glossy. To reproduce real conditions as good as possible, the internodes have to be evenly arranged between the piezometers and therefore losses due to them will be included in the results. Good node removal will improve the roughness coefficients.

Pipe diameter

The variations in bore size along the bamboo pipe are quite considerable. There is no uniformity from one end to the other which results in irregular velocities during the flow. Sudden changes in pipe diameter will enhance greater headlosses due to eddy formation especially for short pipelines (Chadwick and Morfett 1986). Proper selection of bamboos in the forest will reduce these variations.

Culm wall roughness

Naturally, the internal culm wall surface is smooth and glossy, but sometimes it appears rough and tuberculated as a rough pipe. Pipes coated with tar inside show some superiority against unlined pipes. According to Chadwick and Morfett (1986) the laminar sub-layer was of prime importance in explaining the difference between smooth and rough pipes. For bamboo pipes the surface roughness was large enough to break up the laminar sub-layer giving turbulence right across the pipe.

Joints

The tested samples were connected at the ends by means of polythene tubes. These were causing friction also due to the abrupt change of diameter. There was not much notice of a systematic difference between losses due to nodes and those due to joints. Therefore it was considered that the results gave an overall picture of a bamboo pipe having nodes as well as joints.

3.3.4 Comparison with existing literature

Bamboo pipes can be compared to other rough pipes like concrete, tuberculated pipes or cast iron pipes. Otherwise comparison was made basing on existing literature and other results of experiments performed earlier. Table 5 shows comparison of results.

Table 5. Comparison of Manning (n) and Hazen-Williams (C) roughness coefficients.

Pipe material	n	C	Source
Bamboo pipes with good node removal		70	Jacobs and Lindburg (1978)
Bamboo pipes with poor node removal		60	Jacobs and Lindburg (1978)
Bamboo pipes with good node removal	0.013	90	Suhan (1979)
Bamboo pipes with poor node removal	0.016	75	Suhan (1979)
Bamboo pipes	0.019	60	VITA (1975)
Smooth metallic pipes	0.010		Twort et al (1985)
Steel pipes with coal tar lining	0.011		Twort et al (1985)
Smooth concrete pipe	0.012		Twort et al (1985)
Rough concrete pipe	0.017		Twort et al (1985)
Old rough or tuberculated, galvanized-iron pipe	0.020 0.035		Twort et al (1985
Plastic pipes		140	American Society of Civil Engineers (1975), cited by Kayombo (1981)
Cement asbestos pipes		140	American Society of Civil Engineers (1975), cited by Kayombo (1981)
Old plastic or cement asbestos pipe		130	American Society of Civil Engineers (1975), cited by Kayombo (1981)
Unlined or tar dipped cast iron pipe		100	American Society of Civil Engineers (1975), cited by Kayombo (1981)
Old cast iron pipe severely tuberculated or any other pipe with heavy deposits		40-80	American Society of Civil Engineers (1975), cited by Kayombo (1981)

Table 5 deduces that the results of this study are more or less similar to certain pipe materials. Comparison can be done to rough concrete pipes, old rough or tuberculated galvanized-iron pipes, unlined or tar dipped cast iron pipes or older cast iron pipes with heavy deposits. Even for Jacobs' and Lindburg's (1978) results which gave a value of C = 70 for good nodes and C = 60 for bad nodes, it can be assumed that the pipes with bad nodes tested in this experiment were not as bad as those used by Jacobs and Lindburg (1978). Suhan's (1975) results were more or less similar except for the Hazen-Williams roughness coefficient (C) value. The results indicated a little higher values and this is because of tar lining, an improvement made during this experiment.

According to the results of this study, following values are recommended for hydraulic calculations of bamboo pipelines (Table 6).

Table 6. Recommended values for hydraulic design of bamboo pipelines.

Pipe condition	Manning n	Hazen-Williams C
Unlined pipes with poor node removal	0.016	80
Lined pipes with good node removal	0.013	95

According to the experience and literature, most of operating schemes were constructed with lined bamboo pipes. Since the quality of the node is the major problem resulting into excessive head losses, care should be taken in removing these nodes. Otherwise, recommended values will be meaningless if design and construction are done in an ad hoc situation.

3.4 Pressure test results and discussion

3.4.1 Results and discussion

To improve their pressure performance, bamboo pipes are reinforced with wires. The results, however, do not indicate significant improvement particularly considering that in their natural form, bamboos can withstand an average pressure of more than 500 kPa. The results revealed that hard tightening of wires without any device does not make any effective contact on the bamboo pipes. Pressures as high as 800 kPa have consistently been achieved when wires are tightened on bamboo pipes or pretightened by bolt or nut. Table 7 shows a summary of results of pressure tests.

Table 7. Summary of pressure test results.

Pipe no.	Species	Average nodal distance mm	Internal diameter mm	External diameter mm	Average thickness mm	Maximum pressure kPa
1	A. Alpina	326	59	76	17	400
2	B. Vulgaris	271	54	82	28	400
3	B. Vulgaris	297	54	79	25	800
4	B. Vulgaris	287	52	72	20	600
5	B. Vulgaris	317	66	88	22	700
6	A. Alpina	350	56	74	18	350
7	A. Alpina	364	54	71	17	400
8	A. Alpina	324	56	74	18	400
9	B. Vulgaris	295	67	85	18	600
10	B. Vulgaris	307	54	77	23	660
11	B. Vulgaris	332	59	82	23	650
12	B. Vulgaris	287	60	82	22	500
Mean, X		313	58	79	21	540
Standard deviation, S		26.4	4.8	5.4	3.5	14.9

- Correlation coefficient between nodal distance and pressure, $r_{np} = 0.34$.
- Correlation coefficient between wall thickness and pressure, $r_{tp} = -0.17$.

The results show that pressure rating of bamboo pipes is quite surprising. The pressure performance of the tested pipes showed that they vary with species from stem to stem of the same species.

Maximum pressures experienced in this case may signify either inability of bamboos to withstand continuous low pressures or sudden development of pressures higher than rated.

The results also show the superiority of B. Vulgaris species over the A. Alpina species. Maybe due to their shorter nodal distances, B. Vulgaris recorded higher pressure values of 400-800 kPa. This also may be necessitated by their wall thickness being thicker than the A. Alpina if the theory still holds.

However, in the contrary to what was generally believed to influence bamboo pressure performance, i.e. nodal distances, this experiment revealed very poor correlation between pressure performance and nodal distances. The experiment was also extended to study the effect of wall thickness on pressure performance of the pipes. Although again the correlation was poor, it was negative in nature which implies increased pressure withstanding ability with decreased wall thicknesses. Indirectly, this might suggest age of bamboo having some influence on pipes' pressure performance.

Furthermore, it was observed that failure always started from top to bottom of stems. This also strongly suggests a possible correlation between pressure ability and age of bamboo.

3.4.2 Comparison with existing literature

Iringili and Mahungu (1979) suggested that the working pressure for green bamboo should not exceed 150 kPa and 200 - 300 kPa for the yellow bamboo. In their pressure experiments, they revealed that the material is capable of taking very high instantaneous pressures with observed values of up to 600 kPa and 1 000 kPa for green and yellow bamboo respectively. However, no parameters could be established which correlated or predicted pressure withstanding cabability of the pipes.

Recommended values

According to the experience and the results of these experiments, bamboo pipes can withstand high instantaneous pressures as opposed to their low ability under field conditions. With the above arguments the author recommends the working pressures of 200 - 400 kPa regardless of the used species. These values can be increased when there is a proper control of bamboo species as from flowering to harvesting period. This will assist in obtaining bamboos of specific and definite physical dimensions.

4 PLANNING AND DESIGN OF BAMBOO WATER SUPPLY SCHEMES

4.1 Planning principles

Basically bamboo water supply schemes are relevant for small community water supply systems, because design and construction is not difficult. The technology is simple and adapted to the available technical and organizational skills.

The planning and design of bamboo water supply schemes in Tanzania is approached under a programme rather than projects. Since the technology is new, all activities of planning and design are centralized to monitor all key problems like technical and management problems. However, community involvement aspects at this stage assumes greater significance, as their acceptance to the technology is so vital.

4.1.1 Planning procedures in practice

Generally in water project design, engineering decisions are required to determine the area, population, industrial situation, institutions and other consumers to be served (Iikkanen 1989). The per capita consumption, design period, pressure zones, categories of consumers and other water needs have to be established.

Landscape and location of various facilities to be provided such as water source, intake, treatment plants, pumping stations, reservoirs, pipe alignments, distribution points, construction materials in addition to community participation, all form the essential parameters to be considered. Tariffs, project costs and timing must also be determined. The designer has therefore to determine the long term water demand from the outset, hence, before a final design is arrived at, the following studies and reports are required:

- a pre-feasibility study
- feasibility study
- detailed final designs.

At the planning stage, the design period (usually 5 - 15 years) i.e. the time within which the project long term demands are projected at the least project cost should be done, levels and contours plotted on the survey drawings under standard procedures. Other drawings include plans, cross and longitudinal sections.

The bamboo pipeline should not pass through areas with many trees as roots may penetrate the pipe and choke it. If not possible to by-pass such areas, then the pipeline should be covered with a bamboo sheath of larger diameter which in turn will protect the line carrying water (Lipangile 1990).

4.1.2 Financial considerations

In rural areas of Tanzania people are used to get water freely and the aspect of paying for water is not yet conceived. Together with the adoption of bamboo water pipes, it is difficult to rely on this principle. Therefore, all bamboo schemes are financed by the Central Government together with several external donors. The only main contribution from the community is their free labour during construction phase. The villagers dig trenches, lay pipes and participate in construction of intake works, reservoirs and domestic water points, which reduces tremendously the overall construction costs.

4.2 Design principles

Criteria for designing bamboo water supply schemes will be expected to reflect the following considerations:

a) Reliability of the used preservative and the period for which it remains effective.
b) Quality of water at source and whether or not the supply will require treatment prior to distribution.
c) Size of community to be served.
d) Location of the scheme.
e) Desired level of service; bamboo water supply schemes should preferably be restricted to small residential communities and small scale irrigation uses.
f) Attitude of the proposed beneficiaries towards technological changes.

Bamboo technology is mainly feasible for gravity water supply because there are difficulties in securing water pumps and fuel in rural areas. Furthermore, a gravity system ensures a continuous saturation of pipelines which prevents fungal growth. Principles involved in designing bamboo schemes are similar to conventional ones and criteria like design period, pressures, water demands, etc. are considered.

4.2.1 Design period

Bamboo water schemes are designed for a period of 10 years. Performance of the 14 years old Likuyufusi scheme in Songea district, southern Tanzania clearly indicate that a bamboo water supply system can serve for more than 10 years. This scheme was crudely constructed in a relatively warm climate, and when checked in 1989 it showed no signs of failure.

Although the design period is lower compared to 15 years or more normally used in conventional schemes, lack of well defined service levels and their complimentary inputs in short and long terms and the complex dynamics of population, tend to favour use of shorter period for ease of forecasting. World Bank (1977) recommended a design period of not more than 6 - 10 years, due to the uncertainties involved in predicting population change and actual demands.

4.2.2 Design pressure

Each bamboo species has its own strength characteristics to resist water pressure. For A, Alpina, the average pressure resistance in pressurized bamboo pipes is 430 kPa (Iringili and Mahungu 1979). This necessitated by the bond between the parallel fibres in the bamboo culm is weak, while at the nodes the tangential bond is stronger. Results of the pressure tests indicated that apart from the number of nodes per unit length, also the diameter and the wall thickness affect the strength of the bamboo water pipe. The recommended design pressure was 200 - 400 kPa.

In Bauingenieur (1964, cited by van der Heuvel 1983) it was found that the shear stress increases with increasing thickness of the bamboo culm wall. Also the bending stress of bamboo pipes with small diameters is higher because the portion of the strong sklerenchym fibres exceeds the portion of this strong fibres in larger bamboo per unit area.

Increasing bamboo pressure sustainability

To reinforce the bamboo pipes to increase its pressure sustainability, galvanized-iron wires are wound around the pipe at regular intervals (Figure 9).

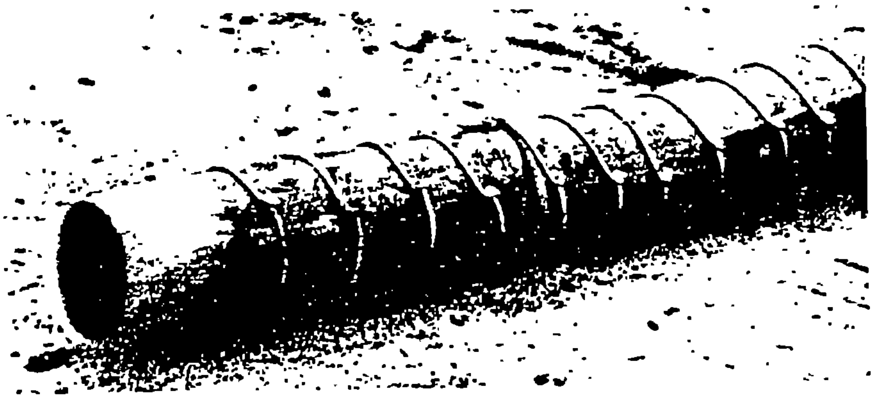


Figure 9. Portion of a finished bamboo pipe with wire reinforcement (Lipangile 1985).

Another method to reinforce the bamboo culm is the application of formaldehyde and sulphuric acid (Mac Conal 1979). These chemicals react with the cellulose of the parallel fibres which are cross linked in the way:

$$2 \text{ Cellulose} - O - OH + HCHO \ldots \text{Cellulose} - O - CH_2 - O - \text{Cellulose} \quad (5)$$

Formaldehyde treatment causes severe embrittlement of wood. The main disadvantage of this method is the introduction of poisonous formaldehyde. According to Mac Conal (1979) the reaction also takes place with a low pH value and with high temperatures.

If the pipe is reinforced, the system ought to be designed for maximum static pressures of 200 kPa and 250 kPa for green and yellow bamboo respectively (increased to 200 kPa and 400 kPa). Under these pressures, developed water hammer pressure is within the ability of bamboo pipes if closing time is restricted to 10 s (Iringili and Mahungu 1979).

4.3 Typical designs of bamboo water supply schemes

Bamboo water supply schemes need standard design to allow rapid and effective construction techniques, through repetitive work by relatively unskilled personnel. Typical technical designs and construction procedures have been developed to be followed in all schemes. To reduce costs, technicians and delegated persons from the community are trained in the repetitive systems during design and construction phases. In all cases the following design aspects are considered.

4.3.1 Design aspects

Water demand

Present and future water demand for people and livestock is established. Allowances for water losses, water demand for industries and public institutions are given in l/capita/d. From the established data on the population and livestock increase, future water demand for 20 years can be extrapolated. Also peak demand should be established for design purposes.

Reservoir

Reservoir storage capacity that can balance peak flows without using emergency reserves is established. If the design extends over 20 years, the tank capacity should be capable of meeting the peak demand in 20 years time. The tank location should be chosen in such a way that a minimum residual head of at least 1 m at the highest domestic point is attained.

Domestic points

On average, a single domestic point (DP) serves 200 people and it should preferably be within a walking distance of 500 m (Ministry of Water 1986). DPs are usually constructed near schools, religious centres, dispensaries, a market or community centre. An additional domestic point with two taps discharging about 0.5 l/s is located at a health centre. The maximum allowable static pressure at DPs should be 200 kPa and the minimum residual head at any tap should not be less than 1 m.

Pipes

Maximum pressure, which should not exceed 200 - 400 kPa, to be taken by the bamboo pipe is established. Assurance is made such that pipe joints are equally capable of withstanding such pressures.

Water flow rate

The flow of 0.25 l/s/DP is recommended. This is established by considering that:

- 200 people require 25 l/capita/d each i.e. total 5 000 l/d.
- Assuming that the distribution network expansion is only feasible after 19 years, by then about 300 people (50 % increase) will depend on each DP. Hence 7 500 l/d will be required.
- Considering that any rural water system has to be supplied within a period of six hours, then to supply 200 people the flow at the tap has to be 0.23 l/s and for 300 people 0.35 l/s.
- At a flow of 0.23 l/s it will take about 65 s to fill a 15 l bucket and when the flow is 0.35 l/s only 43 s.

Although the above illustration shows the preferable flow at each tap to be 0.35 l/s it is recommendable to design the system on the basis of 0.25 l/s. This is because the actual water consumption will be below the assumed 25 l/capita/d, and the filling time of a bucket of 60 s is quite reasonable and acceptable.

Establishment of flow data in pipes

Jacobs and Lindburg (1978) established hydraulic flow charts. These charts are meant to assist the designer in the selection of appropriate pipe diameter at a given flow rate to obtain a desired hydraulic gradient. Appendix 2 shows charts for hydraulic gradients for diameters 40 - 80 mm and flow rates 0.1 - 8.0 l/s. The basis for calculation is the C-value of 75 for unlined bamboo pipes and 85 for lined bamboo pipes.

4.3.2 Theoretical design example

4.3.2.1 Flow in pipes

A flow in a pipe is the result of a difference of head between the beginning and the end of the pipe. If water is discharged in the open air tap, the pressure of this water is atmospheric. The amount of flow is fixed by:

a) The hydraulic gradient = available head-loss per unit length

$$I = H/L \tag{6}$$

b) The pipe characteristics (diameter and inside wall roughness).
c) Additional frictional losses.
d) The fluid characteristics (type of fluid and its temperature).
e) The stream flow characteristics.

In designing a water supply system, issues a) and b) are considered. Additional frictional losses occur in the bigger pipes (ϕ > 32 mm) due to the low velocities that are negligibly small though not at DPs.

4.3.2.2 Domestic points

- The taps at the DPs should always be 1 m above ground level.
- Domestic points comprise of 4 m long galvanized steel (G.S.) pipes with diameters 12.5, 18.8 and 25.0 mm. With these small pipes and high velocities we cannot neglect the additional frictional losses. The effect of these additional losses at DPs can be expressed as follows:

$$T.P. = I \times L \times 3v^2/2g \tag{7}$$

where T.P. = terminal pressure at tap enabling a discharge of Q l/s
I = hydraulic gradient corresponding to the chosen diameter, roughness and Q
L = pipe length (L = 4 m)
3 = number of additional frictional losses expressed as velocity head ($v^2/2g$)
i.e. 2 x $v^2/2g$ due to 90^o bends
1 x $v^2/2g$ due to outlet losses at tap
v = mean water velocity (m/s)
g = acceleration due to gravity (= 9.81 m/s^2)

4.3.2.3 Distribution reservoirs

If sufficient water is available at the intake, the most economical choice between three possibilities has to be made:

a) No tank and 'very big' gravity main which will discharge the peak flow.
b) A 'small' tank and a 'big' gravity main.
c) A 'big' tank and a 'small' gravity main.

Note: 'big' and 'small are used here to distinguish the differences and not to indicate exact sizes of the tanks.

Determination of the tank size

Applied notations:
Qx = peak demand (l/h) after x years
q = discharge of gravity main (l/s)

<u>Generally,</u>

If $q > Q_{20}$, no tank is needed
If $Q_{10} < q < Q_{20}$, no tank is needed in the first 10 years
If $q < Q_{10}$, tank is not to be constructed now, tank is needed within 10 years, tank has to be constructed to cover the peak flow for the next 20 years.

If a tank is needed we can thus determine two situations:

a) A small tank can be constructed if the gravity flow between 9.00 am - 3.00 pm is sufficient to supply the water amount which is lacking between 3.00 pm - 6.00 pm.
b) A 'big' tank has to be constructed if the gravity flow between 6.00 pm - 4.00 pm is required to balance the water requirements during day time.

'Small' tank - capacity: $3 \times (Q_{20} - q)$ possible if:

$$6 \times q \geq 3 \times (Q_{20} - q)$$

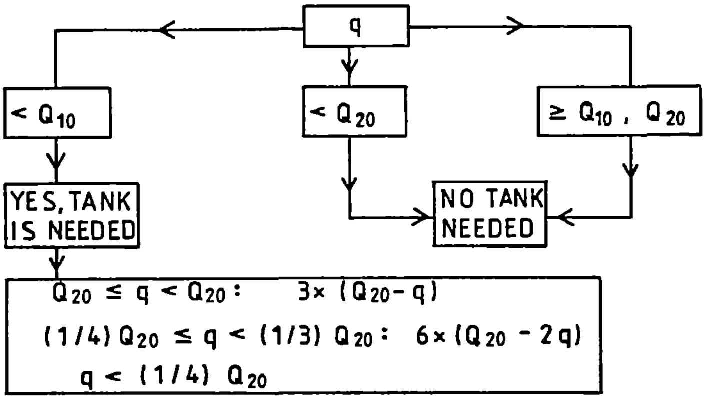
$$q \geq \times Q_{20} \text{ or } q > \times Q_{20} \qquad (8)$$

'Big' tank - capacity: $6 \times (Q_{20} - 2q)$ possible if:

$$12q \geq 6 \times (Q_{20} - 2q)$$

$$q \geq \times Q_{20} \text{ or } q \geq (1/4) \times Q_{20} \qquad (9)$$

Resuming,



If the discharge of the gravity main is less than a quarter of the peak demand after 20 years, it has to be increased by means of a twin line or a pipe with a bigger diameter.

4.3.2.4 Break pressure tanks

A break pressure tank is needed if the pressure in the pipe exceeds maximum static pressure (i.e. 200 - 400 kPa for bamboo pipes). Each break pressure tank requires a ball valve to avoid excessive spilling of water which may lead to unhygienic conditions.

At gravity mains a break pressure tank can sometimes be omitted by choosing a 'small' gravity main which discharges continuously in a 'big' tank without ball valve. Because of the continuous flow only a dynamic pressure will occur which is much smaller than the static pressure.

That is the case if:

- enough water is available at the intake, also at the end of the dry season (one should not waste water in one village at the cost of other villages depending on the same water source down stream)
- a natural drainage is available - close to the tank (to avoid unhygienic situations therein) and if,
- the saving of money is considerable in long gravity mains.

If break pressure tanks are required in the distribution network, the design should start at the break pressure tank which is situated most downstream. Each pipeline system downstream of a break pressure tank can be regarded as a system on itself. If one starts the design work at the most downstream break pressure tank whatever water demand is required for that system can be calculated. This required water amount becomes a constant for the upstream system(s).

Design should be such that the required flow can always discharge in the break pressure tank, leading to the assumption that the break pressure tank is always full.

4.3.2.5 Concept and location of sedimentation tanks

Jacobs and Lindburg (1978) conducted a study on the actual silt loads expected at certain water sources. They indicated that very clear water has a silt load of $> 0.125\ l/m^2$.

Constructing a sedimentation tank at the intake will reduce silt load considerably. The principle of a sedimentation tank is that the tank is long enough to ensure settlement of all particles which exceed a certain diameter (D).

The calculation is implemented by judging from the settling velocity (v_s) of the smallest particle with diameter (D) which must be sedimented in connection with the horizontal mean velocity (v) in the tank (Hukka 1989).

Any particle bigger than (D) will settle in the sedimentation tank. Considering a tank with a height (H) and length (L), then,

$$\frac{H}{L} = \frac{v_s}{v} \quad \text{or} \quad v = v_s \times \frac{L}{H} \tag{10}$$

The horizontal mean velocity (v) is the result of the discharge (Q) of the gravity main divided by the cross-sectional area of the sedimentation tank of width (W), hence:

$$v = \frac{Q}{H} \times W \qquad (11)$$

Combining (10) and (11)

$$v_s \times \frac{L}{H} = \frac{Q}{H} \times W \quad \text{or} \quad L = \frac{Q}{v_s} \times W \qquad (12)$$

With Equation 12 the sedimentation tank can be designed.

Simple example

Assuming a settling velocity $v_s = 0.003$ m/s for a silt of D = 0.05 mm. Consider a water supply system for a village of 1 250 people, which is implemented without a storage tank (thus gravity main produces the peak flow), after 20 years the discharge of the gravity main will be 2.9 l/s.

Assume width $W = 0.8$ m

Thus length $L = \frac{Q}{v_s} \times W = 1.2$ m

Similarly, for a village system of 2 000 people (without tank), the gravity main will after 20 years produce 4.6 l/s. Then, the length of the sedimentation tank has to be:

$$L = 2.0 \text{ m at a width } W = 0.8 \text{ m}$$

5 CONSTRUCTION OF BAMBOO WATER SUPPLY SCHEMES

5.1 Construction process

The construction process will generally involve a total of 20 stages starting from buying bamboos from the forest, production of the pipes and finally laying the pipe into the trench. Figure 10 summarises the construction methodology.

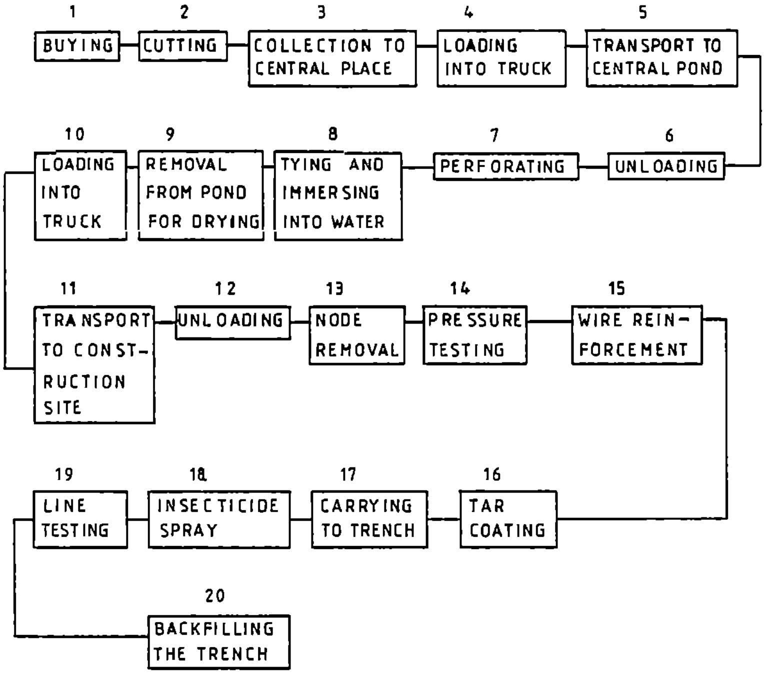


Figure 10. Summary of the construction process.

From Figure 10 comparison can be made with a similar factory of manufacturing conventional pipes. Work studies could be made on different stages of making a pipe as outlined in the summary chart and the cost of the pipe can be determined. However, the major stages include preservation and production of the pipes.

5.2 Pretreatment of bamboo pipes

Generally, in the absence of centralized pipe manufacturing facility construction methodology includes pipe making and laying operations.

After cutting, bamboos are transported from the forest to the central water pond, where they are stored for at least three months for desapping. From the central pond, they are transported to the ponds at the construction sites.

At the construction site the bamboo undergoes the following processes (Figure 10):

a) boring to remove the nodes
b) pressure testing
c) reinforcements by galvanized wires
d) sharpened at both ends for poly connection joints
e) immersed in boiling tar for 2-3 minutes (if internal coating is not desired, the ends are plugged)
f) drying under shed
g) transported to the trench for pipe laying.

5.2.1 Removal of partition walls

The partition walls are drilled twice: first, when submerging the culms into water for desapping purpose, and second to remove all remaining parts in the pipe. The nodes are bored out manually using a home-made bit attached to a 12.5 mm diameter galvanized iron pipe (Figure 11).

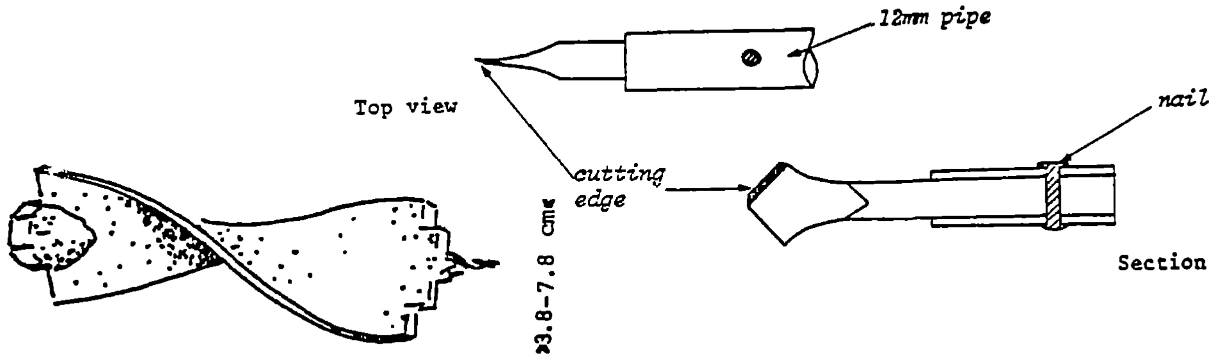


Figure 11. Bits for removal of partition walls (van der Heuvel 1983 and Morgan 1974).

Removal of nodes with a hand-tool is a disadvantageous technique because of insufficient removal of the partition wall material resulting in extra energy losses in the water pipe (van der Heuvel 1983). The use of a flexible drive with adapted bit for the node removal gives better results (Figure 12).

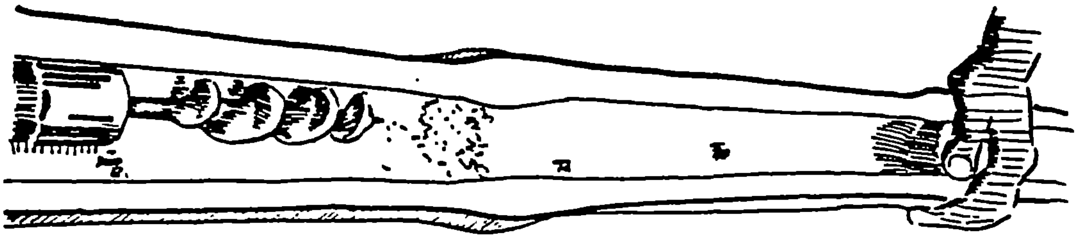


Figure 12. Interior of a smooth bamboo pipe (van der Heuvel 1983).

5.2.2 Desappping

Desapping is the extraction of saps, starch and other substances from the inside of the bamboo culm wall. Fresh cut bamboos when used without desapping treatment may result in odorous water with unpleasant taste. Decomposition of the bamboo pipe is also accelerated by micro-organisms and substances in the pipe which are responsible for the contamination of drinking water. The amount of sap is related to this decomposition.

The common method of desapping is submerging of the pipes into non-stagnant water for two - three months. The submerging procedure is not effective for all species. For example the B. Vulgaris has to be submerged into chlorinated water (Lipangile 1984).

5.2.3 Pressure testing

Pressure testing of bamboo pipes is usually done with a small water pump. Water is pumped through a connection of galvanized steel pipes with a poly joint for bamboo connection. The end of the pipe is closed by a wooden plug while water is being pumped. If the working pressure of the system is 250 kPa, the bamboo pipes are tested with a pressure of up to 300 kPa. The method is crude and the results are in most cases unreliable.

5.3 Preservation

Bamboo being an organic material, once buried in the ground unprotected will naturally decay by action of bacteria, fungi and termite attack. Thus the need to stop natural decay by way of preservation cannot be over-emphasized if bamboo pipes are to be used. Without proper preservation bamboo pipes will not last longer than 2 - 3 years.

Whereas internal attack is restricted to decay by micro-organisms, external decay is caused by both micro-organisms and termites (van der Heuvel 1983). In hot low altitude areas, termites are very aggressive and in the highlands with cold climates they are almost non-existent. van der Heuvel (1983) reported that termites are quite active in Indonesia while fungi are active almost everywhere in the world.

5.3.1 Internal preservation

Internal protection can be affected by the following techniques or their combinations (Msimbe 1984):

a) excluding micro-organisms from the water by careful selection of the water source and by purification
b) preventing microbiological activities in the bamboo culm by impregnation with toxic/non-toxic chemicals such as copper chrome arsenic (CCA), copper chrome (CC) and copper formulations of alkyl ammonium compounds
c) saturation of the bamboo culm with water
d) coating the inner surface by tar of bitumastic materials that are safe for drinking water supply
e) sterilization of the culm with chemical disinfectants.

According to Purushotham et al (1965), copper arsenate formulations have been in use for more than 50 years in the world. Water-borne preservatives containing CCA are considered among the most effective wood preservatives. Because all these chemicals are toxic and when impregnated into the bamboo culm, will eventually leach into water, and thus cannot be used. In this case, non-toxic chemicals are preferred.

5.3.1.1 Impregnation with non-toxic preservatives

Certain copper and borax based compounds are good preservatives against fungi and they are also effective against termites. Such compounds are TIMBOR (Borax) and the copper ammonium compound produced as CQA. These chemicals are harmless even if leaching occurs. Impregnation of these chemical preservatives can be effected in four different methods:

a) open tank method
b) hot and cold bath method
c) diffusion method
d) boucherie method.

Open tank method

This involves submerging fresh bamboo pipes in a cold bath solution of the compound under impregnation for two months. This method is considered adequate for allowing enough chemical to diffuse into the fibres of the bamboo culm.

Hot and cold bath method

Fresh bamboo pipes are soaked in boiling water and immediately dipped in a cold bath containing the preservative solution. The hot bath facilitates the opening of the pores of the bamboo fibres and the sudden change of temperature creates a kind of vacuum in the bamboo fibres which in turn sucks in the preservative solution leading to fixation. Figures 13 and 14 depict the boiling and drying steps of the method respectively.

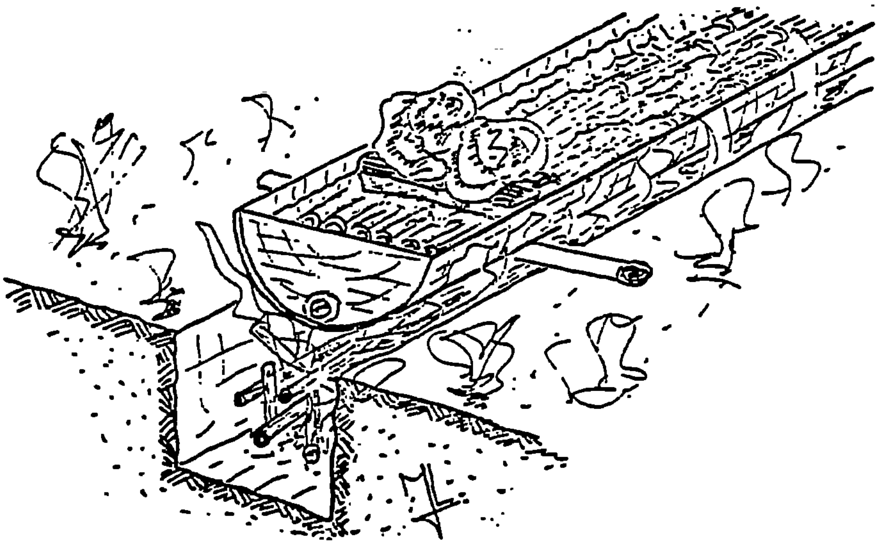


Figure 13. Boiling bamboos for hot and cold bath method (Johan 1979).

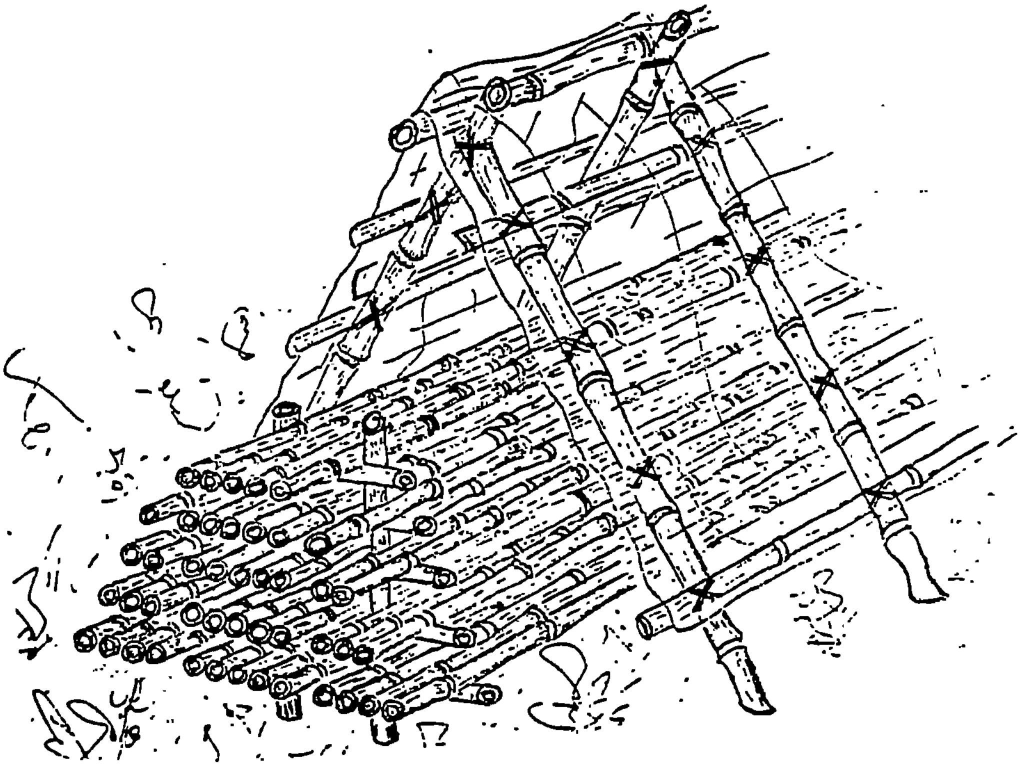


Figure 14. Drying of bamboos for hot and cold bath method (Johan 1979).

Diffusion method

A wet bamboo pipe is dipped in the hot preservative solution for about 20 minutes and then allowed to dry slowly under shade covered with grass. Movement of salts into bamboo tissues is by diffusion. The drying period lasts for four weeks.

According to Johan (1979) these three methods are not very effective as they give rise to crystallization of the salt on the culm wall and result into poor longitudinal distribution of the chemicals.

Boucherie method

Boucherie impregnation is carried out either by using gravity or mechanical pressure. The gravity pressure is best because it saves energy.

A head of 15 m is used between the tank solution and the bamboo pipe under impregnation, which should be fresh with the partition membranes intact. The supply vat is placed on a high elevation connected to a plastic hose with a distribution system at the bottom of the vat. Johan (1979) reported that 80 -100 pipes can be impregnated at a time. Figure 15 shows the method set-up.

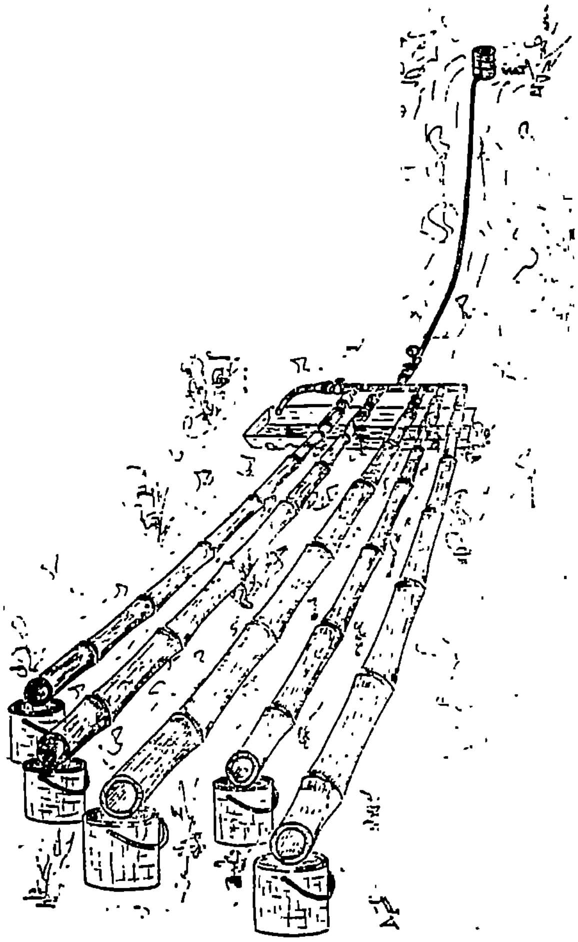


Figure 15. Boucherie low pressure plant (Johan 1979).

5.3.1.2 Saturation of pipelines

Fungi do not grow under 100 % moisture conditions. Usually they require a moisture content of 20 - 30 %. This condition is usually guaranteed under a gravity source of water or where there is a reliable pumping mechanism. Designing a scheme in which the bamboo pipes are always totally filled with water prevents fungal attack from inside.

Intermittent flushing with chlorine water is also helpful in this regard. The flushing should not exceed 10 mg/l of chlorine, and it should go through the entire pipe system within a period of two hours. After this duration almost 86 % of the total chlorine input will be absorbed by the organic reactions between chlorine and the culm wall. If excessive doses are applied, oxidation may occur and this could damage the bamboo culm wall (Hendrikx-Jongerius and de Leer 1986).

5.3.1.3 Internal coatings

Coating the inside surface with approved drinking water linings will deny micro-organisms access to the bamboo culm. Coatings of tar (PF_4), bitumastic materials such as Aquasil 44, Butturos and Orkitik have been used (Lipangile 1990). They are water proof, non-toxic and approved for contact with drinking water.

5.3.2 External preservation

External protection of the bamboo pipe can be achieved by the following techniques or their combinations:

a) soil treatment
b) external coatings
c) chemical impregnation.

<u>Soil treatment</u>

The quintessence of this technique is to make the environment around the bamboo pipe unsuitable for the bamboo destroying organisms to live. Chlorinated insecticides can be used in this aspect. These chemicals are persistent in the environment making them very useful for this purpose. A rapid decomposing chemical would not do because its protective working strength would last only for a short time.

Fears of environmental pollution must not be exaggerated. The chemicals fix well into the soil which reduces the danger of water and soil pollution. Figure 16 shows cross-sections of treated trench and treated pipe.

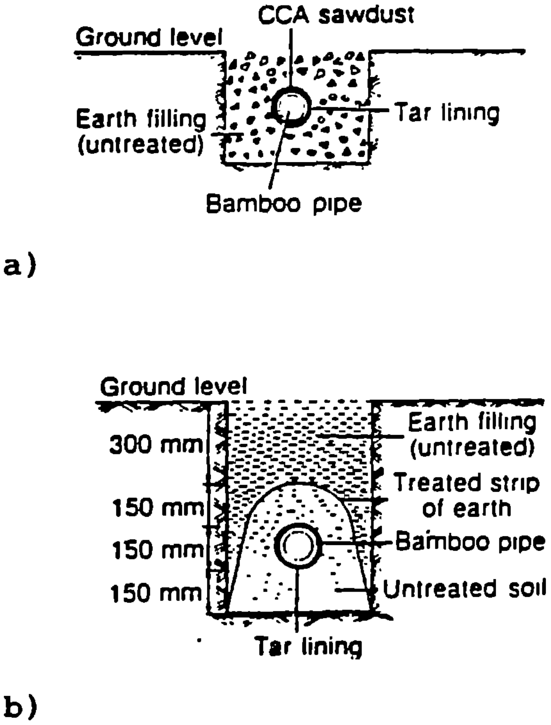


Figure 16. Cross-section of a pipe trench treated with a) pesticide and b) copper chrome arsenic (Lipangile 1985).

External coatings

External coating of the bamboo either by tar or bitumastic paints have a considerable impact on the fungi attack. Tar and its products are not considered to be insecticides and so the treatment is far less effective against termite attack. This problem could be solved by mixing the tar with chlorinated pesticides before coating the bamboo. Lipangile (1985) revealed that thick layers (2 - 3 mm) of tar would enhance considerably the protective working strength against termite attack.

Chemical impregnation

Impregnation of the culm with chemicals will also provide external preservation of the pipe against termite and fungal attack.

The lifetime of a bamboo water supply scheme can also be increased (regardless of the treatment) by selecting villages in cooler, high altitude areas. These areas have the advantage of being less infected with termites. Experience shows that above altitude 2 000 m termites are not thought to pose any significant threat, while also growth of fungi is slowed down considerably (Msimbe 1984).

5.4 Pipe jointing

Water tight joints can be made in several ways. In Ethiopia (Morgan 1974) soaked cow-hide, rubber inner tubes or tar-soaked rope were used to bind the joints tightly. In Tanzania most practical is the polythene or polyvinyl chloride (PVC) pipe sections and a PVC paste called Tangit is used for gluing. The bamboo is sharpened with a knife or with a kind of pencil-like sharpener at the ends to make it suitable for insertion into the plastic joint. The glue is applied to make the joint water-tight. Other methods are rubber winding, rubber string, bamboo collar and bamboo string. Figures 17 and 18 show different water-tight joints.

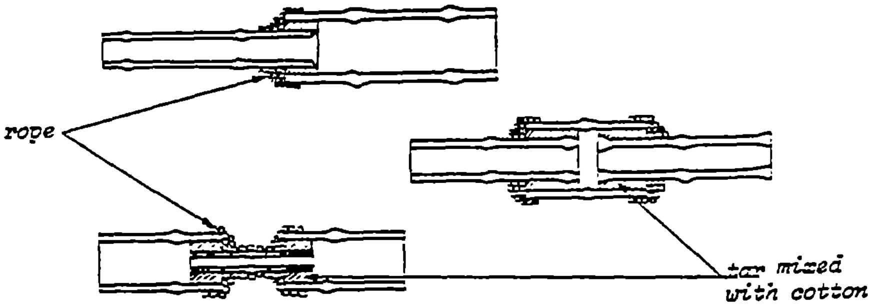


Figure 17. Water-tight joints (Morgan 1974).

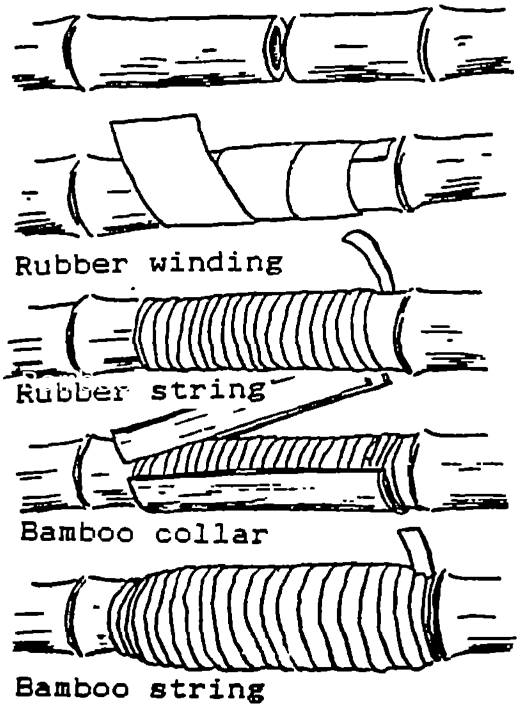


Figure 18. Different types of bamboo pipe joints (van der Heuvel 1983).

5.5 Pipe laying

5.5.1 Procedure

The procedure of pipe laying includes eight operations:

a) trench excavation
b) spraying hydrocarbon insecticides (aldrin or chlordans diluted to 1 %)
c) back-filling of the trench with 50 mm of soil layer to prevent direct contact between the pesticide and the pipe
d) laying of the pipe
e) connecting pipes with a poly joint (before connection, the joint is slightly warmed to guarantee a water-tight joint upon shrinkage)
f) the pipe is covered with soil, preventing it from drying out while the line is tested on pressure resistance and leakage
g) on top of this layer, aldrin solution is sprayed again
h) back-filling of the trench.

Principally, a trench is excavated to about 75 cm deep and 60 cm wide. Treated pipes are laid one after another by pushing a bamboo pipe in one side of a polythene tube or PVC joint. A stone hammer and a piece of plank is used to push the bamboo into joining position.

To secure a water-tight joint, a wire wound is made outside the polythene tube. The layout operations can be carried out by unskilled labourers under supervision. According to Lipangile (1985) under normal conditions 200 m of bamboo pipeline can be laid out by six labourers in a day.

Bamboo water pipelines are first operated at dynamic pressures for a period of 24 hours to ensure that they are fully saturated. Any abrupt change of pressure will result into serious bamboo bursts if not saturated with water for a long period.

5.5.2 Lateral connections, valve connections and pressure relief chambers

Bamboo pipes at lateral connections and valves are connected in similar manner as plastic pipes, by using adapters and T-connectors. Sometimes wooden connectors and joints are used.

In case of anticipated pressure along the bamboo pipeline is higher than the working pressure of the pipes, pressure relief chambers are installed at appropriate locations.

Similarly, water hammer has a serious drawback to bamboo pipes. For this case, a small surge cushion device below the water point is installed to prevent additional pressures resulting from abrupt shut-off of flow.

6 OPERATION AND MAINTENANCE OF BAMBOO WATER SUPPLY SCHEMES

Huisman et al (1987) suggested that it is more difficult to run than to construct a small community water supply. The need for maintenance is generally recognized, but the actual maintenance work is frequently neglected.

In Tanzania, the issue of operation and maintenance (O & M) of rural water supply is the national problem.

In its national strategies on O & M of rural water supply schemes the Ministry of Water (1988) recommended that O & M responsibilities are to be met at village level. This meant that the village shall find the means required to finance O & M activities through levies, contributions, productive projects, etc. During the transitional period not exceeding five years, local and central government bodies shall cover part of the O & M costs.

The Ministry of Water (1988) further recommended that it will be the responsibility of the individual village to:

- create a water committee and a water fund
- determine how best to collect and disburse the funds
- select suitable candidates for the posts of scheme attendants and arrange their training through the district water engineer's office
- through the village committees, monitor the operations of the water schemes and promptly arrange such repairs, which cannot be handled by the scheme attendants.

The Wood/Bamboo Department is now reconstructing itself to operate bamboo schemes as recommended.

6.1 Operational problems

Bamboo water supply schemes constructed in the rural areas of Tanzania reflected the following problems which resulted into uneven operations of the schemes (Lipangile 1990):

a) Use of ungalvanized wires which rust.
b) Plugs used to fill insect-holes in bamboo pipes come loose causing excessive water losses.
c) Occurrence of excessive water pressures due to the following reasons:
   - Constructions and extensions which do not comply with the design.
   - Use of dynamic head in design; should there happen any blockage, static pressures are developed which might be well above bamboo capacity.
   - Surveys for bamboo water schemes are very sensitive. A rough survey with an error of 5 m can cause excessive damages to a bamboo pipe.
   - Use of much longer pipes than the recommended 4 m. This results in pipes which are not of uniform bore size which can have adverse effects pressure-wise.
   - Use of pipes which have been damaged during transport, while removing nodes or during pipeline installation.
   - Careless application of preservatives resulting in termite and fungal attack.

6.2 Assessment of operating bamboo water supply schemes

6.2.1 Present situation

Principally, two persons are chosen among the villagers as scheme caretakers. During construction they are given a day to day training on the importance of drinking water supply and on the operation and repair of the system. They are trained to attend minor repairs and they are also supplied with basic tools and spares. Special forms are filled monthly indicating repairs, situation of spare parts, etc.

Observed water supply schemes constructed of bamboo pipes were found to consist of a minimum 5 % of its entire length of polythene pipes for jointing the separate 4 m bamboo pipes. For the amount of polythene material in all schemes constructed and being maintained varies 5 - 100 % (Table 8).

Table 8. Examples of water supply schemes constructed of bamboo pipes.

Name of scheme	Region	Year of construction	Altitude m	Water source	Present situation	Percentage of polythene PVC %	Remarks
Kilolo	Iringa	1980	1500	Spring	Operating well	5	
Mgama	Iringa	1978	1200	Spring	Rehabilitated in 1983	5	
Igumbilo	Iringa	1983	1100	Shallow well	Operating well	5	
Mafruto	Iringa	1984	500	Shallow well	To be replaced by plastic pipes	56	Termites
Kidogo	Iringa	1980	1300	River	Operating well	5	
Mkiu/Kiyombo	Iringa	1983	1200	Spring	Still operating	5	
Shaurimoyo	Iringa	1979	1000	Spring	Replaced in 1984		
Ihumo	Iringa	1980	1100	Spring	Under replacement	22	
Nyakipambo	Iringa	1978	1200	Spring	Operating well	5	
Kwatwanga	Iringa	1981	1000	Spring	Operating	5	
Lupalilo	Iringa	1978	2000	Spring	Replaced 1988 by lined bamboo	37	
Mago	Rukwa	1978	2000	Stream	Replaced 1988 by lined bamboo	73	Termites
Singiwe	Iringa	1979	1000	Stream	Rehabilitated in 1987	5	
Nyanzwa	Mbeya	1979	500	Spring	Replaced by plastic pipes	5	
Msia	Mbeya	1979	1100	River	Operating, replaced by lined bamboo in 1984	100	Termites
Katabe	Mbeya	1981	1200	Spring	Operating well	5	
Ngumbulu	Mbeya	1979	2200	Spring	Rehabilitated in 1988	5	
Uzia	Rukwa	1979	1000	Stream	Replaced by plastic pipes	100	Termites
Senga	Rukwa	1979	1000	Spring	Rehabilitated in 1987	5	
Likuyufusi	Ruvuma	1976	1100	Spring	Operating-signs of failure	5	
Lipokela	Ruvuma	1981	1100	Spring	Under rehabilitation	16	
Lihale	Ruvuma	1981	1200	River	Operating well	5	

Whereas it is generally accepted that most operating bamboo water supply schemes need rehabilitation after five years, there are some schemes which require shorter replacement intervals and some even require continuous replacement. Figure 19 shows a map of Tanzania indicating operating bamboo water schemes and locations of bamboo forests.

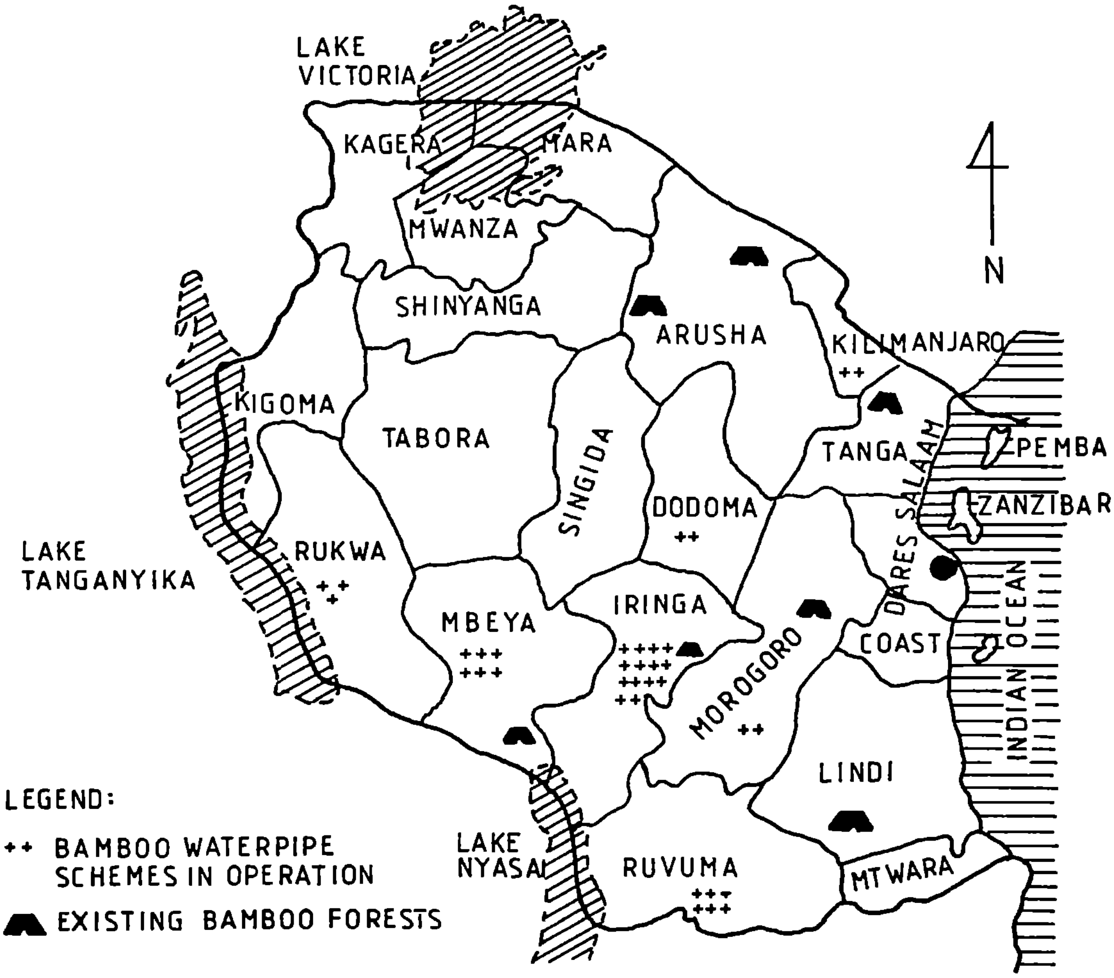


Figure 19. Bamboo water supply schemes and bamboo forests in Tanzania.

6.2.2 Monthly scheme records

The monthly records for some schemes indicated that there is a need of frequent maintenance of bamboo water supply systems. Characterized with bursts, bamboo systems require standby funds, materials and crews for operation and maintenance purposes. Tables 9 and 10 show a summary of average yearly records of Likuyufusi Scheme.

Table 9. Summary of failure records of Likuyufusi Scheme in 1978-1985.

Line	Year of operation							
No.	1978	1979	1980	1981	1982	1983	1984	1985
1	-	-	BB	BB	BB	-	B	-
2	L	-	-	-	LL	-	BBB	-
3	LLLLL	-	B	B	LL	-	BBB	-
4	-	B	B	TBBL	B	LTT	TBBTB	BTTTT
5	-	BB	-	-	T	B	BB	-
6	-	B	-	BBB	-	BBB	BBB	TB
7	B	B	-	-	-	-	-	-
8	-	-	B	-	-	B	B	B
9	-	-	-	B	T	B	BB	B
10	LLLB	L	BB	BBB	L	B	BB	-
11	-	-	BB	BBBB	BB	B	B	BT
12	-	-	-	-	-	-	BBBBT	B

Key: B = Burst, T = Termite, L = Leakage

Table 10. Number of bursts as a function of service life.

Time (years)	1	2	3	4	5	6	7	8
No. of bursts	(2)*	5	9	17	(5)	8	25	(6)

* Values in brackets indicate that number of bursts at beginning of cycles between peak also increases with increased operating life.

Burst seem to increase with age of service to a peak which recurs at irregular intervals. Whereas first peak occurs in the fourth year of operation, the second peak, which is even more severe, occurs in the seventh year. The effect of termite attack is also more felt as the service life increases. Common reasons for the reported failures include loose wire, rust wire, termite attack, immature bamboo, leaking joints and plugging effect (Slob 1985).

7 COSTS AND ECONOMICAL CONSIDERATIONS

7.1 Cost estimation

Estimation of the total cost of constructing a bamboo water supply scheme should be done at the planning stage. Such exercise will facilitate the acquisition and budgeting of the necessary funds. Also on a cost comparative measure it will help to show the competitiveness as compared to other systems constructed from conventional pipes. For the purpose of economical evaluation, the life span of a bamboo water supply scheme is taken 10 years. In the opinion of the author, cost of bamboo pipes can be determined by either of the following two methods:

a) Standard time method which will involve carrying out work studies on the different stages of making a pipe. Knowing the time involved for all operations, other material requirements, manpower requirement and wages, cost the pipes can be calculated. The main assumption of this method is that labour and overhead expenses are uniformly used over the entire year.

b) This method involves determining total relevant expenditure on pipe manufacture and dividing it by total length of pipe laid yearly. This technique seems very realistic, because the necessary labour if full time employed and overhead costs are continuously incurred even if no pipes are manufactured.

7.1.1 Manufacturing costs

There are various costs associated with different stages in the manufacture of bamboo pipe (Table 11). These figures were established in Tanzania based on this technology. In the expenditures the pipe preparation is centralized at a distance of 100 km from the green bamboo forest and 150 km from the yellow bamboo forest. If there is a reliable transport and the roads are good, it is advisable to process the culm at the site instead of using centralized facility. Preparation costs will remain basically the same, the only difference to be considered in the costs will be transport cost.

Bamboo pipes made out of two different species, the A. Alpina (green bamboo) and B. Vulgaris (yellow bamboo) are considered. The figures are expressed in Tanzanian shillings (TZS) (TZS 100 = USD 1, 1988 exchange rate). The standard pipe length is 4 m and the pipeline system is 3 km long.

Table 11. Cost of manufacturing a bamboo pipe (Lipangile 1988).

	Green bamboo TZS/4 m stem	Yellow bamboo TZS/4 m stem
1. Bamboo purchase price	4.00	8.00
2. Cutting in the forest (one person at TZS 1 230/month can cut and carry 15 stems per day)	4.00	8.00
3. Transport (average round trip at TZS 12/km for 200 stems per truck)	6.00	9.00
4. Preservation:		
a) Permethrin	5.00	5.00
b) Tar (interior and exterior)	15.00	15.00
c) CCA	7.50	7.50
d) Polythene film	20.00	20.00
e) Labour (2 persons at TZS 1 230/month for 50 stems stems per day)	2.00	2.00
f) Capital costs - construction of a 25 stem gravity feed at TZS 360 000 depreciated for 10 years	3.00	3.00
5. Boring of internal walls (2 persons at TZS 1 230/month for 50 - 60 stems/day)	2.00	2.00
6. Wire reinforcement:		
a) Wire(a 10 cm spacing i.e. 40 pieces/stem)	9.00	9.00
b) Labour	5.00	5.00
7. Sharpening end joints	2.00	2.00
8. Local storage and handling		
a) Labour	2.00	2.00
b) Capital costs	4.00	4.00
9. Supervision	8.00	8.00
10. Overhead costs (50 %)	49.25	52.75
11. Loss during transport, handling, etc. (15 %)	14.78	15.82
12. Contingency (25 %)	24.62	26.38
Total cost/stem	187.15	200.45
Total cost/m of pipe	46.78	50.11

Note to Table 11:

- In Tanzania an average of TZS 3/green bamboo is paid to the Ministry of Natural Resources and TZS 5/stem to private owners.
- Full truck loads vary from 250 to 350 stems, but it cannot be assumed that full truck loads are always achieved. The average distance to bamboo forests is 50 km for green and 75 km for yellow bamboo.
- Prices:

Permethrin	TZS 200/kg + transport
Tar	TZS 300/kg + transport
CQA	TZS 298/kg + transport
Polythene film	TZS 5/m.

7.1.2 Installation costs

Table 12 shows installation costs for a bamboo water supply scheme.

Table 12. Installation costs for a bamboo water supply scheme (Lipangile 1988).

	Cost TZS/4 stem
1. Transporting cost (from storage to the project site (average round trip TZS 12/km)	42.00
2. Labour (10 people at TZS 45.50/day for 20 metres/day)	9.10
3. Fittings - 25 % of average material cost	48.45
4. Add breakage and loss (10 %)	10.00
5. Contingency (25 %)	24.88
Total cost/stem	134.43
Total cost/m	33.61

7.1.3 Maintenance costs

The average maintenance requirement for bamboo water schemes, assuming proper design and construction is 2 - 3 pipe failures per two months. Since one pipe failure usually requires the replacement of two pipes, it is assumed that thirty spare pipes are needed per year, and that two villagers are paid monthly salaries to do all necessary repair work.

Table 13. Annual bamboo pipe maintenance costs (Lipangile 1988).

	Cost TZS/year
1. Labour (2 people at TZS 1 230/month)	14 760.00
2. Bamboo pipe replacement (30 stems per year including transport and fittings)	32 235.40
Total cost/system	17 995.40
Total cost/m	6.00

7.2 Economics of investment

With the assumptions made in Brokonsult's (1983) evaluation mission report, bamboo pipes of sizes 63 - 75 mm are found to be price competitive to polythene pipes both in terms of financial and economic annualized costs. In terms of actual present expenditure however, bamboo pipes are several time cheaper both in financial and economical terms.

The economical advantage of using bamboo pipes depends on what size of polythene pipe it would replace. The least cost option as a function of hydraulic gradient and discharge (Table 14).

Table 14. Least cost comparison of bamboo and polythene pipe as a function of gradient and required flow (Brokonsult 1983).

Flow l/s	Gradient m/km				
	20	15	10	5	2.5
0.5	P	P	P	P	G
1.0	G	G	G	G	G
2.0	P	P	G	G	G
4.0	P	P	G	G	G
8.0	P	G	G	G	G
0.5	P	P	P	P	Y
1.0	Y	Y	Y	Y	Y
2.0	P	P	Y	Y	Y
4.0	Y	Y	P	Y	Y
8.0	P	P	P	Y	Y

Note: P = Polythene
G = Green bamboo
Y = Yellow bamboo

Table 14 shows clearly the cost competitiveness of green, yellow and polythene pipes. In both cases with the flow requirement of 1 l/s, bamboo is preferred material, but for other flows the gradient becomes critical.

7.3 Cost comparison with polythene pipes

There are various costs associated in manufacture of bamboo pipes (Table 15). Those figures were established recently to have current figures as reflected in Brokonsult's (1983) evaluation mission. The standard pipe length is 4 m and the length of pipeline system is 3 km. For comparison purposes, the ex-factory prices of equivalent diameter polythene pipes are also given (Table 16).

Table 15. Breakdown on cost of bamboo pipes per running metre (TZS 200 = USD 1, 1989).

Pipe diameter mm	Bamboo price TZS/m	Cutting, storage & Transp. TZS/m	Wire cost TZS/m	Preparation cost TZS/m	Treatment cost TZS/m	Joints TZS/m	Total cost TZS/m
38	2	3	4	15	17	9	50
50	2	3	5	20	23	13	66
63	2	3	5	22	25	18	75
75	2	3	5	25	28	21	84

Table 16. Cost of polythene pipes ex-factory (TZS 200 = USD 1, 1989).

Diameter, mm	38	50	63	75
Cost, TZS/m	187	250	350	425

When all the costs are taken into account (Table 17), the bamboo and polythene pipes are price competitive. In financial costs, bamboo pipes are price competitive with polythene pipes 50 - 63 mm outside diameter. Economically they are price competitive with polythene pipes 40 - 50 mm. Both sets of costs are shown here to illustrate that shadow pricing actually has little effect on the cost advantage of bamboo pipes.

Table 17. Financial and economic cost comparison of bamboo and plastic pipes (Brokonsult 1983, modified by the author).

	Financial cost TZS/m							Economic cost TZS/m						
Description	Bamboo		Polythene mm					Bamboo		Polythene mm				
	green	yellow	32	40	50	63	75	green	yellow	32	40	50	63	75
Manufacture of bamboo/purchase of polythene	14	17	10	13	19	30	44	14	16	15	19	29	46	66
Transport, fittings and installations	14	14	16	19	23	31	43	21	21	23	27	33	42	59
Total	28	31	26	32	42	61	87	35	37	38	46	62	88	125
Maintenance costs	3	3						2	2					
Annualized costs	6	6	3	3	4	6	8	7	8	6	7	9	13	18

Notes:

- Transport costs for bamboo were based on weighted average distance to construction sites.
- Manufacture of bamboo pipes was supposed to be centralized.
- Shadow wage rate was assumed 60 % of financial wage rate in 1983 wages.
- Shadow exchange rate was assumed TZS 20 = USD 1 (i.e. 200 %) of fixed rate in March, 1983. Todays value, TZS 200 = USD 1.
- Shadow interest rate assumed 18 % whereas financial interest rate assumed 8 %.
- Overhead expenses assumed 50 % of pipe manufacturing cost in case of bamboo and none in case of plastic pipes.
- Depreciation in 10 years for bamboo pipes assumed to have a residual value of 50 % after 10 years.

Tables 15 and 17 show that transport contributes greatly to both financial and economical costs of bamboo water schemes. To minimize costs, present construction efforts should be concentrated in areas where bamboo grows. In the meantime in other regions where bamboo does not grow naturally, people could be encouraged to grow it.

With bamboo pipes, there is an immense potential of community participation in terms of material contribution in addition to labour, particularly in areas where bamboo grows.

Labour costs for maintenance can in future be significantly reduced if during construction local labourers are employed and get on-the-job training. If provided with materials, the maintenance crew (scheme attendants) could carry out minor repair works under their own village organization.

8 CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are based on two points of view, i.e. the present prevailing economic, and technological hardships.

1. Economic hardships

- From economical point of view bamboo pipes can be justified under two folds. First, while the country is struggling with economic hardships bamboo pipes can be used as a temporary measure to serve the purpose until such a time when conventional materials can be afforded. Secondly, if bamboo pipes are to be considered as a solution or rather permanent solution, then the technology has to be cheaper compared to conventional materials.

- Lack of spare parts and inadequate transport facilities restrict construction of bamboo schemes. Although direct injections of massive foreign aid into the project are not deemed desirable at the moment, aid in the form of materials which are not locally available, will still be sought. Cooperation with donor agencies to assist the project in obtaining spare parts, polythene pipes of sizes not locally made, and the like, should be enhanced.

2. Technological conclusions and recommendations

From technological point of view the following conclusions can be observed:

- Although bamboo pipes were rendering good service, they were not yet considered as engineering pipes due to uncertainty or inadequacy of necessary specifications.

- Bamboo water schemes did not seem to have a definite operating life period which makes the economic analysis complicated.

- Water schemes constructed of bamboo pipes will always need standby funds, materials and crews for the apparent operation and maintenance.

- Since micro-organisms and termites are less destructive in cool high altitude areas, bamboo schemes should concentrate to these areas to reduce high costs of preservatives.

- Pressure still remains the main problem of bamboo pipes. There is no clarity on the factors upon which pressure depends though the age factor was noted to affect the pressure. Investigation should be further carried out to establish other factors that influence field pressure performance of bamboo pipes. It is also recommended that

these factors to be fully investigated to have clear specifications which will facilitate easy understanding between bamboo cutters, water systems designers and construction teams.

- There was little improvement in the hydraulic performance of the pipes. This was a result of introducing internal lining of tar and proper nodal removal. Further investigations can be carried out to improve the hydraulic properties of the pipes. Results of the experiments indicated that Hazen-Williams roughness coefficient C-value as high as 140 can be achieved.

- Designs should always consider static pressures rather than dynamic pressures which encourages enormous water losses. Also construction should always strictly adhere to designs and any extensions should be sanctioned by the engineer. Precise supervision during survey and construction work to overcome such problems like the use of pipes which taper appreciably.

- Bamboo cutting at the forest should also be supervised to avoid cutting immature bamboos.

- The use of chemical preservatives is sensitive. Chemical handling and application should be with maximum care from the health point of view of the workers and the beneficiaries.

- In the past, in the absence of reliable preservation techniques and lack of good understanding of engineering behaviour of bamboo pipes, it did not seem very sensible to embark on large scale implementation.

- Even research was previously done casually though a lot of knowledge was achieved. It is therefore recommended that in future detailed research proposals be properly outlined as desired by institutions responsible in overseeing research activities. By adhering to such formats it is possible to achieve control of input resources, time and easy monitoring of progress.

9 REFERENCES

Brokonsult AB 1983. Evaluation Mission for Wood/Bamboo Project. Final Report to the United Republic of Tanzania. Swedish International Development Authority (SIDA), Sweden. 39 p.

Chadwick, A. and Morfett, J. 1986. Hydraulics in Civil Engineering. Allen and Unwin, London. 492 p.

Mac Conal, O. 1979. The Handbook of Pulp and Paper Technology. University of Oregon, USA. p. 40-41.

Gaur, R. 1985. Bamboo Research in India. Proceedings of the International Bamboo Workshop, Hangzhou, China. IDRC, Canada. 54 p.

Hendrikx-Jongerius, C. and de Leer, E. 1986. Reaction Between Aqueous Chlorine and Bamboo. Report prepared for the Dutch Ministry for Foreign Affairs and the Wood and Bamboo Project, Tanzania. Delft University of Technology. The Netherlands. 22 p.

van der Heuvel, K. 1983. Wood and Bamboo for Rural Water Supply. A Tanzanian Initiative for Self Reliance. Delft University Press, The Netherlands. 76 p.

Hosia, L. 1988. Hydraulics. Lecture Notes. Postgraduate Course in Water Supply and Sanitation. Tampere University of Technology. Tampere, Finland. p. 1-12.

Huisman, L., Hofkes, E., Sunderesan, B., de Azevedo Netto, J. and Lanoix, J. 1987. Small Community Water Supplies. IRC (International Reference Centre). Technical Paper Series No. 18. The Hague, The Netherlands. 442 p.

Hukka, J. 1989. Urban Water Supply and Sanitation; Water Treatment. Lecture Notes. Postgraduate Course in Water Supply and Sanitation. Tampere University of Technology. Tampere, Finland. 145 p.

Iikkanen, M. 1989. Urban Water Supply and Sanitation, Networks. Lecture Notes. Postgraduate Course in Water Supply and Sanitation. Tampere University of Technology. Tampere, Finland. 128 p.

Iringili, M. and Mahungu, D. 1979. Bamboo Pipes Project Report. Department of Mechanical Engineering, University of Dar es Salaam. Tanzania. 12 p.

Jacobs, P. and Lindburg, N. 1978. Engineering Report on Woodstave Pipes and Tanks and Bamboo Pipes. Appendix 1. Iringa, Tanzania. 36 p.

Johan, L. 1979. From Aldrin/Chlordane towards CCA. An Internal Report on Field Trials with CCA Impregnation Methods for Bamboo Pipes. Iringa, Tanzania. 19 p.

Kayombo, W. 1981. Pipe Materials in Transmission Mains. M.Sc. Thesis. Tampere University of Technology. Tampere, Finland. 65 p.

Liese, W. 1986. Bamboo - Biology, Silvics Properties, Utilization. Eischborn, Germany. p. 19.

Lipangile, T. and Landman, C. 1976. Feasibility Study Report on the Use of Wood and Bamboo in Water Supply. Mwanza, Tanzania. 24 p.

Lipangile, T. 1984. Wood and Bamboo Technology. Paper presented at the Rural Hydraulic Development Conference for African/Caribbean, Pacific and Mediterranean Basin Countries. Marseilles, France. 18 p.

Lipangile, T. 1985. Bamboo Water Pipes. Waterlines. Vol. 3, no. 2. p. 18-20.

Lipangile, T. 1988. Wood and Bamboo as an Appropriate Technology. Iringa, Tanzania. 125 p. (Unpublished draft).

Lipangile, T. 1990. Wood and Bamboo as an Appropriate Technology. Iringa, Tanzania. 142 p. (Unpublished final draft).

Ministry of Water. 1986. Water Supply Design Manual. Dar es Salaam, Tanzania. 27 p.

Ministry of Water. 1988. Workshop on National Strategies for Operation and Maintenance of Rural Water Supply Schemes. Morogoro, Tanzania. 26 p.

Morgan, J. 1974. Water Pipes from Bamboo in Mezan Teferi, Ethiopia. Appropriate Technology. Vol. 1, no. 2. p. 8-10.

Msimbe, L. 1984. Wood/Bamboo Technology Development. Paper presented at the Annual Regional Water Engineer's Conference. Tanga, Tanzania. 23 p.

Purushotham, A., Singh, S. and Nigham, P. 1965. Preservation Treatment of Green Bamboo by the Diffusion Process. Journal of the Timber Development Association. Vol. 11, no. 4. p. 8-11.

Sharma, Y. 1980. Bamboo in the Asian Pacific Region. Proceedings of the Workshop on Bamboo Research in Asia. Singapore. p. 23-34.

Slob, J. 1985. Wood-Bamboo Project. Report Prepared for the Government of the Netherlands. Dar es Salaam, Tanzania. 23 p.

Suhan, G. 1979. Hydraulic Properties of Bamboo Pipes. Consulting Report No. CW 79.1. Faculty of Engineering, University of Dar es Salaam, Tanzania. 10 p.

Twort, A., Law, F. and Crowly, F. 1985. Water Supply. AISE. Edward Arnold Ltd, London. p. 371-378.

United Nations. 1972. Use of Bamboo and Reeds in Building Construction Engineering Report No. ST/SOA/113. p. 1-3.

VITA. 1975. Village Technology Handbook. Water Flow Design Charts. USA. p. 89-90.

World Bank. 1977. Rural Water Supply Sector Study. United Republic of Tanzania, Wood Piping. Annex 21. Dar es Salaam, Tanzania. p. 20-21.

Detailed results of the pipe friction experiment.

* Results, which for some experimental shortcomings are obviously meaningless and thus have not been considered, appear in brackets.

* All calculations are based on theoretical considerations given in chapter 3, section 3.3.1.

APPENDIX 1 (2/8)

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PIPE NO. 1

D= 0.0601 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS    FRICTION LOSSES     FRICTION FACTORS      MANNING    n          HAZEN WILLIAMS C   V    REYNOLDS
      *10^-3   1     2     3     4     1-2   2-3   3-4   1-2   2-3   3-4    1-2    2-3     3-4     1-2    2-3   3-4
  m   m^3/s    m     m     m     m                                        ( *10^-3 s/m^(1/3) )                      m/s
======================================================================================================================================

0.175 1.187 1.698 1.690 1.677 1.671 0.008 0.013 0.006 0.090 0.146 0.067 16.801 21.417 14.550  71.5  55.0  83.5 0.418 27941.6
The flow is Turbulent

0.185 1.623 1.678 1.670 1.660 1.640 0.008 0.010 0.020 0.048 0.060 0.120 12.287 13.737 19.427  97.8  86.7  59.6 0.572 38207.2
The flow is Turbulent

0.193 2.032 1.595 1.570 1.550 1.522 0.025 0.020 0.028 0.096 0.077 0.107 17.346 15.515 18.358  66.2  74.7  62.3 0.716 47841.6
The flow is Turbulent

0.200 2.437 1.358 1.320 1.290 1.250 0.038 0.030 0.040 0.101 0.080 0.107 17.837 15.849 18.301  63.3  71.9  61.6 0.859 57358.6
The flow is Turbulent

0.208 2.954 1.310 1.260 1.218 1.158 0.050 0.042 0.060 0.091 0.076 0.109 16.880 15.471 18.491  66.2  72.7  60.0 1.041 69527.7
The flow is Turbulent

0.210 3.092 1.302 1.240 1.190 1.120 0.062 0.050 0.070 0.103 0.083 0.116 17.954 16.123 19.077  61.7  69.3  57.8 1.090 72791.4
The flow is Turbulent

0.208 2.954 1.318 1.262 1.216 1.158 0.056 0.046 0.058 0.102 0.083 0.105 17.864 16.191 18.180  62.2  69.2  61.1 1.041 69527.7
The flow is Turbulent

0.200 2.437 1.356 1.318 1.292 1.250 0.038 0.026 0.042 0.101 0.069 0.112 17.837 14.755 18.753  63.3  77.7  60.0 0.859 57358.6
The flow is Turbulent

0.193 2.032 1.594 1.568 1.550 1.520 0.026 0.018 0.030 0.100 0.069 0.115 17.690 14.719 19.002  64.8  79.0  60.0 0.716 47841.6
The flow is Turbulent

0.185 1.623 1.678 1.670 1.660 1.638 0.008 0.010 0.022 0.048 0.060 0.132 12.287 13.737 20.375  97.8  86.7  56.6 0.572 38207.2
The flow is Turbulent

0.175 1.187 1.700 1.692 1.686 1.678 0.008 0.006 0.008 0.090 0.067 0.090 16.801 14.550 16.801  71.5  83.5  71.5 0.418 27941.6
The flow is Turbulent

0.210 3.092 1.300 1.240 1.188 1.118 0.060 0.052 0.070 0.099 0.086 0.116 17.662 16.442 19.077  62.8  67.8  57.8 1.090 72791.4
The flow is Turbulent


PIPE NO. 2

D= 0.0576 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS    FRICTION LOSSES     FRICTION FACTORS      MANNING    n          HAZEN WILLIAMS C   V    REYNOLDS
      *10^-3   1     2     3     4     1-2   2-3   3-4   1-2   2-3   3-4    1-2    2-3     3-4     1-2    2-3   3-4
  m   m^3/s    m     m     m     m                                        ( *10^-3 s/m^(1/3) )                      m/s
======================================================================================================================================

0.185 1.623 1.650 1.648 1.646 1.638 0.002 0.002 0.008 (0.010)(0.010) 0.039 (5.485)(5.485) 10.971 (231.2)(231.2) 109.4 0.623 39865.5
The flow is Turbulent

0.193 2.032 1.452 1.450 1.448 1.440 0.002 0.002 0.008 (0.006)(0.006)(0.025)(4.381)(4.381)(8.761)(289.5)(289.5)(136.9) 0.780 49918.1
The flow is Turbulent

0.200 2.437 1.124 1.120 1.104 1.082 0.004 0.016 0.022 (0.009) 0.034 0.047 (5.167) 10.335 12.118 (238.7) 112.9  95.1 0.935 59848.1
The flow is Turbulent

0.208 2.954 1.076 1.060 1.032 1.005 0.016 0.028 0.027 (0.023) 0.041 0.040 (8.526) 11.279 11.075 (136.9) 101.2 103.2 1.134 72545.4
The flow is Turbulent

0.210 3.092 1.068 1.040 1.004 0.980 0.028 0.036 0.024 (0.037) 0.048 0.032 (10.773) 12.215 9.974 (105.9)  92.5 (115.1) 1.187 75950.7
The flow is Turbulent

0.208 2.954 1.075 1.060 1.030 1.002 0.015 0.030 0.028 (0.022) 0.044 0.041 (8.255) 11.674 11.279 (141.7)  97.5 101.2 1.134 72545.4
The flow is Turbulent

0.210 3.092 1.066 1.050 1.002 0.980 0.016 0.048 0.022 (0.021) 0.064 0.029 (8.144) 14.105 9.549 (143.3)  79.2 (120.7) 1.187 75950.7
The flow is Turbulent
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PIPE NO. 3

D= 0.0518 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s
 Hvt    Q     PIEZOMETER READINGS   FRICTION LOSSES   FRICTION FACTORS     MANNING    n        HAZEN WILLIAMS C  V    REYNOLDS
     *10^-3   1     2     3     4    1-2   2-3   3-4   1-2   2-3   3-4   1-2     2-3     3-4   1-2   2-3   3-4
  m   m^3/s   m     m     m     m                                       ( *10^-3 s/m^(1/3) )                     m/s
=============================================================================================================================

0.185 1.623 1.732 1.720 1.710 1.672 0.012 0.010 0.038 0.034(0.029) 0.109 10.124(9.242)18.016 116.1 (128.2) 62.3 0.770 44329.2
The flow is Turbulent

0.193 2.032 1.635 1.610 1.600 1.538 0.025 0.010 0.062 0.046(0.018) 0.113 11.670(7.381) 18.379  97.8 (160.5) 59.9 0.964 55507.3
The flow is Turbulent

0.200 2.437 1.540 1.498 1.478 1.376 0.042 0.020 0.102 0.053(0.025) 0.129 12.617(8.706) 19.662  88.6 (132.3) 54.9 1.156 66549.2
The flow is Turbulent

0.208 2.954 1.466 1.420 1.382 1.256 0.046 0.038 0.126 0.040(0.033) 0.109 10.893(9.900) 18.028 102.3 (113.4) 59.4 1.402 80668.2
The flow is Turbulent

0.210 3.092 1.322 1.274 1.228 1.088 0.048 0.046 0.140 0.038(0.036) 0.110 10.628 (10.404) 18.151 104.7(107.1) 58.7 1.467 84454.9
The flow is Turbulent

0.208 2.954 1.468 1.422 1.380 1.254 0.046 0.042 0.126 0.040(0.036) 0.109 10.893 (10.408) 18.028 102.3 (107.5) 59.4 1.402 80668.2
The flow is Turbulent

0.200 2.437 1.542 1.508 1.480 1.378 0.034 0.028 0.102 0.043 (0.035) 0.129 11.352 (10.302) 19.662  99.4 (110.3) 54.9 1.156 66549.2
The flow is Turbulent

0.193 2.032 1.638 1.615 1.598 1.536 0.023 0.017 0.062 0.042(0.031) 0.113 11.194 (9.624) 18.379 102.4 (120.5) 59.9 0.964 55507.3
The flow is Turbulent

0.185 1.623 1.718 1.704 1.698 1.656 0.014 0.006 0.042 0.040 (0.017) 0.120 10.936 (7.159)18.941 106.9 (168.9) 59.0 0.770 44329.2
The flow is Turbulent

0.210 3.092 1.320 1.272 1.230 1.090 0.048 0.042 0.140 0.038(0.033) 0.110 10.628 (9.942)18.151 104.7 (112.5) 58.7 1.467 84454.9
The flow is Turbulent
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PIPE NO. 4

D= 0.0614 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s
 Hvt    Q     PIEZOMETER READINGS   FRICTION LOSSES   FRICTION FACTORS     MANNING  . n        HAZEN WILLIAMS C  V    REYNOLDS
     *10^-3   1     2     3     4    1-2   2-3   3-4   1-2   2-3   3-4   1-2     2-3     3-4   1-2   2-3   3-4
  m   m^3/s   m     m     m     m                                       ( *10^-3 s/m^(1/3) )                     m/s
=============================================================================================================================

0.175 1.187 1.890 1.886 1.882 1.876 0.004 0.004 0.006 0.050 0.050 0.075 12.578 12.578 15.405  98.3  98.3  79.0 0.401 27350.0
The flow is Turbulent

0.185 1.623 1.810 1.806 1.800 1.786 0.004 0.006 0.014 (0.027) 0.040 0.094 (9.198) 11.266 17.208 (134.4)108.0  68.3 0.548 37398.3
The flow is Turbulent

0.193 2.032 1.650 1.640 1.620 1.600 0.010 0.020 0.020 0.043 0.085 0.085 11.615 16.426 16.426 102.6  70.6  70.6 0.686 46828.7
The flow is Turbulent

0.200 2.437 1.590 1.570 1.550 1.520 0.020 0.020 0.030 0.059 0.059 0.089 13.701 13.701 16.780  84.6  84.6  68.0 0.823 56144.1
The flow is Turbulent

0.208 2.954 1.410 1.378 1.340 1.298 0.032 0.038 0.042 0.065 0.077 0.085 14.297 15.580 16.379  79.6  72.5  68.7 0.998 68055.6
The flow is Turbulent

0.210 3.092 1.390 1.358 1.325 1.282 0.032 0.033 0.043 0.059 0.061 0.079 13.656 13.868 15.830  83.3  81.9  71.0 1.044 71250.2
The flow is Turbulent

0.208 2.954 1.398 1.380 1.338 1.290 0.018 0.042 0.048 (0.036) 0.085 0.097 (10.723) 16.379 17.510 (108.6) 68.7  63.9 0.998 68055.6
The flow is Turbulent

0.200 2.437 1.600 1.574 1.550 1.520 0.026 0.024 0.030 0.077 0.071 0.089 15.621 15.008 16.780  73.4  76.7  68.0 0.823 56144.1
The flow is Turbulent

0.193 2.032 1.650 1.642 1.620 1.602 0.008 0.022 0.018 (0.034) 0.094 0.077 (10.389) 17.228 15.583 (115.8) 67.0  74.7 0.686 46828.7
The flow is Turbulent

0.185 1.623 1.808 1.806 1.800 1.785 0.002 0.006 0.015 (0.013) 0.040 0.100 (6.504) 11.266 17.812 (195.4) 108.0  65.8 0.548 37398.3
The flow is Turbulent

0.175 1.187 1.892 1.886 1.880 1.874 0.006 0.006 0.006 0.075 0.075 0.075 15.405 15.405 15.405  79.0  79.0  79.0 0.401 27350.0
The flow is Turbulent

0.210 3.092 1.390 1.360 1.326 1.280 0.030 0.034 0.046 0.055 0.063 0.085 13.222 14.076 16.373  86.3  80.6  68.5 1.044 71250.2
The flow is Turbulent
```

```
PIPE NO. 5

D= 0.0616 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS   FRICTION LOSSES     FRICTION FACTORS      MANNING    n          HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3   1     2     3     4    1-2   2-3   3-4   1-2   2-3   3-4   1-2    2-3    3-4    1-2   2-3   3-4
  m   m^3/s    m     m     m     m                                      ( *10^-3 s/m^(1/3) )                      m/s
==================================================================================================================================

0.175 1.187 1.828 1.816 1.810 1.776 0.012 0.006 0.034 0.152 0.076 0.432 21.975 15.539 36.989  53.9   78.3   30.7 0.398 27261.2
The flow is Turbulent

0.185 1.623 1.850 1.820 1.800 1.740 0.030 0.020 0.060 0.204 0.136 0.407 25.410 20.747 35.935  44.9   55.9   30.9 0.545 37276.9
The flow is Turbulent

0.193 2.032 1.612 1.562 1.540 1.450 0.050 0.022 0.090 0.217 0.095 0.390 26.198 17.378 35.148  42.7   66.5   31.1 0.682 46676.6
The flow is Turbulent

0.200 2.437 1.590 1.512 1.480 1.350 0.078 0.032 0.130 0.235 0.096 0.392 27.292 17.481 35.234  40.2   65.1   30.5 0.818 55961.8
The flow is Turbulent

0.208 2.954 1.510 1.420 1.360 1.210 0.090 0.060 0.150 0.185 0.123 0.308 24.185 19.747 31.223  45.1   56.2   34.3 0.991 67834.6
The flow is Turbulent

0.164 0.798 1.980 1.976 1.975 1.954 0.004 0.001 0.021 0.112 (0.028) 0.589 18.861 (9.431) 43.217  65.6 (138.6)  26.8 0.268 18337.6
The flow is Turbulent

0.200 2.437 1.600 1.510 1.484 1.352 0.090 0.026 0.132 0.271 0.078 0.398 29.317 15.757 35.504  37.2   72.8   30.3 0.818 55961.8
The flow is Turbulent

0.193 2.032 1.610 1.560 1.540 1.450 0.050 0.020 0.090 0.217 0.087 0.390 26.198 16.569 35.148  42.7   70.0   31.1 0.682 46676.6
The flow is Turbulent

0.185 1.623 1.851 1.820 1.800 1.740 0.031 0.020 0.060 0.211 0.136 0.407 25.830 20.747 35.935  44.1   55.9   30.9 0.545 37276.9
The flow is Turbulent

0.175 1.187 1.830 1.816 1.812 1.775 0.014 0.004 0.037 0.178 0.051 0.470 23.736 12.687 38.587  49.6   97.5   29.3 0.398 27261.2
The flow is Turbulent


PIPE NO. 6

D= 0.0541 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS   FRICTION LOSSES     FRICTION FACTORS      MANNING    n          HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3   1     2     3     4    1-2   2-3   3-4   1-2   2-3   3-4   1-2    2-3    3-4    1-2   2-3   3-4
  m   m^3/s    m     m     m     m                                      ( *10^-3 s/m^(1/3) )                      m/s
==================================================================================================================================

0.175 1.187 1.890 1.880 1.872 1.861 0.010 0.008 0.011 0.066 0.053 0.073 14.190 12.692 14.883  83.6   94.3   79.4 0.516 31040.5
The flow is Turbulent

0.185 1.623 1.558 1.550 1.541 1.528 0.008 0.009 0.013 (0.028)(0.032) 0.046 (9.282)(9.845) 11.832 (129.0)(121.0)  99.2 0.706 42444.6
The flow is Turbulent

0.193 2.032 1.480 1.468 1.450 1.321 0.012 0.018 0.129 (0.027)(0.041) 0.292 (9.079)(11.119) 29.766 (129.7)(104.2)  36.0 0.884 53147.5
The flow is Turbulent

0.200 2.437 1.420 1.400 1.262 1.231 0.020 0.138 0.031 (0.031)(0.217) 0.049 (9.776)(25.679) 12.171 (118.0) (41.6)  93.2 1.060 63720.0
The flow is Turbulent

0.208 2.954 1.240 1.215 1.192 1.164 0.025 0.023 0.028 (0.027)(0.025)(0.030)(9.017)(8.648)(9.542)(126.8)(132.7)(119.3) 1.285 77238.7
The flow is Turbulent

0.210 3.092 1.180 1.140 1.126 1.090 0.040 0.014 0.036 (0.039)(0.014)(0.035)(10.894)(6.445)(10.335)(103.0)(181.6)(109.1) 1.345 80864.4
The flow is Turbulent

0.208 2.954 1.240 1.215 1.192 1.164 0.025 0.023 0.028 (0.027)(0.025)(0.030)(9.017)(8.648)(9.542)(126.8)(132.7)(119.3) 1.285 77238.7
The flow is Turbulent

0.200 2.437 1.420 1.400 1.261 1.232 0.020 0.139 0.029 (0.031) 0.219 0.046 (9.776) 25.772 11.772 (118.0)  41.4   96.6 1.060 63720.0
The flow is Turbulent

0.193 2.032 1.480 1.467 1.452 1.324 0.013 0.015 0.128 (0.029) 0.034 0.290 (9.449) 10.150 29.651 (124.2) 115.0  36.1 0.884 53147.5
The flow is Turbulent

0.185 1.623 1.560 1.550 1.528 1.520 0.010 0.022 0.008 (0.035) 0.078 (0.028)(10.377) 15.392 (9.282)(114.3)  74.7 (129.0) 0.706 42444.6
The flow is Turbulent

0.210 3.092 1.150 1.134 1.120 1.034 0.016 0.014 0.086 (0.016)(0.014) 0.084 (6.890)(6.445) 15.974 (169.0)(181.6)  68.1 1.345 80864.4
The flow is Turbulent
```

PIPE NO. 7

```
D= 0.0648 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt     Q      PIEZOMETER READINGS    FRICTION LOSSES    FRICTION FACTORS     MANNING    n         HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3    1     2     3     4     1-2   2-3   3-4   1-2   2-3   3-4   1-2     2-3     3-4     1-2   2-3   3-4
  m   m^3/s     m     m     m     m                                          ( *10^-3 s/m^(1/3) )                      m/s
=====================================================================================================================================

0.175 1.187 1.720 1.718 1.715 1.712 0.002 0.003 0.003 (0.033) 0.049 0.049 (10.268) 12.576 12.576 (124.0) 99.6  99.6 0.360 25915.0
The flow is Turbulent

0.185 1.623 1.650 1.646 1.640 1.630 0.004 0.006 0.010 (0.035) 0.052 0.087 (10.620) 13.007 16.792 (116.7) 93.7  71.1 0.492 35436.0
The flow is Turbulent

0.193 2.032 1.598 1.590 1.580 1.570 0.008 0.010 0.010 (0.045) 0.056 0.056 (11.994) 13.410 13.410 (100.5) 89.1  89.1 0.616 44371.6
The flow is Turbulent

0.200 2.437 1.514 1.500 1.488 1.464 0.014 0.012 0.024 0.054 0.047 0.093 13.234 12.253 17.328  89.0  96.8  66.6 0.739 53198.3
The flow is Turbulent

0.208 2.954 1.378 1.364 1.334 1.298 0.014 0.030 0.036 (0.037) 0.079 0.095 (10.918) 15.983 17.508 (107.9) 71.5  64.8 0.896 64484.8
The flow is Turbulent

0.210 3.092 1.130 1.120 1.082 1.050 0.010 0.038 0.032 (0.024) 0.092 0.077 (8.814) 17.181 15.767 (135.5) 65.9  72.3 0.938 67511.8
The flow is Turbulent

0.208 2.954 1.380 1.365 1.335 1.300 0.015 0.030 0.035 (0.040) 0.079 0.092 (11.301) 15.983 17.263 (104.0) 71.5  65.8 0.896 64484.8
The flow is Turbulent

0.200 2.437 1.510 1.496 1.485 1.463 0.014 0.011 0.022 0.054 (0.043) 0.085 13.234 (11.731) 16.590  89.0 (101.4) 69.8 0.739 53198.3
The flow is Turbulent

0.193 2.032 1.600 1.590 1.580 1.574 0.010 0.010 0.006 0.056 0.056 (0.033) 13.410 13.410 (10.388)  89.1  89.1 (117.3) 0.616 44371.6
The flow is Turbulent

0.185 1.623 1.649 1.645 1.643 1.632 0.004 0.002 0.011 (0.035)(0.017) 0.096 (10.620)(7.510) 17.611 (116.7)(169.6) 67.6 0.492 35436.0
The flow is Turbulent

0.210 3.092 1.128 1.118 1.084 1.048 0.010 0.034 0.036 (0.024) 0.082 0.087 (8.814) 16.252 16.723 (135.5) 70.0  67.8 0.938 67511.8
The flow is Turbulent
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PIPE NO. 8

```
D= 0.0559 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2's

 Hvt     Q      PIEZOMETER READINGS    FRICTION LOSSES    FRICTION FACTORS     MANNING    n         HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3    1     2     3     4     1-2   2-3   3-4   1-2   2-3   3-4   1-2     2-3     3-4     1-2   2-3   3-4
  m   m^3's     m     m     m     m                                          ( *10^-3 s/m^(1/3) )                      m/s
=====================================================================================================================================

0.193 2.032 1.310 1.294 1.280 1.262 0.016 0.014 0.018 (0.043)(0.037) 0.048 (11.439)(10.700) 12.133 (101.9)(109.5) 95.6 0.828 51436.1
The flow is Turbulent

0.200 2.437 1.190 1.168 1.151 1.124 0.022 0.017 0.027 (0.041)(0.032) 0.050 (11.188)(9.835) 12.394 (102.9)(118.2) 92.1 0.993 61668.2
The flow is Turbulent

0.208 2.954 1.100 1.064 1.048 1.020 0.036 0.016 0.028 0.045 (0.020)(0.035) 11.807 (7.871)(10.413)  95.6 (148.1)(109.5) 1.204 74751.6
The flow is Turbulent

0.210 3.092 1.040 1.000 0.960 0.940 0.040 0.040 0.020 0.046 0.046 (0.023) 11.887 11.887 (8.406)  94.5  94.5 (137.4) 1.260 78260.5
The flow is Turbulent

0.208 2.954 1.140 1.066 1.040 1.020 0.074 0.026 0.020 0.093 (0.033)(0.025) 16.928 (10.034)(8.800)  64.8 (113.9)(131.3) 1.204 74751.6
The flow is Turbulent

0.200 2.437 1.189 1.162 1.148 1.122 0.027 0.014 0.026 0.050 (0.026) 0.048 12.394 (8.925) 12.163  92.1 (131.3)  94.0 0.993 61668.2
The flow is Turbulent

0.193 2.032 1.314 1.298 1.278 1.262 0.016 0.020 0.016 (0.043) 0.053 0.043 (11.439) 12.789 11.439 (101.9)  90.3 101.9 0.828 51436.1
The flow is Turbulent

0.185 1.623 1.492 1.480 1.462 1.450 0.012 0.018 0.012 0.050 0.075 0.050 12.405 15.193 12.405  95.1  76.4  95.1 0.661 41077.9
The flow is Turbulent

0.210 3.092 1.035 0.998 0.976 0.940 0.037 0.022 0.036 0.043 (0.025) 0.041 11.433 (8.816) 11.277  98.6 (130.6) 100.1 1.260 78260.5
The flow is Turbulent
```

```
PIPE NO. 9

D= 0.0575 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt     Q      PIEZOMETER READINGS   FRICTION LOSSES    FRICTION FACTORS     MANNING    n         HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3    1     2     3     4     1-2   2-3   3-4   1-2   2-3   3-4   1-2     2-3     3-4    1-2   2-3   3-4
  m    m^3/s    m     m     m     m                                       ( *10^-3 s/m^(1/3) )                      m/s
=================================================================================================================================

0.175 1.187 1.740 1.736 1.730 1.724 0.004 0.006 0.006 (0.036) 0.054 0.054 (10.558) 12.931 12.931 (116.8)  93.9   93.9 0.457 29205.1
The flow is Turbulent

0.185 1.623 1.575 1.570 1.560 1.550 0.005 0.010 0.010 (0.024) 0.048 0.048 (8.633) 12.209 12.209 (141.6)  97.4   97.4 0.625 39934.9
The flow is Turbulent

0.193 2.032 1.450 1.438 1.425 1.410 0.012 0.013 0.015 (0.037)(0.040) 0.046 (10.681)(11.117) 11.942 (110.5)(105.8)  98.0 0.783 50004.9
The flow is Turbulent

0.200 2.437 1.360 1.340 1.320 1.296 0.020 0.020 0.024 0.043 0.043 0.051 11.501 11.501 12.599 100.6 100.6  91.1 0.938 59952.2
The flow is Turbulent

0.208 2.954 1.228 1.190 1.160 1.130 0.038 0.030 0.030 0.055 0.044 0.044 13.078 11.621 11.621  86.2  97.9  97.9 1.137 72671.5
The flow is Turbulent

0.210 3.092 1.130 1.094 1.064 1.030 0.036 0.030 0.034 0.048 0.040 0.045 12.159 11.099 11.816  92.9 102.5  95.8 1.191 76082.8
The flow is Turbulent

0.208 2.954 1.230 1.190 1.160 1.130 0.040 0.030 0.030 0.058 0.044 0.044 13.418 11.621 11.621  83.8  97.9  97.9 1.137 72671.5
The flow is Turbulent

0.200 2.437 1.360 1.343 1.322 1.300 0.017 0.021 0.022 0.036 0.045 0.047 10.603 11.785 12.062 109.8  97.9  95.5 0.938 59952.2
The flow is Turbulent

0.193 2.032 1.454 1.440 1.425 1.414 0.014 0.015 0.011 0.043 0.046 (0.034) 11.537 11.942 (10.226) 101.7  98.0 (115.8) 0.783 50004.9
The flow is Turbulent

0.185 1.623 1.575 1.570 1.561 1.552 0.005 0.009 0.009 (0.024)(0.043)(0.043)(8.633)(11.582)(11.582)(141.6)(103.1) (103.1) 0.625 39934.9
The flow is Turbulent

0.175 1.187 1.750 1.735 1.726 1.718 0.015 0.009 0.008 0.135 0.081 0.072 20.446 15.838 14.932  57.2  75.4  80.3 0.457 29205.1
The flow is Turbulent

0.210 3.092 1.130 1.090 1.060 1.034 0.040 0.030 0.026 0.053 (0.040) 0.034 12.817 (11.099)(10.333)  87.8 (102.5)(110.8) 1.191 76082.8
The flow is Turbulent

PIPE NO. 10

D= 0.0558 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt     Q      PIEZOMETER READINGS   FRICTION LOSSES    FRICTION FACTORS     MANNING    n         HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3    1     2     3     4     1-2   2-3   3-4   1-2   2-3   3-4   1-2     2-3     3-4    1-2   2-3   3-4
  m    m^3/s    m     m     m     m                                       ( *10^-3 s/m^(1/3) )                      m/s
=================================================================================================================================

0.164 0.798 1.980 1.964 1.960 1.950 0.016 0.004 0.010 0.274 0.068 0.171 28.979 14.489 22.910  40.2  85.0  51.8 0.327 20243.6
The flow is Turbulent

0.175 1.187 1.884 1.850 1.835 1.820 0.034 0.015 0.015 0.263 0.116 0.116 28.415 18.874 18.874  39.8  61.9  61.9 0.485 30094.8
The flow is Turbulent

0.185 1.623 1.845 1.778 1.750 1.720 0.067 0.028 0.030 0.278 0.116 0.124 29.171 18.858 19.520  37.7  60.4  58.2 0.664 41151.5
The flow is Turbulent

0.193 2.032 1.720 1.610 1.568 1.524 0.110 0.042 0.044 0.291 0.111 0.116 29.851 18.445 18.879  36.2  60.8  59.3 0.831 51528.3
The flow is Turbulent

0.200 2.437 1.650 1.500 1.435 1.364 0.150 0.065 0.071 0.276 0.119 0.130 29.075 19.139 20.003  36.7  57.6  54.9 0.996 61778.7
The flow is Turbulent

0.208 2.954 1.598 1.374 1.278 1.174 0.224 0.096 0.104 0.280 0.120 0.130 29.311 19.189 19.972  35.8  56.5  54.2 1.208 74885.5
The flow is Turbulent

0.210 3.092 1.546 1.306 1.200 1.098 0.240 0.106 0.102 0.274 0.121 0.116 28.980 19.259 18.892  36.1  56.1  57.3 1.265 78400.8
The flow is Turbulent

0.208 2.954 1.598 1.374 1.278 1.174 0.224 0.096 0.104 0.280 0.120 0.130 29.311 19.189 19.972  35.8  56.5  54.2 1.208 74885.5
The flow is Turbulent

0.200 2.437 1.650 1.500 1.436 1.365 0.150 0.064 0.071 0.276 0.118 0.130 29.075 18.991 20.003  36.7  58.1  54.9 0.996 61778.7
The flow is Turbulent

0.193 2.032 1.722 1.614 1.569 1.520 0.108 0.045 0.049 0.285 0.119 0.129 29.578 19.093 19.923  36.5  58.6  55.9 0.831 51528.3
The flow is Turbulent

0.185 1.623 1.846 1.780 1.750 1.722 0.066 0.030 0.028 0.273 0.124 0.116 28.953 19.520 18.858  38.0  58.2  60.4 0.664 41151.5
The flow is Turbulent

0.175 1.187 1.886 1.854 1.840 1.832 0.032 0.014 0.008 0.248 0.108 0.062 27.567 18.234 13.784  41.1  64.3  86.9 0.485 30094.8
The flow is Turbulent
```

PIPE NO. 11

```
D= 0.0592 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS    FRICTION LOSSES     FRICTION FACTORS      MANNING    n            HAZEN WILLIAMS C   V    REYNOLDS
      *10^-3   1      2     3     4    1-2   2-3   3-4   1-2   2-3   3-4    1-2      2-3      3-4     1-2   2-3   3-4
  m   m^3/s    m      m     m     m                                        ( *10^-3 s/m^(1/3) )                          m/s
===================================================================================================================================

0.175 1.187 1.914 1.912 1.910 1.905 0.002 0.002 0.005(0.021)(0.021) 0.052(8.069)(8.069) 12.759 (157.3)(157.3)  95.9 0.431 28366.4
The flow is Turbulent

0.185 1.623 1.510 1.505 1.500 1.494 0.005 0.005 0.006(0.028)(0.028)(0.033)(9.331)(9.331)(10.221)(131.2)(131.2)(118.9) 0.590 38788.1
The flow is Turbulent

0.193 2.032 1.470 1.464 1.450 1.440 0.006 0.014 0.010(0.021) 0.050(0.036)(8.163) 12.469 (10.538)(148.8)  94.2(113.0) 0.738 48568.9
The flow is Turbulent

0.200 2.437 1.380 1.370 1.350 1.330 0.010 0.020 0.020(0.025) 0.049 0.049(8.790) 12.430 12.430(135.4)  93.1   93.1 0.885 58230.6
The flow is Turbulent

0.208 2.954 1.238 1.225 1.198 1.170 0.013 0.027 0.028(0.022) 0.045 0.047(8.268) 11.915 12.134(142.5)  96.0   94.1 1.073 70584.7
The flow is Turbulent

0.210 3.092 1.198 1.170 1.150 1.120 0.028 0.020 0.030 0.043 0.031 0.046 11.590 9.795 11.996  98.6 118.2   95.0 1.123 73898.0
The flow is Turbulent

0.208 2.954 1.238 1.225 1.198 1.170 0.013 0.027 0.028(0.022) 0.045 0.047(8.268) 11.915 12.134(142.5)  96.0   94.1 1.073 70584.7
The flow is Turbulent

0.200 2.437 1.380 1.370 1.350 1.330 0.010 0.020 0.020(0.025) 0.049 0.049(8.790) 12.430 12.430(135.4)  93.1   93.1 0.885 58230.6
The flow is Turbulent

0.193 2.032 1.470 1.465 1.450 1.444 0.005 0.015 0.006(0.018) 0.053 0.021(7.452) 12.906 8.163(164.2)  90.7(148.8) 0.738 48568.9
The flow is Turbulent

0.185 1.623 1.514 1.508 1.500 1.490 0.006 0.008 0.010(0.033) 0.045 0.056(10.221) 11.802 13.195(118.9) 101.8   90.2 0.590 38788.1
The flow is Turbulent

0.210 3.092 1.200 1.174 1.154 1.120 0.026 0.020 0.034(0.040) 0.031 0.052(11.168) 9.795 12.771(102.6)(118.2)  88.8 1.123 73898.0
The flow is Turbulent
```

PIPE NO. 12

```
D= 0.0629 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS    FRICTION LOSSES     FRICTION FACTORS      MANNING    n            HAZEN WILLIAMS C   V    REYNOLDS
      *10^-3   1      2     3     4    1-2   2-3   3-4   1-2   2-3   3-4    1-2      2-3      3-4     1-2   2-3   3-4
  m   m^3/s    m      m     m     m                                        ( *10^-3 s/m^(1/3) )                          m/s
===================================================================================================================================

0.175 1.187 1.662 1.660 1.655 1.650 0.002 0.005 0.005(0.028) 0.070 0.070(9.485) 14.997 14.997(134.1)  81.8   81.8 0.382 26697.8
The flow is Turbulent

0.185 1.623 1.575 1.568 1.562 1.550 0.007 0.006 0.012 0.053(0.045) 0.090 12.977(12.015) 16.991   93.3(101.3)  69.7 0.522 36506.4
The flow is Turbulent

0.193 2.032 1.380 1.370 1.364 1.350 0.010 0.006 0.014 0.048(0.029) 0.067 12.387(9.595) 14.657   96.3(126.9)  80.3 0.654 45711.9
The flow is Turbulent

0.200 2.437 1.376 1.364 1.350 1.330 0.012 0.014 0.020 0.040 0.047 0.067 11.318 12.225 14.611 104.6   96.3   79.4 0.784 54805.2
The flow is Turbulent

0.208 2.954 1.270 1.250 1.228 1.194 0.020 0.022 0.034 0.046 0.050 0.077 12.054 12.642 15.717  96.3   91.4   72.3 0.951 66432.6
The flow is Turbulent

0.210 3.092 1.134 1.116 1.094 1.054 0.018 0.022 0.040 0.037 0.046 0.083 10.923 12.076 16.283 106.7   95.7   69.3 0.995 69551.1
The flow is Turbulent

0.208 2.954 1.270 1.250 1.228 1.194 0.020 0.022 0.034 0.046 0.050 0.077 12.054 12.642 15.717  96.3   91.4   72.3 0.951 66432.6
The flow is Turbulent

0.200 2.437 1.378 1.365 1.351 1.332 0.013 0.014 0.019 0.043 0.047 0.064 11.780 12.225 14.241 100.2   96.3   81.6 0.784 54805.2
The flow is Turbulent

0.193 2.032 1.383 1.371 1.365 1.352 0.012 0.006 0.013 0.058(0.029) 0.063 13.569(9.595) 14.124   87.3(126.9)  83.6 0.654 45711.9
The flow is Turbulent

0.185 1.623 1.575 1.570 1.560 1.544 0.005 0.010 0.016(0.038) 0.075 0.121(10.968) 15.511 19.620(111.8)  76.9   59.7 0.522 36506.4
The flow is Turbulent

0.210 3.092 1.134 1.116 1.094 1.054 0.018 0.022 0.040(0.037) 0.046 0.083(10.923) 12.076 16.283(106.7)  95.7   69.3 0.995 69551.1
The flow is Turbulent
```

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PIPE NO. 13

D= 0.0594 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS   FRICTION LOSSES    FRICTION FACTORS      MANNING  . n         HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3   1      2      3     4    1-2   2-3   3-4   1-2   2-3   3-4    1-2     2-3     3-4     1-2   2-3   3-4
  m   m^3/s    m      m      m     m                                       ( *10^-3 s/m^(1/3) )                      m/s
=====================================================================================================================================

0.185 1.623 1.665 1.658 1.652 1.640 0.007 0.006 0.012 0.040(0.034)0.068 11.140(10.313)14.585 108.4(117.8) 81.0 0.586 38657.5
The flow is Turbulent

0.193 2.032 1.660 1.650 1.635 1.620 0.010 0.015 0.015(0.036)0.054 0.054(10.633)13.023 13.023(112.0) 89.9  89.9 0.733 48405.4
The flow is Turbulent

0.200 2.437 1.510 1.488 1.462 1.430 0.022 0.026 0.032 0.055 0.065 0.080 13.155 14.301 15.865  87.7  80.1  71.6 0.879 58034.5
The flow is Turbulent

0.208 2.954 1.372 1.338 1.310 1.270 0.034 0.028 0.040 0.058 0.048 0.068 13.491 12.243 14.633  84.0  93.3  77.0 1.066 70347.0
The flow is Turbulent

0.210 3.092 1.208 1.174 1.141 1.091 0.034 0.033 0.050 0.053 0.051 0.078 12.886 12.695 15.627  88.0  89.4  71.4 1.116 73649.2
The flow is Turbulent

0.208 2.954 1.372 1.338 1.310 1.270 0.034 0.028 0.040 0.058 0.048 0.068 13.491 12.243 14.633  84.0  93.3  77.0 1.066 70347.0
The flow is Turbulent

0.200 2.437 1.513 1.490 1.465 1.432 0.023 0.025 0.033 0.058 0.063 0.083 13.450 14.023 16.111  85.6  81.8  70.4 0.879 58034.5
The flow is Turbulent

0.193 2.032 1.660 1.650 1.635 1.620 0.010 0.015 0.015(0.036)0.054 0.054(10.633)13.023 13.023(112.0) 89.9  89.9 0.733 48405.4
The flow is Turbulent

0.185 1.623 1.664 1.656 1.650 1.642 0.008 0.006 0.008 0.045(0.034)0.045 11.909(10.313)11.909 100.9(117.8)100.9 0.586 38657.5
The flow is Turbulent

0.210 3.092 1.210 1.184 1.148 1.000 0.026 0.036 0.148 0.041 0.056(0.231)11.269 13.260(26.886)101.7  85.3 (39.8)1.116 73649.2
The flow is Turbulent

PIPE NO. 14

D= 0.0538 m   Hvo= 0.100 m  Delta L=0.60 m  Viscosity= 9.0E-07m^2/s

 Hvt    Q      PIEZOMETER READINGS   FRICTION LOSSES    FRICTION FACTORS      MANNING    n         HAZEN WILLIAMS C  V    REYNOLDS
      *10^-3   1      2      3     4    1-2   2-3   3-4   1-2   2-3   3-4    1-2     2-3     3-4     1-2   2-3   3-4
  m   m^3/s    m      m      m     m                                       ( *10^-3 s/m^(1/3) )                      m/s
=====================================================================================================================================

0.185 1.623 1.658 1.650 1.648 1.630 0.008 0.002 0.018(0.028)(0.007)0.062(9.145)(4.573 13.718(130.9)(276.7) 84.5 0.714 42681.3
The flow is Turbulent

0.193 2.032 1.460 1.454 1.450 1.415 0.006 0.004 0.035(0.013)(0.009)0.077(6.325)(5.164)15.276(191.4)(238.3) 73.9 0.894 53443.9
The flow is Turbulent

0.200 2.437 1.280 1.264 1.255 1.202 0.016 0.009 0.053(0.024)(0.014)0.081(8.615)(6.461)15.680(135.1)(184.4) 70.8 1.072 64075.3
The flow is Turbulent

0.208 2.954 1.210 1.188 1.170 1.098 0.022 0.018 0.072(0.023)(0.019)0.075(8.334)(7.538)15.077(137.9)(153.7) 72.7 1.299 77669.4
The flow is Turbulent

0.210 3.092 1.127 1.102 1.094 1.012 0.025 0.008 0.082(0.024)(0.008)0.078(8.486)(4.800)15.368(134.8)(249.3) 71.0 1.360 81315.3
The flow is Turbulent

0.208 2.954 1.210 1.188 1.170 1.098 0.022 0.018 0.072(0.023)(0.019)0.075(8.334)(7.538)15.077(137.9)(153.7) 72.7 1.299 77669.4
The flow is Turbulent

0.200 2.437 1.280 1.264 1.255 1.202 0.016 0.009 0.053(0.024)(0.014)0.081(8.615)(6.461)15.680(135.1)(184.4) 70.8 1.072 64075.3
The flow is Turbulent

0.193 2.032 1.459 1.454 1.450 1.414 0.005 0.004 0.036(0.011)(0.009)0.079(5.774)(5.164)15.493(211.2)(238.3) 72.7 0.894 53443.9
The flow is Turbulent

0.185 1.623 1.655 1.650 1.644 1.635 0.005 0.006 0.009(0.017)(0.021)(0.031)(7.230)(7.920)(9.700)(168.7)(152.9)(122.8) 0.714 42681.3
The flow is Turbulent

0.210 3.092 1.135 1.104 1.095 1.010 0.031 0.009 0.085(0.029)(0.009)0.081(9.449)(5.091)15.647(120.0)(234.0) 69.6 1.360 81315.3
The flow is Turbulent
```

APPENDIX 2 (1/3)

Hydraulic gradients of bamboo pipes (water temperature = 15°C).

Discharge,Q	Diameter, ø mm			
l/s	40	50	63	80
0.10	0,00008	0,0002	0,0001	0,0000
0.20	0,0033	0,0009	0,0002	0,0001
0,30	0,0075	0,0021	0,0006	0,0001
0.40	0,0133	0,0038	0,0010	0,0003
0,50	0,0207	0,0060	0,0016	0,0004
0,60	0,0299	0,0087	0,0024	0,0006
0.70	0,0460	0,0118	0,0033	0,0009
0,80	0,0531	0,0154	0,0043	0,0011
0,90	0,0672	0,0195	0,0054	0,0014
1.00	0,0829	0,0240	0,0067	0,0018
1.10	0.1004	0,0291	0,0081	0,0022
1.20	0,1194	0,0346	0,0097	0,0026
1.30	0,1402	0,0406	0,0114	0,0031
1.40	0,1626	0,0471	0,0132	0,0036
1.50	0,1866	0,0541	0,0151	0,0041
1.60	0,2123	0,0616	0,0172	0,0046
1.70	0,2397	0,6095	0,0194	0,0052
1.80	0,2687	0,0779	0,0218	0,0059
1.90	0,2994	0,0868	0,0243	0,0065
2.00		0,0962	0,0269	0,0072
2.10		0,1060	0,0296	0,0080
2.20		0,1164	0,0325	0,0088
2.30		0,1272	0,0355	0,0096

Discharge,Q **l/s**	**Diameter, Ø** **mm** **40**	**50**	**63**	**80**
2.40		0,1385	0,0387	0,0104
2.50		0,1503	0,0420	0,0113
2.60		0,1625		0,0122
2.70		0,1752	0,0490	0,0132
2.80		0,1885	0,0527	0,0142
2.90		0,2022	0,0565	0,0152
3.00			0,0605	0,0163
3.10			0,0646	0,0174
3.20			0,0688	0,0186
3.30			0,0732	0,0197
3.40			0,0777	0,0209
3.50			0,0823	0,0222
3.60			0,0871	0,0235
3.70			0,0920	0,0248
3.80			0,0970	0,0262
3.90			0,1022	0,0276
4.00			0,1075	0,0290
4.10			0,1130	0,0305
4.20			0,1185	0,0320
4.30			0,1242	0,0335
4.40			0,1301	0,0351
4.50			0,1361	0,0367
4.60			0,1422	0,0383

Discharge,Q	Diameter, ø mm			
l/s	40	50	63	80
4.70			0,1484	0,0400
4,80				0,0417
4.90				0,0433
5,00				0,0453
5.20				0,0490
5.40				0,0528
5.60				0,0568
5.80				0,0609
6.00				0,0652
6.20				0,0696
6.40				0,0742
6.60				0,0789
6.80				0,0838
7.00				0,0888
7.20				0,0939
7.40				0,0992
7.60				0,1046
7.80				0,1102
8.00				0,1159