Compendium In Hydraulic Ram-Pumps

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In Hydraulic
Ram-Pumps

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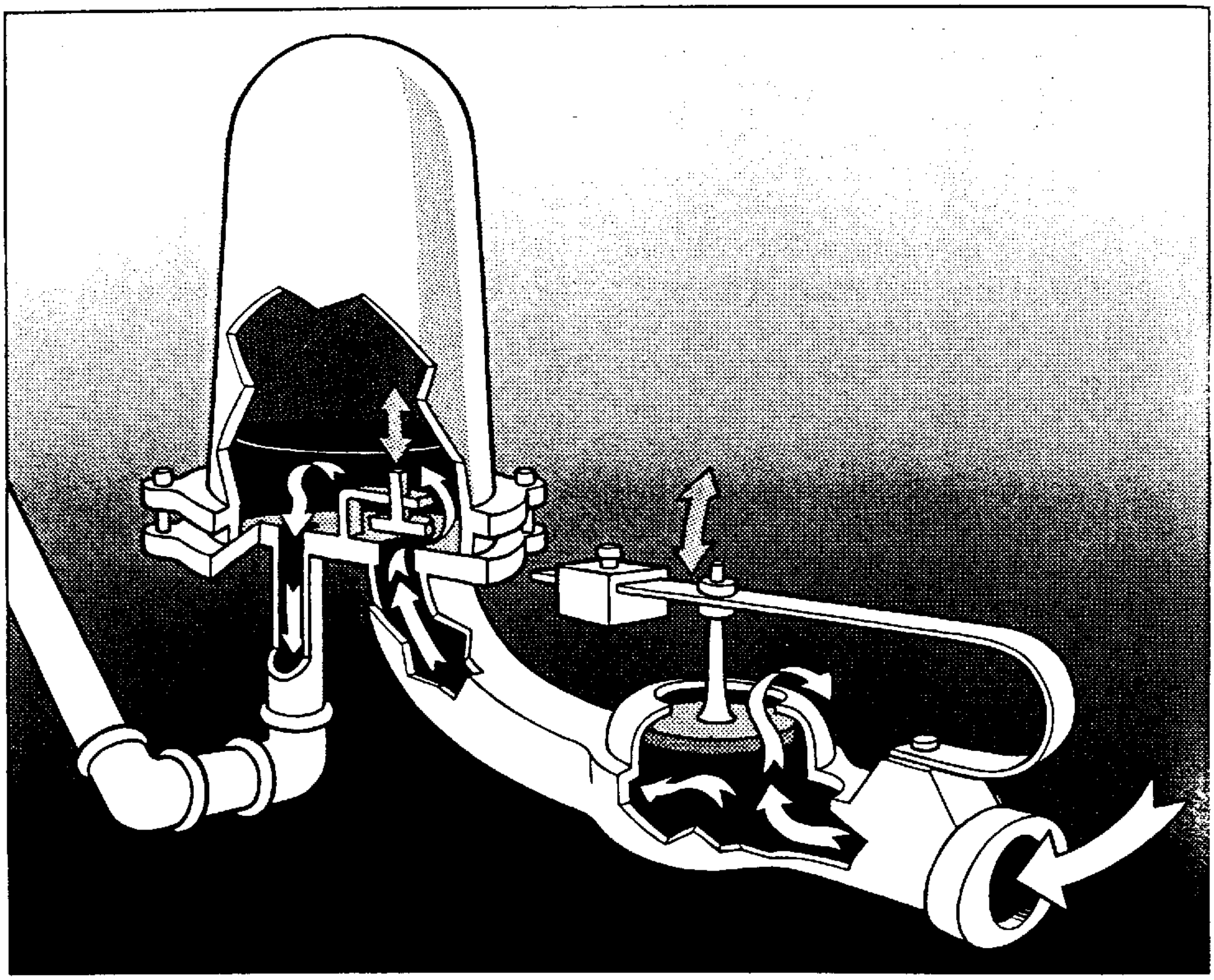

Den hydrauliske rambuk, som ved hjælp af en stor mængde vand med lav beliggenhedsenergi løfter en mindre mængde vand op til en højere beliggenhedsenergi.

NB:

It should be noted that this Compendium is for the express use of students, workers, research and production engineers and technicans, and for political decision-makers at all levels - concerned with development of production capability.

It does not intend nor imply any infringement of any of the copyrights of any of the authors quoted.
Indeed, this Compendium is intended and presented in grateful thanks, and to perhaps bring these authors to a wider public.

CONTENTS.

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ESTIMATING THE POTENTIAL OF A SITE

The first step in deciding whether water power is a good option is to estimate the hydraulic power available and then to compare this with the demand.

Estimation of demand is covered in the introductory sections of this catalogue. Hydro often cannot be expanded to meet a demand which is expected to grow with time, so this aspect should be checked carefully, along with the characteristics of the load. The next section covers some of the economic implications of powering various loads with hydro.

To estimate the available water power it is necessary to find values for head and flow for micro-hydro and hydrams, and the speed of the flow for water current turbines.

Hydraulic ram pump schemes

Hydram systems (Figure 16) have broadly the same weirs or dams, intakes, settling tanks, channels, forebay tanks and penstocks as micro-hydro schemes. Hydram penstocks are generally termed 'drive pipes', however, and are designed on different criteria. They need to be sufficiently rigid and strong to transmit water hammer pressure surges.

The hydram unit is fitted to the end of the drive pipe. From here most of the water will be exhausted into a tailrace, but a proportion will be diverted into the high pressure side of the pump, and from there to the delivery pipe, which is the name given to the pipe connecting the hydram to the point of use of the pumped water. There will normally be a storage tank at this point.

Water current turbines

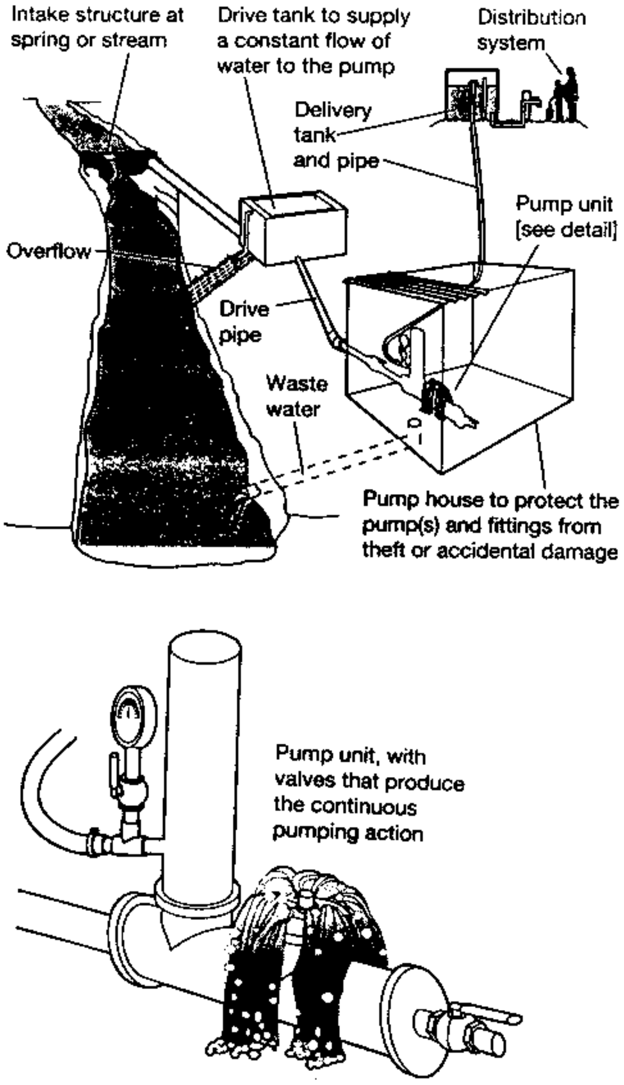
Water current turbines have to be placed in a canal, stream or river at a point where the flow velocity is high. Normally this is done by floating the turbine on a raft, and anchoring this to the shore. The raft and turbine are sold as one unit. The driven machine, a pump or a generator, is mounted on the raft, and the water or electricity delivered to the shore by a pipe or cables.

APPLICATIONS

In order to demonstrate the application of small water power systems, a selection of work in various countries is described here.

China

China has long been the world leader in terms of the number of modern micro-hydro systems installed. Around 80000 systems have been installed in recent years, with an average power of around 40kW. They are used mainly for generating electricity in rural areas, which in turn is used largely for agro-processing and domestic lighting. The machines tend to be heavy, and to make use of castings for the major components. Since the early 1980s, Chinese machines have appeared on the international market, and this exposure has led to the development of electronic load control governing, and technology transfer packages.



Components of a hydraulic ram pump

Load control governing has not been widely used in China, partly because of poor availability of power electronic components, and partly the result of a policy of using manual control initially for small schemes and then linking them in to local 'mini-grids' as soon as they are developed.

Nepal

Hydraulic ram pumps have been manufactured in Nepal in small numbers since the early 1980s, benefiting from technical development mechanisms similar to those used by micro-hydro. They have been used mainly for domestic water supply in the mountainous regions of the country. Unlike electricity or milling services, water is not traditionally sold in Nepal, so the issues of ownership and maintenance are less straightforward. Over the years, the market has concentrated more on higher head devices, usually delivering water to heights of at least 100m, and sometimes 180m, above the pump. These sites save considerable amounts of time for villagers, which provides a strong incentive to ensure good maintenance.

WATER-POWERED PUMPS

Ram Pumps

The ram pump works on a hydraulic principle using the liquid itself as a power source. The only moving parts are two valves. In operation, the water flows from a source down a "drive" pipe to the ram. Once each cycle, a valve closes causing the water in the drive pipe to suddenly stop. This causes a water-hammer effect and high pressure in a one-way valve leading to the "delivery" pipe of the ram, thus forcing a small amount of water up the pipe and into a holding tank. In essence, the ram uses the energy of a large amount of water falling a short distance to lift a small amount of water a greater distance. The ram itself is a highly efficient device; however, only 2% to 10% of the liquid is recoverable. Ram pumps will work on as little as 2 gpm supply flow. The maximum head or vertical lift of a ram is about 500 feet.

Selecting a Ram

Estimate Amount of Water Available to Operate the Ram. This can be determined by the rate the source will fill a container. Avoid selecting a ram that uses more water than available.

Estimate Amount of Fall Available. The fall is the vertical distance between the surface of the water source and the selected ram site. Be sure the ram site has suitable drainage for the tailing water. Often a small stream can be dammed to provide the 1-1/2 feet or more head required to operate the ram.

Estimate Amount of Lift Required. This is the vertical distance between the ram and the water storage tank or use point. The storage tank can be located on a hill or stand above the use point to provide pressurized water. Twenty or thirty feet water head will provide sufficient pressure for household or garden use.

Estimate Amount of Water Required at the Storage Tank. This is the water needed for your use in gallons per day. As examples, a normal household uses 100 to 300 gallons per day, much less with conservation. A 20- by 100-foot garden uses about 50 gallons per day. When supplying potable water, purity of the source must be considered.

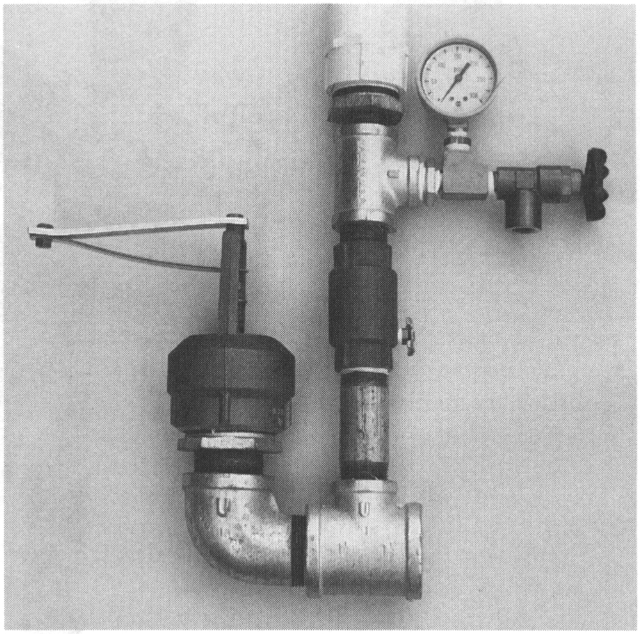
Using these estimates, the ram can be selected from the following performance charts. The ram installation will also require a drive pipe five to ten times as long as the vertical fall, an inlet strainer, and a delivery pipe to the storage tank or use point. These can be obtained from your local hardware or plumbing supply house. Further questions regarding suitability and selection of a ram for your application will be promptly answered by our engineering staff.

Aqua Environment Rams

We've sold these fine rams by Aqua Environment for over 15 years now with virtually no problems. Careful attention to design has resulted in extremely reliable rams with the best efficiencies and lift-to-fall ratio available. Working component construction is of all bronze with O-ring seal valves. Air chamber is PVC pipe. The outlet gauge and valve permit easy start up.

Each unit comes with complete installation and operating instructions.

•41-811	Ram Pump, 3/4"	$249
•41-812	Ram Pump, 1"	$249
•41-813	Ram Pump, 1-1/4"	$299
•41-814	Ram Pump, 1-1/2"	$299



High Lifter Pressure Intensifier Pump

The High Lifter Water Pump offers unique advantages for the rural user. Developed expressly for mountainous terrain and low summertime water flows. This water-powered pump is capable of up to 9:1 lifts in ratio of fall to lift, with just a trickle of inlet water. For example, assume a flow of 2 gallons per minute and a fall of 40 feet from a water source (spring, pond, creek, etc.) to the High Lifter pump with a 200-foot rise (head) from the pump up to a holding tank. The lift-fall ratio between the 40-foot fall and the 200-foot lift would be 5:1. The High Lifter pump (in 9:1 ratio) would deliver 400 gallons of water per day from this working ratio. The 4.5:1 ratio pump wouldn't work at all in this application. If inlet water flow slows or stops the pump will slow or stop, but will self-start when flow starts again.

The High Lifter pump has many advantages over a ram (the only other water-powered pump). Instead of using a "water hammer" effect to lift water as a ram does, the High Lifter is a positive displacement pump that uses pistons to create a kind of hydraulic lever that converts a larger volume of low-pressure water into a smaller volume of high-pressure water. This means that the pump can operate over a broad range of flows and pressures with great mechanical efficiency. This efficiency means more recovered water. While water recovery with a ram is normally about 6% or less, the High Lifter recovers 1 part in 4.5 or 1 part in 9 depending on ratio.

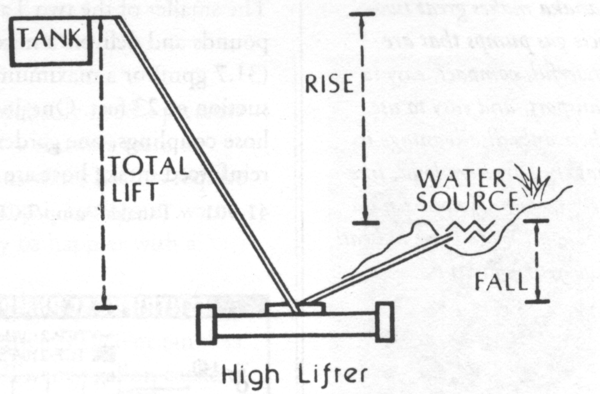
In addition, unlike the ram pump, no "start-up tuning" or special drive lines are necessary. This pump is also quiet.

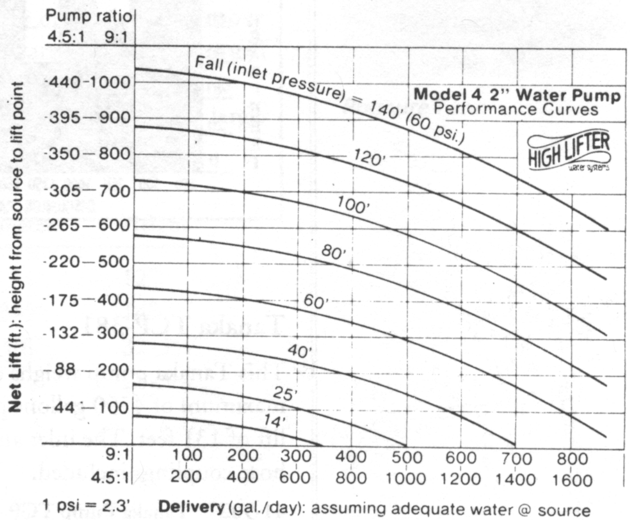
The High Lifter pressure intensifier pump is economical compared to gas and electric pumps, because no fuel is used and no extensive water-source development is necessary.

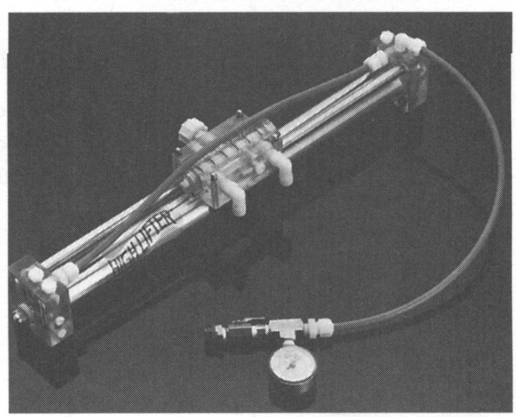
There are two model High Lifter pumps available with 4.5:1 and 9.1:1 working ratios. A kit to change the working ratio of either pump after purchase is available. A maintenance kit is available too. Maintenance consists of simply replacing a handful of O-rings. Choose your model High Lifter pump from the specifications and High Lifter performance curves. One-year parts and labor warranty.

41-801	High Lifter Pump, 4.5:1 Ratio	$895
41-802	High Lifter Pump, 9:1 Ratio	$895
41-803	High Lifter Ratio Conversion Kit	$97
41-804	High Lifter Rebuild Kit	$49

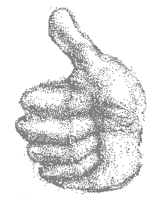
TYPICAL APPLICATION







Things that Work!
Alternative Energy Engineering's High Lifter Pump



Test Conducted by Michael Welch

Let me start by saying that I am completely sold on the High Lifter pump for my application. My High Lifter is pumping 240 gallons per day from a 6 gallons per minute spring that is 132 feet downhill from my water tank. The High Lifter is located 26 vertical feet below my spring.

Shipping Container and Documentation

The High Lifter comes well wrapped in a 6 in. x 6 in. x 28 in.cardboard box. Alternative Energy Engineering uses recycled materials for packaging their products. The shipping weight is 10 pounds. Included with the pump itself is an inlet filter, an inlet pressure gauge, a hose for between the filter and the pump, an output pressure gauge, and a ball valve with a check valve for the outlet.

The Owner's Manual that comes with the pump is one of the best written pieces of documentation that I've ever seen. It is 23 pages long and includes: an introduction, typical applications, how it works, how to install it for various situations, an in depth section on maintenance and troubleshooting, performance curves, a trouble shooting flow-chart, an exploded view showing all the pump parts, and a specifications table.

The Test Site

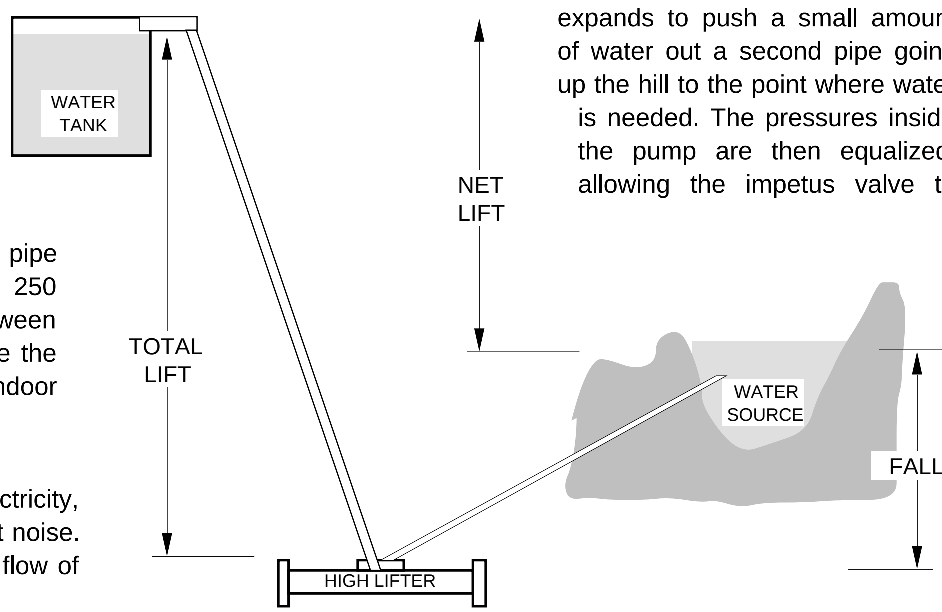
My water system is comprised of a spring which flows into a large 480 gallon settling tank. From there, the water flows at 6 gallons per minute through 3/4 inch Schedule 40 PVC pipe 26 vertical feet to my pump site. The pump then pushes the water up 158 vertical feet through 1" black rolled drinking water pipe (only 1/2 inch pipe is required). The 250 gallon tank at the top is suspended between two sturdy conifers about 20 feet above the taps in my home to obtain sufficient indoor water pressure.

Pumping water without electricity

This pump works great without electricity, without internal combustion, and without noise. This pump will take a steady but small flow of water, and, with a short drop, pump a significant part of the water way up hill to the place it is needed.

Oh, if only all our water supplies were located above the point of use. Alas, it is an imperfect world. Well, then, if only we could afford some of the fine solar water pumping systems that are available. By the time you purchase the pump, wiring and the fair number of PV panels needed, your cookie jar will look like a bottomless pit.

I know two ways to use a downhill flow of water to pump a portion of the water further uphill. One is with the time-tested ram pump. The ram pump lets a flow of water in a pipe build up momentum until the flow causes an impetus valve in the pump to slam shut. The water, still wanting to exert its moving energy, is channeled into a chamber containing air, which is compressed by the force of water. The compressed air bubble in the chamber then expands to push a small amount of water out a second pipe going up the hill to the point where water is needed. The pressures inside the pump are then equalized, allowing the impetus valve to



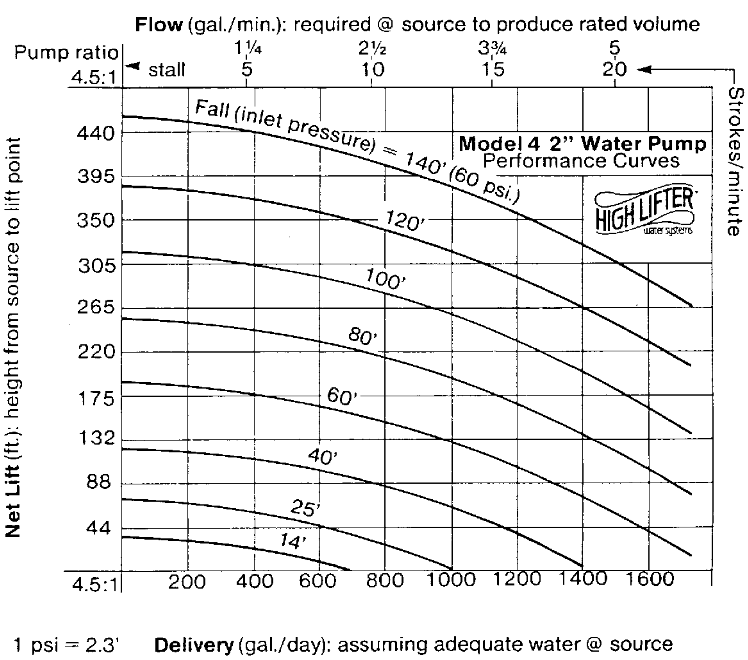
open again thus starting the downhill flow moving again, and the cycle repeats.

The second method is with the relatively new High Lifter. The High Lifter uses head pressure instead of momentum in a downhill pipe. It uses a larger volume of low-pressure water to pump a smaller volume of water at a higher pressure. A larger piston acts with a smaller one to gain mechanical advantage, a kind of "hydraulic lever." A collar inside the pump controls the inlet valve. As the pistons reach the end of their stroke, they contact this collar, pushing it until it directs a small amount of "pilot water" to the end of the spool in the pilot valve, thereby shifting it and changing the direction of the water flow in the pump. The flow moves the two-way pistons in the opposite direction until they again contact the collar, which shifts the pilot valve again, and the process repeats. Thus the pump's innards travel back and forth as it pushes water way up the hill.

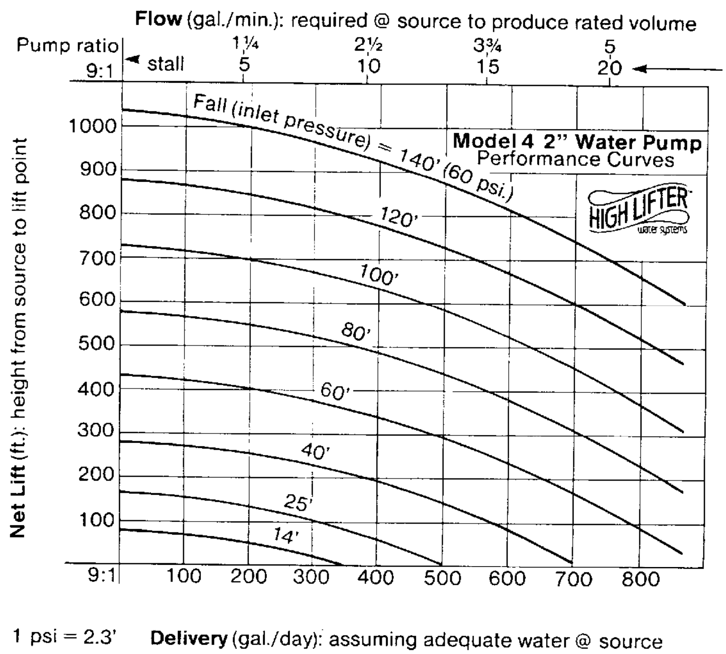
High Lifter Specifications

The cylinders are made of stainless steel, the valve body and head materials are machined from acrylic, and the pistons are made of high quality nylon. The total width is about 4 inches, length 26 inches, and the pump itself weighs about 5.5 pounds. The High Lifter is obtainable in two volumetric pump ratio models, 4.5:1, and 9:1, and changeover kits are available to switch back and forth. The higher the volumetric ratio, the greater the pumping pressure and the lower the output flow.

FOR 4.5:1 VOLUMETRIC RATIO PUMPS



FOR 9:1 VOLUMETRIC RATIO PUMPS



Typical applications

According to the Owner's Manual, the High Lifter can deliver up to 750 or 1500 gallons per day, depending on the model. It can be used with flows as little as one quart per minute. It can achieve net lifts of up to 1,100 feet, depending upon the circumstances. In situations of low fall and high lift, two High Lifters can be used in series.

High Lifter Performance

When I took delivery of my High Lifter, I had nothing but problems. I thought I would be unable to recommend the pump in "Things that Work" because my test site seemed to put to much of a strain on the pump, causing it to stall out with regularity. After trying "everything in the book", and some things that weren't in the book, I took the pump back to Dave Katz's pump experts at Alternative Energy Engineering. (I like going there anyway because they have so much neat renewable energy stuff to look at.) There we discovered that some of the earlier pumps had been assembled with too much silicone glue between the barrel and the valve body. The excess silicone had slopped over to partially plug the pilot valve holes. They gave me a recently rebuilt pump since they didn't have a new one ready to give me.

I installed the newly rebuilt pump, and 30 hours later I checked my previously empty tank. I was totally amazed to discover that the 250 gallon tank was completely full! At that point I began keeping track of the flow: it was an remarkable 240 gallons per day. Two weeks later the flow had decreased to 218 gallons per day so I cleaned the inlet filter. Now that the pump was broken in and the filter cleaned, my flow increased to 294 gallons per day! It seems to have settled in at between 220 and 300 gallons per day, depending on how clean the input filter is.

High Lifter Advantages

The advantages of the High Lifter over the ram pump are numerous. The pump is more efficient in that it uses less water to pump a given amount uphill. Additionally, it is a far piece quieter than the constant and very noisy KA-CHUNK of the ram, and it is quite a bit lighter and easier to move around than the ram. Last, but not least, the High Lifter will operate with relatively thin wall pipe in the input, whereas a ram, because of the intense and constant hydraulic hammering caused by the sudden closing of the impetus valve, requires solid mounting and steel pipe to keep from breaking apart joints.

The High Lifter is not without its disadvantages, though. It has a complex array of pilot valves and check valves, and relies heavily on close tolerance seals. Unlike the ram pump, water must be completely free of sand and grit lest the barrels and seals become scored allowing leakage. The High Lifter comes with a filter which takes out much of the harmful sized particles which may flow from your water supply. The filter must be cleaned regularly to avoid loss of inlet pressure. If a lot of foreign matter flows with your water, then the High Lifter may not be for you.

The Owner's Manual states that there is a danger that a hard knock to the valve body could cause a misalignment, but personal experience proved that it takes 2 large, strong people to successfully dislodge the glued and strapped valve body from the barrel.

Conclusions

The High Lifter has far exceeded my expectations, and definitely lives up to its promises. It is worth the $750. price tag, which includes access to the manufacturer who is willing to go the extra distance to help their customers.

Access

Author: Michael Welch, C/O Redwood Alliance, POB 293, Arcata, CA 95521 • 707-822-7884.

Manufacturer: Alternative Energy Engineering, POB 339, Redway, CA 95560 • 800-777-6609.

Table 6.4 Water-Pumping Capacities for Multiblade Windmills[a]

Distance Water Is Lifted (ft)	Pump Discharge for 15-mph Wind Velocity (gal/hr) 6-ft Fan Diameter	12-ft Fan Diameter
25	350	24,000
50	200	1425
100	150	600
150	—	525
300	—	200

Notes: a. Adapted from *Water Supply for Rural Areas and Small Communities* by Wagner and Lanoix.

Hydraulic Rams

If you have a fairly large stream or have access to a river, you can take advantage of one of the truly fine engineering holdovers from the nineteenth century—the hydraulic ram (Figure 6.16). Here, power is derived from the inherent energy of flowing water itself. The force of the water is captured in a chamber where air is compressed; when the compressed air expands, it pushes a small amount of the water to a higher elevation than that from which it originally came. The water which provided the energy is then released to flow on its way downstream.

A typical hydraulic ram installation consists of two pipes (supply and delivery), an air chamber, and two valves (waste and delivery). You set the hydraulic ram into motion by merely opening the waste valve and allowing the water to run through the ram unit. As the flow is accelerated, the force exerted on the waste valve causes it to close, causing a so-called "water hammer" or pressure build-up. This pressure build-up forces open the delivery valve and water flows into the air chamber, compressing the air inside. Because water is flowing into the air chamber, the pressure on the waste valve is lessened; it then opens, and the delivery valve consequently closes, trapping behind it a small quantity of water and compressed air. As the compressed air expands, it shoves this water into the delivery pipe and, as this process is repeated endlessly, you find—presto!—the water is at a higher elevation, ready to use.

Rife Hydraulic Engine Manufacturing Company (P.O. Box 367, Millburn, N.J. 07041) is the only American-based supplier of hydraulic-ram pumps. They can provide you with pumps taking inlet and outlet pipe sizes from 1.25 to 8 inches. Costs run between $300 up to $3000 (FOB factory).

A few comments concerning the use of the hydraulic ram are in order. First of all, there is a spring on the waste valve of most hydraulic rams which regulates the pressure required to close the waste valve. You can regulate the quantity of water and the height you raise it by varying the tension on this spring. You will have to make a few experimental runs at first to decide what the best setting is for your particular needs. You can compute the quantity of water pumped by a hydraulic ram using the following equation:

E. 6.1
$$\frac{Q_p}{Q_s} = \frac{H_s}{H_p} e$$

where Q_p is the flow pumped to a new location (gal/min); Q_s is the flow supplied to the hydraulic ram (gal/min); H_p is the pumping head, i.e., the vertical distance between the ram and the water surface in the tank where the water is pumped (ft); H_s is the power head, i.e., the vertical distance between the free water surface of the supply water and the ram (ft); and e is the efficiency of the ram, usually about 50 percent.

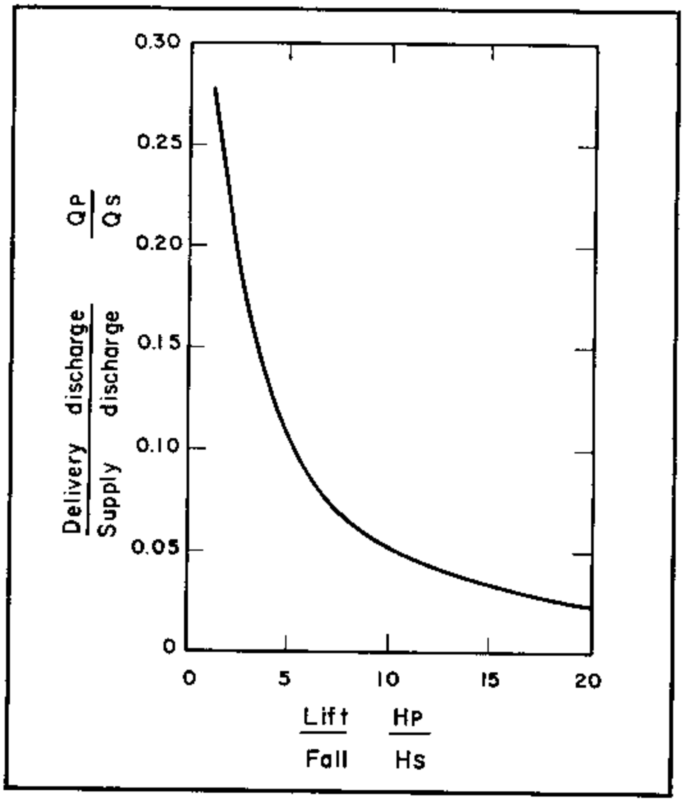


Figure 6.17 Efficiency curve for a hydraulic ram.

Figure 6.17 gives directly the ratio Q_p/Q_s as a function of the ratio H_p/H_s for typical hydraulic rams. If the supply and delivery pipes are long, you must take into consideration the hydraulic losses in these pipes (described in the water-power section of Chapter 3). H_s should be reduced by the equivalent losses in the supply pipe and H_p should be increased by the equivalent losses in the delivery pipe. Here we essentially are accounting

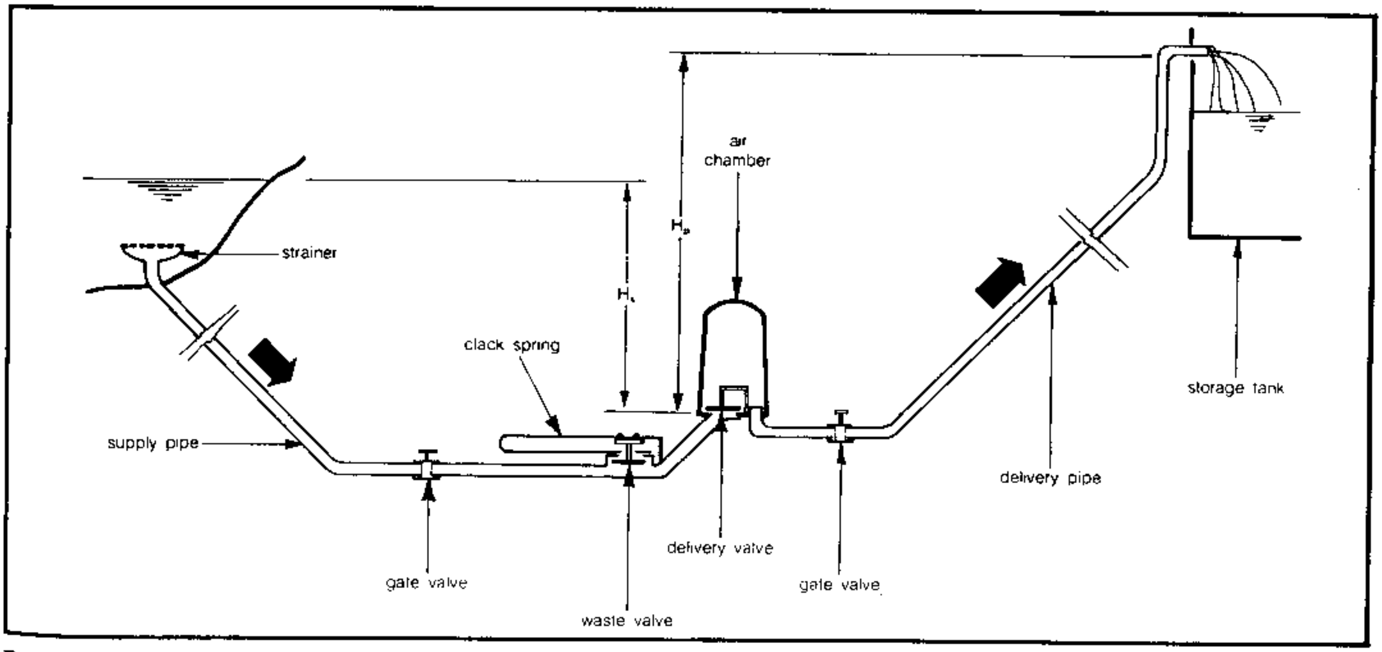


Figure 6.16 A typical hydraulic-ram installation.

for the energy lost due to friction in the pipes.

Example: You have a stream flowing at 10 gal/min on your property and you want to pump water to a tank 8 feet above the level of the stream. If you put the hydraulic ram 2 feet below the surface of the stream, how many gallons per minute can your hydraulic ram deliver to the tank?

Solution: The power head, H_s, is 2 feet and the pumping head, H_p, is 10 feet (8 + 2). From Figure 6.17 you find that for

$$\frac{H_p}{H_s} = \frac{10}{2} = 5$$

you have

$$\frac{Q_p}{Q_s} = 0.1$$

and

$$Q_p = 0.1 \times Q_s = 0.1 \times 10 = 1 \text{ gal/min}$$

Thus we see that we must use 10 gal/min to pump 1 gal/min to a height of 8 feet; the other 9 gallons per minute are returned to the stream. If your ram is allowed to pump continuously, you will pump daily (1 × 60 × 24) about 1440 gallons per day. Not bad considering that the water provides its own energy for pumping!

As you can see from this example, the hydraulic ram requires a lot of water to operate. The higher the ratio of the pumping head to the power head, the more water the ram uses for energy purposes. However, if large flows are available, the hydraulic ram may be a very good choice for your pumping needs: it is durable and inexpensive, requires little maintenance, and can be operated continuously. You should be aware of the fact that the ram is fairly noisy; but with proper siting, this should not be a major problem.

Storage Systems

The amount of water you must have in storage depends upon both a realistic assessment of your needs and a good estimate of the period of time during which your source can be expected to be dry or unavailable. The average value for domestic daily water consumption is about 50 gallons per person, 49 of which are devoted to washing and waste disposal; we drink and cook with the sole remaining gallon. Thus, for example, if you expect your water source to be dry for a maximum of one month at a time, you will need to have a storage volume capable of meeting your normal demands for 30 days. Assuming you have a family of four and use, on the average, 50 gallons per day per person, your required storage volume will be

$$30 \text{ days} \times 50 \text{ gallons/day-person} \times 4 \text{ persons} = 6000 \text{ gallons}$$

The area required to store this quantity of water is

$$6000 \text{ gallons} \times 0.1337 \text{ ft}^3\text{/gallon} = 802 \text{ ft}^3$$

So you will need a tank capable of storing at least 800 cubic feet of water—a tank 10 feet square and 8 feet deep would give the minimum capacity required.

A storage tank is one way of storing water; a reservoir or pond is another (both Chapters 3 and 7 discuss certain aspects of dam construction and maintenance). Of course, there are problems associated with open-surface water-bodies. For instance, the growth of algae may cause deterioration of water quality over the summer months; and the inadvertent introduction of materials into the water-body by animals, birds or wind also can reduce its purity. Because of these problems it is almost always necessary to treat surface water to insure that the water is hygienically acceptable.

In order to avoid pollution, it is advisable to store your drinking water in a covered tank of some sort. A water storage system must be kept reliably watertight to prevent leakage or contamination. This means that seepage, warping, and corrosion must be guarded against and that pipelines to and from the storage container must be sound. To avoid odors, tastes, or toxic materials in the water, the appropriate surfaces need to be constructed or coated with inert materials such as wood or some plastics and paints. In addition, there must be provision for easy access to the storage container above the maximum water height, to permit visual checks of the water level and convenient maintenance when necessary.

Water storage tanks come in a variety of sizes, shapes, and materials. The three main construction materials are wood, steel, and concrete. Wooden tanks are virtually maintenance-free and leave no taste or odor in the water. However, they must be kept from drying out for more than two months at a time; the wood may otherwise warp and allow leakage after refill. Steel tanks are also available. These containers tend to corrode or leave a metallic taste in the water if not properly lined; but minimum maintenance and proper lining can eliminate these problems. New steel tanks can be fabricated to meet specific criteria, while used ones are also available. The third type available, concrete tanks, are usually constructed in place. They are quite inert and require little upkeep. Some small concrete tanks are available commercially.

IRRIGATION PUMP

"CECOCO" MOTORLESS HYDRO-HI-LIFT PUMP

This particular pump will raise water by the power caused by means of declivity of water-flow up to the height 30 times of water head and operates automatically without any motive power such as gasoline, other fuel oils and electricity and no attendance for operation is necessary. It is extensively used in Japan for water supply at home, and field for irrigation, spraying and water reservoir on the top of mountain and hill.

PRINCIPLE: In order to raise the water automatically by multiplied power of (1) the water hammer pressure leading pipe installed with a slight inclination and (2) the specific gravity with effectivity of the air in the delivery pipe taken in by the negative pressure (Vacuum) caused by the reactional flow of the water hammer pressure.

HOW TO INSTALL: Although it is motorless, it has to have a flow of water as the source of power to operate the pump and the "Head" is absolutely necessary. During operation, proportionate amount of water to be delivered, therefore it must have drainage. The gist of such parts are:

(1) Head 0.5—4 meter for small type and 1—8 meter for large type, is considered to be the best for practical use.

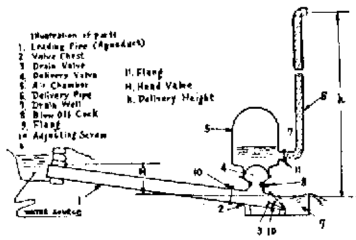
(2) Leading Water Pipe: The length of leading pipe is, for practical use, approximately 8 times of the Water Head and the pipe must be kept straight. It needs to be hard, therefore it is advisable to use steel pipe.

(3) Delivery Pipe: The size of the delivery pipe is half in diameter of the leading pipe.

(4) Drain Well: In order to cause counter current at the moment Drain Valve opens, it is necessary to install Drain Well. Also, in order to take the air, make the water level of drain well equal to red line marked on discharging mouth.

(5) Discharging Water: It may be drained out into well or culvert or any other suitable equipment.

Diagram of motorless pump



HOW TO OPERATE:

(1) After the pump is installed, shut the drain valve by hand and have water flow into the leading pipe. Then push back the drain valve to let the water drain and then take your hand off to let the valve closes. Repeat this action 5 or 6 times. After that the valve operates automatically. The above is the first operation and its purpose is to help the pump operation until sufficient amount of water is stored in the tank. For the second time, no such operation is necessary because the pump will start to operate just by a single push of the drain valve.

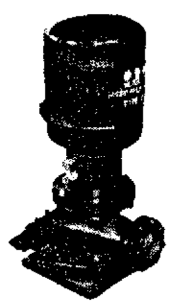
(2) In order to take the proper amount of air into pump at the moment when drain valve opens, it is necessary to make the drain water level unique. For this purpose it is best to install the drain well at the base of the pump.

(3) The number of beating of the drain valve is controlled by adjusting the control screw which is set on the drain valve. In case more water is needed, select the beating number to around 30 to 45 times beats per minute. In case the drained water has to be saved because of insufficient water flow, change the beats to around 60-90 per minute.

(4) To stop the pump, pull the drain valve handle and close the valve and hold it for 5 to 6 seconds to lock the water comes still in the pipe.

(5) While the pump is operating, even though any of delivery pipe is shut out, pumping operation of pipe will not stop.

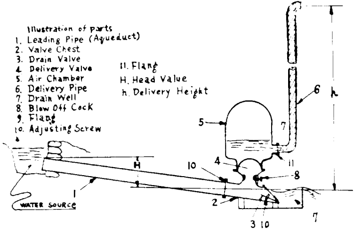
Motorless pump
Type No. 4



Standard Specification of "CeCoCo" Motorless Hydro-Hi-Lift pump

Type	No. 1	No. 2	No. 3	No. 4	No. 6	No. 12
Bore of Suction	1 1/2"	2"	3"	4"	6"	12"
Bore of Discharge	3/4"	1"	1 1/2"	2"	3"	6"
Practical Head value	0.5-4m	0.5-4m	0.5-4m	1-10m	1-10m	1-10m
Net Weight	40 kg	55 kg	68 kg	167 kg	300 kg	1300 kg
Gross Weight	60 kg	85 kg	110 kg	220 kg	400 kg	1800 kg
Ship'g Meas't	3 cft	5 cft	10 cft	20 cft	40 cft	230 cft

Diagram of motorless pump



HOME WATER SUPPLIED 100 METERS HIGH And 940 Meters Delivery In Mountain By "CeCoCo" Motorless Pump

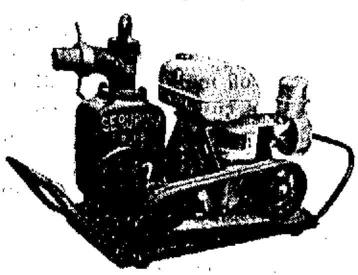
The municipality of Shuzenji, Shizuoka Pref., near Tokyo, Japan, is supplying water through the day and night with no cost for operation to some of it's inhabitants of about 560 families with the water raising 100 meters vertically high in the mountain and leading water about 1,530 meters from the original water spring by means of "CeCoCo" Motorless Automatic Hydro-Hi-Lift Pump Type No. 6 (for high delivery and high pressure, 6 inches pipe in suction and 3 inches pipe in delivery).

550 meters from Water Source to Intermediate Reservoir (8 tons in capacity); 54 meters from Intermediate reservoir to Motorless pump; and 940 meters from Motorless pump to Water Reservoir (50 tons in capacity) in mountain. Discharge capacity is 116,200 litres per day for 24 hours.

This scene shows how "CeCoCo" Motorless pump is functioning as above explained.

"CECOCO" SELF-PRIMING PUMP

"CeCoCo" Self-priming pump



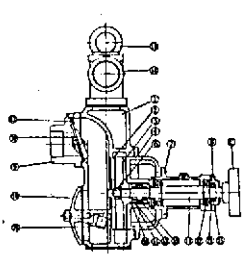
It is not necessary to have foot valve, because vacuum pump, that is it fills up pump-casing with priming-water at first time only, then by pump, action of priming-valve discharges air of suction line automatically and then begins discharge water by pumping up.

It will function well even the suction pipe is not straight or it is set much higher place than the pump is operating continuously.

The pump is air-tightly enclosed with mechanical seal. Specially designed semi-open impeller is well tempered so that it can lift up and deliver any of dirty, and muddy water and also water mixed with foreign substances.

Equipped with a high grade of ball bearings which air tightly protects the shaft with the best grease inserted, so that no oiling is necessary and no dusts can come in. Consequently, it can be used for many hours continuously without any attention. Used for construction, marine, food industry, chemicals, mining and irrigation etc.

Diagram of pump



1. Casing 2. Friction Disc 3. Impeller
4. Case-Cover 6. Impeller Nut 7. Bearing Case
8. Bearing Case Cover 9. Suction Mouth
13. Set Piece Of Suction Valve
14. Discharge Bend 15. Discharge Plug
16. Scavenging Port Cover 19. Shaft
22. Ball Bearing 24. Washer 25. Shaft Nut
26. Priming Valve 30. Suction Mouth
50. Seal Washer 51. Seal Ring 52. Seat Ring
53. Spring C. Flexible Coupling

"CECOCO" VERTICAL PUMP

These particular pumps are precisely constructed with many years of experience in the laboratory and field works and built with a first class workmanship under the unique design, and every one pass through the severe and rigid inspection and test before packed for export. There are many kinds of types according to the requirements, such as axial flow pump, lateral sand pump, under-water sand pump, multiple-stage push up vertical pump etc. Speciality of "CeCoCo" vertical pump is this that it is very handy to install when drawing water in very high degree and the operation is very easy and economical and can endure the rough handling in agricultural irrigation, construction works and chemical industry.

Vertical pump Model TDL is for agricultural irrigation and general work. It is conveniently used in irrigation to the farm field where the water is available near to a pond, bank and reservoir up to the lift of 4 to 14 feet in depth and also for the drainage work in construction for pumping out the waste water very easily. To make it handy, it can be used in set in conjunction of a small and light combustion engine or an electric motor as a portable unit.

The construction is all metal made throughout and very durable.

Vertical pump Model 'TDL'

Standard Discharge Capacity per minute in litres

Type	No. 1	No. 2	No. 3	No. 4	No. 6	No. 12
2 times of Water Head	13.0	23.6	55	100	210	960
4 〃 〃 〃 〃	9.1	18.2	40	76	160	800
6 〃 〃 〃 〃	7.1	14.2	35	60	126	640
8 〃 〃 〃 〃	5.5	11.0	30	46	98	460
10 〃 〃 〃 〃	4.5	9.0	25	38	80	380
15 〃 〃 〃 〃	3.3	6.6	20	28	56	240
20 〃 〃 〃 〃	2.2	4.4	12	18	40	140
25 〃 〃 〃 〃	1.9	3.3	11	16	36	120
30 〃 〃 〃 〃	1.3	2.6	8	11	30	100

Upon receipt of the detailed specification of your requirements with condition of environment of the place the pump to be installed as well as discharge per minute or per day, head value, or water head, delivery lift (vertical height, between the level of pump to discharge end), and usages etc., "CeCoCo" will send you at once our proforma invoice with the best prices together with the illustrated literatures.

"CeCoCo" is ready to welcome to guide you to many places where the pumps are functioning for homes, villages, spas and reservoirs near in Tokyo and never miss to call on us while you are in Japan.

HIGH HILL IRRIGATION at the Shizuoka Citrus Experiment Station, Inatori, Izu Peninsula of Japan.

Installed at the Shizuoka Citrus Experiment Station

Type of pump Special No. 6 with Pressure Gauge.
Head Valve-6 meters; Delivery Lift-150 meters; Length of Delivery pipe- 700 meters; Lengh of Leading pipe- 32 meter.

"CeCoCo" Special No. 3 Type Motorless pump is installed at the above place to take care for citrus fruits for obtaining the best qualified varieties of Japanese Orange.

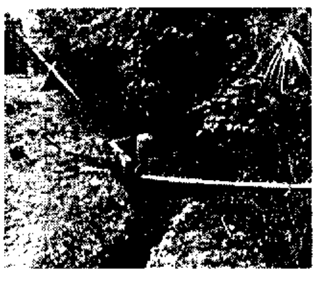
The reason why the prefectural Government has decided to install "CeCoCo" motorless pump is that if they adapt usual electrically operated pump in order to lift the water up to 150 meters and about 80 meters further in extension above the seashore where spring water is flowing, it will surely require at least 2 or 3 pumps and the cost of maintenance will be very high. However, by installing "CeCoCo" Motorless pump, the cost of installation is greatly saved and no operating expense is necessary in running water all day and night and no attendance required.

Attention: When operating, be sure that no air creeps in the pump, otherwise pump will stop running at once. Due to a strong vibration given to the pipes which lead the water from a water tank and to the pump. In order to prevent the leakage at the outlet and inlet connections, the shock absorber such as rubber pipe should be connected in between the incoming water pipe and the pump or the water-tank and the said pipe. Pay attention listening to the noise which can be heard at a far distance where and when pump is satisfactorily working. But when the pump fails to make such noise, the pump is in trouble, so that examine if an air is leaked in or valve is out of order or worn out, if so displace it with a new one.

At Tukuda village. Akagimura, Setagun, Gunma Prefecture, about 110 kilos north east Tokyo, Japan, "CeCoCo" Motorless pump of Type No. 4 (4-inch suction and 2" delivery) was installed about 7 years ago and is now supplying a pure water to 100 households for their drinking, bathing, laundry etc. up to the hill about 75 feet above the water spring at the base.

The water is first pumped up into two large water-reservoir-tanks upon the hill and is distributed into each household by means of vinyl-pipes installed individually. Mr. Kyuhei Kanon, the supervisor of the villlage Water Suppy Section said that during the last 7 years, there was no mechanical trouble in the operation at all, no attendance in looking after oiling etc. is necessary but only in replacing the valve in pump which wears out once a year. Therefore, no maintenance expense required, however he is collecting about 20 to 30 yen, equivalent of U. S. $ 0. 08 from each family per month as a reserve fund to purchase a new pump when present one becomes too old.

Installed at the Tukuda Village, Type No. 4



Before installing the said pump, they have adapted a ready-made-water-reservoir lifting up the water from stream down and they have suffered a trouble when an epidemic of dysentery has spread over. However, since they have installed "CeCoCo" Motorless pump, they have succeeded to get a quite fresh water, and they have not experienced such miserable troubles since then.

Standard Specification of "CeCoCo" Vertical Pump Model TDL

Type	Dia. of Barrel	Discharge per hour	Horse Power Required and Revolution per minute					
			4 ft.	6 ft.	8 ft.	10 ft.	12 ft.	14 ft.
7 L	178 mm (7 inch)	81 M³ 17,820 gal.	0.90 HP	0.96 HP	1.16 HP	1.45 HP	1.75 HP	—
			850 rpm	1000rpm	1200 rpm	1300 rpm	1400 rpm	—
9 L	228 mm (9 inch)	126 M³ 27,720 gal.	1.30 HP	1.60 HP	1.90 HP	2.30 HP	2.75 HP	—
			770 rpm	840 rpm	960 rpm	1100 rpm	1200 rpm	—
10 L	254 mm (10 inch)	154 M³ 33,880 gal.	1.50 HP	1.80 HP	2.28 HP	2.68 HP	3.23 HP	—
			650 rpm	790 rpm	920 rpm	1010 rpm	1100 rpm	—
11½L	292 mm (11½ inch)	200 M³ 44,000 gal.	1.80 HP	2.43 HP	2.75 HP	3.50 HP	4.12 HP	—
			550 rpm	680 rpm	770 rpm	850 rpm	900 rpm	—
13½L	342 mm (13½ inch)	290 M³ 63,800 gal.	2.40 HP	3.60 HP	4.00 HP	5.12 HP	6.30 HP	—
			540 rpm	580 rpm	620 rpm	600 rpm	700 rpm	—
15 L	380 mm (15 inch)	360 M³ 79,200 gal.	2.94 HP	4.40 HP	5.00 HP	5.90 HP	7.40 HP	8.80 HP
			450 rpm	500 rpm	540 rpm	580 rpm	620 rpm	670 rpm
19 L	482 mm (19 inch)	631 M³ 138,820 gal.	4.90 HP	7.10 HP	8.50 HP	11.60 HP	13.00 HP	14.90 HP
			370 rpm	400 rpm	430 rpm	460 rpm	490 rpm	515 rpm
25 L	635 mm (25 inch)	1,262 M³ 277,640 gal.	11.60 HP	16.50 HP	17.4 HP	21.0 HP	24.60 HP	29.00 HP
			350 rpm	340 rpm	350 rpm	380 rpm	400 rpm	415 rpm

Multi-Stage Push-up Vertical Pump Model TVM is for construction work, mining, factory drainage, agricultural irrigation etc.

These pumps are chiefly intended for the operation under the conditions of a high lift and a narrow space of work.

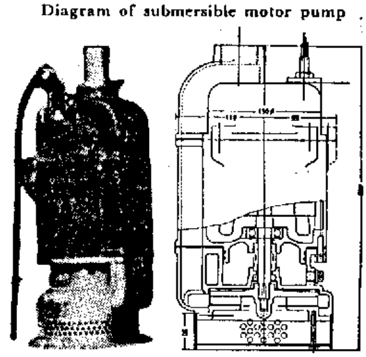
They are installed with the pump axis directly coupled with the electric motor, and are easy to operate. The pump for fixed installation is particularly suitable for use in case where the lift is relatively large and the distance between the sites of drainage is very large.

Standard Specification of "CeCoCo" Vertical pump Model TVM

Bore	Dia. of Barrel	Discharge per hour	Character of Motor		Single Stage Type		Two Stage Type	
			Frequency	Revolution	Total Lift	HP Req'd	Total Lift	HP Req'd
75mm (3 inch)	140 mm (5½ inch)	40.5 M³ 8,910 gal.	60-cycle	1,750 rpm	9.10 meter	2.3 HP	18.2 meter	4.6 HP
			50-cycle	1,450 rpm	5.15 meter	1.32 HP	10.3 meter	2.64 HP
125mm (5 inch)	228 mm (9 inch)	126 M³ 27,720 gal.	60-cycle	1,750 rpm	9.10 meter	8.8 HP	18.2 meter	17.6 HP
			50-cycle	1,450 rpm	5.15 meter	5 HP	10.3 meter	10 HP
150mm (6 inch)	254 mm (10 inch)	154 M³ 33,880 gal.	60-cycle	1,750 rpm	10.60 meter	11.0 HP	21.2 meter	22 HP
			50-cycle	1,450 rpm	6.05 meter	4.72 HP	12.1 meter	12.6 HP
200mm (8 inch)	292 mm (11½ inch)	200 M³ 44,000 gal.	60-cycle	1,750 rpm	15.20 meter	18.0 HP	30.4 meter	36 HP
			50-cycle	1,450 rpm	9.10 meter	10.5 HP	18.2 meter	21 HP

"CECOCO" SUBMERSIBLE MOTOR PUMP

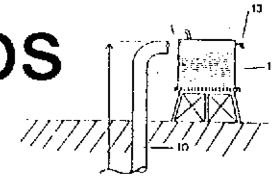
Diagram of submersible motor pump



Specification

- Bore .... 40mm of Submersible Motor Pump
- Suction Capacity ...... 7,000 litres/hour
- Total Head .... 6m (max. 7m)
- Motor .... 4-poles, 250-watts Condenser motor with Cabtyre cord 8 meters
- Revolution .... 1,440 rpm at 50-cycle; 1,720 rpm at 60-cycle
- For the use .... Civil Construction Works, Cable Laying Works, Drainage, etc.

Hydraulic Ram Pumps



Pump water for *FREE:*

- Needs no petrol or electricity
- Has no noisy motor
- Harness your own hydraulic power
- Runs 24 hours a day, 7 days a week with no attention.

This pump uses the power from falling water to force a small portion of the water to a height greater than its source:

- Heads to 120 metres with 3 metre supply fall.
- 3600 litres a day at 60 metre head.
- 8000 litres a day at 30 metre head.
- Provides more water than most homes need.

Water can be forced about as far horizontally as you desire, but because of friction, greater distances require a larger pipe. There is no external power needed, and the ram has only two working parts. There is almost no expense except for the original cost. The greater the height to which the water must be raised, the less water will be pumped, under a given set of circumstances.

The pump is made in one size but is adjustable for many situations.

The maximum flow of water that can pass down the inlet pipe and through the ram even under high supply fall conditions is 126 litres/min.

The following table is a guide to the expected delivery rates in litres per minute under various conditions.

Multiply by 1440 to give litres/24 hrs.
TOTAL HEAD (metres) is the height from the pump to the storage.

Supply Fall	Pumping Head 20	25	30	35	45	60	75	90	100	120
2	2.7	2.2	1.3	.9	.4					
2.5	4.5	3.6	3.2	2.7	2.2	1.8	1.3			
3	7.2	6.8	5.9	4.0	3.2	2.2	1.8	1.3	.9	.4
3.5	10.0	9.0	7.2	6.3	5.4	3.6	2.7	2.2	1.4	.9
4.5	11.8	11.3	9.0	7.7	6.8	5.4	3.6	3.2	1.8	1.3
6		13.6	12.7	10.0	9.0	7.7	5.9	3.6	2.7	1.8
7.5		15.4	14.5	11.3	10.4	9.0	6.3	5.4	3.2	2.2

"Do I have a suitable site?"

You must have sufficient water to run the ram and sufficient fall (head) from the dam to the pump.

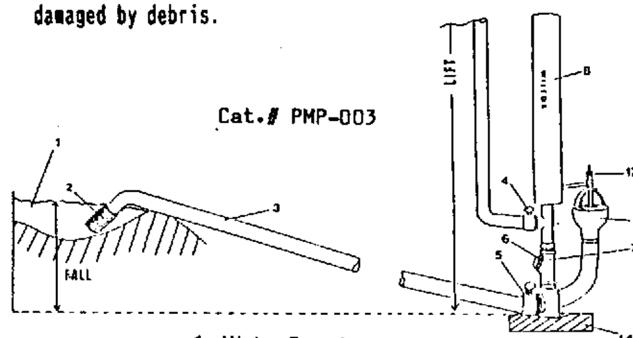
The amount of water required is about 36 litres per minute and a fall of at least 1.5 metres; but 2.5 metres is preferable.

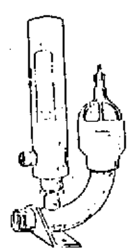
Select a site along the water course from your dam or spring that will enable you to get about 20' drop. The length of the pipe must be at least 3 times the working fall. Most of the water is not pumped by the ram but flows on after its falling energy has been spent, so make sure the water can get away.

EXAMPLE: If you have a 3 metre fall from the intake level to the ram then the ram inlet pipe should be at least 9 metres long.

Muddy water won't upset the pump greatly. The pump can be totally immersed in a flood without damage, but it will not work while under water although there is a danger that it might be washed away or damaged by debris.

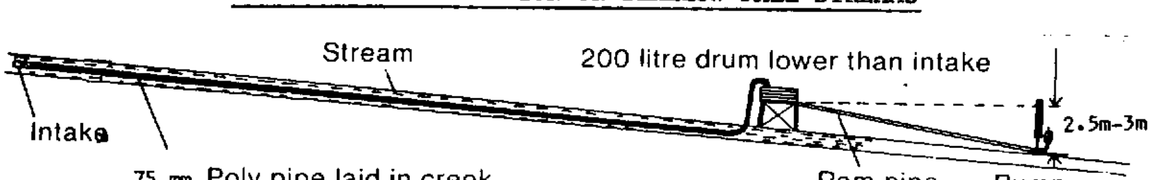
Cat.# PMP-003





1. Water Supply
2. Wire Mesh Filter
3. 2" Gal. Ram Pipe
4. Valve
5. Valve
6. Non-return valve
7. Snifter Hole
8. Chamber
9. Valve Housing
10. 1" Delivery Pipe
11. Storage Tank
12. Adjustment nut and Locknut
13. Overflow
14. Concrete or wood base

SUGGESTED INSTALLATION ON SHALLOW FALL STREAMS



Cat.# PMP-003

GLOCKEMANN PECK ENGINEERING

The Glockemann Pump

The 'Glockemann' pump has revolutionised water powered water pumping. Incorporating modern design and manufacturing the 'user friendly' Glockemann has eliminated many of the problems normally associated with water powered pumps. Quiet, reliable, versatile, easy to install and maintain, the 'Glockemann' has built an outstanding reputation in southern NSW and is generating enormous interest elsewhere in Australia and overseas.

Made from cast ductile iron with stainless steel fittings, the 'Glockemann' represents outstanding long term value. With many advantages including a throttle which allows the 'Glockemann' to be turned down in dry times when the stream is low, an easily interchangeable piston 'bore' and a 6-9 metre P.V.C. drive tube which can be customised to your site using 30, 45 or 90 degree elbows. Perhaps the most exciting feature of this amazing pump is its ability to achieve remarkable outputs to very high heads from supply heads or 'drops' of as little as 0.6 of a metre, unheard of until now!

Built to last, the Australian made, environmentally friendly 'Glockemann' is an efficient, durable, flood proof alternative to fuel powered pumping, providing odour free, noise free, trouble free water with no fuel cost for year after year.

Specifications

Glockemann Peck Engineering, NSW, Australia.

For further information please contact Rainbow Power Company at details below

Glockemann
Water Powered Pump

Revolutionary technology which, for the first time allows pumping of water using very low supply heads - 0.6 metre supply drop can deliver 3,000 litres per day to a head of 50 metres.

This Australian designed and manufactured product uses the energy of water falling only a short distance to power a diaphragm piston pump. The **Glockemann Water Pump** is highly efficient, runs silently and is simple to operate and maintain, even for non technical users. Manufactured from heavy guage galvanised steel and stainless steel. The pump incorporates a shut off mechanism which prevents damage by severe flooding and also prevents the pumping of heavily silted water.

Parts

All nuts, bolts and springs are of stainless steel. The diaphragm rubber is the exact consistency of tractor or truck inner tube and can easily be replaced by cutting one from a used truck or tractor tube. The leather piston cups are stock sizes and are obtainable from any irrigation supplier. Both diaphragm rubbers and piston cups are available from the Rainbow Power Company.

Water Powered: needs no fuel or electricity, just a creek or stream.

Low Supply Head: as low as 0.6 metre.

High Delivery Head: up to 200 metres or more.

Quiet: no mechanical noises, no metal to metal action.

Runs Reliably: 24 hours per day, 7 days per week with no attention.

Built to Withstand Heavy Flooding.

Easy Installation: needs no concrete mounting, uses PVC drive tubes.

Requires Minimal Maintenance.

Versatile: no need for straight drivetubes, use 45, 90 or 30 elbows to suit your site.

Automatic Flood Shut Off: prevents polluted water being pumped to the tank, restart with the flick of a switch.

Adjustable Throttle: in dry times just turn it down, as low as 25% capacity.

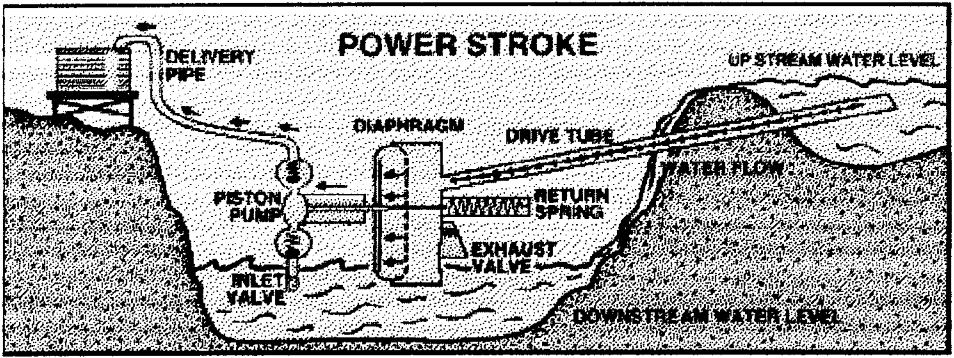
Low Flow Rate: as little as 1 litre per second.

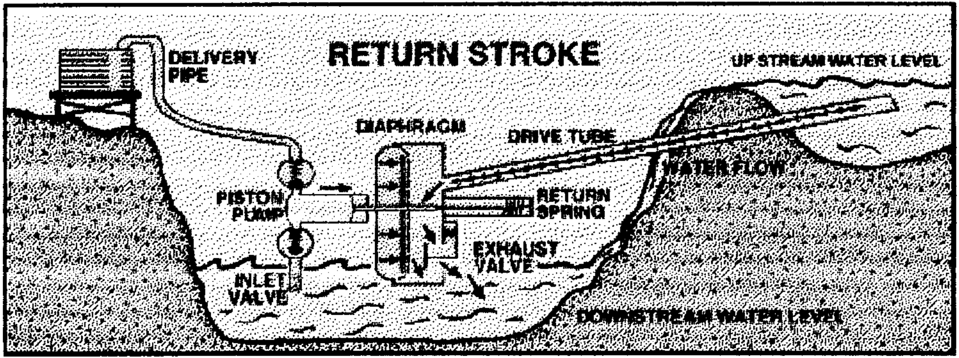
Length of Drive Pipe:

The drive pipe must not be less than 6 times the drive head and not more than 12 times the drive head.

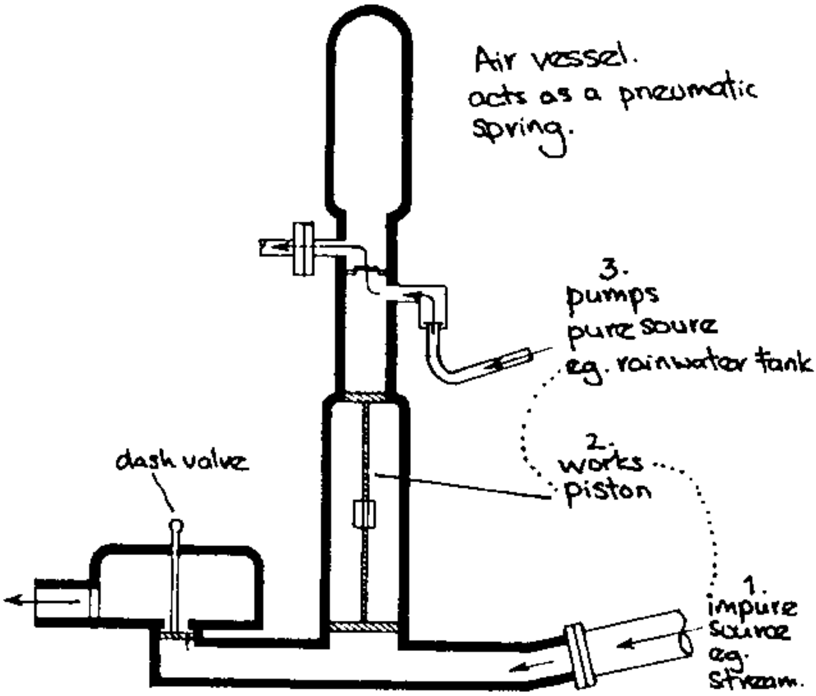
Note: With Water Dragon 160 use 2" poly pipe as the drive pipe with drive heads of between 1.4 and 3 metres.

Glockemann	Supply Rate	Drop in	Drive Pipe	Delivery Height (metres) - Output (Litres per day)								
Model	Litres/sec	Metres	Size	5m	10m	20m	35m	50m	75m	100m	150m	200m
	6.5	**2.0m**	100mm			16000 f	9200 f	6800 d	4500 c	3400 b	2300 b	1700 a
	8.0	**1.6m**	150mm			22100 f	13400 e	9400 e	6900 d	5200 b	3500 b	2600 b
	6.0	**1.6m**	100mm		21000 f	11700 e	7400 e	5200 c	3500 b	2600 c	1700 a	1300 a
	7.0	**1.2m**	150mm			16000 e	9500 e	7400 d	5000 c	3700 a	2500 b	1900 a
	5.5	**1.2m**	100mm		16000 f	8600 e	5300 e	3700 c	2500 b	1900 c	1200 a	900 a
	7.0	**1.0m**	150mm		21000 f	12400 e	7900 d	5500 c	3700 c	2800 a	1800 a	1400 a
Oasis	5.0	**1.0m**	100mm	21000 f	13000 e	7250 d	4100 d	2900 b	1900 a	1450 b	1000 a	700 a
320	6.0	**0.8m**	150mm	21000 f	14500 e	8000 d	4600 c	3200 b	2100 b	1600 a	1100 a	800 a
	4.5	**0.8m**	100mm	16000 f	8600 e	5000 c	3100 c	2000 a	1300 a	1000 a	600 a	
	5.5	**0.6m**	150mm	15500 e	8600 d	4600 c	2600 b	1800 a	1200 a	900 a	600 a	
	4.0	**0.6m**	100mm	12200 e	6500 d	3300 b	1850 b	1300 a	850 a	600 a	Bore Diameters	
	5.0	**0.4m**	150mm	7200 d	3800 c	1900 b	1100 a	700 a	500 a		**Oasis**	
	3.5	**0.4m**	100mm	6000 d	3200 b	1600 a	900 a	600 a			**d=73mm**	
	4.5	**0.3m**	150mm	2700 b	1400 a	700 a					**e=98mm**	
											f=124mm	
	1.0	**3.0m**	50mm				5000 c	4400 c	2800 b	1700 a		
	1.1	**2.5m**	50mm				4000 c	3300 b	2100 b	1300 a		
	1.2	**2.0m**	50mm			5000 c	3000 b	2200 b	1400 a	900 a	Bore Diameters	
Water	1.4	**1.6m**	50mm			3700 b	2400 b	1700 a	1100 a	500 a	**Both Models**	
Dragon	1.7	**1.2m**	50mm		5000 c	2500 b	1800 a	1300 a	900 a		**a=35mm**	
160	1.8	**1.0m**	50mm		4000 c	2000 b	1400 a	900 a			**b=48mm**	
	1.4	**0.8m**	62mm	5000 c	3000 b	1500 a	1100 a	700 a			**c=60mm**	
	1.4	**0.6m**	62mm	4000 c	2000 b	1000 a	600 a					
	1.4	**0.4m**	62mm	1200 a	600 a							
	1.4	**0.3m**	62mm	700 a								


POWER STROKE
DELIVERY PIPE
UP STREAM WATER LEVEL
DIAPHRAGM
DRIVE TUBE
WATER FLOW
PISTON PUMP
RETURN SPRING
EXHAUST VALVE
INLET VALVE
DOWNSTREAM WATER LEVEL


RETURN STROKE
DELIVERY PIPE
UP STREAM WATER LEVEL
DIAPHRAGM
DRIVE TUBE
WATER FLOW
PISTON PUMP
RETURN SPRING
EXHAUST VALVE
INLET VALVE
DOWNSTREAM WATER LEVEL

HYDRAULIC RAM. DOUBLE ACTION



This pump will use the pressure of water from an impure water source such as a polluted stream to raise water from a pure source such as a well. A ram will work with an 18" head but 3ft. is best. One seventh of the water entering a simple ram can be raised to four times the height of the head.

<u>The considerations for choosing a pump.</u>

1. Maintenance service available.

2. Capital cost of pump and equipment.

3. Operating cost.

4. Capacity and lift required.

When a large amount of water is required for irrigation or to supply a large community, wind pumps are the best, low cost power source.

WILLIAM J. HEBERT: PERPETUAL MOTION FOR THE HOMESTEAD...

THE HYDRAULIC RAM PUMP

Are you planning to add a farm pond to your homestead, but bothered by the fact that the site you've selected is not naturally furnished with water year round? Or do you already have a pool which suffers from one or more of the maladies connected with a lack of sufficient incoming fresh water? Well –if your property contains a spring, creek, small stream or other source with a flow of at least three gallons per minute (gpm)–you can probably solve your problem easily and inexpensively with a hydraulic ram pump.

As I write this, it's been three months since we installed our ram pump in a nearby creek . . . at a total cost of under $200. All that time the device has been pumping clear, cool spring water up over a 25-foot hill–a distance of 150 feet–and into our farm pond, without the use of any fuel whatsoever. In short, we're getting about 500 gallons of water per day at an operating cost of zero . . . and we expect this to continue for ten years or more.

Prior to this installation, the water level of our 15-foot-deep, half-acre fishing and swimming hole dropped at least two feet each July and August, the pond's temperature rose to the tepid bathtub stage and the algae blossomed. Not so these days! The level remains constant, the water is clearer, cooler and more invigorating and the plant population has been drastically reduced. Even the largemouth bass and bluegills (now five years old) put up a stiffer fight when we hook them.

Although our own pump is used solely to replenish that pond, the ram is a versatile machine with many other possible applications. For instance, it can drive water to a storage tank in or near a house . . . with the overflow first diverted to a barn or watering trough for animals and then finally to a pool. Or the device can be used purely for irrigation.

Before this country's rural electrification program such pumps were in wide use, since they employ only water power for activation. In Japan, in fact, the ram still commonly serves to bring water from the mountains into villages a mile or more away.

These days, a revival of the hydraulic ram seems to be underway among back-to-the-landers . . . and you may be thinking about putting the water-current-driven pump to work on your own spread. Whether or not you can do this successfully depends on five important and interdependent conditions:

[1] The amount of water (gpm) available from the source.

[2] The length of the main pipe from the source to the pump.

[3] The drop in feet from the source to the pump.

[4] The height in feet that water must be lifted.

[5] The distance in feet that water must be delivered.

(See Don Marier's accompanying piece for a graphic summary of the relationships among these factors, and see the explanation that follows the diagram for a guide to how much water you can expect your pump to deliver.–MOTHER.)

Here's how we measured the first of these variables on our own place: We temporarily dammed up a creek a few feet downstream from its source (a spring) and inserted a pipe near the top of the dam. The water from the conduit was allowed to run into a gallon bucket while we timed the flow with a sweep second hand on a watch. During the dry month of August, the figure we obtained was three-and-a-half gpm.

Our next step was to construct a more permanent dam in order to form a small pool of at least 50 gallons. This reservoir would constantly be filled from the brook, and out of it would run our main pipe to the pump downstream. We began this project by building plywood forms across the creek in the shape of an elongated letter "U", with a base width of five feet and with two-foot arms extending back upstream. The walls were to be four inches thick and only two feet high.

After the forms were laid–but before the concrete was mixed and poured–we temporarily diverted the stream around one side of the plywood mold to permit the box's contents to dry without being diluted or washed away. We also inserted a one-foot length of one-inch pipe, threaded on both ends, through the walls of the form about six inches from its top and inclined downstream. The upstream opening of this tube would later be covered with a strainer, and the lower outlet would connect with the long steel pipe leading to the ram pump.

The position for the ram itself was selected with the knowledge that we wanted at least a five-foot "head" or "fall" of water . . . that is, a five-foot vertical distance from the pool's surface to the base of the pump. With the aid of a transit on a five-foot stand (a simple carpenter's level does just as well) we found that a distance downstream of 42 feet gave us a level sight with the top of the newly poured dam. At that spot beside the creek we built a simple concrete slab (2' X 2' X 8" thick) upon which we would later bolt the ram.

Next, two sections of one-inch black pipe–each a standard length of 21 feet–were joined together with nipples and then connected to the one-foot piece of pipe which pierced the dam. We used more nipples and a simple one-inch union to hook the waterline to the pump, and then attached the strainer (supplied by the ram's manufacturer) to the intake in the pool area. We completed our pipe-laying by running 150 feet of three-quarter-inch, flexible plastic tubing (the high-pressure type for durability) from the pump outlet up over a 25-foot hill to our pond.

Finally, we allowed the pool in the creek to fill by simply blocking up the temporary, diversionary stream around the side of the forms. Within ten minutes, and after a minor adjustment to the ram's release valve, the water rushing down the main pipe activated the device and commenced its "perpetual motion". Sure enough, a steady stream of water emerged from the plastic tubing into our pond. At first the flow looked disappointingly small . . . only after careful measurement did we suddenly realize that our swimming hole would be receiving about 500 gallons of fresh spring water each day. That amounts to about 15,000 gallons per month or 180,000 gallons per year!

As I've already suggested, the same system could just as easily be used to solve more sophisticated problems pertaining to the delivery of drinking water or to the supply of storage tanks, irrigation networks, dairy barn needs or livestock troughs. The higher and further water must be pumped, of course, the larger the ram required. All the same, we feel that the hydraulic ram offers a homesteader the most pollution-free and least expensive method of getting water from Point X to Point Y next to hauling it by hand in buckets . . . and it's a helluva lot easier. Happy swimming and fishing!

HOW IT WORKS

DON MARIER *(Reprinted from* Alternative Sources of Energy, *No. 1, July 1971.)*

A diagram of a typical ram is shown in Fig. 1. Here's how it works: Water rushes down the drive pipe and escapes out the waste valve until enough pressure is built up to close that outlet. (The amount of this pressure increases with the "fall" or vertical distance from the source to the ram.)

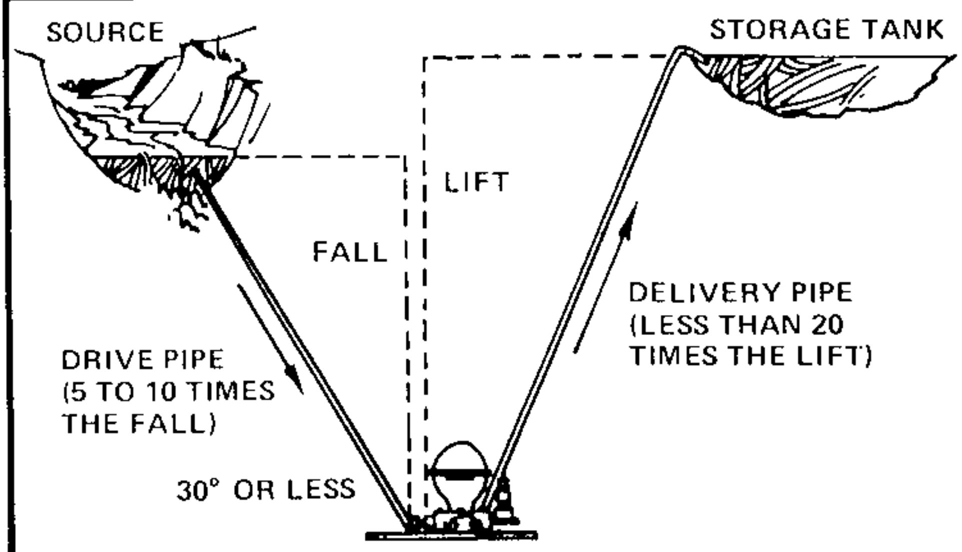


FIGURE 1

The shutting of the waste valve forces water through the check valve and into the air chamber. The rushing liquid compresses the air enclosed in the compartment so that it pushes back like a piston. This action closes the check valve and forces water up the delivery pipe to a storage tank.

When the check valve closes, the water in the drive pipe rebounds for a moment and creates a partial vacuum that allows the waste valve to drop open again. The excess fluid which was not pushed up the delivery pipe thus flows out of the opening. At the same time, the vacuum draws a small amount of air into the ram through the air valve or "snifter" just below the air chamber. This gas—which is needed to replace the enclosed air because some is mixed with the water during each cycle—will be forced into the compartment when the incoming stream starts flowing down the drive pipe again. A small amount of water is lost through the air valve during each stroke of the pump, but the leakage is minute and serves to keep the opening clean.

The cycle just described is repeated about 25 to 100 times per minute . . . the exact rate depends on how much tension is put on the waste valve spring by adjustment of the screws. The slower the ram works, the more water it will pump. The ideal setting is for the minimum number of strokes per minute at which the pump will still operate. I had to rework the waste valve spring on my ram a couple of times until it lined up properly and had the correct tension; otherwise, the pressure failed to build properly and the machine wouldn't work.

How much water the ram will pump can be calculated from the following formula:

$$D = \frac{S \times F}{L} \times \frac{2}{3}$$

where,

D is the amount of water delivered in gallons per minute (gpm).
S is the amount of water supplied to the machine in gallons per minute.
F is the fall or vertical distance in height between the supply of water and the ram.
L is the lift or vertical distance the water is lifted from the pump to the storage tank.
The fraction of 2/3 represents the efficiency of the ram. Older models had efficiencies of about 40%.

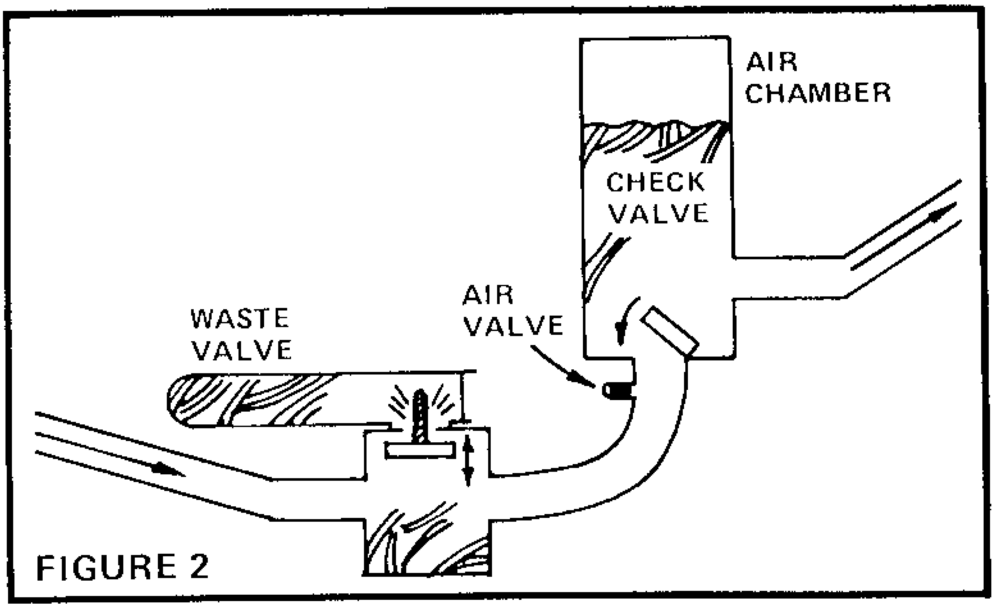


FIGURE 2

The minimum fall from which a ram will operate is 18 inches, and that's the vertical distance I had to work with. I measured the supply flow at 10 gallons per minute by catching the water in a pail and timing how long the container took to fill. The lift I used was 10 feet. Thus the amount of water I should have expected to be delivered was:

$$D = \frac{10 \text{ gpm} \times 1\text{-}1/2 \text{ feet}}{10 \text{ feet}} \times \frac{2}{3} = 1 \text{ gpm}$$

I actually measured about nine-tenths of a gallon per minute.

It sounds inefficient to use 10 gallons of water to pump one gallon, but remember that the ram works constantly (unlike a windmill) . . . so that one gpm adds up to 1,440 gallons per day. Besides, the nine gallons which go out the waste valve aren't really wasted since they can be returned to the stream or used for any convenient purpose.

Note that you can't pump the water to an indefinite height since pipe friction slows the flow down. This effect is reduced by using a sufficiently large water line and by keeping connections and bends to a minimum. It is much better to shape a long piece of pipe into a gradual curve than to use sections of tubing connected at a sharp angle. Garden hose is out of the question because all the kinks would produce too much friction. ⊖

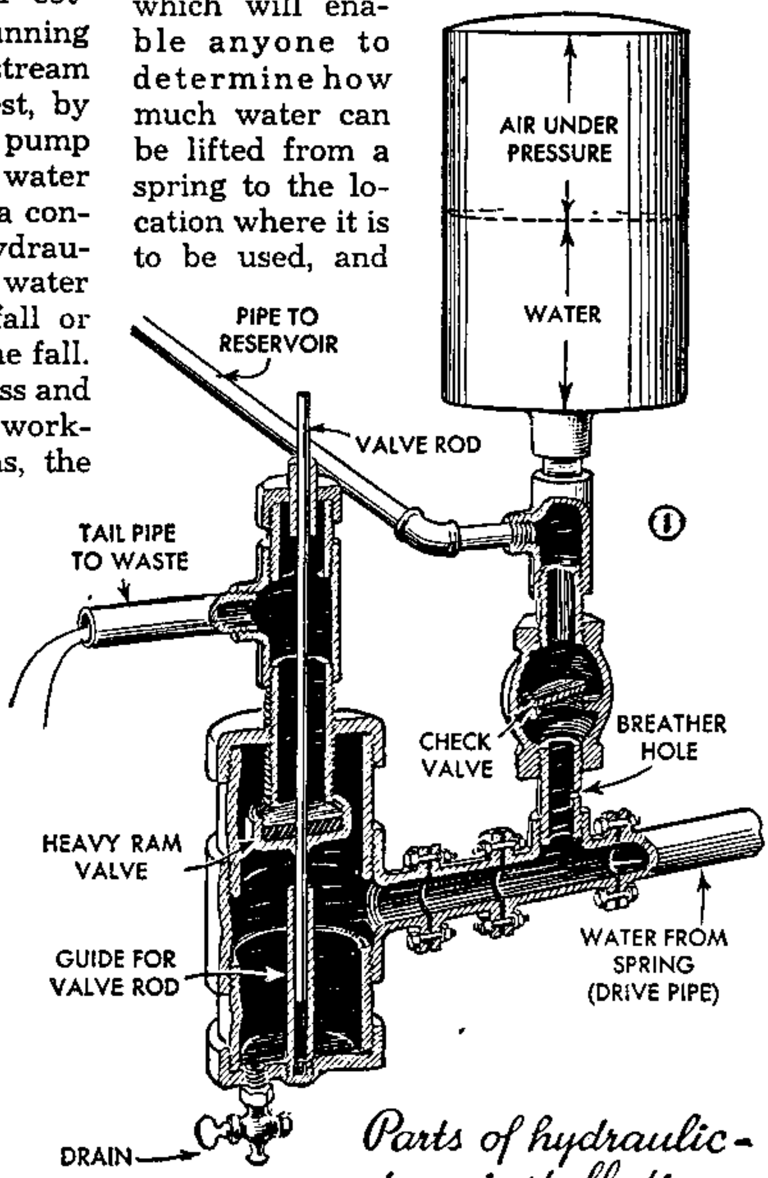
If you don't feel up to building your own hydraulic ram, you'll find manufacturers of the units listed in the bibliography at the back of this book. Look in the Hardware *section under* Water.

HYDRAULIC RAMS
furnish water supply to country homes

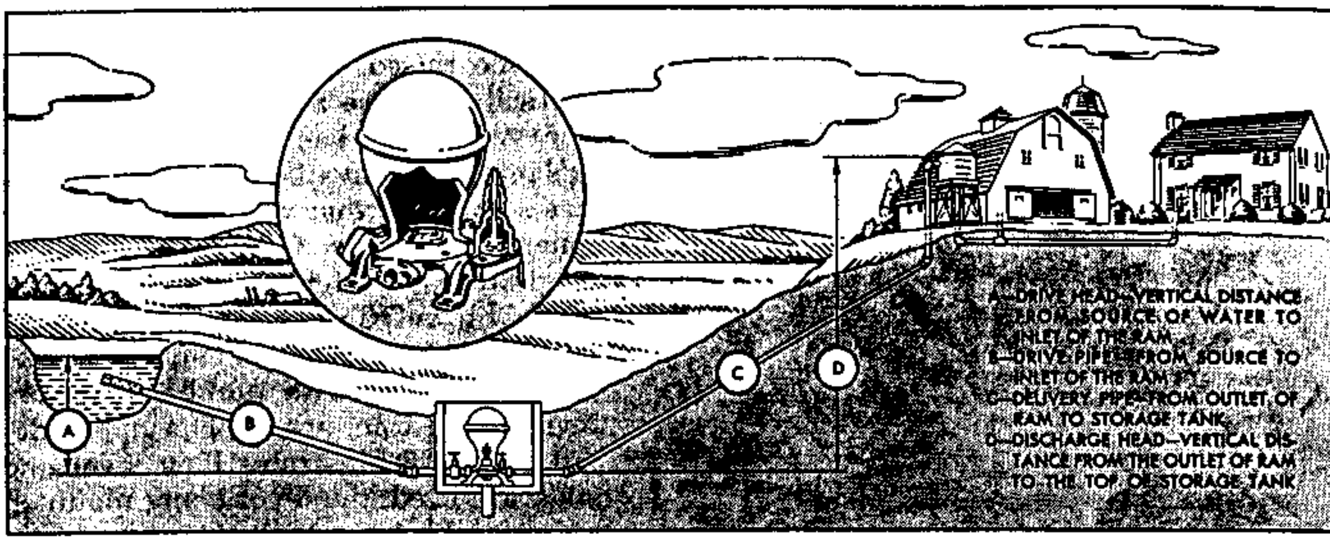
PART I

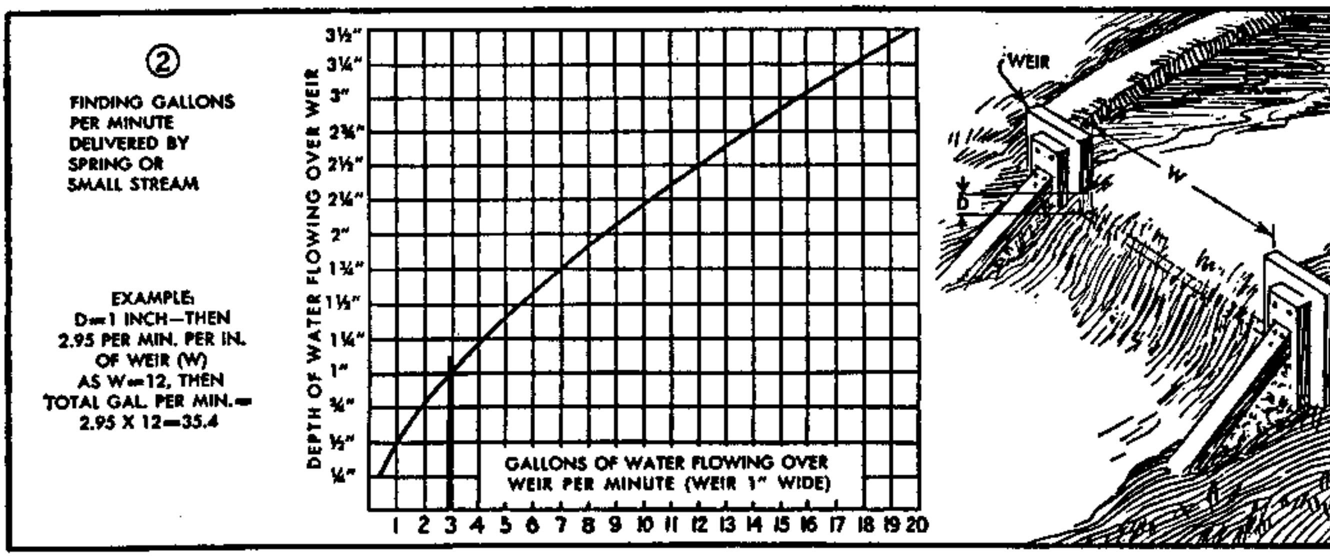
MANY rural homes and summer cottages can be furnished with running water from a near-by spring or stream even though its daily flow is modest, by installing a hydraulic ram. This is a pump which takes advantage of a small water fall to lift a portion of the water to a considerable height. Theoretically, a hydraulic ram should lift one half of the water available twice the height of the fall or 1/20 of it twenty times the height of the fall. But the actual efficiency of rams is less and varies considerably. Fig. 1 shows the working parts. Under normal conditions, the ram valve is open, thus allowing water to flow through the ram. As water flows, its velocity increases until the valve is lifted and quickly closed. Since water in motion possesses energy, a considerable pressure is developed. This pressure opens the check valve, thus admitting a quantity of water to the pressure chamber. When enough water has entered to relieve the excess pressure, the check valve automatically closes, thus preventing water from flowing back. At this instant a small volume of air enters through the breather hole to replenish the air dissolved and carried away by the water. Upon the next stroke of the ram this air will be forced into the pressure chamber. The addition of water to the pressure chamber compresses the air which in turn forces water through the delivery pipe to the reservoir. When the check valve closes, the weight of the ram valve overcomes the pressure against it and drops, thus allowing water to again flow through the tail or discharge pipe, and so the cycle is repeated. Where the water is to be used for drinking, it is best to obtain it from a spring, but if it is to be used for washing, stock watering and other purposes, the supply can be obtained from a small stream.

We shall first explain simplified methods which will enable anyone to determine how much water can be lifted from a spring to the location where it is to be used, and



Parts of hydraulic-ram installation



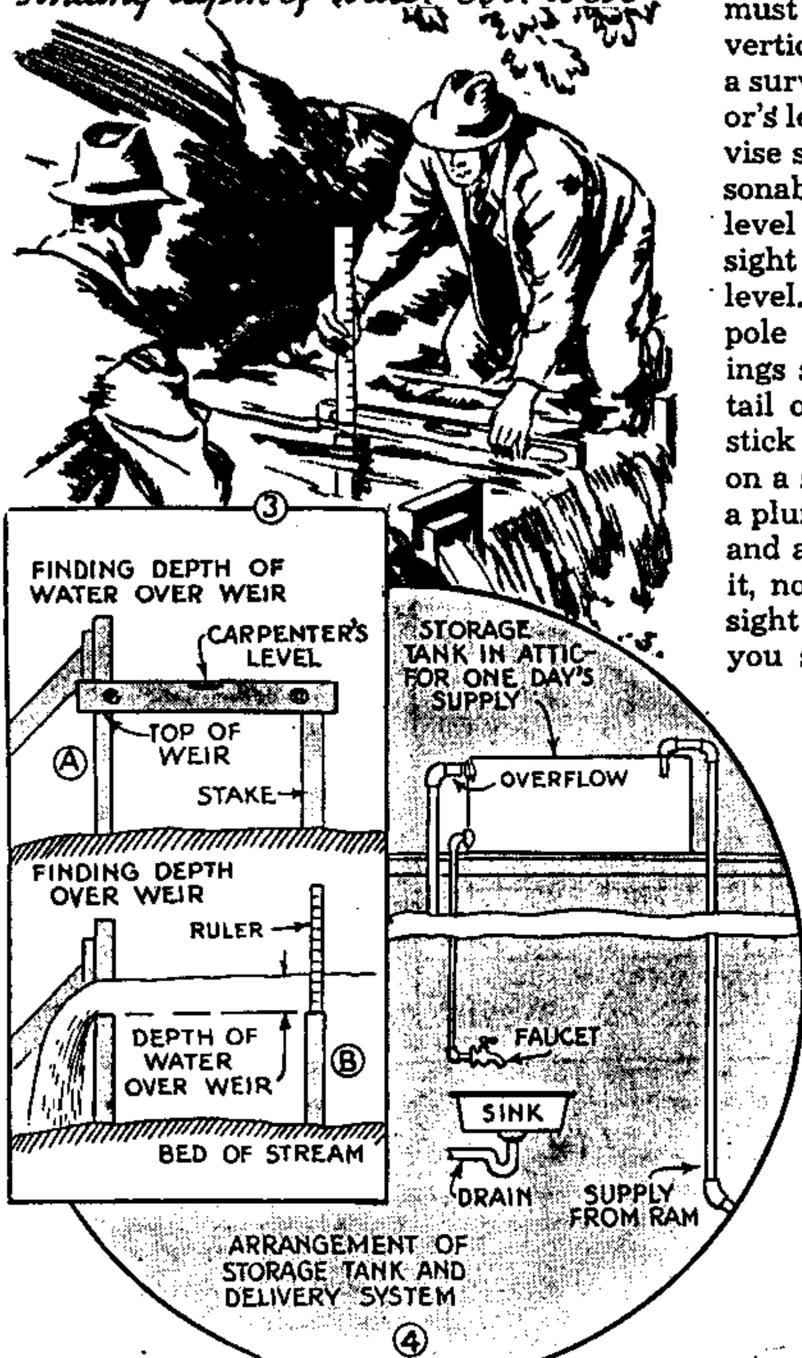


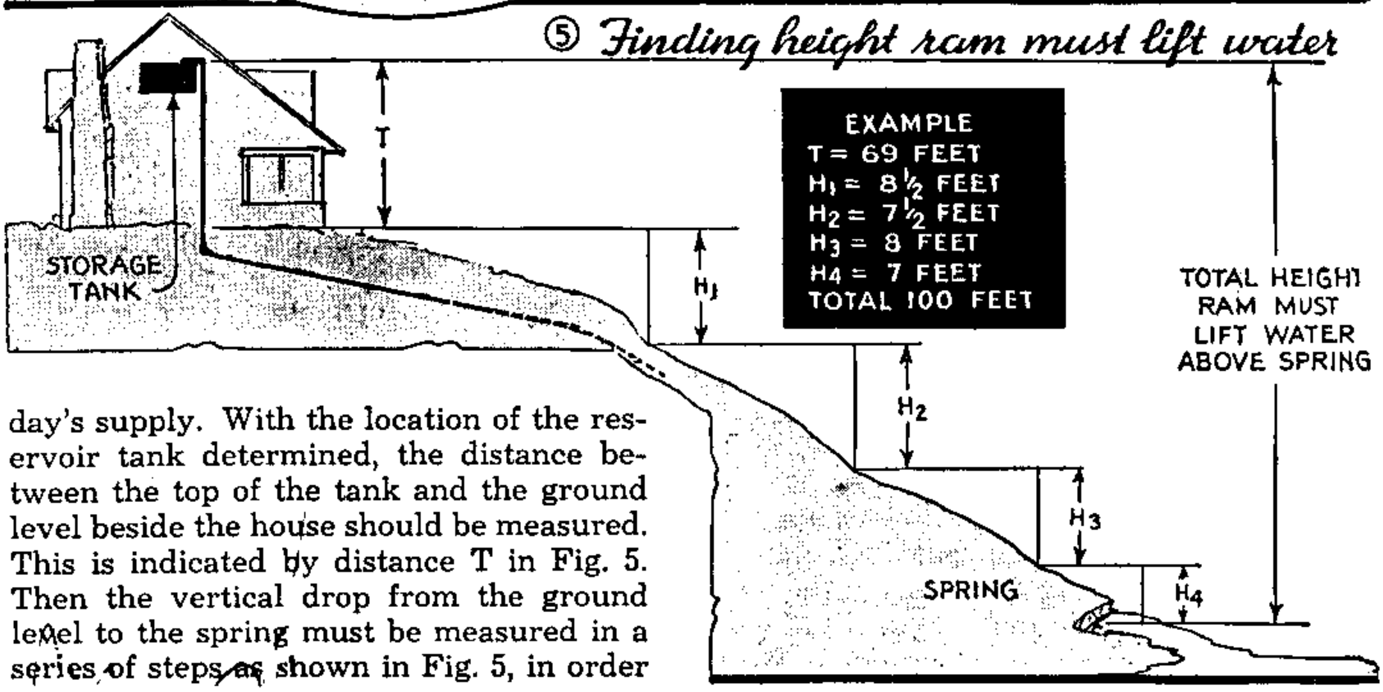
First measure distance D, which is the depth of water flowing over the weir, by the method shown in Fig. 3. Locate this value at the left-hand side of the chart, follow across to the curve, and then drop down where the amount of water in gallons per minute for each inch of weir length is given. Multiplying this number by the length of the weir in inches gives the total amount of water passing over the weir per minute

then illustrate methods of surveying the spring and determining the other necessary values. Then the spring must be surveyed first to find whether it will deliver enough water. To do this it is dammed as shown in Fig. 2, so that all of the water flows over the edge of the board or "weir." The weir must be perfectly level and so arranged that no water can flow under or around it. The flow should be slow and free from turbulence. The depth of the water flowing over it is measured as shown in Fig. 3. First drive a stake a couple of feet above the weir, the top of both stake and weir being level, which can be determined by the method shown in detail A. Then the distance from the top of the stake to the surface of the water is measured as in detail B. We can now determine the amount of water in number of gals. per min., by referring to Fig. 2. To illustrate the method we will assume that the depth of water flowing over the weir is one inch. We locate one inch on the left-hand side, following across to where this line meets the curve, and drop down to read a trifle below 3, say 2.95, as the gals. per min. for each inch of weir. Next we multiply this by the length of the weir which we will assume to be 25 in., giving a total of 73.75 gals. per minute. As the flow of springs varies with the seasons, it is necessary to estimate the minimum flow if this is not known. Let us assume that the flow during the dry season is 10 gals. per min. This value can, of course, be determined during the dry season by the weir method as explained.

Next, it is necessary to determine how high the ram will have to pump water to fill the supply reservoir, which may be located in the attic or other convenient place. Some use an outside tank. Fig. 4 shows a practical arrangement for the water-supply system. The reservoir or supply tank should be large enough to hold an entire

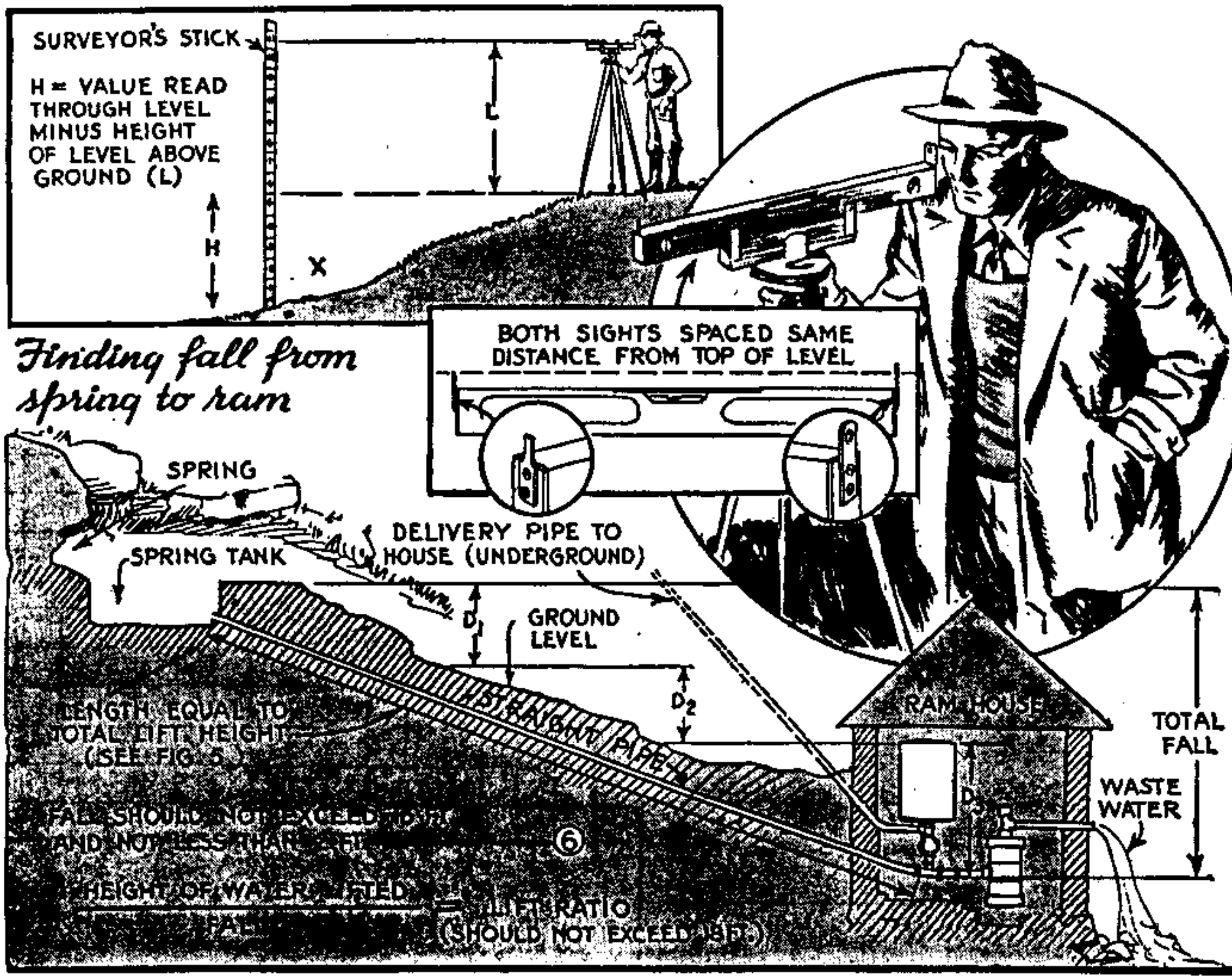
Finding depth of water over weir





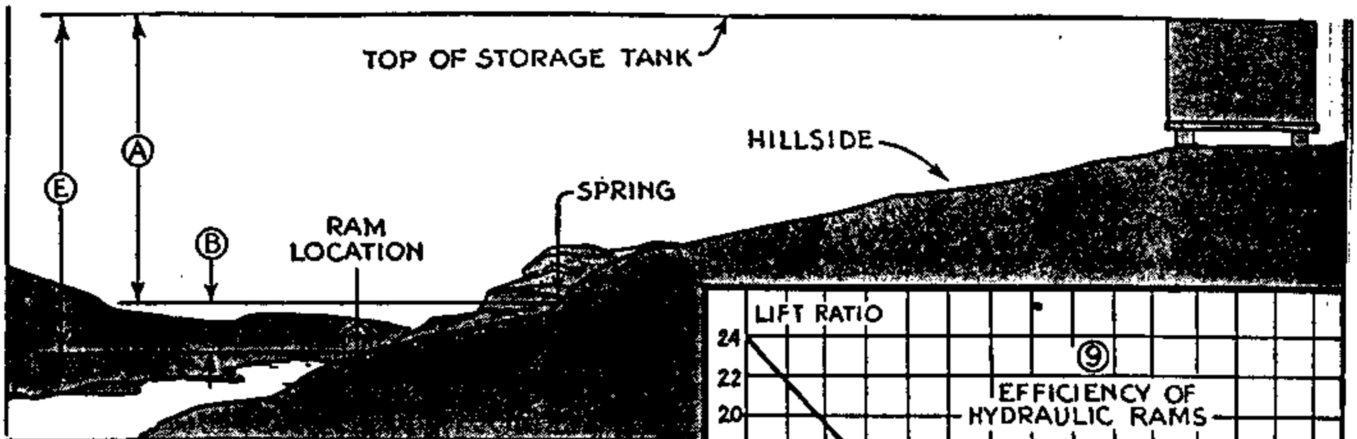
day's supply. With the location of the reservoir tank determined, the distance between the top of the tank and the ground level beside the house should be measured. This is indicated by distance T in Fig. 5. Then the vertical drop from the ground level to the spring must be measured in a series of steps as shown in Fig. 5, in order to determine the height that the water must be raised. The measurements of vertical drop are made with the use of a surveyor's level and stick. If a surveyor's level is not available you can improvise something that will work with reasonable accuracy from a carpenter's level fitted with sights so that the line of sight will be parallel to the top of the level. For the stick you can use a long pole graduated with numbered markings spaced 6 in. apart. The upper detail of Fig. 6 illustrates how level and stick are used, the level being mounted on a suitable tripod which is fitted with a plumb bob. Set the stick at location X and after adjusting the level, sight over it, noting the height where the line of sight crosses the stick. From this height you subtract L, which is the distance from the level to the ground, and the remainder is distance H. Then set the level with the plumb bob at point X and repeat the process. In this way distances H_1, H_2, H_3 and H_4 of Fig. 5 are measured. Adding all of these to distance T gives the height that water must be lifted from the spring to the top of the tank. It is not necessary that the path taken between the house and the spring be straight.

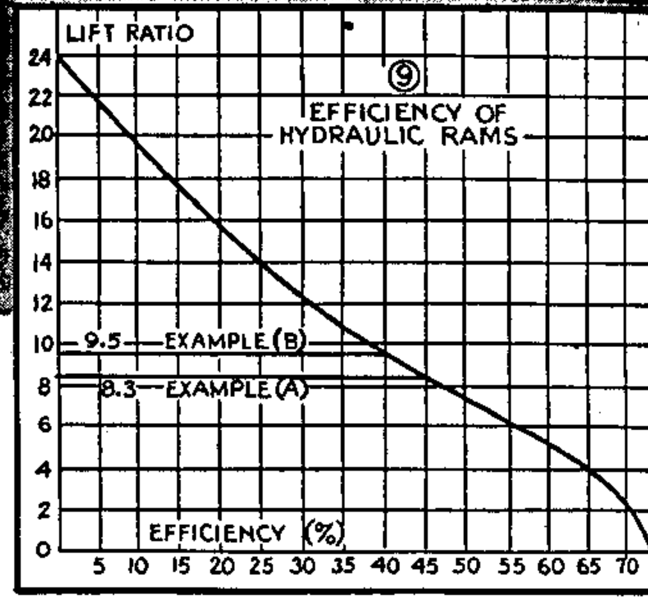
It must then be determined how great a fall of water is available for operating the ram. To do this, locate a point below



Besides measuring the vertical drop from the top of the reservoir tank to the spring, the additional drop from the spring to the ram, located not over 16 ft. below the spring, should be measured in the same way, using the level system shown in the upper details

the level of the spring from which the waste water from the ram can easily drain away. The straight pipe-line distance between the spring and the ram should be about the same as the vertical height to which the ram must lift the water. To continue with the example, we will assume that the top of the supply tank was found to be 100 ft. from the spring. This means that a pipe at least 100 ft. long will have to be run from the spring, straight but sloping downward, to a place below the spring where the ram will be located. Having determined the ram location, which should not be less than 2 ft. nor more than about 16 ft. below spring level and 100 ft. or more from the spring as shown in Fig. 6, we are ready to find the fall or head available for pumping water. This is the vertical height of the spring above the ram location and is found with a surveyor's level and stick as previously explained. We will assume our survey shows that the total fall (Fig. 6) is 14 ft. Then from Fig. 7 it is easy to determine whether a spring will pump as much water as is required. Assuming that the ram will be located 14 ft. vertically below the spring, Fig. 6, we deduct 2 ft. to allow for frictional loss in the drive pipe. This leaves 12 ft. as the fall available for pumping water. We will also assume that the requirements are 550 gals. of water per day. Referring to Fig. 6, we add the lift to the fall and multiply this by the number of gals. per day, that is, 550 multiplied by 114 or 62,700. Next, according to G of Fig. 7, the fall available for operating the ram, which is 12 ft., is multiplied by 14.4 which equals 172.8. We must next determine the efficiency of the ram by referring to Fig. 9. To do this we divide the height the water is to be lifted above the ram, or 114 ft., by the fall from the spring to the ram, or 14 ft., to get the lift ratio. In this case 114 divided by 14 equals 8. We locate this at the left side of Fig. 9, example A, follow across to the curve and down to the bottom and read 45 percent as the efficiency. Multiplying this by 172.8, as shown in Fig. 7, we get





To find the efficiency of a ram, you first determine the lift ratio by dividing the height that water is to be lifted above the ram, by the fall from the spring to the ram

⑦ FINDING SPRING FLOW REQUIRED TO OPERATE RAM

Method	Example
A—Find vertical height to lift water (Call this A)	A = 100 feet (found by surveying—(Fig. 5)
B—Find vertical fall from spring to ram (Call this B)	B = 14 feet (found by surveying—(Fig. 6)
C—Subtract 2 from B to allow for losses in ram (Call the answer C)	C = 14 − 2 = 12 feet
D—Estimate gallons of water per day required (Call this D)	D = 550 gallons per day (estimated)
E—Add A and B to find total lift (Call this sum E)	E = 100 + 14 = 114 feet
F—Multiply D by E (Call this product F)	F = 550 X 114 = 62,700 foot gallons per day
G—Multiply C by 14.4 and this product by efficiency of ram (Fig. 9) (Call this G)	Since efficiency = 45% (Fig. 9) G = 14.4 X 12 X 45 = 7776
H—Divide F by G to find gallons per minute required of spring	H = 62,700 ÷ 7776 = 8 gallons per minute required from spring

⑧ FINDING GALLONS OF WATER PER DAY AVAILABLE FROM SPRING

Method	Example
I—Multiply 14.4 by gallons per minute from spring (Call this product I)	Spring delivers 10 gallons per minute and the fall is 14 feet. Water must be lifted 100 feet above spring. I = 14.4 X 10 = 144
J—Multiply I by C (See Fig. 7) and by the efficiency (See Fig. 9 for C) (Call this product J)	Since C = 14 − 2 = 12 and efficiency 45% J = 144 X 12 X 45 = 77,760
K—Divide J by E to get gallons pumped per day (See Fig. 7 for E)	K = 77,760 ÷ 114 = 682 gallons per day

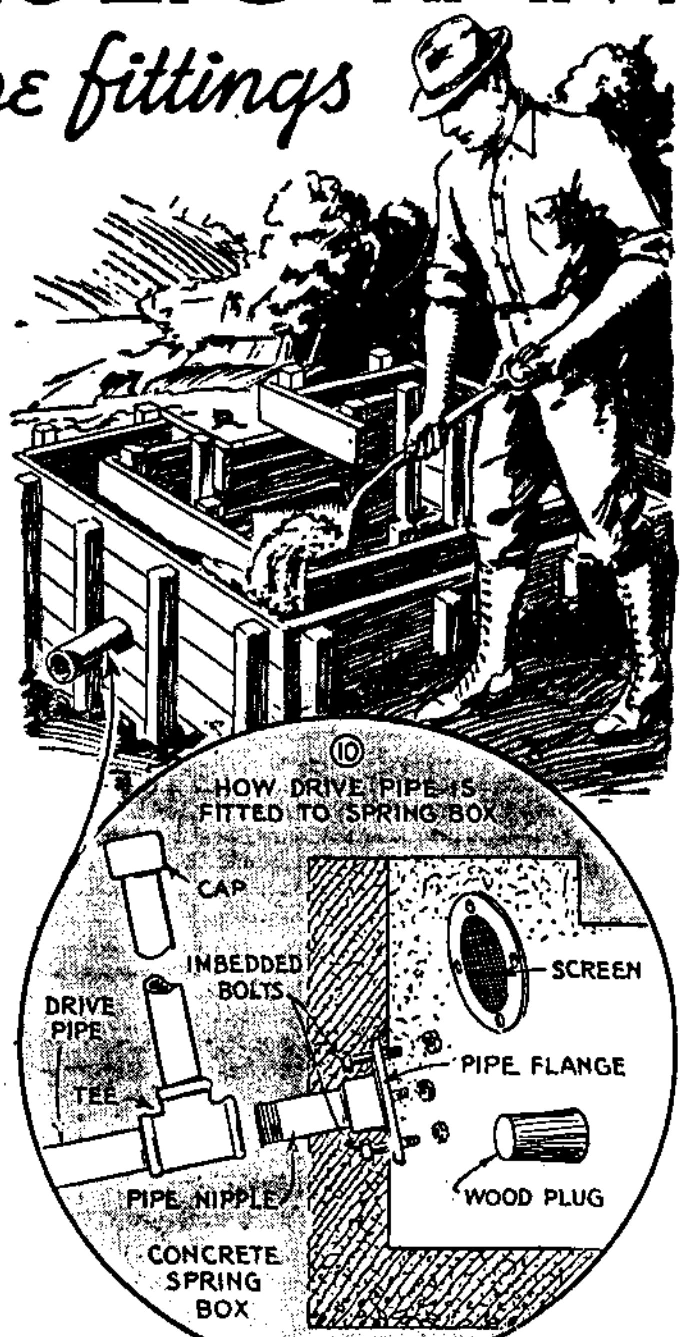
7776 as the answer. The next step is to divide the first product, or F, by the second product G, or 62,700 divided by 7776, which equals 8 gals. per min. as the amount of water which the spring will have to supply in order to furnish the required amount of water.

If the spring supplies 12 gals. of water per min. during the dry season, we will be safe in installing the ram. But if, after making these determinations, it should be found that the spring will not deliver sufficient water, the next thing to do would be to figure how much water could be pumped per day during the dry season. Fig. 8 illustrates the method of making this calculation. Then, after you have found that there is sufficient fall available to operate a ram, the job of figuring the exact size required, and how to install it, comes next. This is thoroughly covered in the following pages, which also contain workable methods of making parts cheaply from pipe fittings. Hydraulic rams are made in a number of sizes and varieties; their advantage over homemade rams is that they have been developed for long use and minimum trouble.

HYDRAULIC RAM

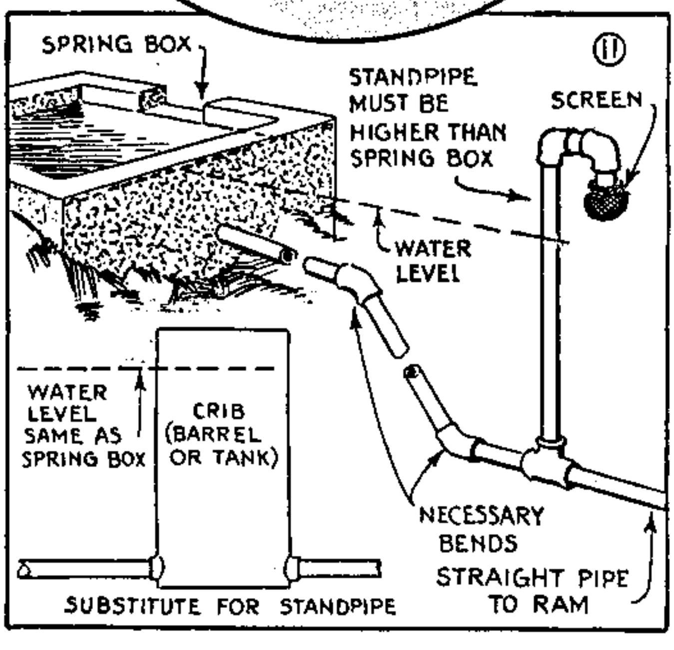
is made from pipe fittings

Part II—Design, Construction and Installation of Rams

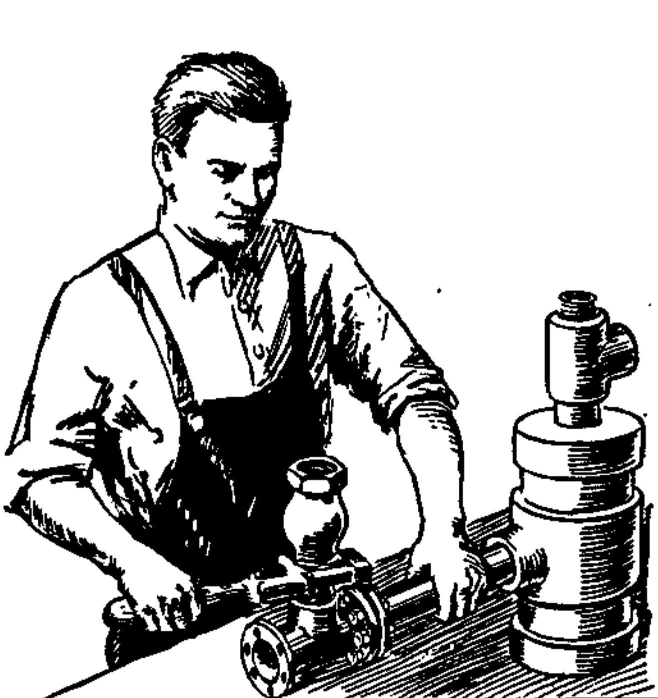


AFTER surveying the spring or stream we will now proceed with the design and construction of a ram. The initial step is to find the size of the drive pipe, that is, the pipe which runs from the spring to the ram. The chart shown in Fig. 12 makes this easy. First refer to the bottom of the chart and locate the number corresponding to the gallons of water per minute which must be furnished to the ram. Continuing with the example that was followed in Part I, which required 8 gals. per minute, we locate 8 gals. per minute at the bottom of the chart, draw a vertical line to the curve, and at the point where this line crosses the curve, draw a horizontal line to the left-hand side of the chart and find that a ram-pipe size between 1¼ and 1½ in. will be required. Accordingly, we will select the nearest larger standard pipe size, or a 1½-in. pipe. The delivery pipe that runs from the ram to the supply tank should be one half this diameter, or in this case, ¾ in. In all cases where the size of pipe required comes out a fraction under standard size of pipe, then the next larger standard size should be used. In no case should the smaller size be used as this would tend to reduce the rate of flow to an extent which would probably interfere with the satisfactory performance of the installation.

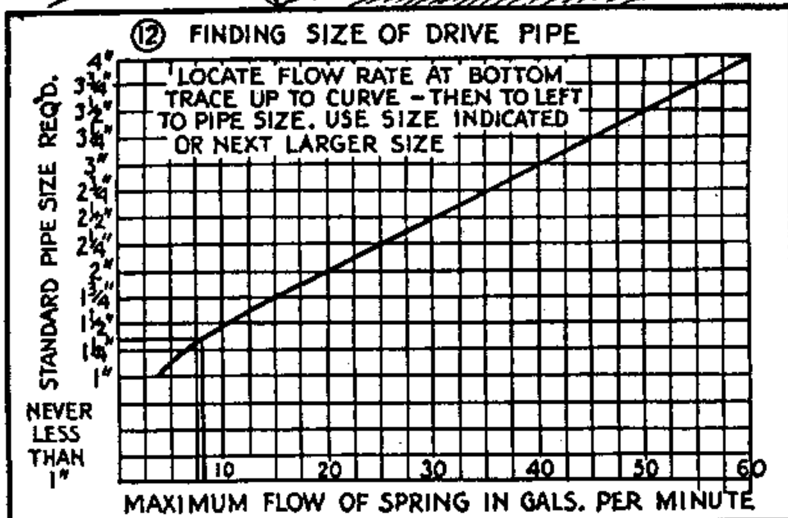
Fig. 10 shows a method of attaching the drive pipe to the crib or spring box. The spring box, preferably of concrete, should be constructed so that all of the water, or a sufficient amount of it, flows into the box. The side from which the excess water is to be allowed to overflow should be made a few inches lower than the rest of the box so that the surplus will flow in the proper direction. The pipe from the ram should enter the side of the box as shown. By this means all of the water issuing from the spring can be used for operating the ram during dry seasons. If the tem-



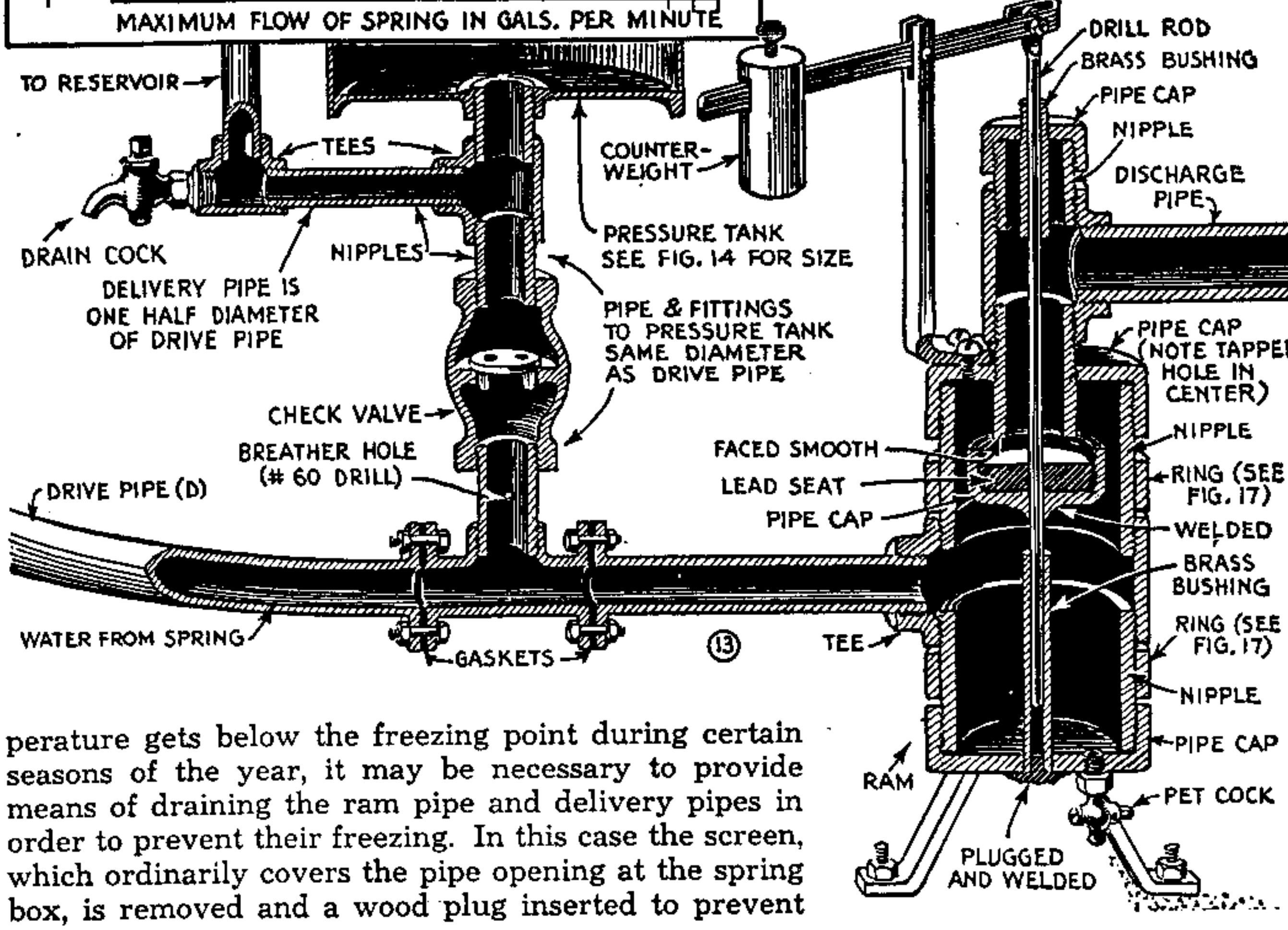
perature gets below the freezing point during certain seasons of the year, it may be necessary to provide means of draining the ram pipe and delivery pipes in order to prevent their freezing. In this case the screen, which ordinarily covers the pipe opening at the spring box, is removed and a wood plug inserted to prevent further flow, after which the cap on the vent pipe is unscrewed so that the draining of the pipe is assured. Then drain cocks at the ram and pressure tank are opened to allow all water in the installation to drain off.



The ram pipe should be run straight from spring to ram, if possible. If this is impossible, one of the methods shown in Fig. 11 may be used. The standpipe must be of the same or of larger diameter than the drive pipe and must extend vertically to a height a few inches above the level of the water in the spring tank. This pipe has a "goose neck" at the top to prevent the entry of dirt. A screen should also be placed over the open end to prevent insects from entering. Similar cautions are required in the use of the crib which may be used as a substitute for the standpipe.



Having determined the pipe sizes and laid out the ram line, we are ready to construct the ram. Fig. 13 shows details for the assembly of an effective type of ram which can be made from ordinary pipe fittings. Note that all of the dimensions are figured from the diameter and length of

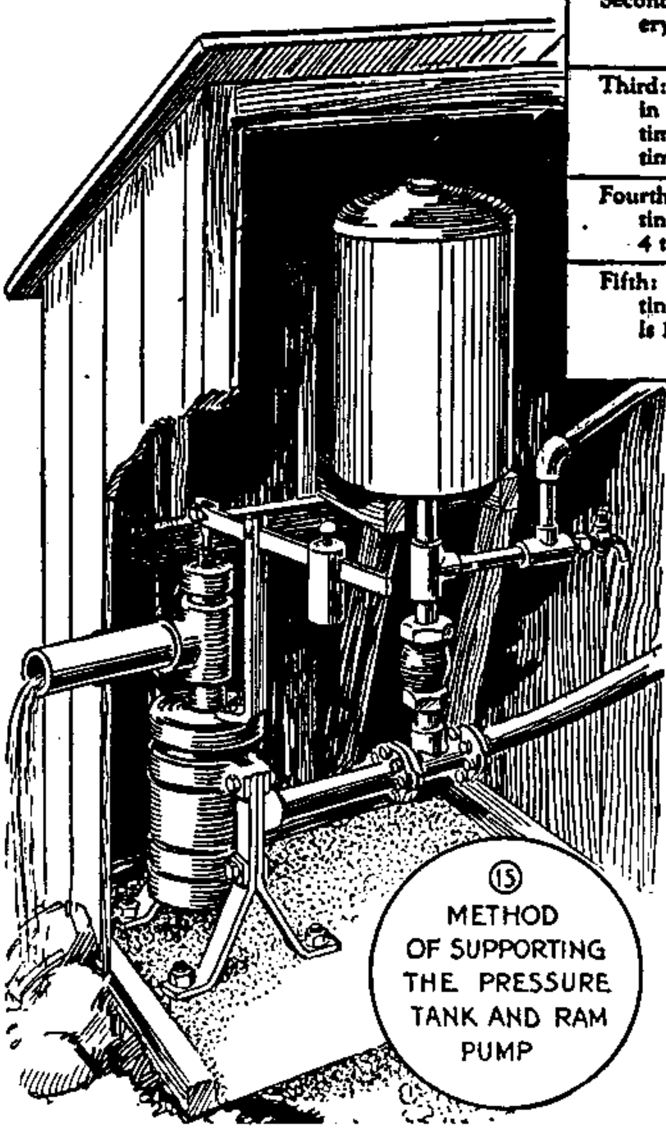


the ram pipe as shown in Fig. 14. The pressure tank should have a capacity in gallons approximately equal to the volume of the drive pipe. Applying the simplified formula given in Fig. 14 to our example, we first multiply the diameter of the drive pipe by itself. Thus for a 1½-in. drive pipe, we get 2.25. Next we multiply this by the length of the drive pipe in feet, assumed to be 100 ft. and then by 0.041 to find the size of the pressure tank in gallons. Performing this operation, we get 2.25 times 100 times 0.041 equals 9.2 gallons. A 10-gal. expansion tank of the kind used on hot-water heating systems will be satisfactory. The tank selected should not be smaller than 9.2 gals. and not much over 15 percent larger.

The ram proper is made from sections of pipe and fittings whose diameters are four times the diameter of the drive pipe. Therefore, in our example, we must use 6-in. pipe and fittings for the ram. The ram discharge pipe should be 1½ times the diameter of the drive pipe. All

DESIGN DATA TO DETERMINE SIZE OF PIPE, ETC.
FIG. 14

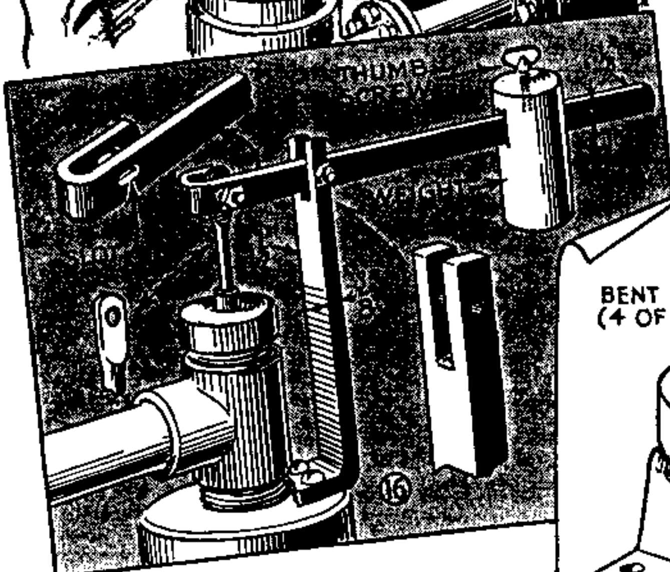
Procedure	Example
First: Find drive-pipe diameter from Fig. 12. Call this "D"	As 8 gal. per min. is flow from spring, Fig. 12 shows drive pipe should be 1½ in.
Second: Find diameter of delivery pipe. This should be ½ D	½ of 1½ gives ¾ in. for size of delivery pipe. Never use pipe less than ½ in.
Third: Find size of pressure tank in gallons. This is D times D times the length of drive pipe, times .041	1½ times 1½ times 100 (length of drive pipe) times .041 equals 9.2 gal. required size of pressure tank
Fourth: Find size of pipe and fittings for ram. This should be 4 times D	Drive-pipe dia. 1½ in. times 4 gives 6 in. for size of ram pipe and fittings
Fifth: Find size of pipe and fittings for discharge pipe. This is 1½ times D	Drive-pipe dia. 1½ in. times 1½ gives 2¼ in. for size of discharge pipe and fittings.

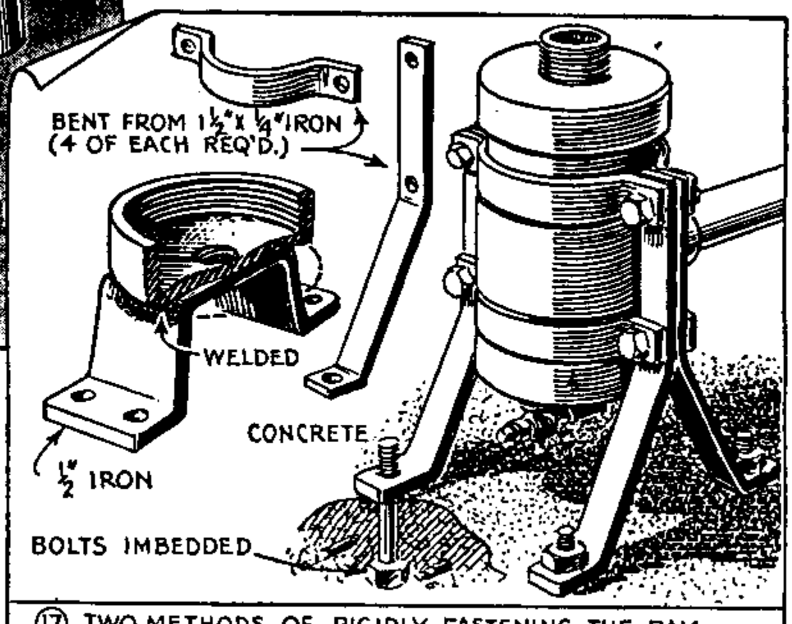


(15) METHOD OF SUPPORTING THE PRESSURE TANK AND RAM PUMP

of these values are given in Fig. 14. The ram valve is made by drilling a hole exactly through the center of a pipe cap and pressing a length of drill rod through it as shown. The drill rod should be welded to the pipe cap as shown to prevent it from slipping. Next, the pipe cap is filled with molten lead as indicated. The purpose of the lead is to form a soft bed which can easily seat on the end of the faced pipe nipple which extends from the top of the ram. This rod is guided by the top insert of brass tubing and a similar length of brass tubing in the bottom cap of the ram. The drill-rod end which projects through the top pipe cap should be drilled and coupled to the counterbalance, Fig. 16.

When these parts are properly assembled and the ram installed rigidly, which can be done as shown in Fig. 17, it will be





⑰ TWO METHODS OF RIGIDLY FASTENING THE RAM

found that there is a position at which the counterweight can be located so that merely touching the lever arm will cause the valve to close or open. The exact location of the weight will be found after the ram has been installed. A length of pipe may be connected to the discharge "tee" in order to guide the tail water away from the ram house. In no case should this pipe be bent or should fittings be used, as bends would slow down the flow of water and interfere with operation. This, and a good method of mounting both the ram and pressure tank, are shown in Fig. 15.

The check valve between the drive pipe and pressure tank, Fig. 13, should be arranged so that water can flow from the ram pipe into the pressure chamber but not in the reverse direction. A substantial type of check valve of good quality should be used. Unused holes in the pressure tank should be closed carefully with pipe plugs. The tank must be tested for leaks carefully. If there is even a small leak, the "hammer" of the ram will burst it. There is one other important point which must be noted in connection with the assembly of the ram and that is the small breather hole below the check valve. This hole should be drilled with a No. 60 drill. It should be located where it can be inspected easily. The purpose of this hole is to allow the entrance of air immediately after the check valve closes. The air that enters during this period collects under the valve and is forced into the pressure chamber during the next stroke of the ram. If this small hole is omitted, the air in the pressure chamber will slowly decrease, as it is absorbed by the water, and thus no air pressure will be available for lifting the water. When the installation is complete it is only necessary to remove the plug from the ram pipe in the spring box or crib, and adjust the counterweight until the ram operates at between 25 and 30 strokes per minute or faster.

If a homemade ram does not stand up under the constant hammering and requires too frequent replacement of the valve, it might be advisable to improve this part of the installation by substituting a manufactured ram. The instructions contained in these articles apply whether a homemade or manufactured ram is used.

Hydraulic Rams

Volunteers in Technical Assistance (VITA)

How They Work

A hydraulic ram is a simple device, invented in the early 19th century. It uses the power from falling water to force a small portion of the water to a height greater than the source. Water can be forced about as far horizontally as you desire, but because of friction, greater distances require larger pipe. There is no external power needed, and the ram has only two working parts. The only maintenance needed is to keep leaves and trash cleaned away from the strainer on the intake and to replace the clack and non-return or delivery valve rubbers if they get worn. There is almost no expense except for the original cost. And a home-built ram costs about one-tenth the cost of a manufactured one.

Two things are needed to make the ram work: (a) enough water to run the ram and (b) enough height for water to fall through the drive pipe to work the ram. A small amount of water with plenty of fall will pump as much water as a greater amount of water with only a little fall. The greater the height to which the water must be raised, the less water will be pumped, under a given set of circumstances.

Water may come from a spring on a hillside or from a river. It must be led into a position from which it can pass through a relatively short supply pipe to the ram, at a fairly steep angle (about 30 degrees below the horizontal is good). Often a catch basin or cistern is used as the source for the drive pipe, but an open ditch could be used. (See Figure 36.) Be sure to put a strainer on the top of the drive pipe to keep trash out of the pipe and ram.

The ram works on simple principles. The water starts to run down through the drive pipe, going faster and faster until it forces the automatic valve or clack to close suddenly. The weight of the moving water suddenly stopped, creates very high pressure, and

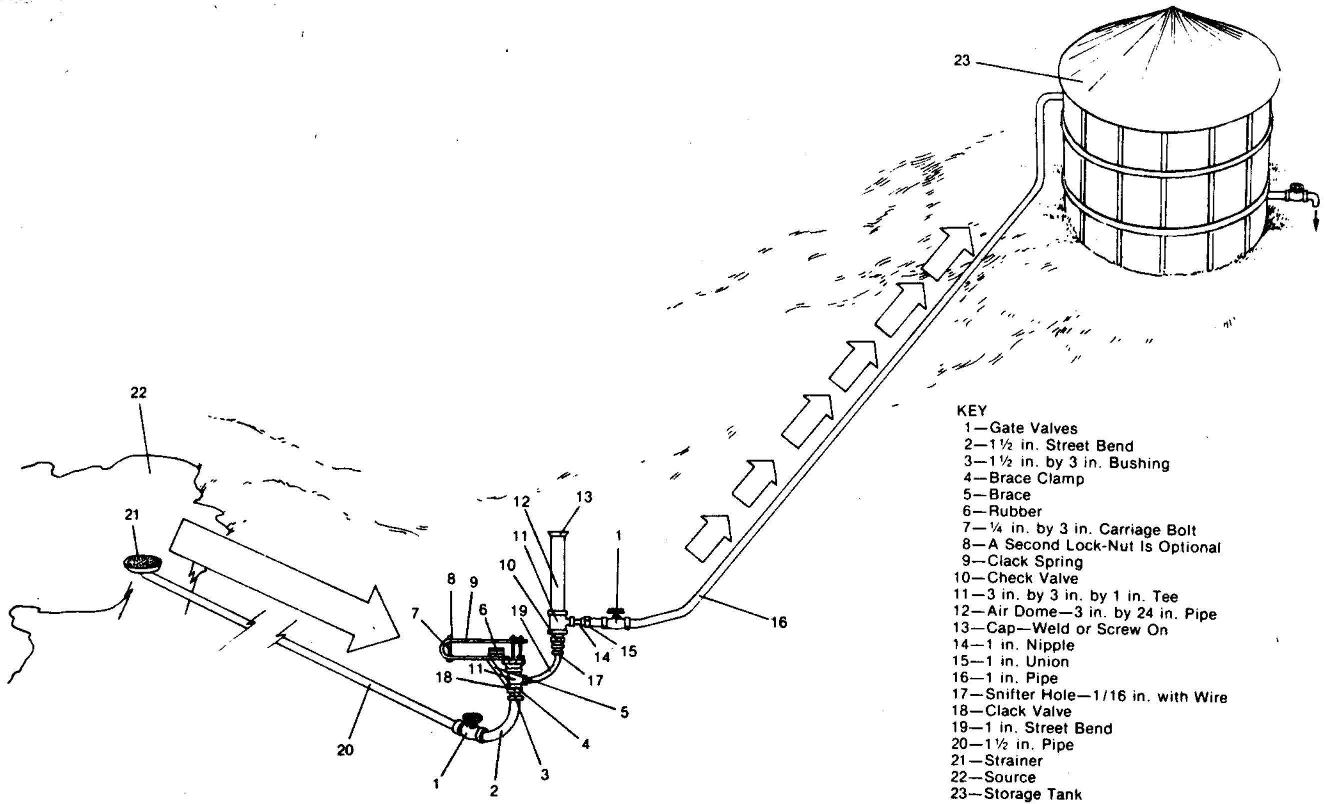


FIGURE 36. Hydraulic ram in operation.

forces some of the water past the non-return or delivery valve and into the air chamber, compressing the air more and more until the energy of the moving water is spent. This compressed air acts as a spring and forces the water up the delivery pipe to the storage tank in a steady stream.

It takes a lot of falling water to pump a little water up a hill. Often about one part in ten is delivered to the storage tank at the top of the delivery pipe. The snifter hole wastes a bit of water but takes in a bubble of air with each stroke. This is necessary to keep air in the air dome, which must not get plugged or it will get filled with water and the ram will stop.

The small ram works best at about 75 to 90 strokes per minute, depending on the amount of drive water available. The slower it goes, the more water it uses and the more it pumps.

Any working fall from 18 inches to 100 feet can be used to work a ram, but in general, the more working fall you obtain, the less the ram will cost and the less drive water it will require to raise a given amount of water. If there is plenty of water, a fall of 4 feet could be made to raise water 800 feet, but this would be an expensive installation. The following is a rough formula that will give you an idea of the amount of water which can be raised:

$$\frac{\text{Driving water per minute in gallons or liters} \times \text{twice the working fall in feet or meters}}{3 \times \text{vertical lift above ram in feet or meters}} = \text{Amount of water raised by the ram}$$

EXAMPLE: Working fall = 18 feet, lift above ram = 200 feet, driving water = 160 gallon/minute

$$\text{Water raised} = \frac{160 \times 2 \times 18}{3 \times 200} = \text{9.6 gallons per minute or 13,824 gallons per 24 hours}$$

This would require a No. 7 Blake ram.
100 gallons falling 10 feet would elevate 10 gallons to 80 feet.
100 gallons falling 5 feet would elevate 1 gallon to 300 feet.
Double the working fall and you just about double the water delivered.

Unless you have practically unlimited water available, measure it exactly by making a temporary dam and putting a large pipe or two through it. Then catch and measure the water for, say, 15

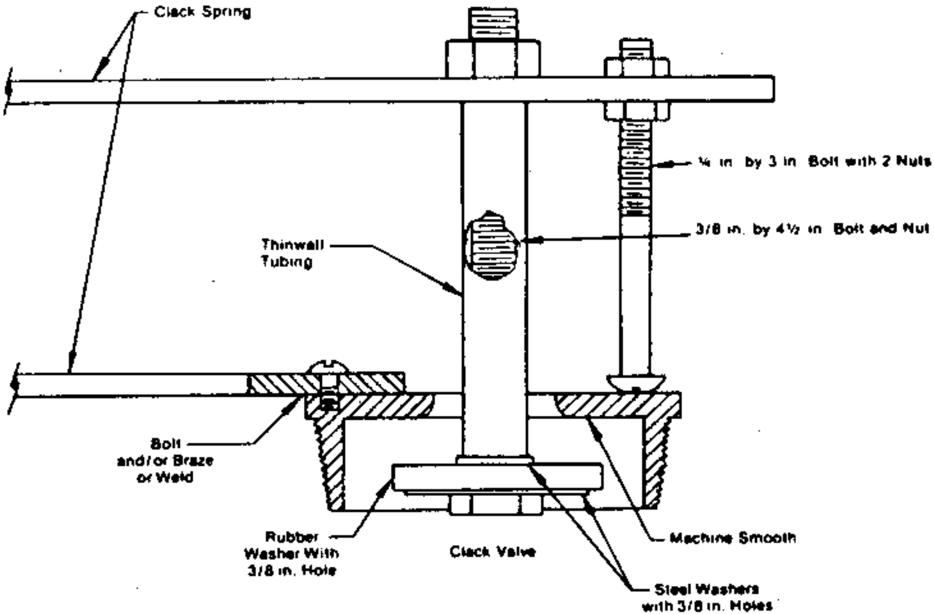


FIGURE 37. Clack valve for hydraulic ram.

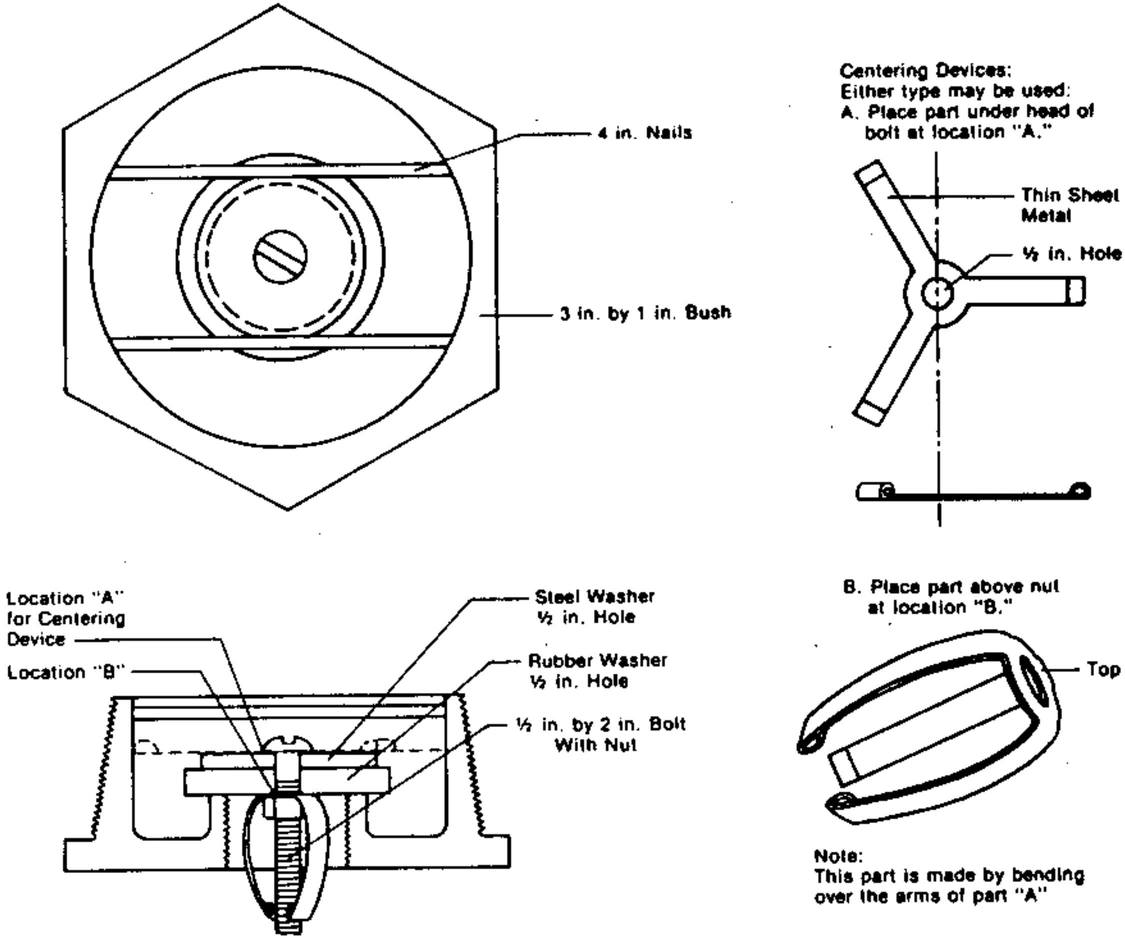


FIGURE 38. Check valve for hydraulic ram. (The purpose of the centering device—see detail on the right—is to prevent the moving assembly from slipping off-center or to the side.)

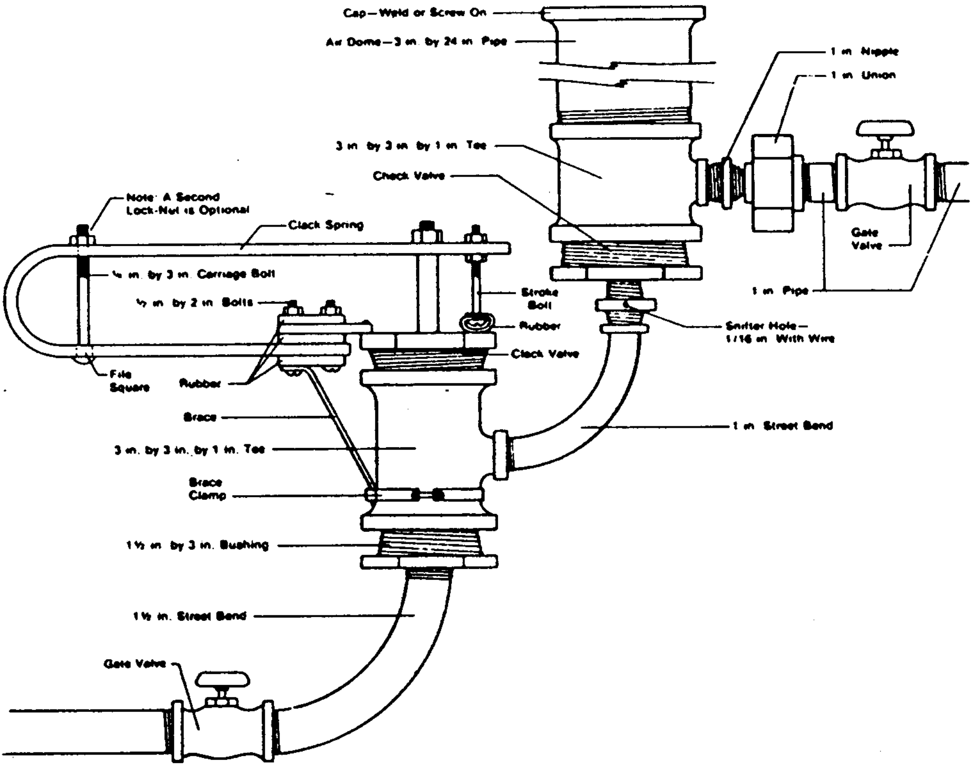
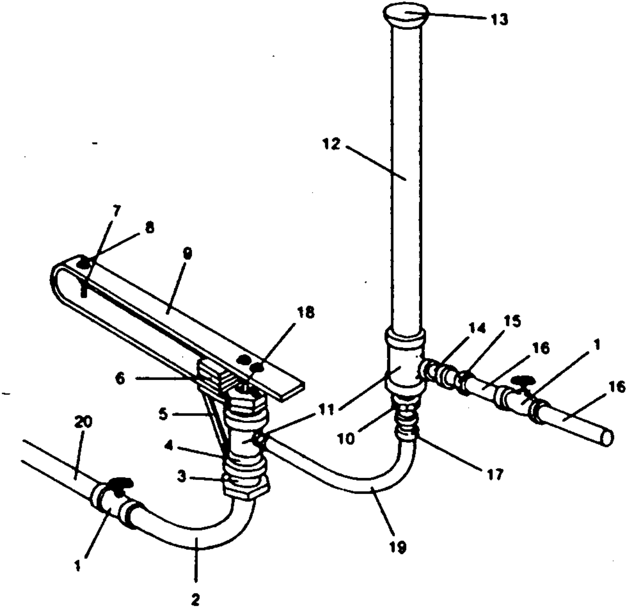


FIGURE 39. Complete assembly of hydraulic ram.



KEY
1—Gate Valves
2—1½ in. Street Bend
3—1½ in. by 3 in. Bushing
4—Brace Clamp
5—Brace
6—Rubber
7—¼ in. by 3 in. Carriage Bolt
8—A Second Lock-Nut Is Optional
9—Clack Spring
10—Check Valve—See Detail
11—3 in. by 3 in. by 1 in. Tee
12—Air Dome—3 in. by 24 in. Pipe
13—Cap Weld or Screw On
14—1 in. Nipple
15—1 in. Union
16—1 in. Pipe
17—Snifter Hole—1/16 in. with Wire Insert
18—Clack Valve—See Detail
19—1 in. Street Bend
20—1½ in. Pipe

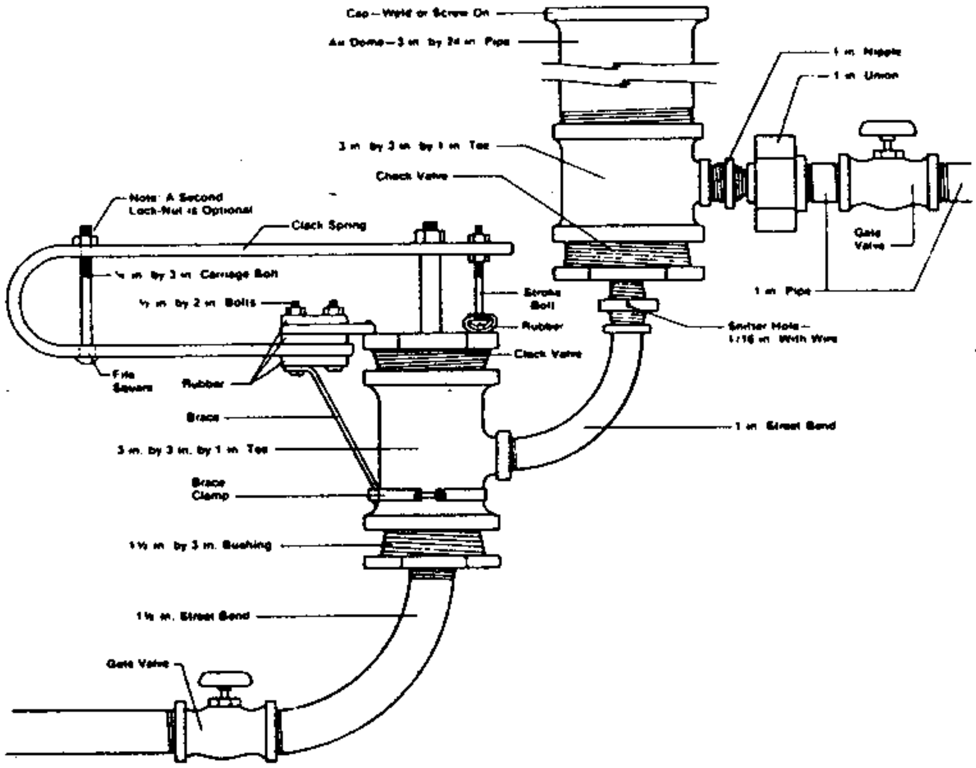


FIGURE 39. Complete assembly of hydraulic ram.

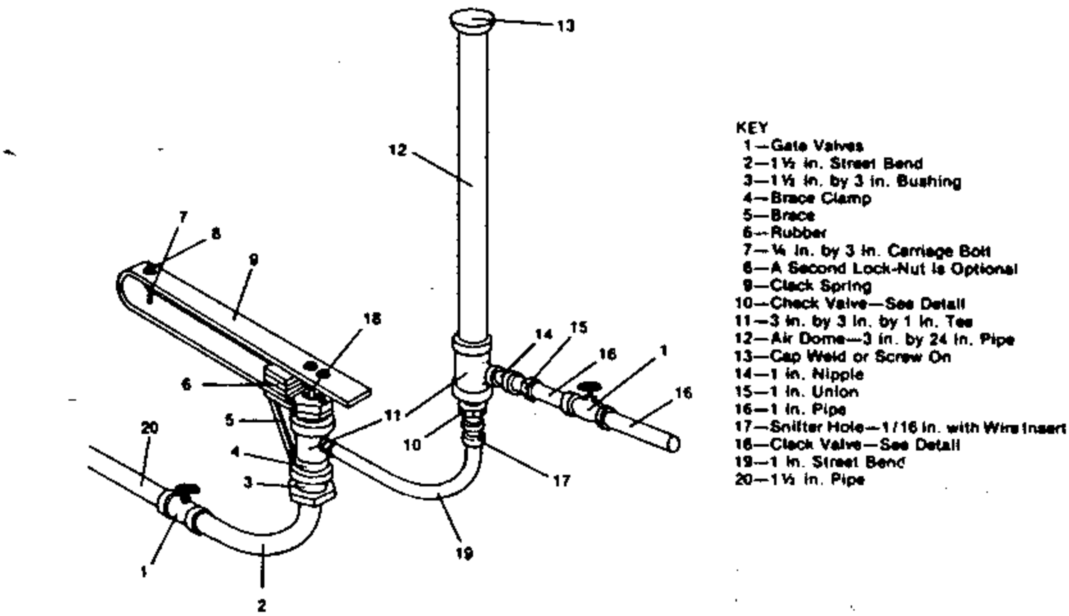


FIGURE 40. Assembly drawing of hydraulic ram.

minutes. Next, sight along a carpenter's level to the top of a 10-foot pole set on the ground down the hill at a lower level. Then move the level to the pole's position and sight again to the top of the pole, finding how many levels or fractions you have; this will give you, when added together, the amount of fall for the drive pipe. Do the same for the height to which the water must be raised. This height is measured from the ram level.

Building the Ram

Start by building the clack valve. (See Figure 37.) If you do not have a metal lathe, a machine shop will do the work for a small price. Chuck a 3-by-1-inch pipe bushing in the lathe and turn the inside smooth, where the clack strikes. Turn out the threads and eliminate any sharp edges. Drill two ¼-inch holes near the end of a piece of strap iron ¼-by-1½-by-3-inch, and using it as a template, drill and tap holes in the top of the pipe bushing. Grind off the galvanizing, then bolt the clack spring support solidly to the bushing and braze it.

Bend a 36-inch iron strap, 1½-by-⅛ inches, around a 2-inch pipe to make the clack spring. Drill two ½-inch holes through the end and also through both the support and the two short pieces to make up the pad as shown in Figure 37.

Cut pieces of rubber inner tube and assemble the sandwich. This sandwich will keep vibrations from breaking the support off the pipe bushing. A brace can be added for additional support, but it is not absolutely necessary.

The clack valve itself is made up of a rubber disc and metal washer ⅜ inch smaller than the inside of your bushing and assembled on a ⅜-by-4½-inch bolt. One of the best sources of rubber for the disc is an old tractor tire—it shows no wear at all after eight months' use. Cut it on a band saw and sand it flat and even on a disc sander with coarse paper. A similar piece of rubber is used for the check valve.

Slip a washer over the bolt and a short length of thin wall steel tube (¾ inch o.d. conduit) with the ends filed exactly square. Then slip it through a hole in the clack spring. Adjust it by bending, so that the rubber clack strikes true and doesn't rub on the sides of the bushing.

Drill a hole for a carriage bolt to adjust the stroke of the spring, then drill a pair of holes about 3 inches from the round end of the spring for a tension bolt. If the bottom hole is filed square to fit the underside of the bolt, it will not turn when adjustments are made.

The check valve (Figure 38) is similar in construction, but a

½-by-2-inch galvanized bolt is used. Machine the lip true where the valve rests, but do not cut it down farther than necessary. This gives a bit of clearance for the water to pass. Drill two holes on each side of the middle for a 4-inch common nail to pass just above the valve metal washer, to keep it in place. Leave enough clearance so the valve can open just about $^1/_{16}$ inch. Spread the bolt with a center punch just below the nut, so that the nut can't work loose. Cut the nails off and file threads across their ends so the bushing will screw into the tee above it.

Just one other small job is necessary before assembly: Drill a $^1/_{16}$-inch hole in the center of the 1-inch nipple just below the check valve. Then bend a piece of copper wire to the shape of a cotter pin and insert it from the inside of the nipple with long nosed pliers. Spread the outside ends. This copper wire restricts the jet of water coming out, yet moves enough to keep the hole clean.

The air dome can be a 2-foot length of 3-inch pipe, threaded on both ends with a cap or a welded plate on the top end. The dome must be airtight at great pressure. Coat the inside of the pipe with asphalt paint to protect it from rust and to seal any small leaks in the weld. Let it dry in the sun while assembling the rest of the ram.

Assembly

Use plenty of good grade pipe joint compound, both on inside and outside threads. Screw components together firmly, but not excessively tight, and leave them in the correct position for your installation. (See Figures 39 and 40.) Set the ram reasonably level. The snifter hole must be immediately below the air dome so that the bubbles will go up into the dome. Clack and check valves must be free from binding and touch evenly all around. The old tractor tire rubber with some fabric on the back seems to be just the right toughness and resiliency to last a long time—much longer than either gasket rubber or live rubber.

There is no reason at all to mount the ram in concrete as has been suggested by some. In fact, it is very convenient to have a "portable" ram and to be able to shut off the two valves, loosen the unions, and take the ram to the shop for cleaning and painting. Painting, of course, doesn't improve operation, but it does improve your ram's appearance.

A bit of rubber stretched over the head of the stroke bolt will help to quiet the ram. Adjust the spring tension bolt and stroke bolt together to get the best period for your particular ram. Support the drive and delivery pipes so they don't bounce and vibrate.

The ram described here is a small one, but larger rams can be built. VITA has built two with 3-inch drive pipes and correspondingly larger ram parts. One of our larger hydraulic rams lifts water about 150 feet and drives it through 3600 feet of pipe.

Installation and Adjustments

The drive pipe should have a strainer on the top made of ½-inch coffee tray wire, hardware cloth, or anything similar. This wire will keep out trash, frogs, and leaves, all capable of clogging up the ram. The drive pipe should be 1½ inch or larger (we use 2-inch pipe) and, if possible, it should be new, solidly put together, straight, and well supported throughout its length. A gate valve on the drive pipe about 4 feet from the ram is a great convenience, but is not necessary. Another gate valve on the delivery pipe is almost a necessity since it will prevent the entire delivery pipe from draining whenever the ram is cleaned. The ram should be connected to the delivery and drive pipes by unions so it can be removed for cleaning. (See Figure 36.)

If it is desirable to use two rams, they must have separate drive pipes, but the delivery pipes can be joined, provided the pipe is large enough to carry the increased quantity of water.

The delivery pipe should lead off from the ram with about two lengths of 1-inch galvanized iron pipe. From there ¾-inch plastic pipe can make up the remainder of the delivery pipe. The iron pipe will give the ram better support, but plastic pipe is smoother inside and can be a size smaller than the iron pipe. Also, plastic pipe is cheaper, but it must be protected from mechanical injury and sunlight.

The length of the supply line must be at least three times the length of working fall. If it is shorter the ram will stop when the tap is turned on. (A float valve, however, might prevent this from happening.)

The small bolt at the end of the clack spring controls the length of the stroke of the ram. The bolt at the back (rounded) end of the spring controls the tension of the clack spring. (See Figure 38.) Experiment for the best length of stroke and tension for your set of conditions. Adjust the length of stroke first, then the spring tension. The greater the tension and length of stroke, the slower the ram will work and the more water it will pump, but it will take more water to keep it working.

For a reliable, constant supply of water, lead all the water from the ram directly into a storage tank and use it from there. The overflow can be used to irrigate your garden or field.

IF ACTION IS FAULTY:

•See that the clack valve closes squarely, evenly, and completely. If it does not, the clack spring may have been bent somehow, and it will have to be straightened.

•See that the clack valve does not rub on the front, side, or back of the valve body.

•Check for trash in the ram, delivery valve, or in snifter hole.

•Check to see that the air dome is not filled with water. If it is filled with water, the ram will knock loudly and one or more parts may break. The snifter should allow a small amount of air to enter between each of the strokes to keep the dome full of compressed air.

•Check the rubber clack and delivery valve for wear or looseness.

•If drive water is in supply, speed up the stroke by loosening spring tension and shorten the stroke by lowering the stroke-adjusting bolt. More water is delivered by a faster stroke and continuous running than a slower stroke that stops every day.

•Check for leaks in the drive pipe. If air bubbles come out of the drive pipe after it has been stopped for a while, air is leaking into the drive pipe and is interfering with the ram action.

Building a Hydraulic Ram

by Don Marier

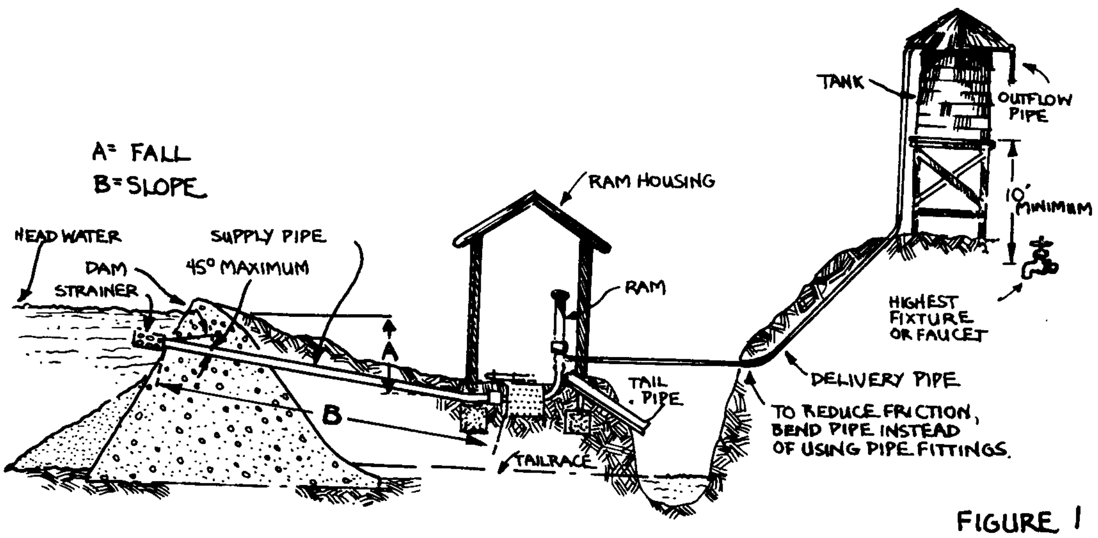


FIGURE 1

I'm always interested in getting something for nothing, so I find hydraulic rams intriguing. They pump water using water – no gas, oil, or electricity is needed. You do need a stream, artesian well, or a spring as a source, though, so not everyone can use one.

The hydraulic ram was invented about 150 years ago and was fairly well widespread in use, until electricity came to the countryside. There are still a few of them around and you may be lucky enough to find one, on an old farm.

I first saw a ram in 1970, when I noticed one in my father-in-law's toolshed in northern Wisconsin. It looked like some type of pump with an octopus- or bulb-shaped chamber on top. My father-in-law still had copies of the sales information on the ram (see references 1 and 2 at end). I was able to get the ram working by reading this information. It's too bad they don't explain how things work anymore.

I took the ram apart, expecting to find a series of chambers and valves inside the bulb, but all I found was one simple leather valve. The leather had lost its zip after 25 years, so I replaced it. With this simple repair done, I installed the ram near a pond with a two-foot dam on it. The ram was irrigating the garden within a few hours.

The ram looked so simple that I began to think of ways to build one out of regular plumbing parts. Two weeks later, I found out that the people at VITA had just put out a manual – **A Hydraulic Ram for Village Use** – on how to do just that (page 52). Since then, I also found a **Popular Science** article on building a ram (page 57). As a future project, I'd like to combine the best of both designs.

I built a ram according to VITA's plans and I'm satisfied with the results. It cost me about $18 worth of parts but that's only about one-tenth the cost of buying a factory-made ram. The parts list calls for regular plumbing parts such as tees, couplings, and bushings. A two-foot section of three-inch pipe with a cap on it serves as the air chamber. The plans are detailed and the parts list is complete.

I made one major modification in VITA's plans that I wouldn't recommend. I used plastic sewer pipe rather than galvanized pipe. I did this because I didn't have the facilities for some of the machining operations called for in the plans and plastic is easier to work with. I got by with this variation, as it turns out, because the ram was operated at very low pressure. If it had operated at higher pressures, chances are it wouldn't have worked. I don't see why plastic **water** pipe wouldn't work, though.

I also modified VITA's plans by using a leather valve from a hand pump rather than the homemade one called for in the plans.

A diagram of a typical ram is shown in Fig. 1. Here's how it works. Water rushes down the drive pipe and escapes out the waste valve until enough pressure is built up to close the waste valve. The amount of this pressure increases as the fall increases. The fall is the vertical distance from the water to the ram.

When the waste valve closes, water is forced through the check valve and into the air chamber. The rushing water compresses the air in the chamber and the compressed air pushes back like a piston. This action closes the check valve and forces water up the delivery pipe to a storage tank.

When the check valve closes, the water in the drive pipe rebounds for a moment. This action created a partial vacuum which allows the waste valve to drop open again. When the waste valve opens, the excess water which was not forced up the delivery pipe flows out of the waste valve. The partial vacuum also draws a small amount of air into the ram through the air valve or "snifter" which is just below the air chamber. This air will be forced into the air chamber when the water starts slowing down the drive pipe again. The air is needed to replenish the air supply in the chamber because some is mixed with the water during each cycle. A small amount of water is lost through the air valve during each cycle but it is very small and it serves to keep the valve clean.

The cycle just described is repeated about 25 to 100 times a minute. How fast it is repeated depends on how much tension is put on the waste valve spring by means of adjusting screws. The slower the ram pumps, the more water it will pump, so the waste valve tension is adjusted for the minimum number of strokes per minute at which the ram will still operate. I had to build the waste valve spring a couple of times so that it lined up properly and had the correct tension. Otherwise, the pressure would not build up properly and the ram would not work.

How much water the ram will pump can be calculated from the following formula:

$$D = \frac{S \times F}{L} \times \frac{2}{3}$$

Where:

D is the amount of water delivered in gal./min.

S is the amount of water supplied to the ram in gal./min.

F is the fall, or the vertical difference in height between the ram and the storage tank

L is the lift, or the vertical distance the water is lifted from the ram to the storage tank

The 2/3 represents the efficiency of the ram. Older rams had efficiences of about 40%

The minimum fall a ram will work with is 18" and this is the fall I had to work with. I measured the supply flow to be 10 gallons per minute by catching the water in a pail and timing how long it took to fill. The lift I used was 10'. Thus the amount of water I should have expected to be delivered was:

$$D = \frac{10 \text{ gal./min.} \times 1\frac{1}{2}'}{10 \text{ ft.}} \times 2 = 1 \text{ gal./min.}$$

I actually measured about .5 gallons per minute.

It sounds "inefficient" to use 10 gallons of water to pump one gallon, but if you figured it out, one gallon per minute adds up to 1440 gallons per day, since the ram pumps constantly, unlike a windmill. Besides, that nine gallons which went out the waste valve isn't really wasted since it can be returned to the stream or can be used for any convenient purpose.

You can't pump the water to an indefinite height since pipe friction slows the water down. Friction is kept to a minimum by using sufficiently large pipe and by keeping connections and bends to a minimum. It is much better to bend a long piece of pipe at a gradual angle than to use sections of pipe which are connected together at a sharp angle. The VITA ram calls for a 1½" drive pipe with a 1" delivery pipe. Garden hose is out of the question because all the bends would produce too much friction.

The drive pipe should be between five and ten times the height of the fall and should not be more than 30 degrees from the horizontal. Audel's book on water supply has a good chapter on hydraulic rams. According to Audel, the delivery pipe should not be more 20 times the lift height in length. Also, according to Audel, if a storage tank is used, it should be at least 20' from the highest plumbing outlet. This is to guarantee a minimum of eight pounds of pressure. Storage tanks must be insulated from freezing in cold climates so a better solution might be to use a pressure tank like those used with electric pumps.

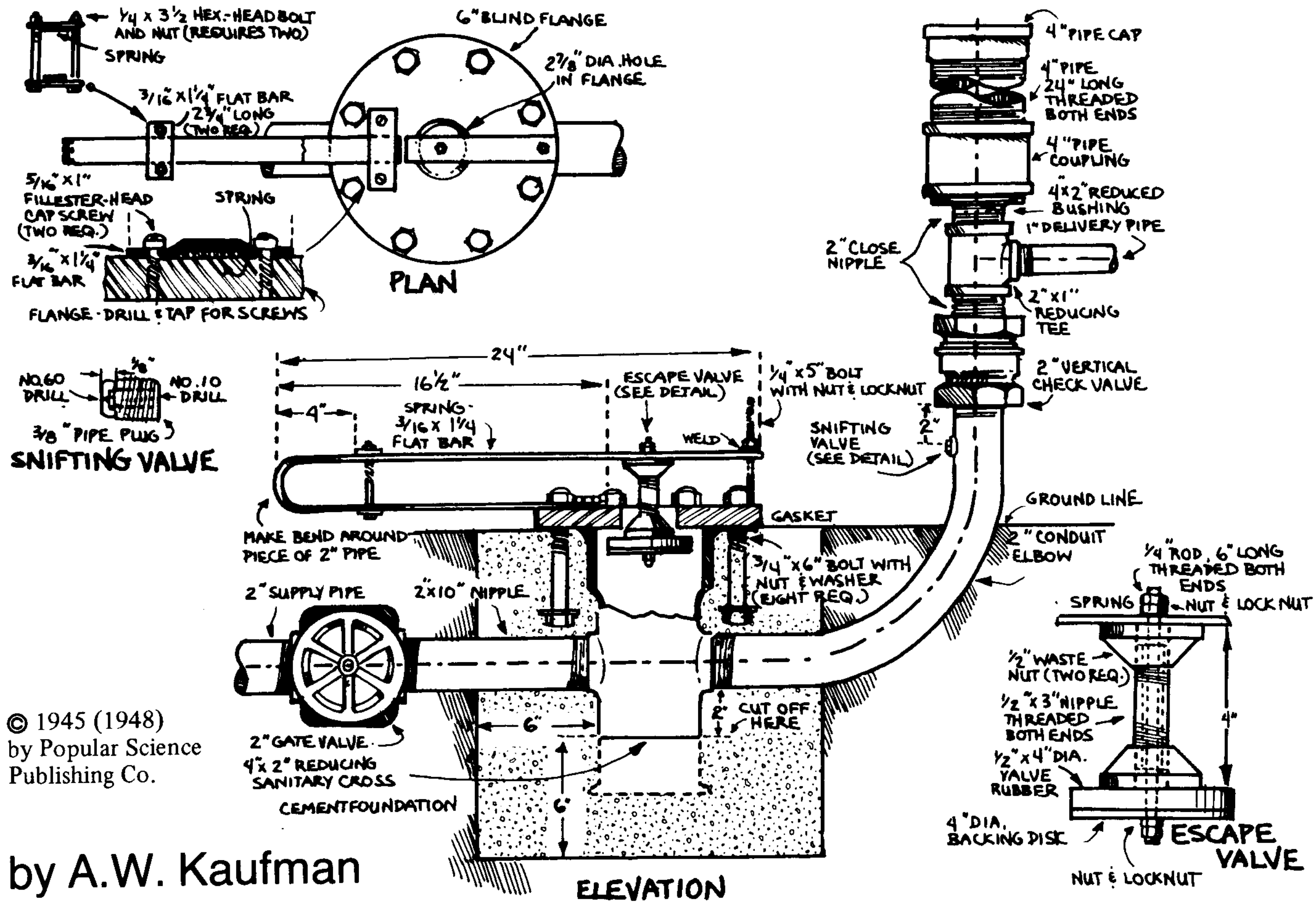
Other precautions are to put a small house around the ram to keep it from freezing and to put a piece of screen over the supply pipe intake to prevent leaves from clogging the ram.

The only company I know of that still makes hydraulic rams is the Rife Company. Their rams cost about $180 and up. This is more than the cost of a regular pump but then there are no electricity costs and, with only two moving parts, a ram should last a lifetime. Rife also sells double-acting rams which allow you to pump pure spring water using water from a nearby stream.

My next project is to build another ram based on the VITA and **Popular Science** designs. My objective is to use only parts that can be bought in a hardware store and to limit machining operations to drilling a couple of holes.

References

1. **Gould's Hydraulic Rams**, Gould Pumps, Inc., Seneca Falls, N.Y. (about 1945). No longer available.
2. **Montgomery Ward Hydraulic Rams for Running Water Without Power**, Montgomery Ward Co., Chicago (about 1945). No longer available.
3. **A Hydraulic Ram for Village Use** by Ersal W. Kindel, Volunteers for International Technical Assistance (VITA), 3706 Rhode Island Ave., Mt. Rainier, MD 20822.
4. "Hydraulic Ram Forces Water to Pump Itself", **Popular Science**, by A. W. Kaufmann, October 1948, pp 231-233.
5. **Domestic Water Supply and Sewage Disposal Guide**, by Edwin P. Anderson. Theodore Audel & Co., New York, 1967. (Chapt. 10 is on hydraulic rams.)
6. **Manual of Information: Rife Hydraulic Water Rams**, Rife Hydraulic Engine Mfg. Co., Box 367, Millburn, NJ 07041. 1968.



by A.W. Kaufman

The Popular Science Ram

A small but efficient ram may easily be built at home. For the base, use a 2" x 4" cast-iron reducing sanitary cross. Saw off the small 4" end 2" below the threads. Face or dress the bell end flat and true.

Make the spring, strap, and clamp from 3/16" x 1¼" galvanized flat-bar stock. For the escape valve, assemble a ½" x 3" nipple, ½" galvanized waste nuts with the ears cut off, a 4" valve rubber, and a backing disk. A ¼" rod threaded at each end holds the assembly together.

The flange is made from a blind flange for 6" pipe. Drill a 2-7/8" hole in the centre and drill and tap two holes for the 5/16" cap screws that retain the spring. Carefully dress one side of the flange to provide a smooth valve seat.

Assemble the cross with a 2" x 10" nipple and a 2" conduit elbow. Tap the latter for 3/8" pipe about 2" below the threads at one end for the snifting valve.

Invert this assembly on the flange, with the bolts and clamp screws in place. Centre the anchor bolts in the flange holes with tape, and wire the washers in position. Stuff the interior of the cross with crumpled newspaper, topping off the stuffing with a small piece of chicken wire. Also wrap several layers of wire fencing loosely around the cross to reinforce the cement. Then build a wood form to enclose the cross.

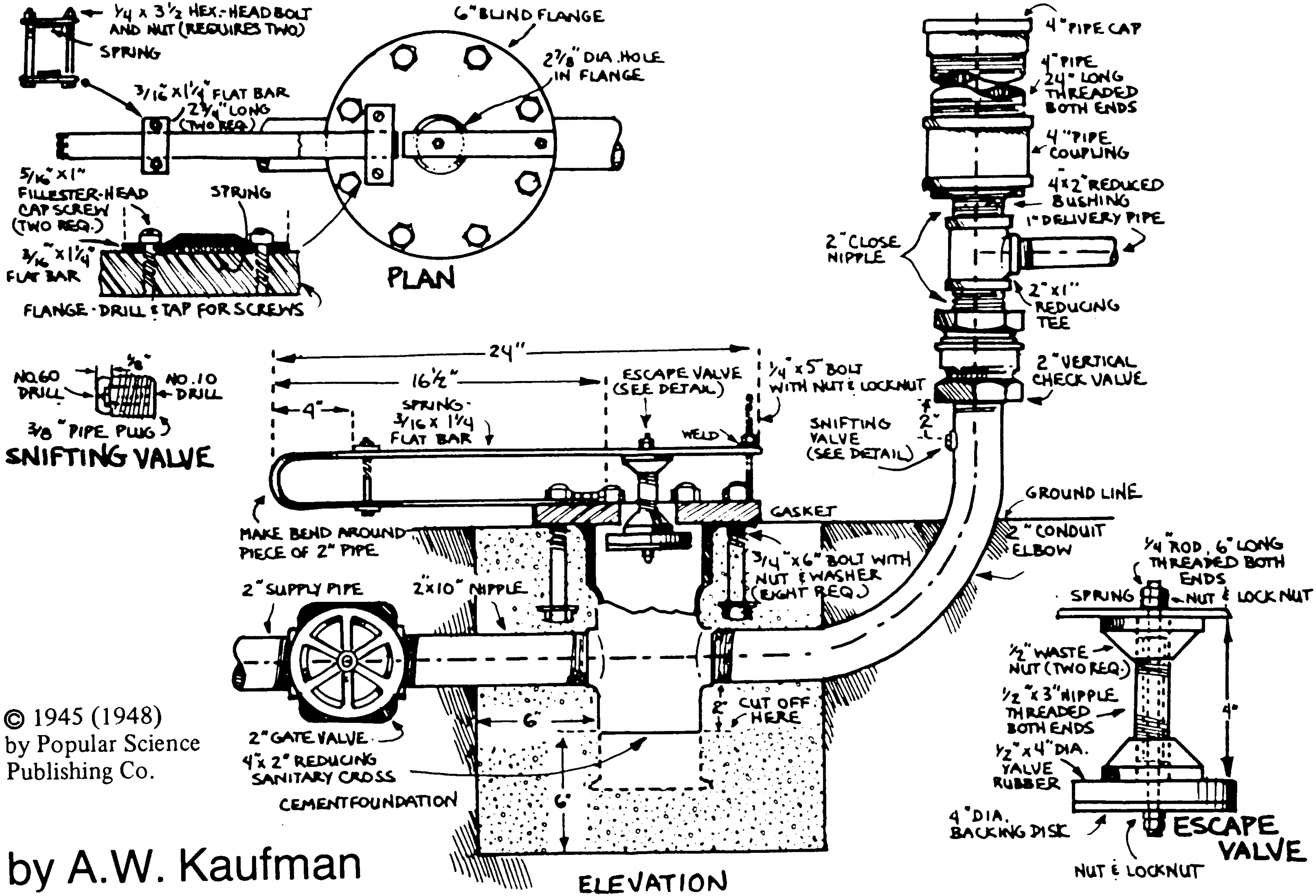
The cement block must supply a solidity and mass that absorbs the ramming shocks of the water. Hence it should be carefully made. Thoroughly mix equal parts of sharp coarse plaster sand and lump-free cement. Wet slowly until jellylike and tamp into the mold. When the cement has set, knock off the form, remove the flange and the newspaper stuffing, and fill the interior with cement up to the lower level of the inside of the 2" pipes. Smooth this to reduce friction.

The ram is now ready for installation. Lay a 2" supply pipe of a length equal to the height the water must be raised, keeping it straight and uniformly slanted. The fall should be as great as possible.

Cement the ram in position, connect the supply pipe, fit a gasket to the top of the cross, and bolt on the flange. Then assemble the escape valve and spring. Finally, attach the check valve and the capped 4" x 24" pipe nipple that functions as an air dome.

To start operation, open the gate valve, permitting the water to close the escape valve. Then push the escape valve open and allow the water pressure to close it. Repeat this action several times and the ram should pick up the cycle and operate automatically thereafter.

If you house the ram and use a tail pipe to carry away the waste water that flows out of the ram, be careful to locate the tail pipe high enough so it won't be submerged in times of flood.



by A.W. Kaufman

TRUE CONFESSIONS:
"I made a hydraulic ram pump - and I can't even weld!"

by Chris Harkin

I admit it. I have not yet done the A.T.A. Home Welding Skills course. So I can't weld. I wanted to make a ram pump, so I went to the Friends Of The Earth bookshop in Fitzroy and got a book by Volunteers in Technological Assistance on how to make one. Then I modified the plan so it didn't require welding. No doubt the original would work better, but this one works fine.

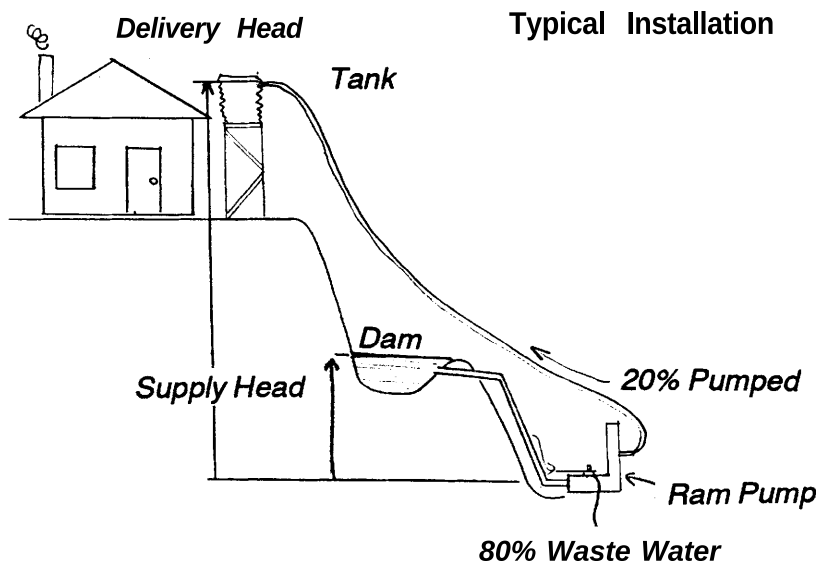
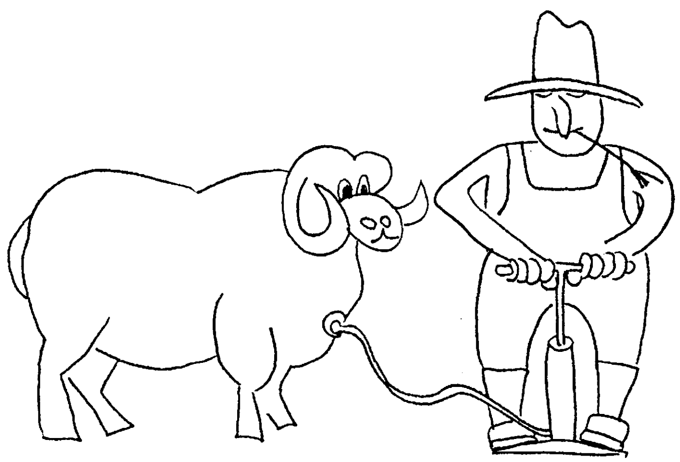


Diagram showing the typical installation for a hydraulic ram pump

What is it?

A hydraulic ram pump is a pump that uses the power of falling water to pump a small proportion of that water up the hill. There is no external source of fuel or electricity, just water pumping water. They have been around for more than a hundred years, so they are hardly new technology. So why aren't they more common? Well, they do have their limitations.



The original non-welded Ram Pump?

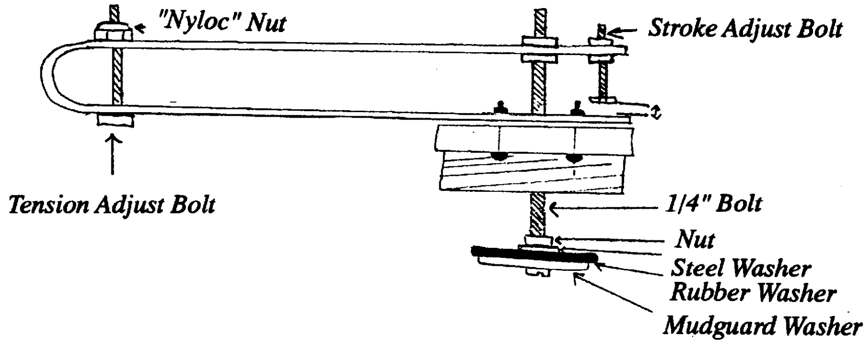
You need a suitable site, where the water source is higher than the pump site. (NB: The vertical distance from the water source to the pump is called the Supply Head). Unfortunately, in many places the water is at the BOTTOM of the hill, so you can't drop water down to the pump. Secondly the vertical distance from the pump to the destination of the pumped water (Delivery Head) can't be more than about twenty times the supply head. Finally the water has to be abundant enough to afford to waste about 80% to get the other 20% up the hill.

Fortunately at Lot 5, Great Ocean Road, Lavers Hill this is not a problem, with two metres average annual rainfall. (See "Typical installation" diagram, previous page.)

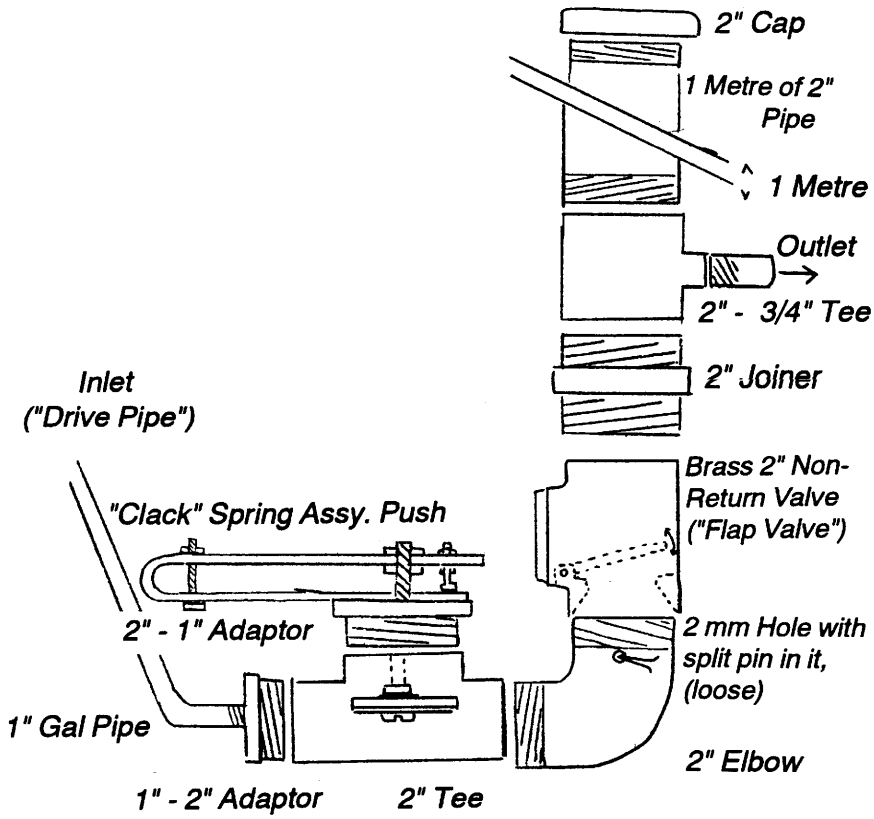
How does it work?

Water comes barrelling down the drive pipe and goes to waste through the clack valve. As the water passes through the valve, it pushes up on the rubber washer, as the water has to 'squeeze' past the washer. The spring is pushing down on the valve, holding it open. As the water increases speed through the valve, the upward pressure on the washer increases until the valve suddenly slams shut. The water's path through the valve has been cut off, but it doesn't want to stop (inertia). This is just like the pounding in a pipe when a tap is suddenly turned off. The moving water has only one other path - through the non-return valve (flap valve). The column of water shoots through the flap valve into the metre of two inch pipe. The pipe was already full of air, which gets compressed against the end cap. The moving column of water quickly runs out of momentum. The compressed air pushes back down on the water. But the water can't go backwards - the flap valve snaps shut. So the compressed air dutifully pushes the water up the delivery pipe and into your tank. Now let's go back a step. When the flow of water ran out of momentum, the force of water up on the washer dropped off to less than that of the spring, so the spring opens the valve again. Water rushes out of the valve and the whole cycle starts over again, about one beat per second. (See "Ram Pump - Exploded Diagram", this page.)

Clack Valve Assembly



Ram Pump
Exploded Diagram

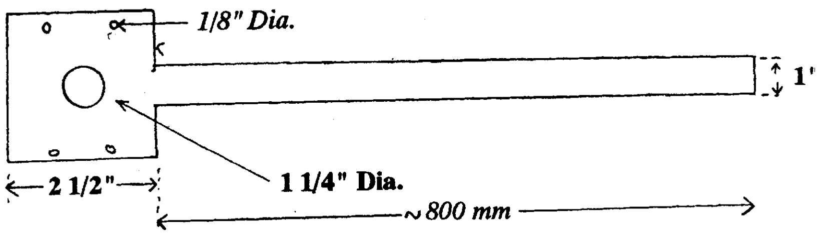


Flow

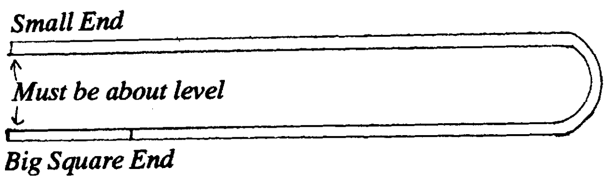
The flow of water into the tank is nothing spectacular - mine pumps about 1.8 litres/minute. But as it is not gobbling up petrol or electricity, it can be left on constantly. Flows will vary with each installation, depending on supply and delivery heads, and the diameter of pipes used. A strainer

Clack Spring

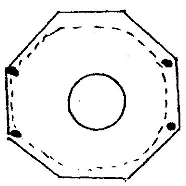
Made from 2 mm Steel



Fold Clack Spring
At about 450 mm from small end



Drill 4 Holes



In the Tips of the Nut Flats as shown - 1/8" Diameter

The holes must be right in the corner so that the bolts will be on the outside of the pipe.

should be used on the inlet from the creek or dam, and a tap installed, so you can turn it off. The tap must have a large opening when "on". Some taps have a large casing but a weeny opening inside. I think the correct type is called a gate valve.

How to make it,

I believe the diagrams are pretty well self explanatory, bearing in mind the following:

1. The drive pipe must be steel, 1" or 1 1/2". It takes a real pounding so plastic isn't up to the job.
2. The body of the pump is of 2" gal water pipe. Use teflon tape on all joints.
3. The non return valve is a 2" brass flap valve (or disc-type non return valve.)
4. The elbow has a 2mm hole with a 1.6mm split pin just below the flap valve. This is called the 'sniffer', and it allows a wee bit of air into the pipe with each pulse. This is important as the air in the metre of pipe (air chamber slowly dissolves in the water. It needs to be replaced, as otherwise the cushion of air would be lost and the pump would pound itself to bits. Really. A tiny squirt of water is lost through this hole with each stroke. The split pin is just to keep it clear in case any rubbish gets in.
5. The rubber washer is a 1 1/2" dia. toilet cistern washer. Try to get one that is fairly thick and rubbery. It has a mudguard washer behind it for support.
6. Polypipe is fine for the delivery pipe, as it doesn't take the same pounding. I used 3/4" poly.
7. Adjustments. There are three adjustments on it. The length of the bolt holding the rubber washer can be adjusted for length. The stroke bolt adjusts how far the washer moves - should be AROUND 3-5mm. The tension bolt adjusts how hard the spring pushes down on the washer.

Basically, you muck around with the adjustments to get the maximum water pumped for the minimum water wasted, so you need to measure both. About sixty to eighty beats per minute should be right. Try to keep the stroke fairly short, as a long stroke pounds harder, so wears rubber and spring faster. The diagram shows components with a longer stroke - this is just for clarity.

8. Do your wallet and the world a favour - use secondhand components. I spent about $80 for the lot including the drive pipe. Everything was secondhand or scrap. That's why my pump has a funny bend in the air chamber. The only bit they had long enough had a bend in it. If I bought all new it would have cost close to a new, commercial ram pump (around $300). It wouldn't be hard to do it for much less again. I bought everything on one day and didn't shop around much.
9. Buy the VITA book from FOE. It has a lot of other info about sites and variations. Cost in 1990 was $15.
10. Good Luck and happy pumping.

USING A HYDRAULIC RAM

A hydraulic ram is a self-powered pump which uses the energy of falling water to lift some of this water to a level above the original source. This entry explains the use of commercial hydraulic rams, which are available in some countries.

Tools and Materials

Commercial hydraulic ram

Steel pipe and fittings

Pipe wrenches

Materials to make a small dam or reservoir

Use of the Hydraulic Ram

A hydraulic ram can be used wherever a spring or stream of water flows with at least a 91.5cm (3') fall in altitude. The source must be a flow of at least 11.4 liters (3 gallons) a minute. Water can be lifted about 7.6 meters (25') for each 30.5cm (12") of fall in altitude. It can be lifted as high as 152 meters (500'), but a more common lift is 45 meters (150').

The pumping cycle (see Figure 1) is:

1. Water flows through the drive pipe (D) and out the outside valve (F).
2. The drag of the moving water closes the valve (F).
3. The momentum of water in the drive pipe (D) drives some water into the air chamber (A) and out the delivery pipe (I).
4. The flow stops.
5. The check valve (B) closes.
6. The outside valve (F) opens to start the next cycle.

   This cycle is repeated 25 to 100 times a minute; the frequency is regulated by moving the adjustment weight (C).

The length of the drive pipe must be between five and ten times the length of the fall (see Figure 2). If the

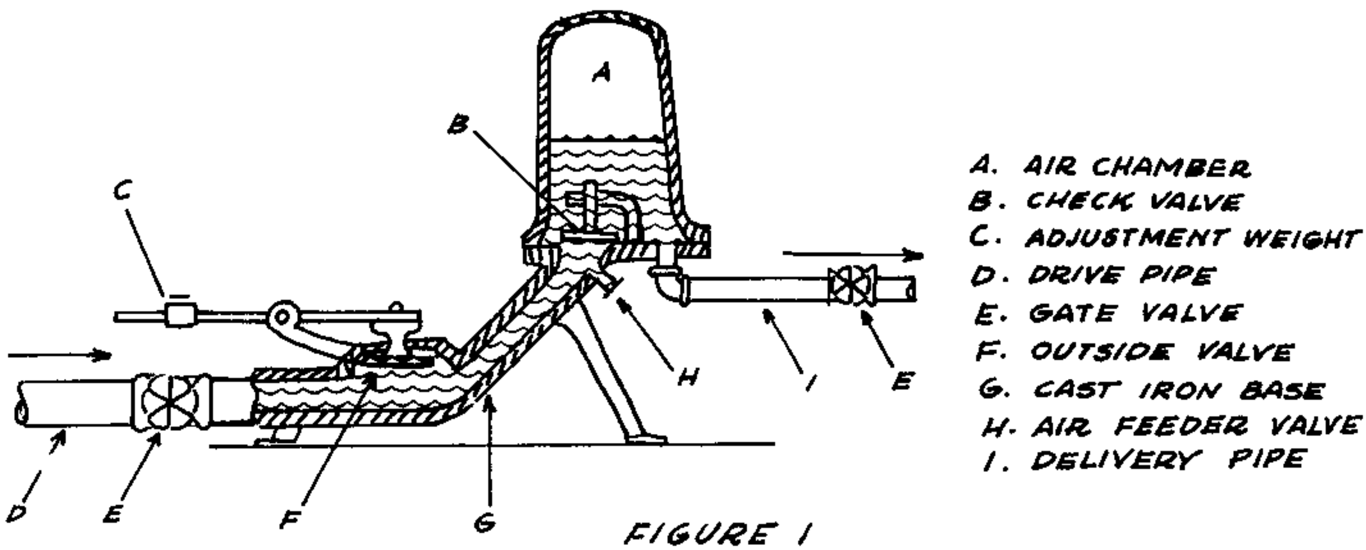
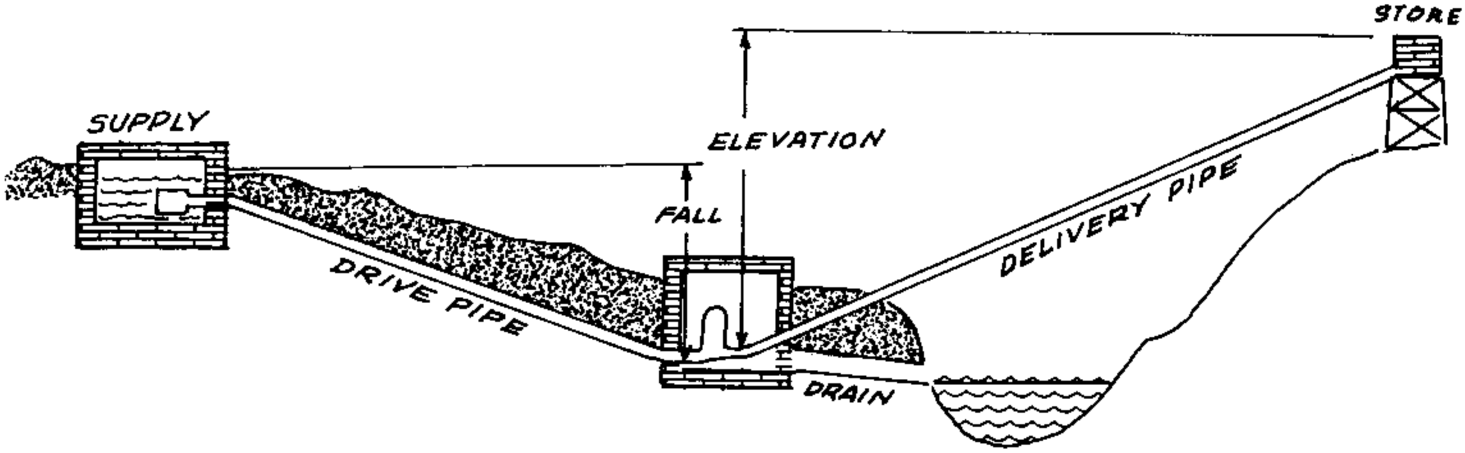
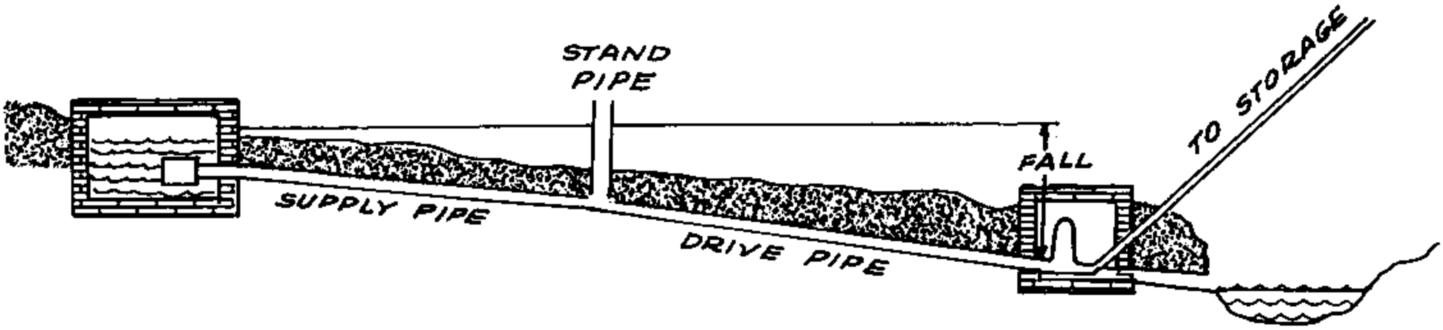


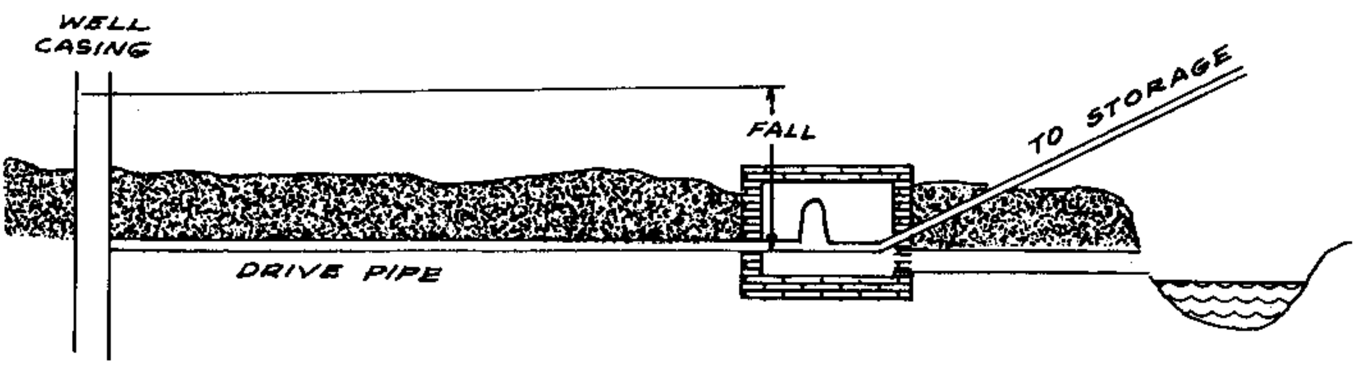
FIGURE 1



A. COMMON ARRANGEMENT OF DRIVE PIPE, RAM AND STORAGE



B. ARRANGEMENT OF DRIVE PIPE FOR A DISTANT WATER SUPPLY



C. ARTESIAN WELL OPERATING A RAM

FIGURE 2

distance from the source to the ram is greater than ten times the length of the fall, the length of the drive pipe can be adjusted by installing a stand pipe between the source and the ram (see B in Figure 2).

Once the ram is installed there is little need for maintenance and no need for skilled labor. The cost of a small ram which will raise water about 45 meters (150') is about U.S. $150, not including the cost of the pipe and installation. Although the cost may seem high, it must be remembered that there is no further power cost and a ram will last for 30 years or more. A ram used in freezing climates must be insulated.

A double-acting ram will use an impure water supply to pump two-thirds of the pure water from a spring or similar source. A third of the pure water mixes with the impure water. A supplier should be consulted for this special application.

To calculate the approximate pumping rate, use the following equation:

$$\text{Capacity (gallons per hour)} = \frac{V \times F \times 40}{E}$$

V = gallons per minute from source
F = fall in feet
E = height the water is to be raised in feet

Data Needed for Ordering a Hydraulic Ram

1. Quantity of water available at the source of supply in liters (or gallons) per minute ________
2. Vertical fall in meters (or feet) from supply to ram ________
3. Height to which the water must be raised above the ram ________
4. Quantity of water required per day ________
5. Distance from the source of supply to the ram ________
6. Distance from the ram to the storage tank ________

Sources:

Loren G. Sadler, New Holland, Pennsylvania, VITA Chapter

Rife Hydraulic Engine Manufacturing Company, Box 367, Millburn, New Jersey, U.S.A.

The Hydraulic Ram, by W. H. Sheldon, Extension Bulletin 171, July 1943, Michigan State College of Agriculture and Applied Science.

"Country Workshop," Australian Country, September 1961, pages 32-33.

"Hydraulic Ram Forces Water to Pump Itself," Popular Science, October 1948, pages 231-233.

"Hydraulic Ram," The Home Craftsman, March-April 1963, pages 20-22.

Things that Work!

Things that Work!
tested by *Home Power*

The Folk Ram Pump

Michael Welch

Tested by Michael Welch, Cara Smith and classmates of Humboldt State University's International Development Program (Susan Brinton, Christopher Herbst, Christine Parra, David Potter, Jon Raybourn, Dav Camras, Daniel Oros, Mike Orr, and Wallapa Wongsuwan).

The Site

Cara Smith of Fieldbrook, California had a problem. Every year in August, her spring flow reduces to a mere trickle. As the Northern California drought got worse year after year, so did her spring's ability to supply her household needs. She needed a permanent solution to her problem.

Fortunately, a nice creek crosses Cara's property, and it flows year round. But, it is 360 feet in elevation below her water storage tank, which gravity feeds to her home. I had been looking for a site to adequately test the Folk ram pump, and this seemed like it would work. I had been attempting to test the pump on my own system at my home. While it worked well enough for me, my flow was too small to really put the pump through its paces.

So what is a ram pump anyway? Ram pumps use a downhill water pressure to pump a portion of that water even higher uphill to a holding tank. No other source of power is needed.

We enlisted the help of HSU's International Development Program to design, build and test the ram pump system. But that's a story in and of itself that we may tell in a future *HP* article. For now, suffice it to say that this academic program prepares students to help third world countries with their development requirements, and strongly emphasizes appropriate technology to meet these countries' needs.

The Pump Arrives

When I received the Folk ram, I was surprised to see that it was in pieces. Normally, Jim Folk ships his pumps completely assembled, ready to install. But, Jim knew that I was very interested in the workings of his pumps, so he sent it to me disassembled, with a labeling tag on each component explaining the why's and the how's of its design and use. I really appreciated that, but any other customer can expect the pump to arrive well-packed and already assembled.

His largest pump, however, is too heavy to ship by UPS, so it comes in two pieces easily bolted together.

This pump is heavy-duty. Its body is thickly cast and machined from high-grade aluminum alloy, and the inner components and the bolts make use of stainless steel. The internal "valves" are made of thick, bonded rubber seals.

A feature of the Folk ram not found in most ram pumps is a strong rubber diaphragm which separates the delivery water from the pressurized air chamber. This diaphragm keeps the air from mixing and exiting with the delivery water, thus eliminating the need for a "snifter valve" to replenish the air chamber.

Other features of the Folk ram pump include larger-than-usual impetus and check valves for faster reaction time and a large air dome to minimize delivery water pressure pulsations and thus decrease friction loss. The impetus valve stroke length is easily adjustable to change the frequency of pump cycles, which changes the amount of water the pump uses and delivers.

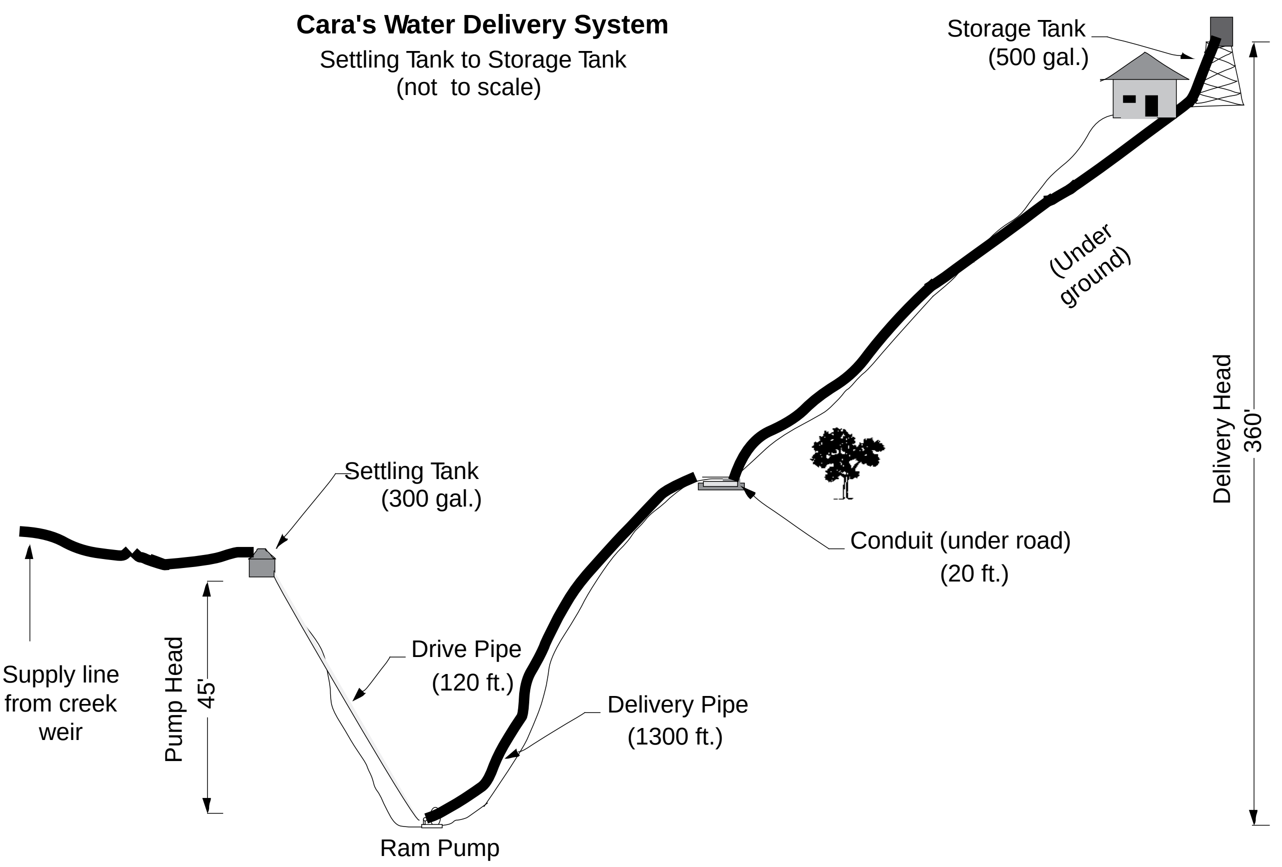
Installation
The Folk ram arrived with adequate instructions on how to install, maintain and run it, but there is some room for improvement. Jim Folk told me that he wanted to do a better and more detailed manual for the pump.

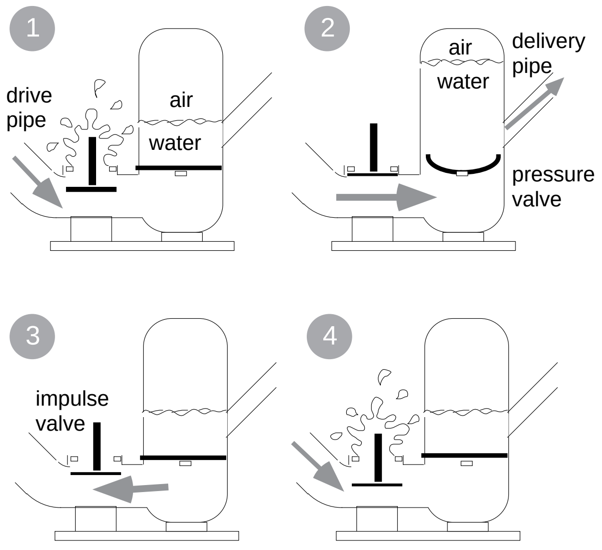
One great thing about Jim Folk is that it is as important to him that the pump works well as it is to sell the pump in the first place. If you have problems with your installation or operation, he will work with you in detail. It's just how he is, and most people can really appreciate it. For example, there was a problem with the bonded rubber the pumps used in their valves. When Jim discovered the defect, he automatically sent every pump owner a new set of valves, using improved materials, and he did it free of charge.

Long distance water pumping systems have so many variables that every installation is different. In our case, the terrain was very steep and somewhat rugged. In order to get adequate vertical drop to run the pump, we had to snake the supply pipe 420 horizontal feet from the source to a settling tank, and then go steeply down the hillside to the pump site with the drive pipe. The cost of having to run such a long horizontal distance was a reduced supply available to the pump. While Cara's creek flows at about 72,000 gallons per day, our 420 feet long, two inch diameter supply pipe with five feet of head between the creek inlet and the settling tank would make 5,400 gallons per day available to the pump.

Most installations will be more straightforward than ours, and less expensive as a result. The price of the

Cara's Water Delivery System
Settling Tank to Storage Tank
(not to scale)





How a Ram Pump Works

All ram pumps work on the principle of momentum which is controlled by a cycle set up by the interaction of two valves in the pump.

When the impetus valve is opened (this must initially be done by hand to start the pump cycling), water begins to flow down the drive pipe and through the impetus valve as in Figure 1. When the drive water reaches a certain velocity, water friction slams shut the impetus valve as in Figure 2. The momentum of the water carries past the closed impetus valve, forcing open the flapper valve and pushing water past it to pressurize the air chamber above the water level. In Figure 3, the water pressure above the flapper valve overcomes the spent momentum below it, forcing the flapper closed again. The water that made it past the flapper in Figure 2 is then forced by the extra air pressure up the delivery pipe. Since the momentum of the water coming down the drive pipe was stopped, the impetus valve falls open, allowing the water to flow down the drive pipe again as in Figure 4 (just like Figure 1), starting the cycle over again.

This process occurs over and over again until something happens to stop the cycle. Ram pumps can cycle anywhere from 25 to 300 times per minute. The frequency of the cycle is adjustable by changing the length of the stroke of the impetus valve. A longer stroke produces a lower frequency. This means more of the supply flows to and through the pump and more is pumped up the delivery pipe.

The stroke is adjusted to restrict the amount of water used to the amount available, or if supply is unlimited, to regulate the amount delivered to match the amount needed.

pump remains a fixed cost for everyone, but the installation costs can vary widely. Because of the long supply line and the uncommonly high delivery elevation, Cara's installation costs were about double the average installation. I estimate the average to be about $1,000 for system components including the Folk ram pump which runs about $695. Labor is not included in these approximations.

A typical installation includes a 1.5 inch steel drive pipe from the source to the ram pump, a poured concrete foundation to secure the pump, a one inch poly delivery pipe to the household supply tank, and valves and unions to control flow and allow access to the various components of the system.

Pump Performance

Because the Folk ram's capabilities could easily outstrip our supply, we choked it back so it wouldn't run out of water. When a ram pump stops cycling, it needs to be restarted by hand. Once we had the pump properly set, it just kept running on and on for months without the need for further attention. This reminds me of a ram pump story I heard:

Friends were hiking near the New River in the Trinity Mountains of Northern California. This river is peppered with old gold mining claims. Far away from any other form of civilization, the hikers were surprised to come to an otherwise pristine spot where they heard a muffled "ka-chunk ka-chunk ka-chunk...." Taken by surprise, they were unable to discover the source of the mechanical noise until they dug down several inches through the forest humus finding a rotten board covering a hollow box. The box contained an old ram pump that had been operating on its own, unattended for as long as it took the box cover to become buried under many layers of duff.

Commercial ram pumps are known to provide years of trouble-free service. We expect that the Folk ram will furnish Cara with water for decades to come.

Even with the pump choked back for the decreased supply, we obtained delivery rates of 600 gallons per day. This is a far cry from the 2,400 gallons per day that this pump could achieve under the same drive and delivery heads with unlimited access to the creek's supply. However, it was more than adequate for Cara's needs which max out at 475 gallons per day. Jim Folk states that, under ideal supply, drive, and delivery conditions, this particular model of his pump will produce up to 5,000 gallons per day. He has a second model that will produce up to 25,000 gallons per day.

For you folks with super low flow situations, this pump may still work for you. For several months, I had this pump installed on my own spring which was flowing at about 1,500 gallons per day, with 26 feet of drive head, and 158 feet of delivery height. This is really running the pump on the low end of its capabilities, yet it still was able to provide my home with about 190 gallons of water per day.

Conclusion

Folk ram pumps are well-made, dependable, and work as promised. While there are other ram pumps available, the Folk has features that are unique and proven. At $695 for a pump that will likely outlast its owner, it is an excellent buy. A larger model is available that lists for $995. These pumps are handmade in Conyers, Georgia.

Access

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Ram Pump Maker: Folk Water Powered Ram Pumps, 2770 White Court N.E., Conyers, GA 30207 • 404-922-4918

Hydraulic Ram Pump

adapted from *A Manual for Constructing and Operating a Hydraulic Ram Pump* by Kurt Janke & Louise Finger

Here's a design for a hydraulic ram pump that requires readily available materials and few tools to construct. Ram pumps are commercially available that are potentially more efficient and durable, but are also more expensive. This pump can be built for under $75, and is capable of pushing 130 gallons per day 150 feet high, with a drive head of 20 feet.

A ram pump uses the potential energy of falling water to lift a fraction of that water to a higher elevation. (See Figure 1) Water accelerates through the drive pipe and open waste valve. Its velocity increases until the flow and upward force causes the waste valve to shut suddenly. The momentum of water produces a short-lived pressure, called the "ram", which is greater than that in the pressure tank. This causes a small amount of water to be released through the check valve into the tank. After the exerted energy is transferred into the pressure tank, the pressure below the check valve is less than that in the tank. The check valve shuts and the waste valve falls open, allowing the cycle to repeat continuously. The compressed air in the tank acts like a spring to drive the water that had passed through the check valve into the delivery pipe and on to a higher elevation.

The output volume of a ram pump is determined by the drive head, delivery head, amount of available water, and stroke length of the waste valve. The greater the drive head, the greater the acceleration in the drive pipe, and thus the potential energy at the pump. A longer stroke length also allows a greater velocity to reach the pump. Similarly, the greater the flow, the greater the mass of the moving water, and thus greater the potential energy. The greater the delivery head, the greater the energy required to pump a given volume of water.

Tools required for this homebrew ram pump are: two 24 inch pipe wrenches, two 7/16 inch wrenches, utility knife and/or circle cutter, drill and metal bits, #8 tap, and a screwdriver. For materials, see the list on right.

Waste Valve Assembly

Figure 2 illustrates the waste valve assembly. Use only half of the 1 1/4 inch union for the base/seat of the valve. It will be necessary to drill a 3/8 inch hole through the 1 1/4 inch male plug and a 5/16 inch hole in the shoe heel material. Attach the shoe heel disk to the bottom of the all-thread by securing the lock nuts and washers around it. The rubber washer at the top of the valve serves to reduce the stress induced on the adjustment nuts by the continuous pounding of the ram. The relatively soft all-thread used in the waste valve might stretch (or even break occasionally), so we recommend having replacements on site, or using a more durable material.

Be as accurate as possible with the tolerance between the all-thread and the plug. Cut the shoe material accurately round, and center the holes carefully. The success of the pump depends on the waste valve running up and down precisely as well as how it seats on the union.

Materials Required

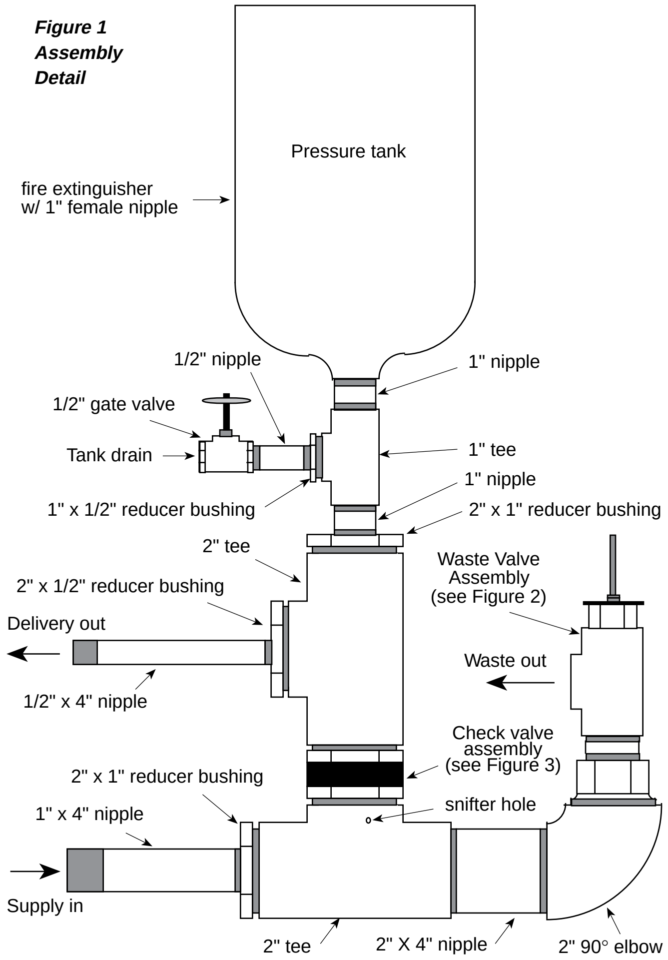
Pump
10 liter fire extingisher (1" thread[@])
1/2" gate valve
Two 2" tees
1" tee
2" 90° elbow
2" x 4" nipple
1" x 4" nipple
Two 1" close nipples
1/2" x 4" nipple
1/2" x 2" nipple
Two 2" x 1" reducer bushings
2" x 1/2" reducer bushing
1" x 1/2" reducer bushing
Teflon tape
Waste Valve
1/4" tee
1/4" close nipple
1/4" male plug
1/4" union
5/16" x 10" all-thread*
Two 5/16" nuts
Two 5/16" lock nuts
3/4" ID x 7/8" OD flat washer
5/16" ID x 3/4" OD flat washer
5/16" ID x 1" OD flat washer
rubber washer
7/8" diam. x 3/8" shoe heel material[+]
Check valve
Two 2" x 3/4" reducer bushings
3/4" close nipple
#8 x 1/4" machine
tractor tire rubber or leather[+]

[@]Other types of tanks or larger diameter pipes may work better, as fire extinguisher bodies are often made from soft aluminum with a potential for thread failure.

*A steel bolt with threads over its full length will also work and may be more durable.

[+]Available at shoe repair or leather-working shops.

Figure 1
Assembly
Detail



Check Valve Assembly

Figure 3 illustrates the check valve assembly. A reducer bushing is used as the valve seat. Drill a 1/16 inch hole in the bushing flange and thread the hole with a #8 tap. From tough rubber, such as a tire, cut a disk approximately 1/8 inch thick so that it fits loosely inside the bushing. Secure the disk with a screw. Cut additional disks to be used as spacers and support between the two bushings. Use Teflon tape on the nipple threads to prevent leakage.

Thick leather makes excellent check valve material, as well. Putting a heavy washer acting as a weight on top of the valve material may also increase the sealing ability of the valve. This washer should be centered over and cover the width of the seat, and can be secured with a short bolt and locknut, with a small washer on the underside.

Pump Assembly

Valves, fittings, and pipes are assembled together as shown in Figure 1, using two pipe wrenches. In the same fashion as the check valve, all threaded pipe should be Teflon taped and tightly secured.

A very small snifter hole may be drilled in the tee below the check valve. This will allow air to be sucked into the pressure tank to replace the air that inadvertently mixes with water and exits through the delivery pipe. Many homemade pumps just leave this hole open, but efficiency can be lessened as water squirts out during the ram. Without a snifter, the pressure tank will eventually fill with water and need to be emptied regularly.

One marginal remedy is to put a nail through the hole with the head on the inside, bending the shank on the outside to prevent the nail from being sucked into the pump. Shoot for a loose back and forth fit so that air can be sucked in, yet the head of the nail can close off the inside of the hole during the ram.

Installation, Operation and Maintenance

Both the drive and delivery pipes should have a shut-off valve and union on the pump end of the pipe. The only mounting apparatus needed is a stable pad for the pump to rest (i.e., a board). The pump should be held upright and installed so that the waste valve unit is clear of water and obstruction.

Figure 3
Check valve detail

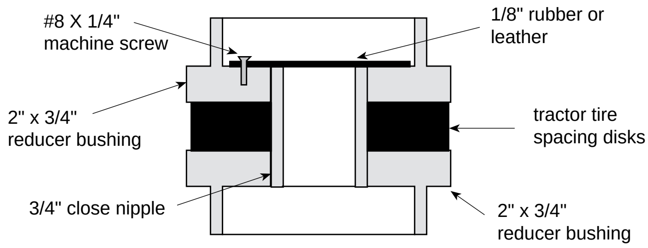
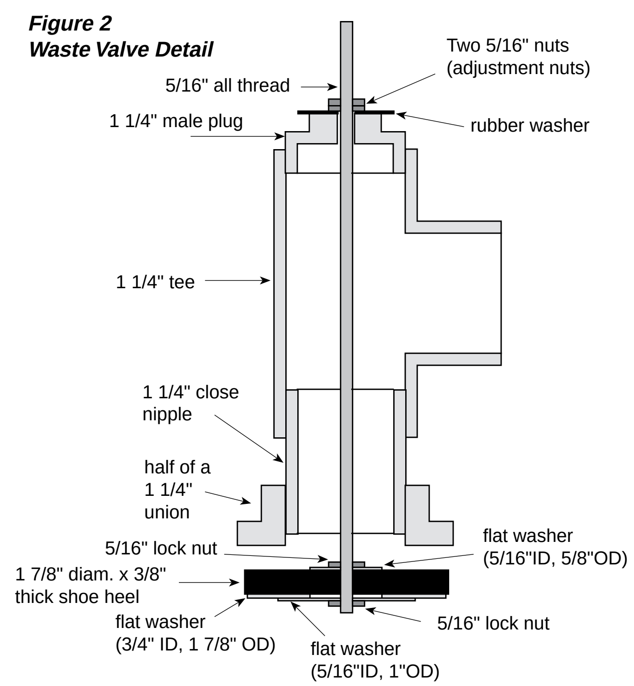
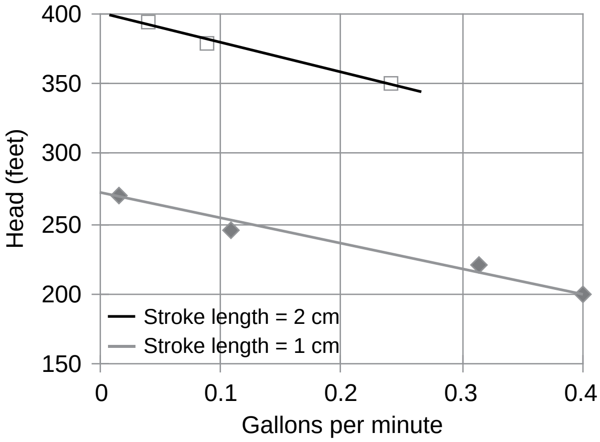


Figure 2
Waste Valve Detail



Ram Pump Performance



To start the pump, set the stroke length between one and two centimeters and open the inflow valve, keeping the outflow valve closed. Manually open and close the waste valve until it will operate on its own. Wait approximately one minute and then crack open the outflow valve a little at a time. If the pump fails to continue operating, repeat the process, lengthening the lag time prior to opening the outflow valve.

The stroke length can then be experimentally varied to optimize pump output. Shorter stroke lengths work better at lower flows and longer stroke lengths are better for higher flows. A longer stroke length provides a greater velocity in the drive pipe, thus increasing the potential energy in the falling water at the pump. However, more water is “wasted” which may result in possible source depletion.

If the pump is operated continuously without a snifter valve, it should be drained, via the tank drain, before the pressure tank becomes full of water. One should expect to drain the tank approximately once a month, unless you have a working snifter valve. The rubber used in the valves should withstand continuous use for several years. Periodic inspections will help determine when replacement is necessary.

This homemade ram pump is a “folk project”, with improvements by each person who built it. If you find new solutions for keeping the waste valve in better alignment, or a good snifter design, please share them.

Access

Louise Finger & Kurt Janke developed this pump through Humboldt State University’s International Development Program (see page 78). For information, call 707-826-3619.

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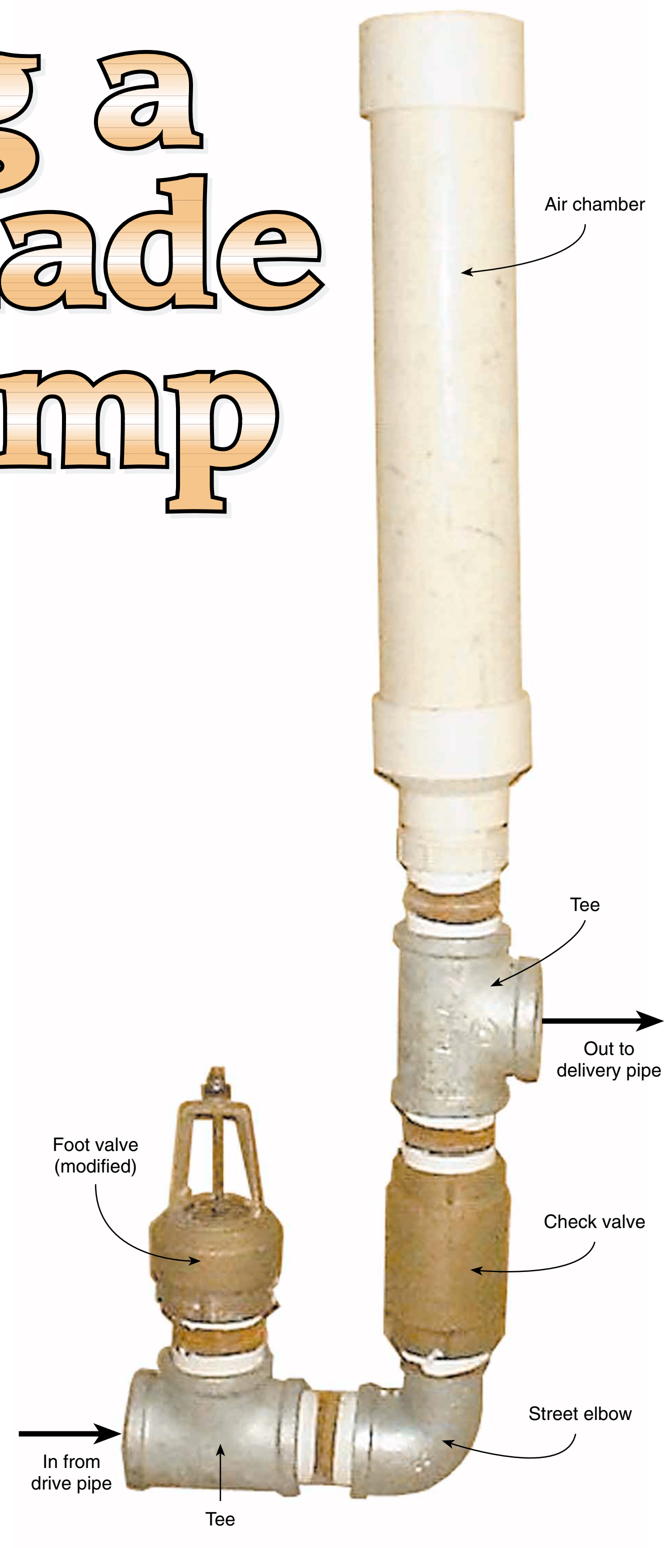
Building a Homemade Ram Pump

Scott Lee



During the mid 1970s, I first encountered the hydraulic ram water pump. A friend of mine was interested in a water pump for irrigating a garden. I had also purchased some land with a stream and a nice garden spot, but no electrical service. The combination of a stream below my garden spot and no electrical power seemed to be a perfect situation for a hydraulic ram.

Three Tries

The manufactured rams back in the '70s were fairly expensive—US$250 and up. Some publications had home-built designs. One in particular was by an organization called VITA (Volunteers in Technical Assistance). Based on the cost of the manufactured rams, I set out to construct a home-built ram pump. The first two versions of my ram were based loosely on VITA's descriptions and plans. They weren't followed exactly, due to the difficulty in obtaining some of the parts that were mentioned.

Scott Lee's ram pump in operation.

I recently went to the local hardware store to check out the cost of these parts. The 2 inch version of my homebrew ram will cost about US$130 (see parts list). A 1 inch ram will be cheaper, and might cost a little more than half that amount. The cost of the pipes needed to hook up the ram may exceed the cost of the ram itself.

Ram Pump Parts List

Qty	Item
1	2 inch foot valve (brass)
1	2 inch check valve (brass)
2	2 inch tees (galvanized)
6	2 inch close nipples (galvanized)
1	2 inch street elbow (galvanized)
1	2 by 1 inch bushing (galvanized)
1	1 inch close nipple (galvanized)
1	3 inch pipe cap (PVC)
1	3 inch pipe, 18 inches long (PVC)
1	3 by 2 inch reducer (PVC)
1	2 inch PVC to IPT adapter (PVC)
1	1/4 inch threaded rod (stainless)
6	1/4 inch nuts (stainless)
2	1/4 inch washers (stainless)
1	Faucet washer
1	14 gauge copper wire, 2 inches

The first version of my ram was built entirely out of galvanized steel pipe and fittings. The waste (or impetus) valve proved to be the hardest to construct. The first version's valve was constructed from a 1 1/2 by 1 inch bushing. While this valve worked after a fashion, it was very leaky. I figured that the ram would perform better if this valve would seal tightly. My second version had a valve that was constructed from a 1 1/2 inch pipe plug. The plug was bored with a 1 inch hole, and had the inside surface of the plug machined smooth. This resulted in better ram performance.

I never used the first two versions in working applications, though I did test them. Shortly after the second one was operational, an article appeared in *The Mother Earth News* (May/June 1979, #57, page 120) with instructions on how to build a ram mainly out of PVC pipe fittings. Using this design as a guide, I developed a third version. This version was also built from galvanized steel pipe fittings, with the exception of the air chamber, which was constructed from PVC pipe and fittings. This version still required machining of a sort—cutting threads on the outside of a 1 1/2 inch hose barb, so that it would thread into a 2 by 1 inch bushing.

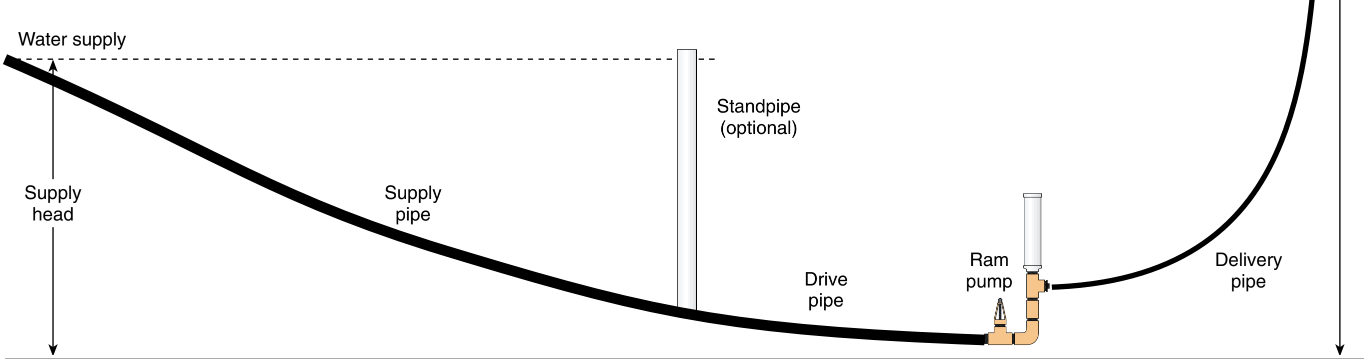
Although this was a workable system for constructing the waste valve, it still was not as simple as I wanted. For a time, this ram was used to pump water to my garden. The water was also used to provide showers, with the use of 200 feet (60 m) of 3/4 inch black poly pipe for a solar water heater. This pump was installed with a 4 foot (1.2 m) fall (head) to the ram, developed over the distance of 100 feet (30 m). It had a delivery lift of 30 feet (9 m) to a 3 by 12 foot (0.9 x 3.7 m) pool used as a storage tank. The point of use was 15 feet (4.5 m) lower than this storage pool.

Standpipe

When the ram was first put into service, it operated very slowly—about 15 to 20 cycles per minute. Everything that I'd read stated that rams of this size should operate at about 45 to 60 cycles per minute. I fabricated a standpipe and inserted it in the drive line about 30 feet (9 m) from the ram. This is within the recommended 5–10 times ratio of head to drive pipe length. This allowed the ram to operate in the 45 to 60 cycles per minute range. The flow of water delivered to the tank increased from 0.25 to 0.75 gallons (0.9 to 2.8 l) per minute.

Ideally, the length of the drive pipe should be in the range of 5 to 10 times the head. So for a head of 3 feet (0.9 m), the length of the drive pipe should be in the range of 15 to 30 feet (4.5–9 m).

If the drive pipe is too long, the cycle frequency that the ram can operate at will be limited to some low value. The standpipe provides a closer location for the ram pump's supply. This means that there is less resistance in the drive pipe, and the flow can reach full velocity more



How a Ram Pump Works

The energy required to make a ram lift water to a higher elevation comes from water falling downhill due to gravity, as in all other water-powered devices. But unlike a water wheel or turbine, the ram uses the inertia of moving water rather than water pressure, and operates in a cycle.

1. When the waste valve is opened, water flows from the source, through the water inlet (drive) pipe, and out the waste valve.

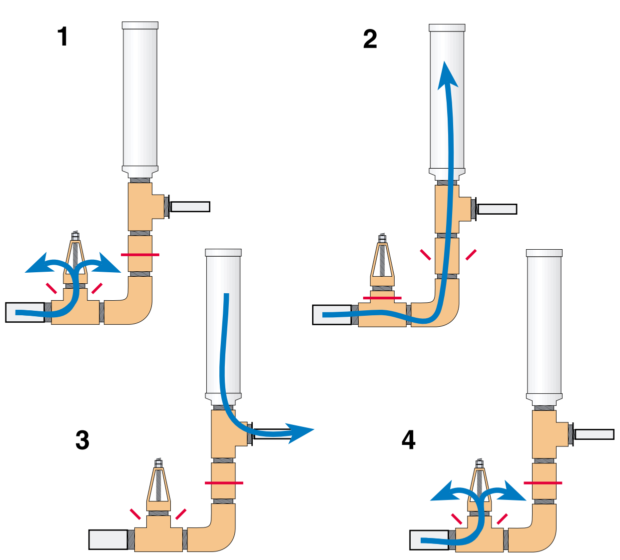
2. After a short time, the velocity of the flow is high enough to force the waste valve closed. The water, due to its inertia, wants to continue moving past the valve. The pressure inside the ram will rapidly increase enough to force the check valve open. This forces some water into the air chamber, compressing the chamber's air bubble. The pressurized bubble forces that water through the delivery pipe to the point of use.

For a ram pumping one gallon (3.8 l) per minute, and cycling 60 times per minute, each cycle pumps one-sixtieth of a gallon—about two ounces (60 ml). The compressed air in the air chamber helps smooth out the flow on the delivery side of the ram, so the flow tends to be more continuous, rather than a small spurt during each cycle of the ram.

3. Soon after the check valve has opened, the pressure surge (generated by the waste valve closing) is spent. Flow will try to start backwards, but the check valve will close, preventing this from happening.

4. At about this time, the pressure in the drive pipe will be low enough so that the waste valve can open, allowing water to start flowing from the source to the ram, beginning a new cycle.

The cycle that the ram goes through can occur 30 to 120 times per minute, depending upon conditions such as head, flow, and the size of the ram.



quickly than without the standpipe. Basically, a standpipe allows the ram to operate as if it had a shorter drive pipe.

The diagram on page 43 shows a standpipe inserted between the supply pipe and the drive pipe. The critical distance is now only the distance between the standpipe and the ram, not the total distance to the source of supply.

A standpipe can easily be constructed out of PVC pipe and fittings. The pipe needs to be long enough so that it is a few inches higher, in its installed location, than the elevation of the water source. Consider screening the top of the standpipe to keep out birds, insects, and detritus if you are pumping potable water.

The standpipe is usually inserted at a distance from the ram that is 5 to 10 times the supply head. This will vary from installation to installation. Since my installation had 3 feet (0.9 m) of supply head, I inserted the standpipe 30 feet (9 m) from the ram. This allows the ram to cycle properly, which results in more water pumped.

It's also important to consider the diameter of pipe on long drive runs, to minimize flow loss due to pipe friction. When in doubt, go up in size. It's recommended that the standpipe be at least two full pipe sizes larger than the drive pipe. I've used 4 inch standpipes with 2 inch rams, and 2 inch standpipes with 1 inch rams. It's also recommended that the pipe from the supply to the standpipe be one full pipe size larger than the drive pipe. This will insure that the flow to the standpipe will be able to keep up with the ram pump's usage.

Drive Pipe

This configuration operated for about six months, after which it was dismantled for the winter. It was later installed at a new location with 3 feet (0.9 m) of head and 12 feet (3.7 m) of lift. Most of the time it supplied garden soaker hoses, with an old 52 gallon (200 l) hot water tank being used for a small storage volume, operated as a pressure tank.

One day, we were operating the ram with the discharge valve shut, and we noticed that the 2 inch black poly drive pipe was actually expanding visibly with each closing of the waste valve. We concluded that a portion of the energy was being wasted expanding the drive pipe, rather than pumping water. We also noticed that the max discharge pressure was 21 psi.

So I replaced the 30 feet (9 m) of black poly pipe between the standpipe and the ram with schedule 40 PVC pipe. With this pipe in place, I noted that the maximum discharge pressure was now 57 psi. This meant an almost threefold increase in the amount of water delivered. With a 12 foot (3.7 m) lift, we measured the flow at 2 gpm after the installation of the PVC drive pipe.

Based on these observations, I suggest that you don't use black poly pipe or other flexible pipe for the drive pipe. If you are using a standpipe, the pipe from the standpipe to the ram is the only section that needs to be rigid. The supply pipe from the source to the standpipe can be flexible. If your drive head is higher than a few feet, steel drive pipe is recommended, since high pressures can blow out plastic pipe joints.

The foot valve on its way to becoming the waste valve—the stem is cut off the valve disc and the lower crosspiece has been cut away from the casting.

Versions Four & Five

Although this ram was successful, it still was not completely satisfactory. The waste valve needed a lot of maintenance, and also required a pipe threading machine to make it. In light of these shortcomings, a fourth version was built using a standard plumbing check valve for the basis of the waste valve. This worked well, but required a lot of work to cut discharge ports into the check valve.

In a matter of days after version four was put in operation, it was discovered that a foot valve would serve the purpose as well as a check valve, with very little work required to convert. This valve was built and put into operation successfully and performed well. The fifth version is still in use. I think that it was first used in 1980 or '81. This ram continues to provide irrigation for a garden, and water for keeping a compost pile moist enough for proper decomposition.

It should be noted that this is not a year-round installation. Before winter weather starts, the ram and standpipe are removed from the stream to prevent freezing. They are reinstalled the following spring. This has worked well, since there is no demand for the water during the winter.

I built and installed another ram of this size for a neighbor, to supply water from a spring to two houses. This ram was a slightly improved version. The main differences were that I used a larger check valve and foot valve, which improved the performance slightly. This ram was supplied by 4 feet (1.2 m) of head and lifted the water 30 feet (9 m) to a 1,500 gallon (5,700 l) storage tank about 1,400 feet (425 m) away.

At the storage tank, separate centrifugal pumps and pressure tanks were used to supply water to both houses. The ram delivers almost 1 gpm to the storage tank, which has proved to be plenty of water for all normal household uses. This ram installation is freeze-proof, with the delivery line buried and the ram in an enclosure. The ram has proved to be superior to trekking to the spring and running a gasoline engine-driven pump every two to three days to fill the storage tank.

How to Build The Ram

All of the parts for the ram were obtained from a local hardware store's plumbing section. The foot and check valves were Simmons brand, but any other good quality valves should work as long as they are of the same general configuration.

Begin the fabrication of the waste valve by removing the screen that is supplied as part of the foot valve. Then use wrenches to remove the valve disc from the foot valve, and cut off the supplied stem from the valve.

Now take the disc and drill a 1/4 inch (6 mm) hole in the center of it.

Use extreme care in drilling this hole to make sure that it is straight and centered. Use a drill press if you can. It is possible to get this right by hand if you are careful.

Now cut a 6 inch (15 cm) piece of 1/4 inch (6 mm) threaded stainless steel rod for the new valve stem. Thread on one of the 1/4 inch nuts, far enough to allow the valve disc to be placed on the threaded rod with room for another 1/4 inch nut. Lock the disc to the threaded rod by tightening both nuts against the disc.

The valve disc is reassembled with a 6 inch long piece of 0.25 inch stainless steel threaded rod, and locked in place with nuts top and bottom.

Now take the valve body and enlarge the threaded hole in the top crosspiece to 1/4 inch with a drill. Again, use care to get this hole straight. Using a hacksaw, remove the lower crosspiece.

After these modifications have been made, take the modified valve disc and insert it up through the valve body. After you have inserted it, put on a 1/4 inch washer, a faucet washer with its hole enlarged to 1/4 inch, and another 1/4 inch washer. The faucet washer provides some cushion to help quiet the waste valve when it falls open. Then thread on two 1/4 inch nuts, adjusting them so that they allow about 1/2 inch (13 mm) of movement of the valve disc and stem within the body. This is a good starting point—further adjustments can be made later, after the ram is operating. Your assembled valve should look like the diagram at right.

Air Sniffer

The next step is to modify the 2 inch check valve by adding an air sniffer hole. This hole will allow a little air to be taken in on each stroke of the ram, replacing air in the air chamber that has dissolved in the water and gone up the delivery pipe. Loss of all the air in the air chamber can result in something breaking. I once saw the bonnet of a 2 inch PVC valve blow off. This valve was used to isolate the ram from the drive pipe. If you choose not to use an air sniffer, you must shut down the ram every few days and drain some water from the air chamber.

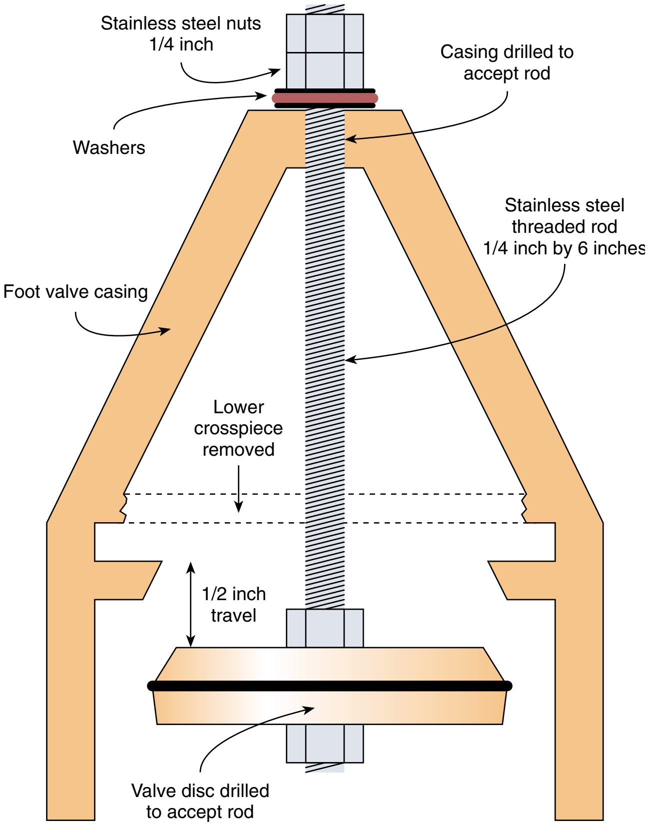
Begin the construction of the air sniffer by stripping the insulation from a piece of #14 (2 mm^2) copper wire. Select a drill bit that is just slightly larger than this wire. Use this bit to drill a hole in the check valve as shown in the next sketch.

Make sure that you drill this hole on the correct side of the valve seat, as shown on page 47. After you have drilled this hole, twist a small loop in one end of the wire you have stripped. Insert the straight end of this wire into the hole, and twist another small loop in the wire on the inside of the check valve. If you are building the ram for a low-head installation, you may want to remove the spring from the check valve at this time. Otherwise it can be left in place.

Air Chamber

The air chamber is the last piece you will need to assemble before the ram can be completely finished. A 4 inch diameter air chamber should be okay for up to 10 feet (3 m), while a 6 inch chamber should work for about 15 feet (4.5 m). When in doubt, it's probably better to err on the large side. The air chambers are usually about 18 inches (46 cm) plus the length of the fittings, but could be made longer if necessary.

Assembled Waste Valve Detail



The modified foot valve ready to assemble onto the ram.

To assemble the air chamber, glue a cap to one end of the 3 inch PVC pipe. Then glue the 3 by 2 inch reducer to the other end of the pipe. After these are complete, glue in the PVC to IPT adapter. The air chamber should now be complete, and the final assembly of the ram can proceed.

Assembly

Screw a 2 inch close nipple into one of the end branches, and another into the side branch, of a 2 inch tee. Teflon tape should be used on all of the threaded connections. This will aid in any disassembly that may be required in the future. Screw your waste valve onto the nipple on the tee's side branch.

Screw the street bend onto the nipple on the end branch. Screw the check valve onto the end of the street bend. The flow directional arrow should point away from the street bend. Screw a 2 inch close nipple into the check valve. Screw an end branch of the other 2 inch tee onto the close nipple.

Screw another close nipple into the other end branch of the 2 inch tee. Screw your air chamber onto this nipple. Screw the 2 by 1 inch bushing into the side branch of the tee. Screw the 1 inch close nipple into this bushing. Go back to the first 2 inch tee and screw in the last 2 inch close nipple.

Your completed ram should look approximately like the photo on page 42. The 3 inch air chamber size on this ram should be adequate for supply heads of up to 5 feet (1.5 m). If the head is greater than this, the air chamber should be larger.

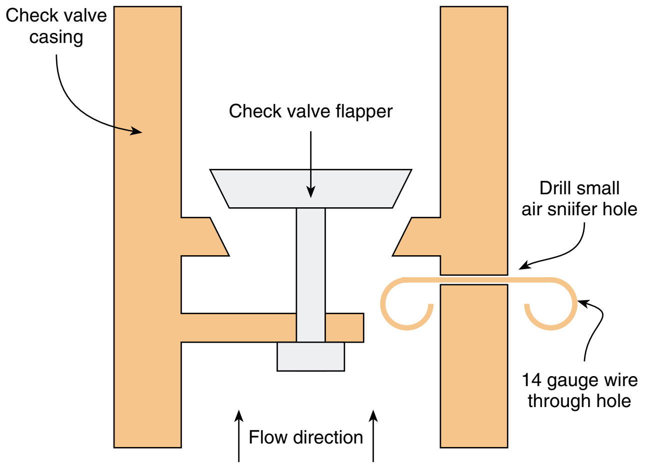
Installation

This completes the ram pump construction, but you may find that this is the easiest part of the job. As much or more depends on a good installation. I recommend that you use a union on either end of the ram. A gate valve on both the drive and discharge lines will also facilitate any maintenance that is required on the ram itself. The diagram on page 43 is a typical ram installation, showing head, lift, supply, delivery, and the length of the drive pipe.

To calculate how much a ram will deliver, divide the head by the lift, multiply by the flow, and finally multiply by 0.6. It takes at least 5 gpm to run this ram, with at least 2 feet (0.6 m) of head. In general it is easier to pump more water with more head, so run more drive pipe to get the head you need.

The check valve with the wire poking out of the air sniffer hole.

Check Valve Cutaway



Using this equation, a site with 3 feet (0.9 m) of head, 20 feet (6 m) of lift, and a supply flow of 10 gpm would deliver 0.9 gpm. The same flow and lift, with 4 feet (1.2 m) of head, would result in 1.2 gpm delivered to the point of use. Or the same delivery could be accomplished with less supply flow. The delivered flow of 0.9 gpm could be achieved with 7.5 gpm of supply flow, using 4 feet (1.2 m) of head.

Maintenance on this ram is not very demanding. I've had to replace the faucet washer a couple of times per year. Otherwise the ram is noisy, and tends to wear the metal parts more. The O-rings on the valves will have to be replaced about every five years. The wire in the air sniffer will last two to four years.

Consider a Ram

Hydraulic rams can be very useful in providing a supply of water from a lower to a higher elevation. They can pump in a remote location, with no other energy required besides the falling water. Don't be discouraged about the small flow of water delivered by a ram, since they can pump 24 hours a day. Remember that one gallon per minute times 1,440 minutes per day will be 1,440 gallons per day delivered to wherever it is needed. It can also be used year-round if the ram and piping are protected from freezing.

The most important step in deciding if a ram is for you is a site survey. This will ensure that you have the flow and head required to operate a ram. Once this has been determined, build a ram to supply the water. Rams are inexpensive, easy to construct, and dependable, so there's no reason not to use one, if you have a location that meets the requirements.

Access

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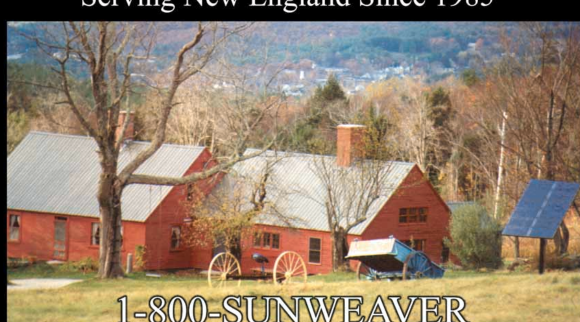
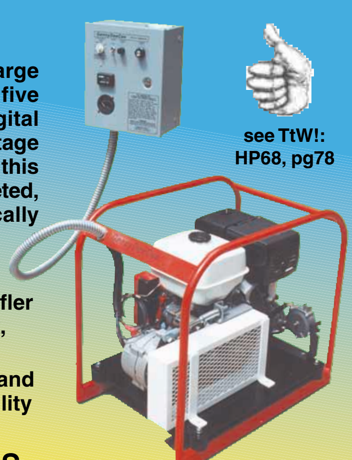
Other *Home Power* articles on ram pumps:

Hydraulic Ram Pump, by Kurt Janke & Louise Finger, *HP41,* page 74.

Things that Work! on the Folk Ram Pump, by Michael Welch, *HP40,* page 44.





Hydraulic Ram-Pumps

How to build a Ram Pump of scrap materials:

1: Understand the working principle.

2: Look over your workshop and find the materials required.

3: Build the Pump.

4: Enjoy your work.

This is a universal recipe for survival. It is also a healthy principle for both mind and body, - and a money-saver.

1: Understand the principle. As a rule a mathematical formula can always be found.

Ram Pump Formula:

$$\textbf{Pump effect} \ (\text{amount of water pumped}) = \frac{\textbf{Water to pump} \times \textbf{Fall height} \times \textbf{2}}{\textbf{Lift height} \times \textbf{3}}$$

This formula indicates the following:

a: The more water that can be brought to the pump, and the greater the height of fall => the greater is the amount of water pumped.

b: Do not lift the water higher than necessary.
To ensure an even flow, - built a water column. If an even flow is not necessary, do not include a water-column. An increase in the amount of water pumped will be the result if a water column is not used.

The principle of the Ram Pump is simple.

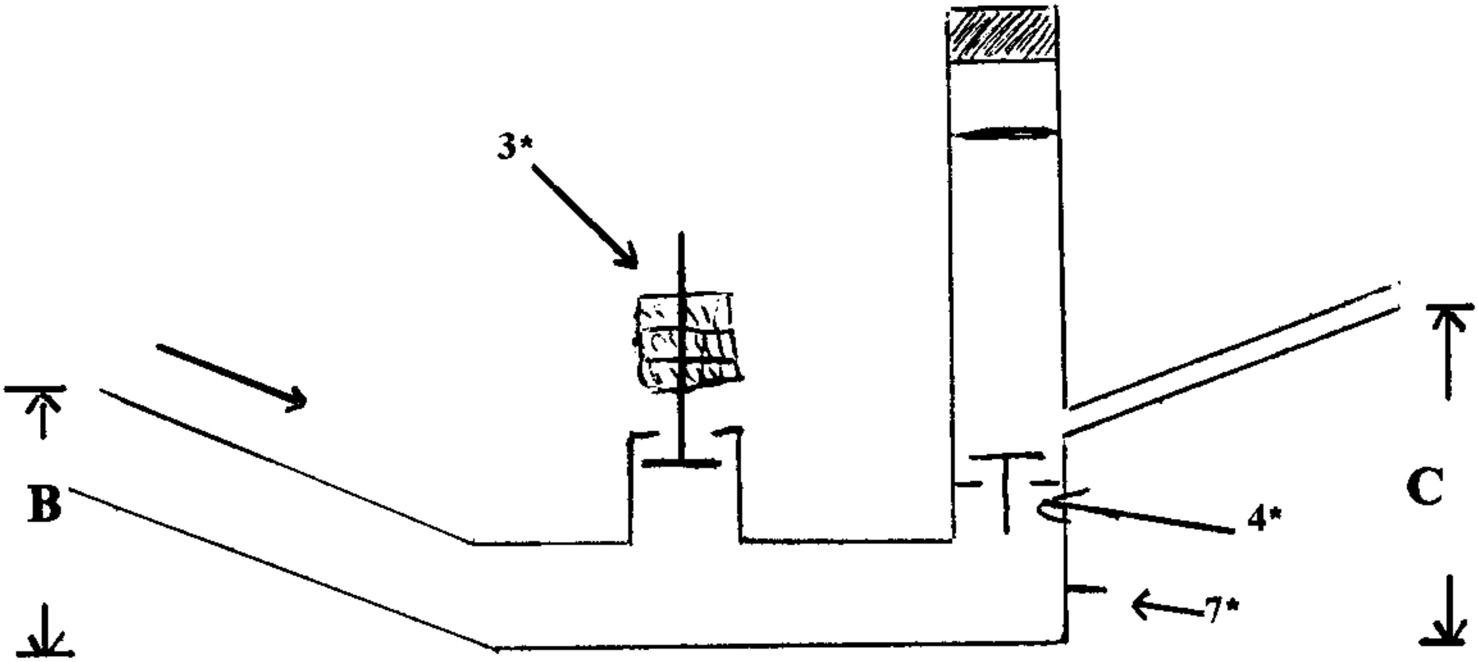
a: Water flows to the pump through the drive pipe **1*.**
However it is essential that the following conditions are observed:

— The fall height must be over **40 cms.**

— The pipe must be in horizontal-length **6 -7** times the vertical fall height.
The reason for these being:

— The driving force for the pump, - partly comes from the speed of the water-flow, and partly from the amount of water (volume) - available.

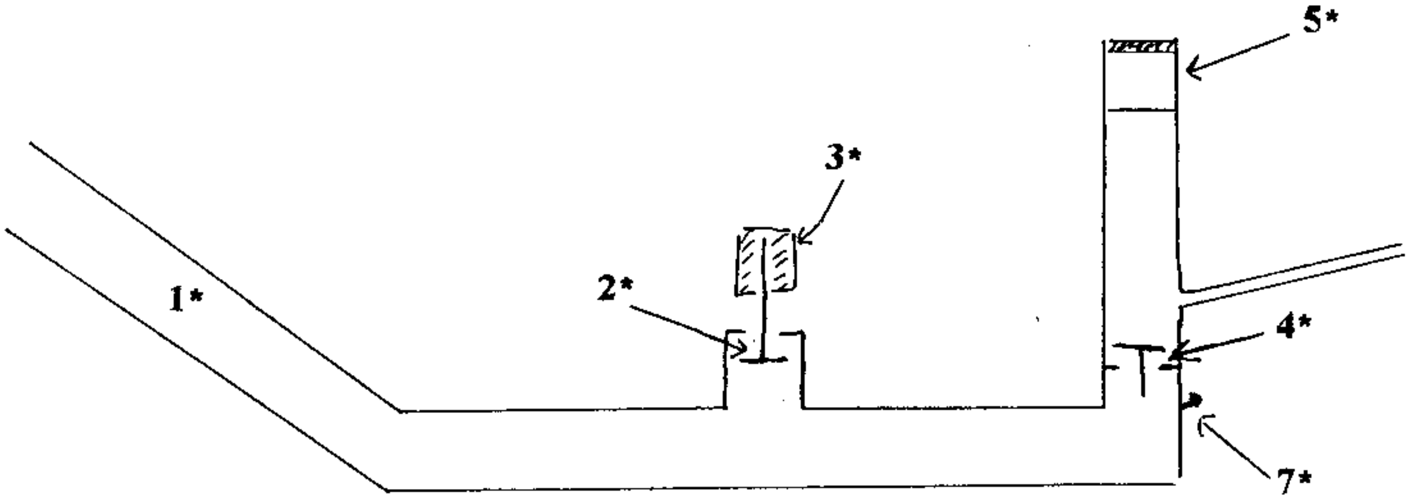
When the pump is in operation:
The water flows faster and faster through the drive pipe **1*** and spills out of the valve **2*.** The valve **2*** is held open with the help of weights or a bent piece of strong steel that will act as a spring **3*.**At a certain moment, the force of the flowing water is so great that the valve **2***is forced shut. This therefore creates a shock-effect in the drive pipe **1***.(The longer the drive pipe **1*** => the greater the shock-effect).

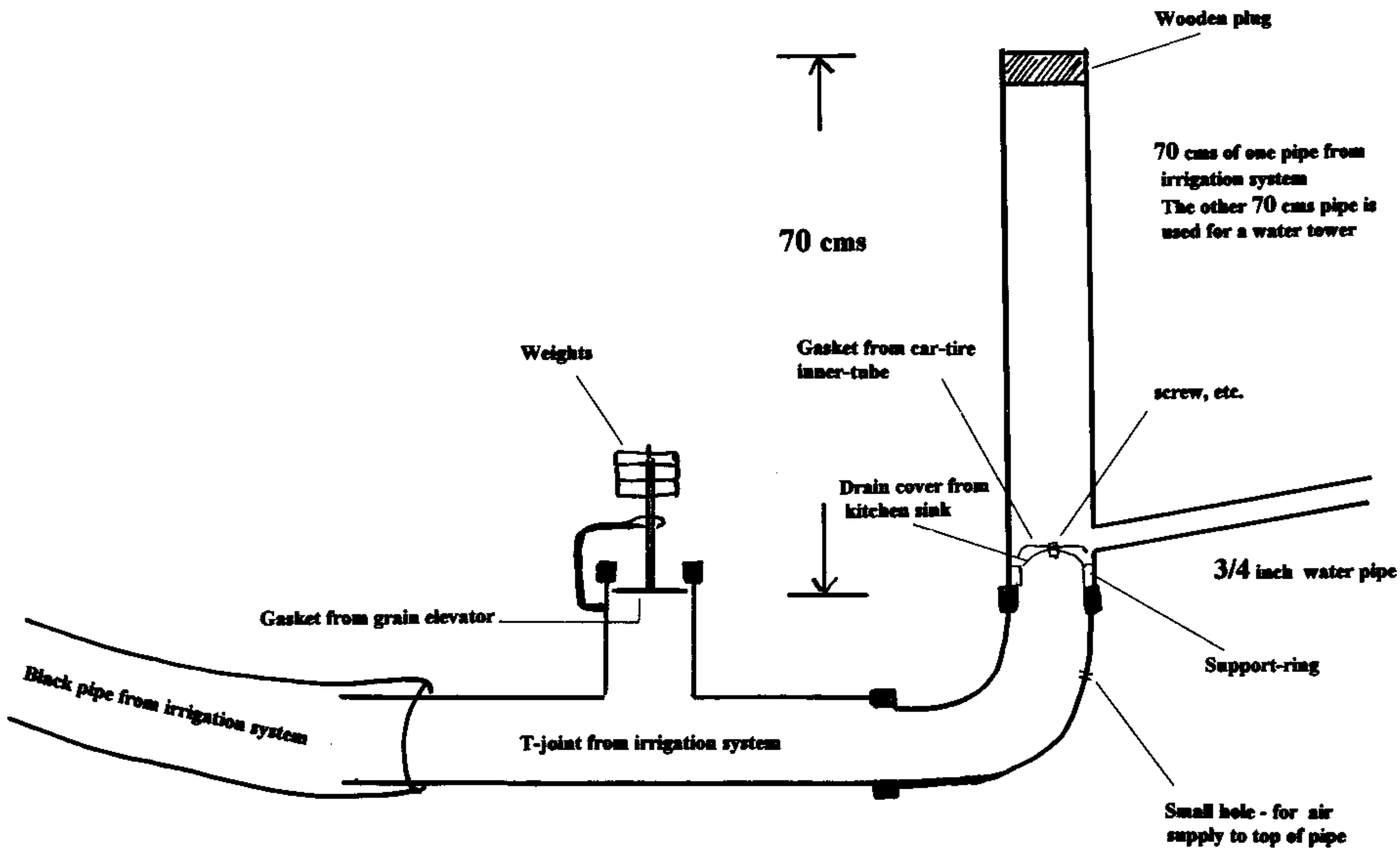


$$\text{Pump effect} = \frac{\text{Water to pump} \times \text{Fall height} \times 2}{\text{Lift height} \times 3}$$

(amount of water pumped)

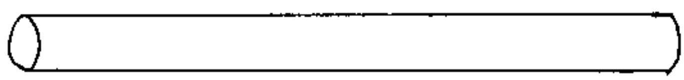
$$= \frac{A \times B \times 2}{C \times 3}$$



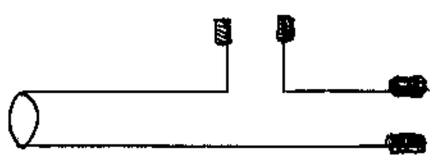

Wooden plug
70 cms
70 cms of one pipe from irrigation system
The other 70 cms pipe is used for a water tower
Weights
Gasket from car-tire inner-tube
screw, etc.
Drain cover from kitchen sink
3/4 inch water pipe
Gasket from grain elevator
Support-ring
Black pipe from irrigation system
T-joint from irrigation system
Small hole - for air supply to top of pipe

As the drive pipe is now blocked - the water attempts to stop flowing, but before the flow stops; - some of the water is pressed out through the valve **4***.
This pipe is blocked at the top-end by an airtight prop or plug. Under this prop is a pocket of air- **5***. This air is compressed and therefore forces the water back. However the **one-way valve 4*** is now shut, and the water is therefore forced out, - through the pipe **6***.
7* indicates a small hole in the pipe, - this hole ensures that the air at the top of the pipe **5*** is constantly replenished.

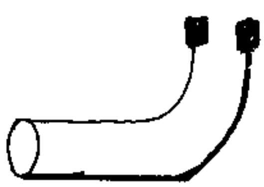
After having understood the principle - go to the scrap pile and look for suitable materials. All piles of junk, spares and bits and pieces, are not the same. However this is the list of material that was used for the hydraulic ram in the illustrations.



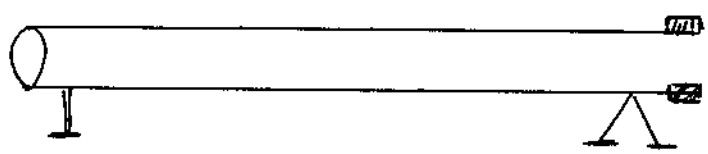
a: Black tube from a field irrigation system, - **7.5** cms in diameter.



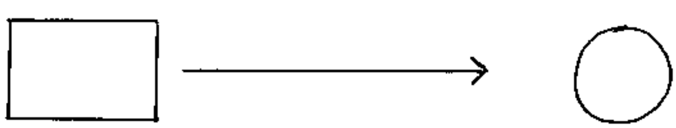
b: T-joint from field irrigation system, - **7.5** cms and **7** cms in diameter.



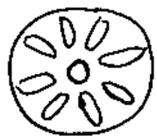
c: **90** degree pipe-bend.



d: 2 pipes from irrigation system.



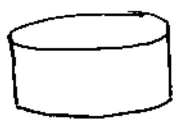
e: A piece of rubber from a grain-elevator.



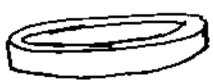
f: A drain-cover from a kitchen sink.

g: A piece from a car-tire inner-tube.

h: A bolt and 2 washers and a nut.

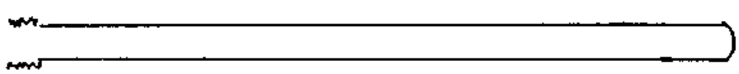


i: A wooden prop/plug, with the same diameter as the inside diameter of the pipe from the irrigation system.



j: Support-ring, - a metal ring with a collar, having the same diameter as the inside diameter of the pipe/tube from the irrigation system.

k: Weights with a center-hole.



l: **3/4** inch water pipe.

L'INSTALLATION D'UN BELIER HYDRAULIQUE A BUDI

Hermans A.
1984

ATOL

Blijde Inkomststraat 9 — B-3000 Leuven, België — tel. 016/22 45 17

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1. PRÉSENTATION

Cette brochure décrit l'installation d'un bélier hydraulique à Budi, Rép. du Zaire. Le père spiritain Albert Hermans, qui a mis en marche toute l'installation, a bien voulu partager ses expériences. Nous lui sommes reconnaissants. Il suit pas à pas l'évolution des travaux, qui est illustrée par des photos prises sur place pendant l'exécution. Les travaux ont duré 8 mois.

Evidemment, la brochure ne se veut pas un manuel complet, ni pour l'installation ni pour l'entretien. Les problèmes d'ordre financier ne sont mentionnés que superficiellement. Plusieurs éléments sont approfondis, pourtant, et, ce qui est plus important, le lecteur peut se former une idée très concrète de la façon dont on a réalisé cette installation à Budi.

Des données techniques additionnelles, ainsi que des dessins de construction et des adresses de fabricants commerciaux, sont disponibles chez ATOL.

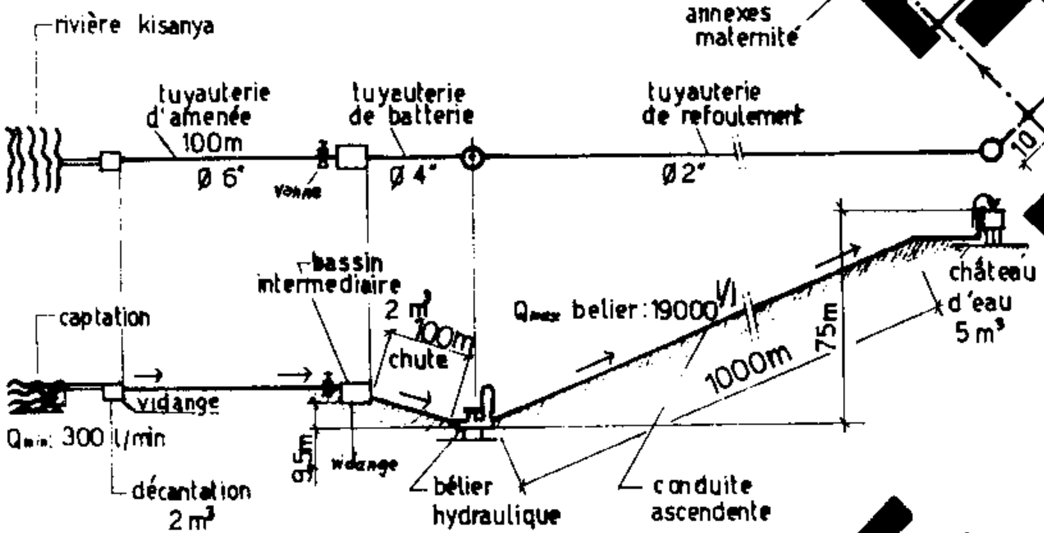
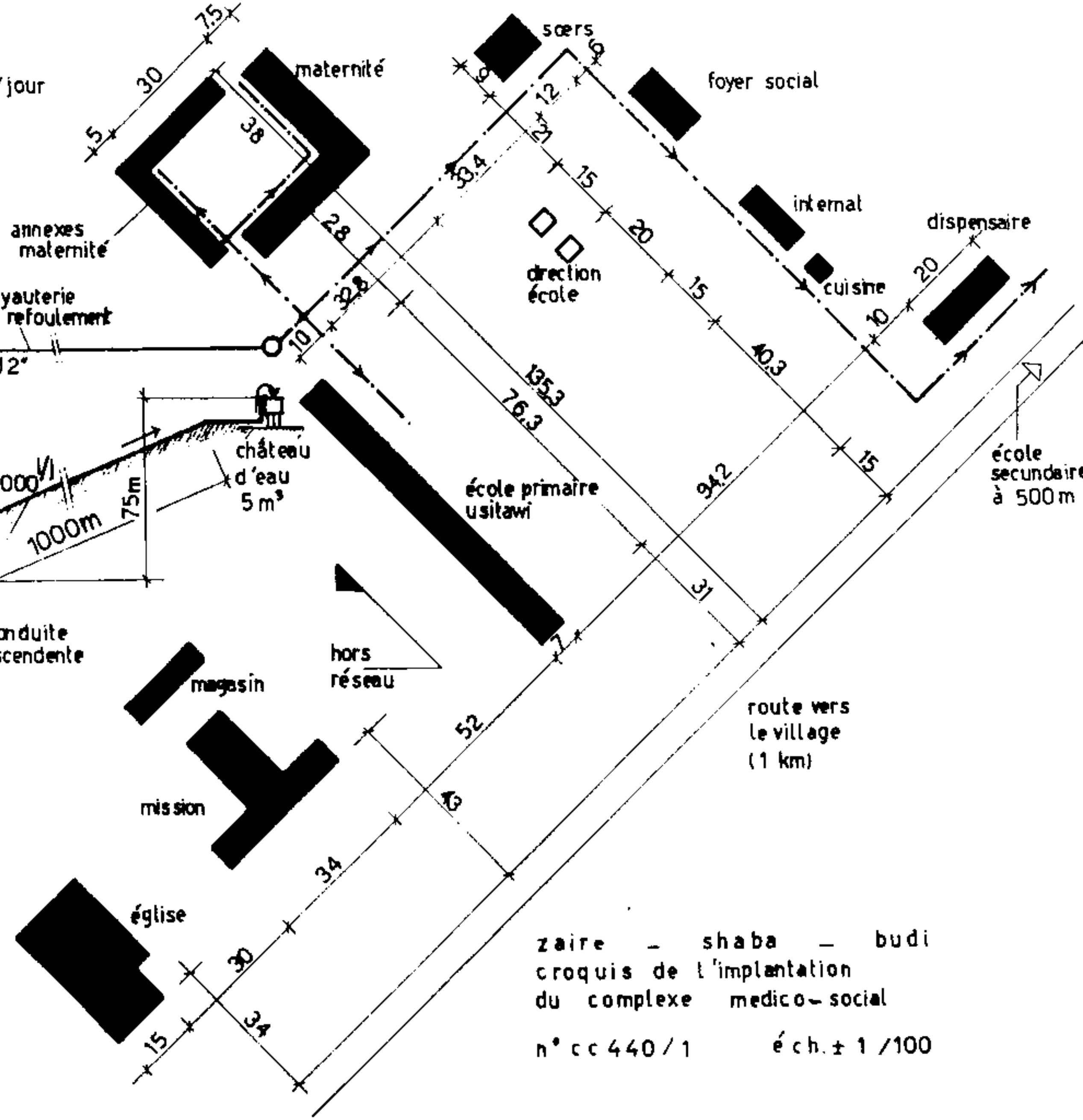


SCHÉMA DE L'INSTALLATION d'AMENÉE ET DE DISTRIBUTION d'EAU

section verticale justqu'au tank



zaire – shaba – budi
croquis de l'implantation
du complexe medico – social

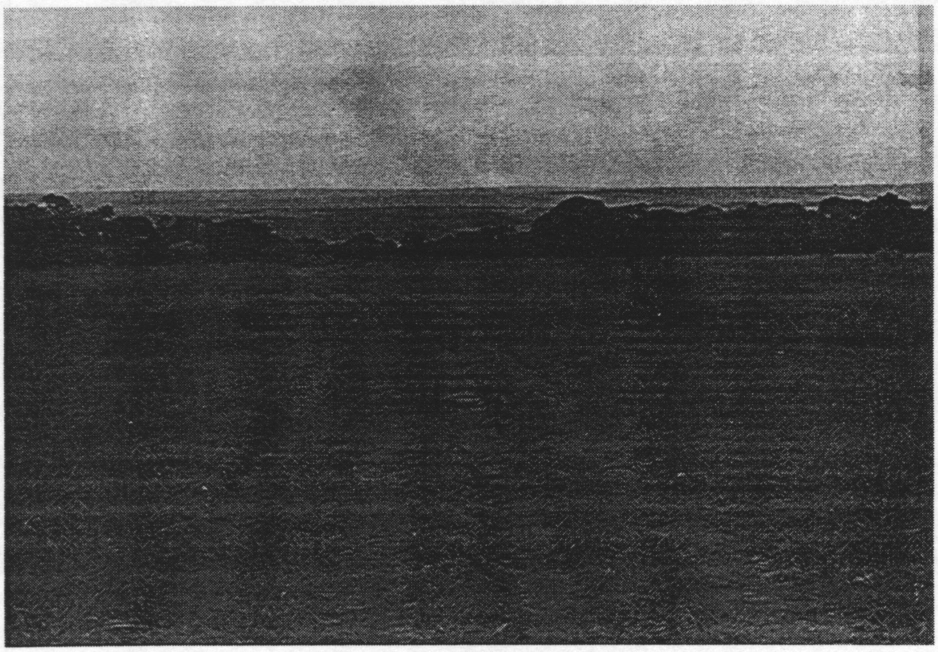
n° cc 440 / 1 éch. ± 1 /100

3. INSTALLATION D'UN BÉLIER À BUDI

INTRODUCTION

La mission de Budi fait partie du diocèse de Kongolo au Nord-Shaba, Zaire. C'est une mission de brousse ; à partir d'un poste central les Pères visitent de nombreux villages dans un rayon de 100 km. A Budi sont groupés plusieurs oeuvres : communautés de pères et de soeurs, maternité, dispensaire, formation des catéchistes ; en plus il y a un élevage de vaches avec un dipping-tank. Les besoins en eau augmentent chaque année.
Un puits de 18 m de profondeur, foré avant l'indépendance par le F.B.I. (Fonds du Bien-Etre Indigène) ne suffisait plus ; surtout pendant la saison sèche il fallait aller tous les jours à la rivière, avec le tracteur, pour remplir une dizaine de touques. Depuis vingt ans les pères rêvaient d'installer un bélier.

REALISATION

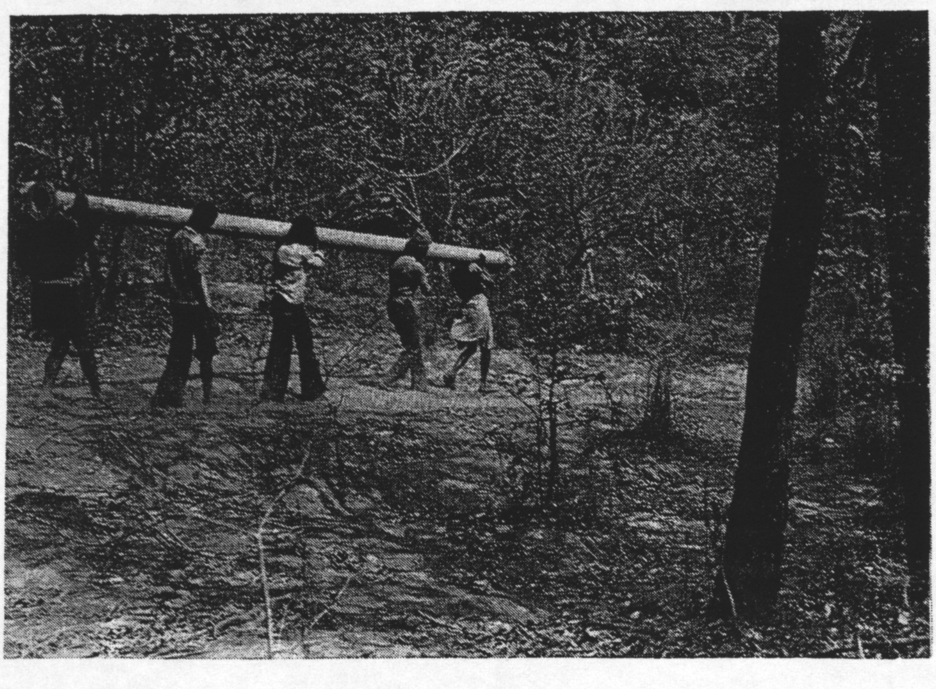


1. Dans le haut-plateau, à 1.000 m d'altitude, des ruisseaux ont creusé des vallées, larges de 400 m et profondes de 30 à 40 m. Sur les deux versants de cette vallée pousse une forêt dense. Sur la photo les cîmes des arbres forment une ligne noire au milieu du plateau qui s'étend devant et derrière le bois. De nombreuses sources alimentent le petit ruisseau, la Kisanya, qui coule au fond, au milieu des rochers. Le débit, au milieu de la saison sèche, est de 500 litres à la minute ; même au moment le plus sec de l'année, nous estimons qu'il y a encore 300 litres à minute. Nous avons cherché la partie du parcours où la pente est la plus forte ; 9,5 m sur une distance de 100 m. C'est là que nous avons installé le bélier.

2. A un endroit où la Kisanya coule entre deux rochers nous avons construit, avec des pierres trouvées sur place, un petit barrage, haut de 1 m et large de 3 m. Le petit lac, formé en amont, est un premier moyen pour décanter l'eau. Un canal à ciel-ouvert bifurque en fourche, ce qui nous permet de conduire l'eau soit directement vers le lit du ruisseau, soit vers un premier bassin de décantation d'environ 2 m^3. Il suffit de barrer l'une ou l'autre voie avec une planche.

Ainsi, quand le bélier ne fonctionne pas, le ruisseau suit son cours normal. Quand il fonctionne sa consommation est bien inférieure au débit du ruisseau ; ce surplus d'eau déborde par le trop-plein du premier bassin et retrourne ainsi directement au ruisseau. L'équilibre écologique de la vallée n'est certainement pas perturbé.

3. Les tuyaux étaient amenés en tracteur avec remorque jusqu'à l'orée du bois ; à partir de là, il fallait tout transporter à dos d'homme ; après avoir taillé une route praticable.
Pour faciliter le transport de la Belgique vers l'intérieur du Zaire tout les tuyaux étaient fournis en longeurs de 6 m. Pour pouvoir s'adapter aux conditions du terrain on avait commandé aussi quelques longueurs de 3 m et de 1 m. Un seul tuyau de 6 "de 6m pèse 130 kg. Parce que le terrain est fort inégal et qu'il fallait traverser le ruisseau, nous avons exigé que chaque tuyau soit porté par 4 ou 5 travailleurs.



4. La "conduite d'amenée", en tuyaux de 6 pouces, est possée presque horizontalement dans la berge. Puisque le ruisseau descend en pente on obtiendra ainsi une différence de niveau (une chute d'eau). Il est souhaitable de poser toutes les conduites en terre ; une conduite aerienne, posée sur socles, pose trop de problèmes de maçonnerie. Il fallait donc chercher sur un terrain inégal et accidenté le tracé le plus facile, évitant autant que possible des travaux de terrassement dans un sol rocailleux. Il fallait également éviter, autant que possible, les "courbes" puisqu'il nous était impossible de plier ou de réduire ces gros tuyaux. Là où nous n'avons pas pu éviter de faire une courbe nous avons coulé un manchon en béton autour des extrémités des deux tuyaux formant un angle.

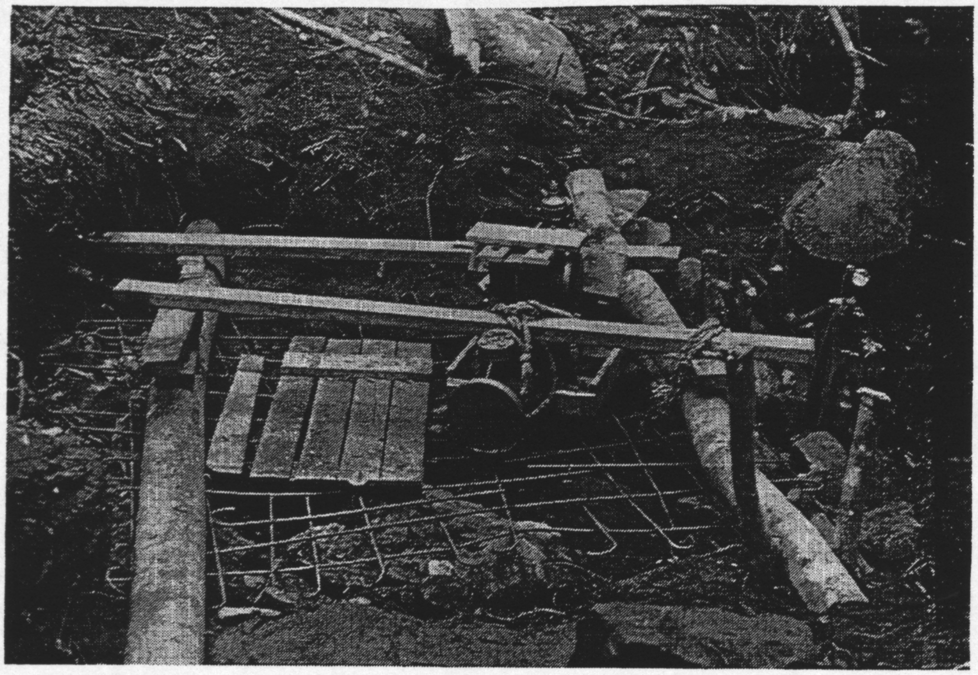
5. Monsieur Alfons Verwerft, professeur à l'école technique de Lier, est venu nous aider bénévolement pendant les grandes vacances de 1983. Il est assis à l'endroit où devra être construit le deuxième bassin de décantation. Il montre, à gauche, l'arrivée de la conduite d'amenée et à droite le départ de la conduite de chute (en tuyaux de quatre pouces).

Sur l'extrémité de la conduite d'amenée, nous avons boulonné une vanne ; ce qui nous permet de vider le bassin 2 pour nettoyage sans vider à la fois toute la conduite d'amenée.
Les tuyaux de la conduite de chute sont fabriqués "sans soudure" ce qui leur assure la résistance nécessaire pour résister aux "coups" du bélier.

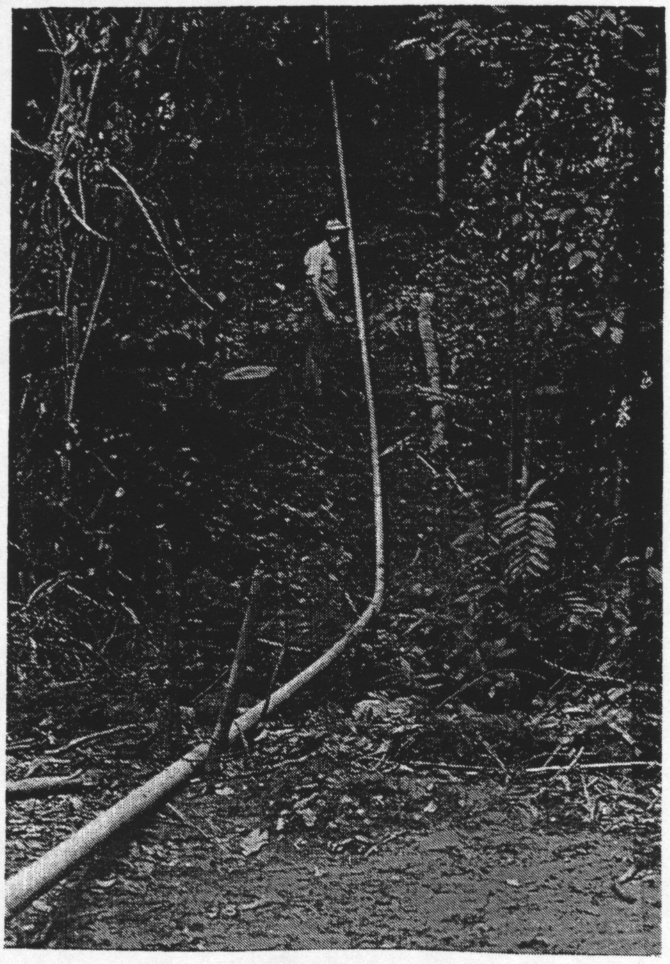
6. La conduite de chute doit être posée en ligne presque droite et bien fixée en terre pour que les tuyaux ne bougent pas sous l'énorme pression causée par les 'coups' du bélier.
Les tuyaux sont boulonnés ensemble, en entreposant un joint en cuir.

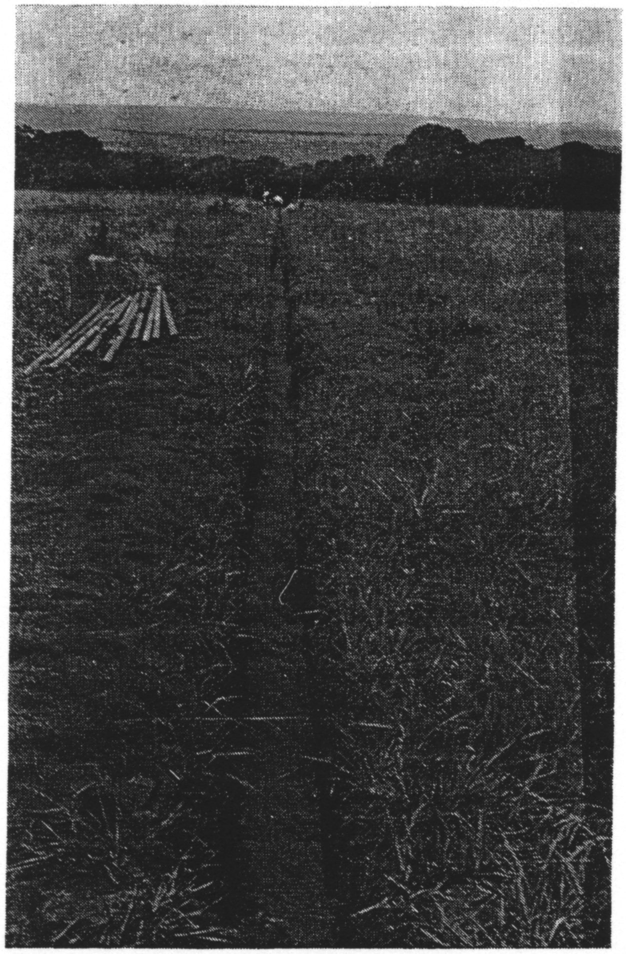
7. Une pièce du bélier démonté est transportée, fixée sur un traîneau qu'on fait glisser sur des planches.

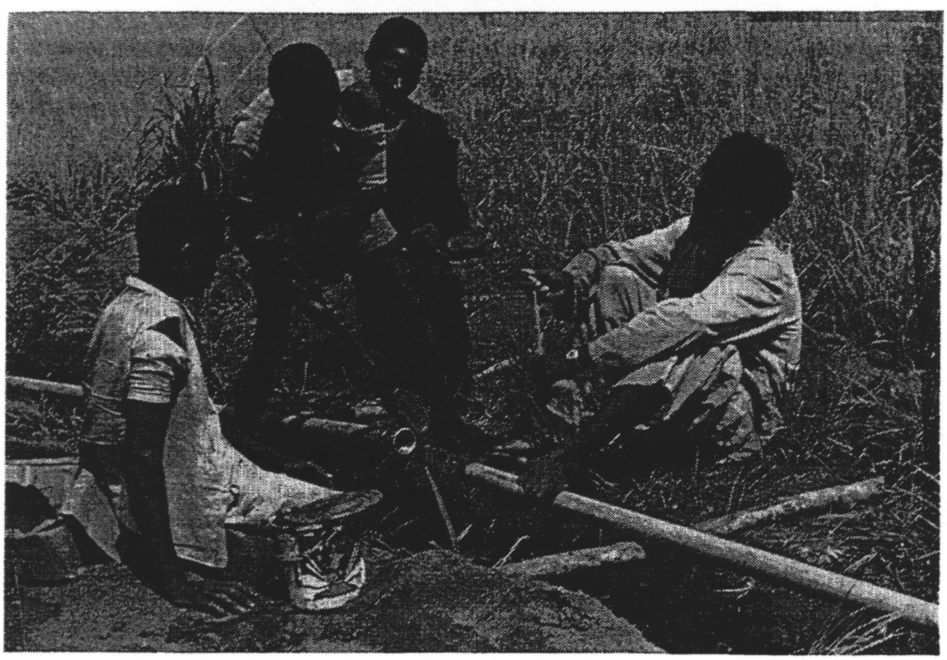
8. Pour ancrer le bélier solidement et correctement sur son socle on l'a suspendu avant de couler le béton.



9 - 10 - 11 - 12. Une fois le bélier mis en place, on peut commencer à poser la conduite d'écoulement qui amène l'eau jusqu'à la mission, distante de 1 km, à une hauteur de 75 m. Nous aurions pu nous servir de tuyaux en P.V.C. Nous avons préféré du galvanisé, plus solide et durable.





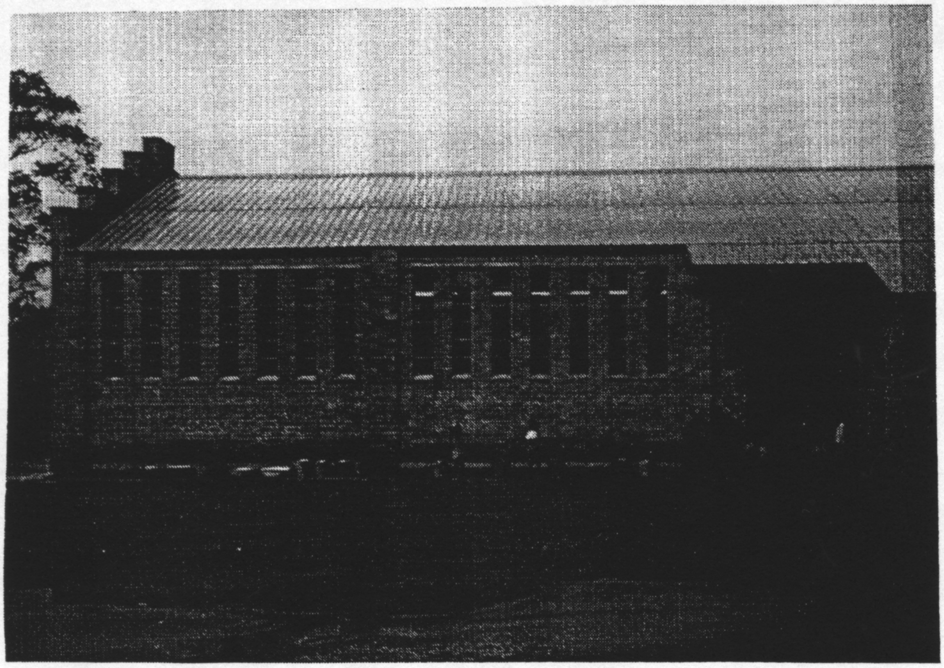


13 - 14. Enfin le premier essai.
Le bélier, du type RAM - G 10, a été livré par la firme Pompes Ledoux - Bordeaux, pour le prix de 227.500 BF. Cette firme nous a donné des conseils techniques sur la qualité, le diamètre et la longueur des différentes conduites, en se basant sur les données locales que nous lui avons fournis (débit et hauteur de la chute d'eau, distance et altitude de la mission, quantité journalière d'eau désirée

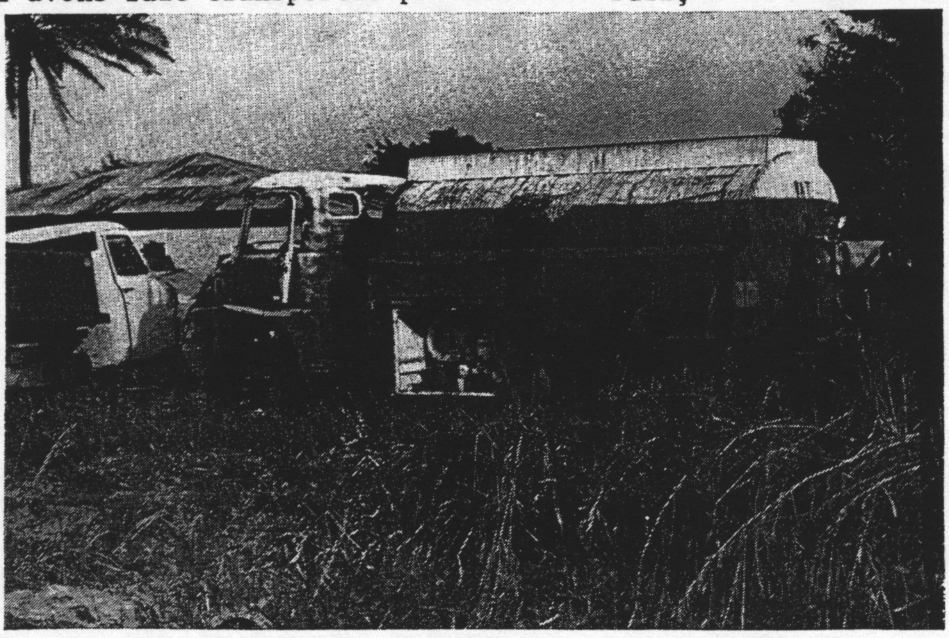
Sur les deux photos on voit, à gauche en bas, l'arrivée de la conduite de chute et, à droite, le départ de la conduite d'écoulement.
Au centre on voit la grande valve. Sur la photo 13 celle-çi est ouverte ; sur la photo 14 elle vient de se fermer sous la poussée de l'eau. La valve est faite d'un disque mobile, suspendu à une tige qui se termine par un capuchon. En comparant la place de ce capuchon sur les deux photos, on remarque qu'il peut se déplacer de quelques centimètres. Ce déplacement est réglable ; le nombre de coups de bélier par minute en dépend.
Au début des premiers essais, il n'y a pas encore de pression à l'intérieur de la cloche d'air. L'eau amenée par la conduite de chute, ferme la vanne.
Il faut l'ouvrir, en poussant sur la capuchon (à l'aide d'un lévier). L'eau sortira les trous de la vanne. Toute la colonne d'eau dans le tuyau de chute acquiert une vitesse accélérée et devient ainsi assez forte pour soulever le disque de la vanne et donc pour fermer brusquement celle-çi. La colonne d'eau cogne la vanne, ce qui cause une pression énorme. Cette pression

ouvre une seconde vanne qui se trouve à l'intérieur du bélier à l'entrée de la cloche d'air. Une certaine quantité d'eau sera injectée de force dans cette cloche.
Après quelques dizaines de coups de bélier, quand la pression à l'intérieur de la cloche d'air aura atteint une valeur suffisante, le bélier se met à fonctionner tout seul, sans aide extérieure.

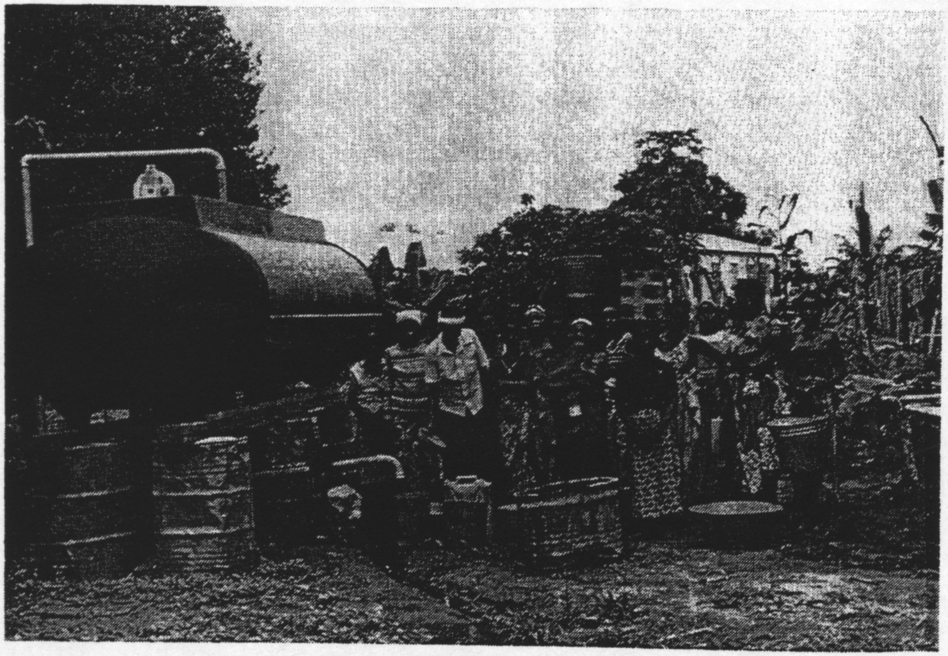
15. Pour alléger la corvée d'eau, les femmes du village récoltaient l'eau de pluie en plaçant des récipients sous le toît de l'église.



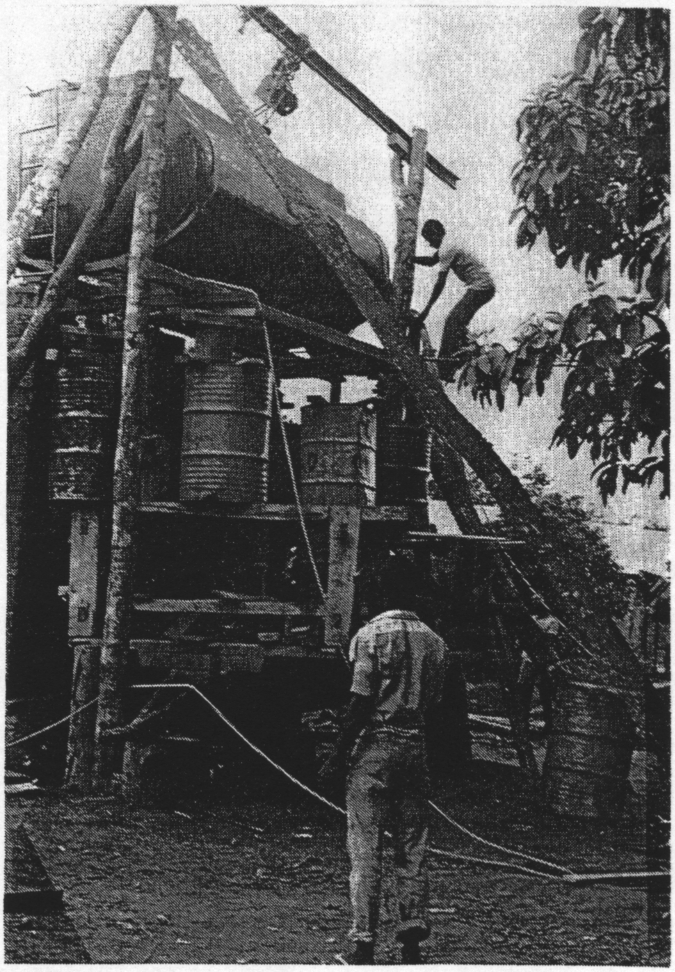
16. Il fallait un château d'eau. Construire une citerne étanche n'est pas facile. Heureusement nous avons trouvé, au cimetière de voitures à Kamina, un camion citerne provenant de la base militaire. La citerne de 5 m^3 était en bon état. Nous l'avons fait transporter par camion à Budi, à 300 km.



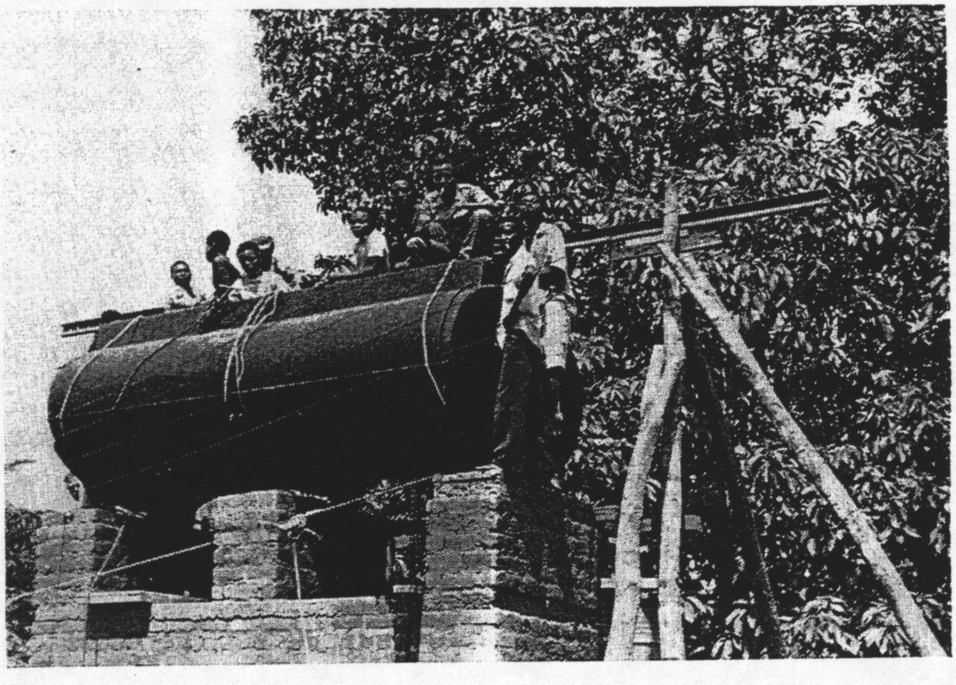
17 - 18. Dès avant l'installation définitive de la citerne, femmes et enfants viennent puiser l'eau au robinet. Après l'installation de la citerne sur son socle, nous avons monté trois robinets à l'extérieur de la clôture du jardin de la mission. Du matin au soir, les gens du village viennent puiser gratuitement une eau bien plus propre et claire que celle qu'ils trouvaient auparavant à la rivière.



19. Monter la citerne sur son socle était une grosse affaire. On ne disposait que d'un treuil d'une tonne alors que le poids de la citerne devait être bien plus élévé.



20. Finis coronat opus. Le fin couronne l'oeuvre.
Le socle est construit de manière à servir comme citerne supplémentaire pour recevoir le trop-plein de la citerne principale.



A partir de ce château d'eau, celle-çi est distribuée aux différents bâtiments de la maison.
Le bélier peut fournir environ 19.000 litres par jour, ce qui dépasse nos besoins actuels. Aussi, chaque nuit nous arrêtons le bélier. Chaque soir un ouvrier va fermer la vanne qui se trouve à l'entrée du bélier et le matin il va l'ouvrir.
A chaque grande pluie, l'eau dévale le long des berges, entrainant avec elle brindilles et sable. Ces brindilles obstruent un treillis qui se trouve à l'entrée de la conduite d'amencée ; ce qui provoque heureusement l'arrêt automatique du bélier.
Il faut nettoyer les deux bassins de décantation après chaque grande pluie ; même pendant le saison sèche il convient de les nettoyer tous les deux à trois jours. Pour cela nous avons prévu un tuyau de vidange à chaque bassin.

L'installation d'eau à Budi a été approuvée comme un "Petit Projet" par le Gouvernement Belge. Ce qui veut dire que le Gouvernement payait les 3/4 de budget. Le quart restant à été payé par les Soeurs Franciscaines de Manage, dont dépend la communauté des Soeurs à Budi. Le budget total était évalué à 1.630.500 FB.

4. ANNEXES

4.1. APPROVISIONNEMENT D'EAU A LA MATERNITE ET AU DISPENSAIRE DE BUDI, ZAIRE - COUTS DE L'INSTALLATION 82-83.

Frais d'investissement		Montant en Z	Montant en FB
1. Bellekens	Outillages		44.557
2. Grand Sud-Ouest Industriel	Bélier RAM + pièces de rechange et accessoires		227.237
3. Fabrijoint	Joints de cuir		28.495
4. Dofny	Soupapes, vannes, tubes, coudes, etc.		548.054
5. Procure des Missions	Dédouanement 13 colis + accessoires pour tubes	6.890	
6. Agetraf	Frais de transport et expédition de 44 colis	42.757	
7. Ets. Merka	1 citerne	15.000	
8. Dep. Agriculture	Soudure tuyau frein	167	
9. Mission Kitenge	Salaires ouvriers	6.648	840.769
10. Mission Kitenge	Fers à béton, briques, ciment, gravier, sable	21.980	
11. Mission Kitenge	Transport de 14 T de matériel	3.600	
12. Ets. Mutende Kitamba	Transport du réservoir	4.500	
Frais d'envoi, d'emballage et d'assurance			543.604

A quoi s'ajoutent les frais d'administration et les frais bancaires.

4.2. PRINCIPES DE FONCTIONNEMENT D'UN BELIER.

Le fonctionnement du bélier hydraulique est basé sur les principes de l'inertie de la matière et de la conservation de l'énergie.
Un corps en mouvement est animé d'une force vive ou énergie cinétique qui est égale au produit de la masse du corps par la carré de sa vitesse.
Dans le bélier hydraulique, on utilise la force vive d'une masse d'eau en mouvement comme force motrice ascensionnelle d'une partie de la masse d'eau.
Un bélier peut se schématiser comme suite (voir fig. 1) :

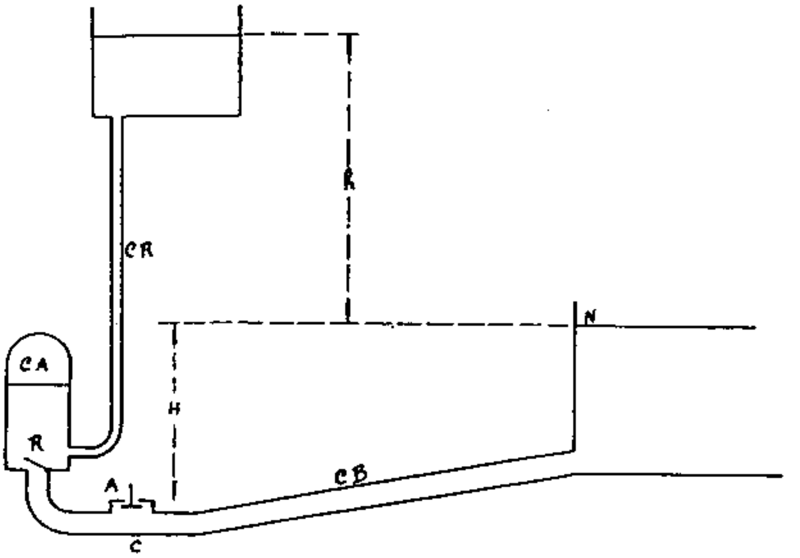


Fig. 1 : Schéma d'un bélier hydraulique.

Un tuyau CB, appelé conduite de batterie (certains auteurs emploient les désignations de tuyau conducteur, ou tuyau d'amenée, ou tuyau d'alimentation, et l'appellation anglaise est 'drive pipe') part d'un réservoir à niveau constant N, et se termine dans le corps du bélier C.
Le corps du bélier comporte une soupape d'arrêt A, par où les eaux peuvent se déverser dans le canal d'évacuation des eaux motrices. Cette soupape est munie d'un contrepoids ou d'un ressort.
Enfin, le corps du bélier communique par l'intermédiaire de la soupape de refoulement R (parfois appelée soupape d'ascension) avec la cloche à air CA. La conduite de refoulement CR (ou tuyau d'ascension et en anglais : 'delivery pipe') s'amorce à la partie inférieure de la cloche à air et débouche dans le réser-soir supérieur.

Le fonctionnement du bélier est le suivant :
La soupape d'arrêt A, maintenue ouverte par son contrepoids ou son ressort, donne libre évacuation aux eaux du réservoir d'alimentation. Lorsque la vitesse d'écoulement des eaux atteint une valeur suffisante, la soupape est soulevée par le courant de l'eau et se ferme brusquement.
Le mouvement de la masse d'eau de la conduite de batterie est brusquement arrêté. La force vive de cette masse provoque une forte élévation de la pression dans l'eau qui remplit le corps de l'appareil (coup de bélier). Sous l'effet de cette pression, la soupape de refoulement R. s'ouvre et laisse pénétrer dans la cloche à air et dans la conduite de refoulement une certaine quantité d'eau.
Dès que le mouvement d'entrée de l'eau dans la cloche à air s'arrête, la soupape de refoulement retombe sur son siège et empêche les eaux de la conduite de refoulement de redescendre dans le bélier.
L'eau du corps de bélier et de la conduite de batterie ayant arrêté son mouvement, la soupape d'arrêt A s'ouvre à nouveau et le même cycle d'opérations re-

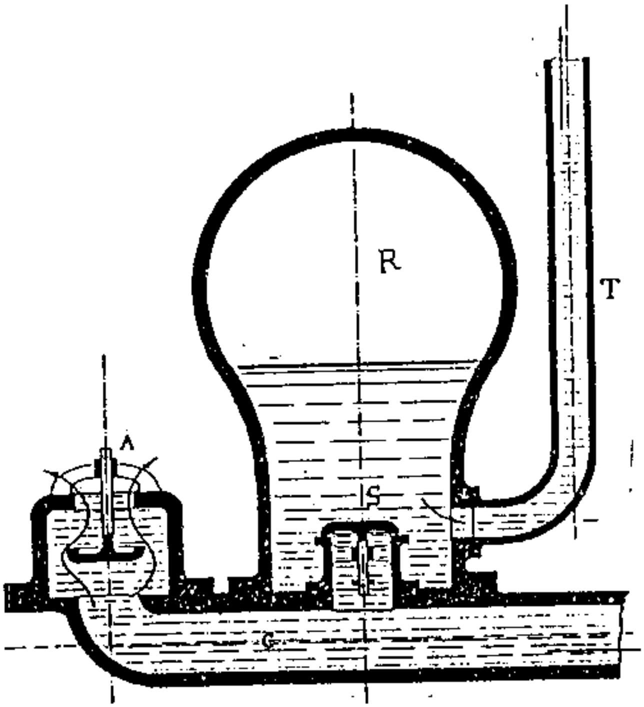


Fig. 2 : Coupe d'un bélier. Période de refondement. Soupape d'arrêt fermée.

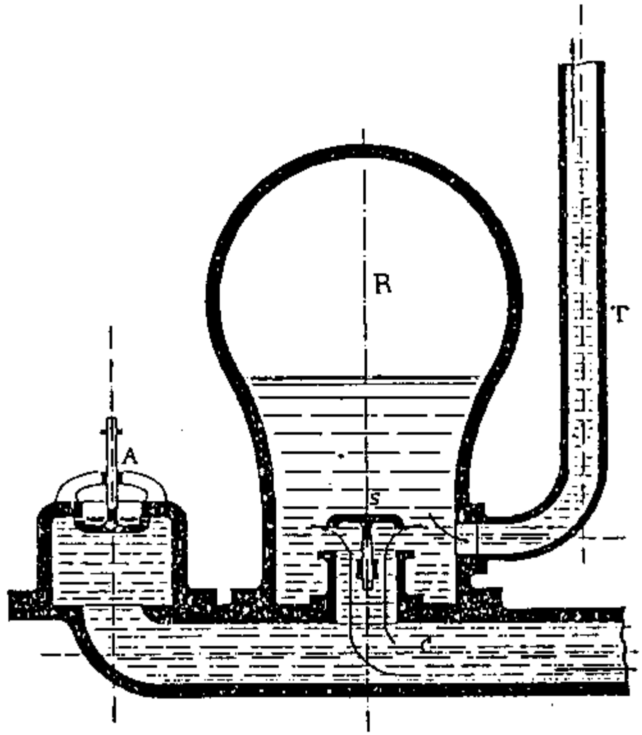


Fig. 3 : Coupe d'un bélier. Période d'écoulement. Soupape d'arrêt ouverte.

commence. Chacune de ces périodes constitue un battement ou coup de bélier.
Le rôle de la cloche à air est d'amortir la violence des chocs et d'uniformiser l'ascension et l'écoulement.
Les constructeurs ont apporté divers perfectionnements aux béliers, mais le principe du fonctionnement reste le même. Parmi les dispositifs supplémentaires qui furent ainsi ajoutés, je citerai le reniflard, soupape spéciale qui permet à l'air de rentrer dans la cloche pour compenser les pertes dues à la dissolution de l'air dans l'eau sous pression. Parfois, le reniflard est remplacé par une pompe à air avec injecteur. Certains béliers comportent une soupape ou une cloche à air supplémentaire, pour amortir la brutalité du coup de bélier et régulariser le débit.

4.3. INSTRUCTIONS POUR L'INSTALLATION, LE REGLAGE ET L'ENTRETIEN DES BELIERS HYDRAULIQUES "RAM" DE LA FIRME LEDOUX A BORDEAUX

I. INSTALLATION D'UN BELIER

a) Généralités

Une installation de bélier n'est possible que si l'on dispose d'une chute d'eau et si les eaux perdues déversées par l'appareil peuvent être évacuées. Il faut disposer, en outre, entre la chute d'eau et l'emplacement du bélier, d'une certaine distance correspondant sensiblement à la longueur de la conduite de batterie ou conduite d'alimentation, dont les caractéristiques sont déterminées par le constructeur de l'appareil. Enfin quelques considérations essentielles sont à retenir conformément aux indications ci-après.

b) Prise d'eau

La prise d'eau peut être, soit naturelle, soit aménagée suivant la qualité de l'eau et suivant le type de bélier employé.

Lorsq'il s'agit d'une source, la crépine sera noyée dans le bassin naturel de cette source ou bien dans un réservoir construit à l'intention de recevoir les eaux de cette source.

Si l'eau est propre et pure, la crépine de départ sera suffisante. Si l'eau provient d'un étang ou d'un cours d'eau, la chambre de prise d'eau sera aménagée de telle sorte qu'il y ait décantation des matières lourdes en suspension par diminution de la vitesse de circulation de l'eau et arrêt des matières flottantes par interposition d'une grille.

On aura soin de déterminer très exactement le régime des débits de la source, de l'étang ou du ruisseau en prenant comme débit normal d'alimentation du bélier celui qui correspond au débit d'étiage ou débit le plus réduit de cette source, de cet étang ou de ce ruisseau.

On aura soin également de modifier éventuellement le bassin naturel de la source ou de construire le réservoir de telle sorte que la crépine, constituant le départ de la conduite de batterie ou conduite d'alimentation, soit toujours noyée sous 0 m 40 à 0 m 60 de hauteur d'eau.

Pour les moyennes et grosses installations, il sera utile également de soumettre l'eau à une analyse chimique et éventuellement bactériologique si cette eau doit être consommable.

c) Chute

La chute naturelle ou artificielle sera choisie au plus près de l'endroit d'utilisation des eaux élevées, pour éviter une trop longue conduite de refoulement et résoudre le problème le plus économiquement possible.

La hauteur de la chute est tributaire des conditions d'installation et, particulièrement, de la hauteur manométrique de refoulement. Elle a pour valeur la différence de niveau entre le niveau de l'eau la prise d'eau et celui de sortie de ces eaux au bélier ou du plan d'évacuation si le bélier est noyé. Nous devons ici ouvrir une parenthèse sur les expressions : hauteur géométrique et hauteur manométrique, qui sont si souvent mal interprétées ou confondues.
- La hauteur géométrique est la hauteur qui correspond à la différence d'altitude ou différence de niveau de 2 points données - dans notre cas entre le bélier et le point de déversement des eaux - pour la hauteur géométrique de refoulement.
- La hauteur manométrique est celle qui est ou serait lue sur un manomètre placé

sur la conduite de refoulement à la sortie du bélier.
Cette hauteur manométrique est toujours supérieure à la hauteur géométrique car elle comprend également les frottements de l'eau sur les parois intérieures de la canalisation de refoulement.
Cette frottements qui sont traduits ici par une augmentation de la hauteur des différences de niveaux, seront plus ou moins importants suivant que la conduite de refoulement sera longue et que le diamètre intérieur sera important ou faible.

Pour en revenir à la hauteur de chute, cette dernière sera autant que possible choisie dans les conditions suivantes :
1° de 1 mètre minimum à 30 mètres environ
2° de 4 à 20 fois plus petite que la hauteur manomètrique de refoulement.

Si le terrain le permet, on choisira autant que possible la hauteur de chute de 6 à 12 fois plus petite que la hauteur manomètrique de refoulement, ce qui correspond au rapport ou le rendement propre du bélier est le plus élevé.

On aura donc :

$$6 < \frac{\text{Hauteur manomètrique de refoulement}}{\text{Hauteur de chute}} > 12$$

Les hauteurs de chute inférieures à 1 mètre ne sont pas recommandées car elles exigent l'emploi de béliers spéciaux à clapet de batterie légers et le fonctionnement ne peut être garanti d'une manière incertain.

Les hauteurs de chute de 1 à 10 mètres s'adaptent à tous nos béliers et celles de 10 à 30 mètres à nos béliers renforcés.

Le fonctionnement est également incertain si la hauteur manomètrique de refoulement n'est pas au moins 4 fois supérieure à la hauteur de chute. On réduira donc la hauteur de chute pour atteindre ce rapport minimum acceptable mais sans pour cela descendre au dessous de la valeur de 1 mètre.

Si la hauteur manomètrique de refoulement excéda 15 à 20 fois la hauteur de chute, il y aura lieu de vérifier si 2 béliers installés en cascade n'aurent pas un meilleur rendement.

En effet, à partir de 15 fois la hauteur de chute, le rendement de l'appareil diminue très rapidement et si nous prenons comme exemple un bélier refoulant à 50 mètres de hauteur anomètrique avec une chute de 2 mètres, son rendement n'est plus pour ce rapport de $\frac{50}{2} = 25$ que de 25 %.

Si nous installons deux béliers en cascade, le premier refoulant dans le réservoir d'alimentation du second et si nous plaçons comme dans l'exemple précédent ce réservoir intermédiaire à 10 mètres, nous aurons les rapports suivants :
pour le premier bélier : $\frac{10}{2} = 5$, d'où rendement de : 65 %

pour le deuxième bélier : $\frac{50}{10} = 5$, d'où rendement de : 65 %.
Le rendement global de l'installation devient alors de = 0,65 x 65 = 42 % environ.

Le débit refoulé dans le deuxième cas sera alors :
$100 \frac{42 - 25}{25} = 68$ %, supérieur à l'emploi d'un seul bélier.

d) Conduite d'alimentation ou conduite de batterie du bélier

Cette conduite réunit la prise d'eau au bélier. Elle représente à elle seule la partie où l'installateur aura à apporter le plus de soins en suivant les règles énumérées ci-après.

1° - La longueur et le diamètre de cette conduite qui dépendent des conditions d'installation et du bélier choisi, devront être ceux donnés par le constructeur du bélier.

2° - Elle sera toujours et dans la mesure du possibile installée rectiligne, en porte régulière ou non, mais obligatoirement sans contre-pente.

Si, pour une cause quelconque, la distance entre la prise d'eau et l'emplacement du bélier, ne correspond pas à la longueur de cette conduite, on aura recours aux différents artifices suivants :

A. Si la distance entre la prise d'eau et le bélier est identique à la longueur de la conduite de batterie, l'installation peut être réalisée suivant les schémas d'installation 1 et 2 ci-après.
B. Si la distance entre la prise d'eau et le bélier est plus courte que la longueur de la conduite de batterie, cette conduite pourra être installée en forme de S ou de 8 avec des coudes à grand rayes et en surveillant bien qu'il a'y ait aucune contre-pente.
C. Si la distance entre la prise d'eau et le bélier est plus grande que la longueur de la conduite de batterie, on pourra alors placer un réservoir intermédiaire suivant les schémas d'installation no. 3 et 4 ci-après.

La conduite de batterie devient alors la distance entre le réservoir intermédiaire et le bélier. On aura soin toutefois, afin de ne pas diminuer la hauteur de chute, de choisir un diamètre suffisamment grand pour la conduite qui réunira la prise d'eau à ce réservoir intermédiaire.

Il est possible également de résoudre cet inconvénient par un autre moyen qui consiste à supprimer le réservoir intermédiaire en augmentant le diamètre de la conduite de batterie, soit dans la totalité, soit dans une partie de sa longueur.

C'est cette solution qu'on adoptera lorsque la hauteur de chute entrainera de gros frais pour la construction du réservoir intermédiaire ou que cette construction sera d'un prix plus élevé que l'augmentation entrainée par le changement de diamètre de la conduite de batterie.

3° - Suivant la nature des eaux, elle sera en fer, acier, fonte ou cuivre, mais jamais en métal mou tel que plomb.

4° - Les joints de ces tuyaux doivent être particulièrement bien établis de façon à assurer l'étanchéité parfaite de la conduite de batterie.

Cette conduite doit toujours être constamment pleine d'eau et absolument privée d'air.

5° - Cette conduite de batterie peut être équipée avec un ou deux robinets vannes, l'un placé à côté du bélier, l'autre à la prise d'eau, au départ de la conduite de batterie. Ces robinets-vannes doivent toujours être maintenus ouverts. Ils ne peuvent être utilisés que comme robinets d'arrêt en cas de visite du bélier ou de la conduite de batterie.

Dans certains cas, mais nous ne le recommandons pas, le robinet-vanne à la prise d'eau à été utilisé pour le règlage du débit dans une proportion de 10 à 20 %.

L'extrémité du tuyau de batterie (côté prise d'eau) devra être manie d'une crépine fine à grande surface pour éviter l'introduction de crops solides, graviers, débris végétaux, poissons, etc... dans le bélier.

6° - Dans les installations à hautes chutes ou de gros débits et quand les pressions mises en jeu par les coups de bélier peuvent atteindre des valeurs importantes pouvant provoquer des ruptures de conduites ou des béliers eux-mêmes, on place sur la conduite de batterie des soupapes de sûreté.

Ces soupapes de sûrteté laissent évacuer l'eau lorsque la pression est supérieure à la pression manométrique de refoulement.

Les causes de ces surpressions sont nombreuses et peuvant être : fermeture du robinet-vanne de refoulement, clapet de refoulement coincé, cloche du bélier emplie d'eau, etc.

e. <u>Conduite de refoulement</u>

La conduite de refoulement peut être réalisée comme toutes conduites ordinaires. en fer, fonte, cuivre, plomb, fibre-ciment, etc.

Les joints seront étanches pour éviter les pertes d'eau mais, contrairement à la conduite de batterie, ces pertes ou fuites n'auront que peu d'action sur le mauvais fonctionnement du bélier.

Un robinet-vanne sera placé au départ de cette conduite et à proximité du bélier. Il aura pour but principal d'éviter de vider le tuyau de refoulement quand on veut visiter ou nettoyer le bélier.

Dans un cas, à éviter d'ailleurs, le robinet-vanne peut être utilisé pour le règlage du débit, c'est le cas, par exemple, d'une hauteur manométrique de refoulement trop faible par rapport à une hauteur de chute trop grande qu'il est impossible de réduire.

Lorsque le tuyau de refoulement est très long et surtout dans les cas de grandes hauteurs de chute, on a souvent intérêt à installer un réservoir d'air supplémentaire, avec ou sans clapet de retenue, sur le départ de ce tuyau.

4.4. LES CONDITIONS NECESSAIRES POUR LE FONCTIONNEMENT D'UN BELIER. SYNTHESE

Les données suivantes sont nécessaires pour l'établissement technique d'un projet (voir aussi : 2. Dessin de l'implantation).

1. Le débit de la rivière (à mesurer pendant la saison sèche)
2. La qualité de l'eau (pollution)
3. La hauteur de la chute
4. La hauteur du refoulement
5. La longueur de la tuyauterie d'amenée, de batterie et de refoulement
6. Le débit souhaité
7. La manière d'utiliser l'eau.

Pourque le système fonctionne bien, un nombre de conditions doivent être remplies :

- <u>l'environnement</u>

a. Il doit y avoir de l'eau courrante, avec une chute naturelle ou artificielle de min. ± 1 mètre et max. ± 10 mètres (± 30 mètres pour les béliers commerciaux) ou une source.
b. Suffisamment d'eau, c.à.d. un débit min. de ± 15 l./min.
c. La possibilité d'installer une conduite d'alimentation d'un longueur de 3 à 7 fois la hauteur de la chute.
d. La possibilité d'évacuer l'eau.

- <u>l'adduction d'eau</u>

e. Des réservoir avec trop-plein et filtres (pas d'eau sale dans le bélier !).
f. Prévoir éventuellement un complement de conduites amortisant.
g. La conduite d'alimentation ne peut pas être flexible.

- <u>le bélier</u>

h. Une soupape d'arrêt réglable.
i. Un réservoir d'air (de 0,3 jusqu'à 10 fois le contunu de la conduite d'alimentation)
j. Une vanne de prise d'air, le reniflard permettant à l'air de rentrer dans la cloche.
k. Une vanne de répulsion restant sous eau.
l. La possibilité de fermer la conduite d'alimentation et de refoulement.

4.5. COMMENTAIRES

Beaucoup de questions ont trouvé une réponse, d'autres restent dans le vague. Un texte ne peut pas tout expliquer. La pratique est le meilleur professeur.

Les gens de Budi pensaient depuis long temps à l'installation d'un bélier. La firme Ledoux à Bordeaux, qui fut le fournisseur, leurs a fait le calcul de la capacité du bélier même et des conduites, se basant sur les données fournis par les pères. Par l'intermédiaire de COMIDE le projet fut introduit et approuvé pour le cofinancement de l'état belge. C'est aussi COMIDE qui a fait tout les démarches nécessaires en Belgique (commandes, transport, assurances). Une organisation pareille est indispensable, si on veut acheter les matériaux en Europe.

Bien sûr, il y a d'autres constructeurs de béliers. En outre, il existe un nombre de brochures qui décrivent différentes constructions simples, à faire avec du matériel trouvé sur place. A toute évidence, ces béliers ne sont pas chers, beaucoup en ont été installés et fonctionnement avec un bon résultat.

Les problèmes techniques étaient résolus sur place. Le bélier pesait presque 600 kg. Trop lourd pour le transport et dificile à manier dans sa totalité. Il était démonté et transporté en pièces. Tout le matériel arrivait à temps, sauf les boulons et les joints pour boullonner les tubes à brides de 6" et 4". Ceci causait quelques problèmes pendant l'installation. Les tubes était beaucoup plus flexibles que l'on ne le pensait, ce qui a largement facilité la mise en place, même dans une grande courbe.

Les coûts de l'installation à Budi peuvent sembler très élevés, à cause de l'achat du bélier et des tuyauteries nécessaires. Pourtant, le financement pour la réalisation d'un projet pareil est encore facile à trouver, vu qu'il s'agit de frais d'investissement. Le fonctionnement même ne coute rien. Contacter les instances appropriées et aussi rassembler toutes les données nécessaires (débit de la rivière, distances, hauteur, débit souhaité, ...) pour écrire un projet réaliste, prendra beaucoup de temps.

La participation de la population locale peut fournir des renseignements très valables. Les gens ont d'ailleur une idée précise de la quantité et de la qualité désirée. Une recherche commune s'impose. Il y a des mesures à prendre. Par exemple il faut éviter toute pollution par les vaches en amont du barrage. Ceci sera plus facile si la population a été engagé dans le projet dès le début et surtout si ils ont participé à l'execution des travaux (creuser les canaux, transporter les tuyaux, etc...).

Un effort spécial doit être fait pour expliquer au gens le fonctionnement du bélier; ceci pour deux raisons. Il est évident que l'on ne peut parler de transfer de technologies ou d'appropriation que si au moins un petit nombres de representants de la communauté locale comprennent la technologie en question. Si ce n'est pas le cas, on va se heurter à des problèmes très graves d'entretien. Il faut nettoyer les réservoir après chaque grande pluie, contrôler le débit de la rivière, comprendre les arrêts qui vont se produire (à cause d'un débit trop grand, trop petit, de la pollution de l'eau, etc ...).

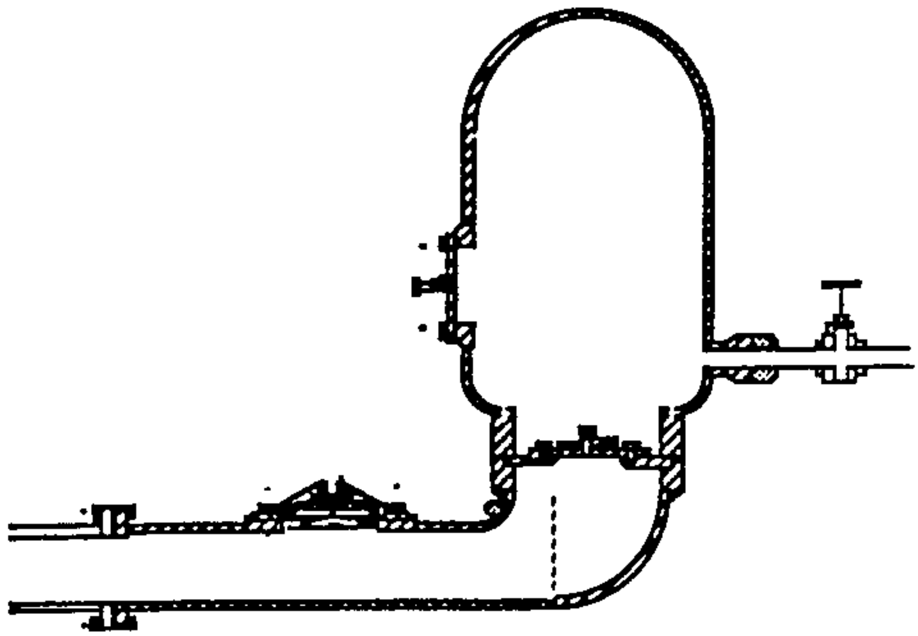
A Budi, le travail a été fait par les pères et leurs ouvriers. Le contrôle et l'entretien du système est pris en charge par eux. La population est le bénificiaire net de l'entreprise : l'eau est disponible plus près du village. Le projet pourrait constituer le point de départ d'une initiative de développement plus globale se concentrant autour de l'organisation pour la gestion de l'installation, les soins de santé et l'hygiène. Peut-on penser à une campagne pour améliorer la qualité de l'eau (la filter et faire bouillir avant la consommation), maintenant que la quantité est assurée.

Il y a un bon bout de temps, quelqu'un a lancé une idée. Un nombre d'années passent. Et soudain, sans faire appel à des moyens financières et techniques extra-ordinaires, l'idée est reprise et mise en réalisation. Petit à petit les problèmes ont été résolus et maintenant l'eau coule à Budi.

HYDRAULIC RAMS

Consumers guide

P. de Jong



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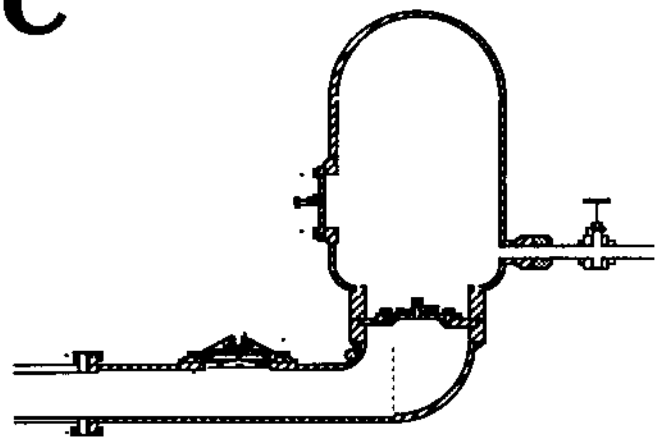
HYDRAULIC RAMS



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1. Introduction

This report is the result of a project, called "comparative tests on commercial and newly designed waterrams", carried out by the Delft University of Technology and the Foundation of Dutch Volunteers in Rwanda.
The aim of this project was twofold:
- to test new, and cheap (i.e. locally constructable and maintainable) types of hydraulic rams,
- to compare several commercial types, in order to make a "consumers guide" for developing countries.

At the Laboratory of Fluid Mechanics of the Delft University of Technology the most essential aspects of the behaviour of commercially available rams were compared. Valve behaviour, delivery head, delivered quantity and efficiency were accentuated.
Samples of the rams, tested in the laboratory were checked in Rwanda on reliability, durability and possibilities for local maintenance.

2. Appropriate water supply

A reliable water supply is one of the basic needs of people. It is a rather disappointing experience to find a dried-up well after several miles of walking, or to get just a few drips of brown water out of an expensive pump. Many people are dealing with this sort of problems, especially in the arid areas of the Third World.
A lot of pumping systems were developed to fulfill this need:
hand-driven pumps, using human energy to get water out of the earth or river into a bucket or to lift water to a certain level (into a storage tank) from which it can be distributed.
an improvement is found in using animal traction instead of human energy. Transmission is necessary, but outputs are five to ten times greater than that of man.
the next step is to use fossil fuels or renewable energy for pumping. Animals can be used for other activities, instead of pumping for many hours, the pump can be used 24 hours per day and delivery of larger quantities of water are possible.
The pump itself, of course, has to be appropriated to its use and to its energy system. A donkey will pull harder than a man, the beats of a diesel pump will effect the pump in a totally different way than the constant rounds of the cattle. The hand pump is a simple design, means less maintenance and is easy to repair. Diesel and electric pumps are more sophisticated, but they require technical know-how and installation, maintenance and repair facilities.
Another disadvantage of diesel and electric pumps, is the dependence on fuel. Disruptions in the fuel supply will stop the pump and the total water installation.
For this reason 'appropriate technologists' have been looking for renewable energy sources: solar, wind and biomass energy and hydropower. Depending on the environmental and economical situation and, again, the available facilities, a choice can be made:
solar energy (photovoltaic cells, control device and a electric pump) requires a high level of technical skills and investment. The systems

can only be imported from industrialized countries.

wind energy (rotor, power transmission mechanism and a pump or a wind-driven electro-generator and an electric pump) requires also an investment higher than for diesel pumps, but has lower running costs and it can have a longer service life. A suitable wind regime is necessary; the average wind speed has to be higher than 3.5 m/s.

biomass can be processed to combustible gasses or liquids, which can be used as fuel for small engines to drive water pumps. Special energy crop production will be necessary most of the time; a trained operator is essential. Due to the minimum size of a biomass plant, such systems will not be adequate under quantities of 150 m^3 of delivered water daily.

hydro-powered pumping systems, which could be devided into three main types:

- turbine pumps, a water turbine with a centrifugal pump (flow of river, stream or channel 15 m/s, drive head of at least 0.5 m),
- river current pumps, a vertical shaft rotor with transmission to a small centrifugal pump on a floating pontoon (e.g. flow of river 1.0 - 1.5 m/s, delivered quantity 100 - 300 l/min to a delivery head of 5 m),
- hydraulic rams, a good solution if the conditions are favourable.

A more complete overview of the possibilities is given in 'Renewable Energy Sources for Rural Water Supply' (litt. 9).

3. Hydraulic rams

The decision to choose rams could be made after surveying the situation, measuring the available source supply, the obtainable supply head and the required delivery head as well as some additional data.
If the basic requirements could be fulfilled and the possible site meets its criteria (§ 5 and § 6), rams can be considered.
A final aspect of such a decision is the price of the system (§ 8).
In appendix A the operation of the ram is described including some specifications of the normally used characteristics. Furthermore, a comparison of rams in the laboratory and in the field, as well as a calculation example and adresses of manufacturers are given in the appendices.

4. Description of hydraulic rams

The various components from which a typical hydraulic ram installation is constructed are supply reservoir, drive pipe, hydraulic ram, delivery pipe and a storage tank.
The hydraulic ram itself is structurally simple, consisting of a pump chamber fitted with only two moving parts: an impulse valve through which the driving water is wasted (waste valve) and a delivery valve (check valve) through which the pumped water is delivered.

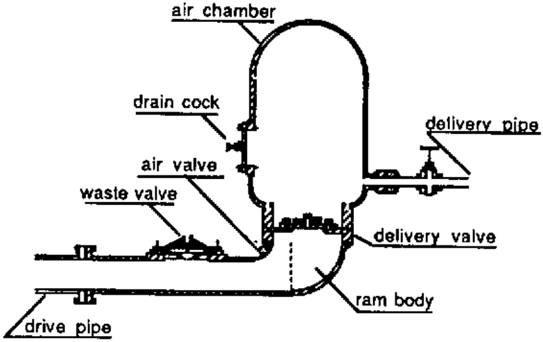


Fig. 1. Nomenclature of a hydraulic ram

In empty condition the waste valve normally falls open by gravity. Some designs of hydraulic ram use spring-activated waste valves. The delivery valve usually is a simple rubber disc covering a ring of holes. Surmounting the delivery valve is the air chamber or surge tank. When the ram operates, this tank is partly filled with water and partly with air. Connected to the air chamber is the delivery pipe, so the pressure in the air chamber is the delivery pressure. An inclined conduit, the so-called drive pipe, connects the ram body with the water supply. This drive pipe is the essential part of the installation in which the potential energy of the supply water is first converted into kinetic energy and subsequently into the potential energy of water delivered.

5. Basic Requirements

The use of a hydraulic ram requires the availability of suitable and reliable supply of water, with a sufficient fall to operate the ram. The supply can be any source of flowing or stagnant water such as a spring, stream, river, lake, dam or even a pond fed by an artesian well. Small size rams require a supply flow of at least 5 to 25 litres per minute, whereas very large rams may need as much as 750 to 1500 l/min. For most hydraulic rams the fall in driving water from the source to the ram must be at least 1 m.

Of course, not every spring, river etc. is suitable. The quality of the water is very important and has to be checked first. Most countries and communities have their own quality standards and methods of control. If the quality is not sufficient, complementary measurements have to be taken.

6. Site selection

When selecting a potential site for the hydraulic ram installation it is essential that provisions can be made both for water input to the ram and for proper drainage of the waste water away from the ram. The waste valve should under no circumstances, flood conditions included, be submerged, since this will seriously affect its operation.

Before any possible lay-out of the installation can be designed, information must be gathered on the following items:

1) Amount of water available to power the ram (source flow) [l/min]
2) Minimum quantity of water to be pumped (delivery flow) [l/day]
3) Working fall (supply head) which can be obtained [m]
4) Distance in which the working fall can be obtained [m]
5) Vertical lift from ram site to delivery site [m]
6) Length of delivery pipe from ram to delivery site [m]

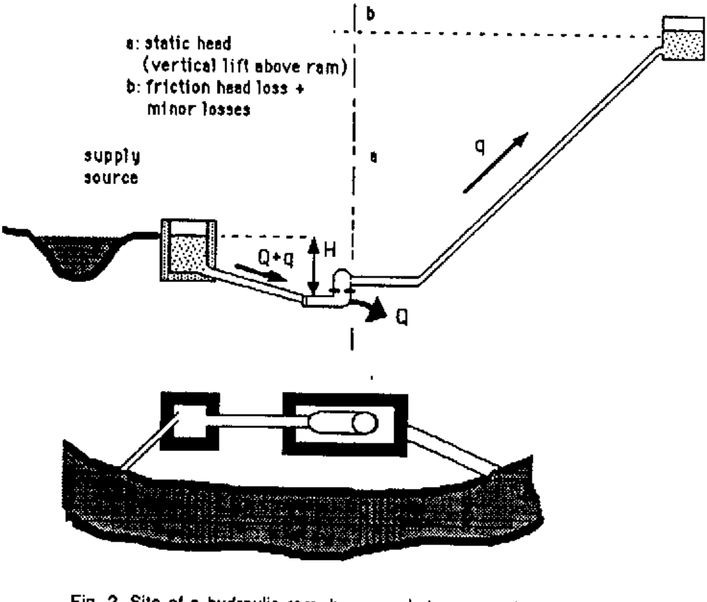


Fig. 2. Site of a hydraulic ram, $h_d = a + b$ (cross-section and top view)

Unless the supply water is obviously more than adequate, the source flow must be measured with reasonable accuracy. The possible change of flow at different times of the year should be established in order to determine the minimum guaranteed flow available.

The total daily volume of water required to be pumped can be calculated according to the purpose of use. For example, if the water is to be used for domestic consumption, the daily demand may be approximated by:

Water Demand = Users * Per Capita Consumption

A typical per capita consumption could be 40 to 50 litres/person/day. If

live- stock is present, its water use should be included also.
Given the fact that the hydraulic ram is capable of operating continuously twenty-four hours per day, the required pumping rate (q) is obtained by dividing the daily water demand by 24 * 60 = 1440 minutes; in formula:

$$\text{Pumping Rate q [l/min]} = \frac{\text{Water Demand [l/day]}}{1440\ \text{[min/day]}}$$

The working fall (supply head Hs) is measured vertically from the supply source level to the output level at the waste valve of the ram. The pumping capacity varies directly with the supply head.
The supply head can be increased by increasing the input level (e.g. by selecting the water input further upstream) and/or by lowering the position of the ram itself (as long as it can be placed on a spot from which the waste water can be easily drained away, e.g. to a suitable discharge point further downstream).

The next question to be answered is what pressure head the hydraulic ram will need in order to lift the water to the storage tank and to overcome all energy losses. In general this will be equal to:

$$\text{Delivery Head } (h_d) = \text{Vertical Lift above Ram} + \left[\frac{f\,L_d}{d} + \xi_d\right]\frac{v^2}{2\,g}$$

where

f	= pipe friction factor	[-]	(0.02 - 0.04)
Ld	= length of delivery pipe	[m]	(50 - 2000)
d	= internal diameter of delivery pipe	[m]	(0.02 - 0.05)
ξd	= sum of minor loss factors	[-]	(0 - 10)
v	= average velocity in delivery pipe	[ms^{-1}]	(0.2 - 0.5)
g	= acceleration due to gravity	[ms^{-2}]	(9.8)

Vertical lift must be measured from the location of the ram to the highest possible water surface level (overflow level) in the storage tank.
Minor losses may usually be neglected (or roughly estimated) as compared with vertical lift and friction head loss.
Knowing the available source supply (Q_{source}), the required pumping rate (q), the supply head (Hs) and the delivery head (hd) the size of the hydraulic ram can be selected with the aid of the appropriate performance tables or, when available, with use of empirically obtained q/Q vs hd/Hs- curves:
The sum of the waste flow (Q) used by the ram and the pumping rate (q) must be less than the minimum source flow, i.e. $Q + q < Q_{source}$

Since supply head (Hs) and delivery head (hd) are more or less fixed by the terrain conditions (topography), the size of the hydraulic ram is mainly determined by the desired pumping rate, or limited by the available source supply to drive the ram.

In cases where the installation has not enough capacity to meet the daily water demand, a battery of several rams may be used. Of course, this requires a source which can supply water at a sufficient rate. Each ram must have its own individual drive pipe, but they may use the same delivery pipe unless they are meant to supply different places.

A battery of hydraulic rams is also very useful in situations where the minimum flow during periods of drought only can power one or two rams and the maximum flow can drive more rams.

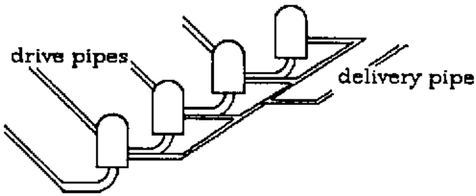


Fig. 3. Battery of a hydraulic rams

In a case where the supply water can power only one hydraulic ram, but the delivery flow does not quite meet the water demand, the waste water from the initial ram could be used to drive another ram.

7. Installation and maintenance

Since the hydraulic ram undergoes savage pounding under operation, it should be firmly bolted to a concrete base.

The drive pipe is by far the most important part of the installation; it carries the water from the supply reservoir to the ram and contains the high pressure surges (waterhammer) during the pumping stage of the operating cycle of the ram. The drive pipe should therefore be made of strong, rigid material, preferably galvanized iron. It should be watertight and rigidly anchored. The length should be approximately 4 to 7 times the supply head H_s.

The inlet to the drive pipe must always be submerged to prevent air from entering the pipe; air bubbles in the drive pipe will dramatically affect the operation of the ram or even lead to complete failure. For this reason the drive pipe should be laid as straight as possible throughout its entire length without any elevated sections which could trap air. A dip to allow the drive pipe to follow the contour of the ground is permissible.

The delivery pipe may be made of any material (e.g. P.V.C. - polyvinyl chloride or HDP - high density polyethylene) provided it can withstand the delivery pressure.

If the delivery head exceeds the pipe's pressure specification, than the lower portion of the delivery pipe must be galvanized iron pipe. In fact it may be advisable always to use an initial length of galvanized iron pipe to ensure a sturdy connection to the ram.

To facilitate operation and maintenance of the hydraulic ram the drive pipe and the delivery pipe should each be connected to the ram with union joints and stop-valves. The stop-valve in the drive pipe should be incorporated in such a manner as to prevent the formation of air pockets; a rotary type of valve (globe valve) is preferable to an ordinary gate valve since the latter may not be strong enough against the severe loads of the waterhammer pressures.

The maintenance required for a hydraulic ram is, compared to most other pumping systems, very little and infrequent. It includes:
- replacement of the valve rubbers when they are worked out
- adjustment of the tuning of the waste valve
- tightening bolts which have worked loose.

Occasionally the hydraulic ram may need dismantling for cleaning. It is essential that as little debris as possible enters the drive pipe. It is therefore necessary to provide a grate at the intake of the supply source as well as a strainer at the inlet side of the drive pipe to hold up floating leaves and debris. The grate and strainer must be checked every now and then and cleaned if necessary to ensure that the water supply is flowing at the maximum rate.

It must be stated that the foregoing remarks on the practical use of the hydraulic ram only highlights some of the main features of the installation. Every situation may vary in detail; specific design and techniques suited to the particular site may be necessary to create the most appropriate hydraulic ram installation.
More detailed information on how to construct, operate and maintain the ram installation is depending on the type of ram and can be found in the appropriate product information. Some manufacturers (e.g. Blake, Jandu, Schlumpf and Vulcan) do supply comprehensive information.

8. Prices and costs

Prices of hydraulic rams vary from US $ 1000 to US $ 3500. During the research in Rwanda it became clear that this price is a small part of the total costs of a complete water supply system. A rough breakdown of these costs looks as follows

pipes and accessories	45 %
construction works	30 %
transportation (including transport from Europe to Africa)	15 %
hydraulic rams	10 %

Allthough rams do not have fuel costs, expenses for spare parts and maintenance are most common. There has to be someone available for regular check-ups and reparations (weekly to monthly). This person should be trained first.
The percentual breakdown of the total costs leads to the conclusion that the price of the ram itself is of less importance. A cheap ram with a low output and a bad performance could throw the whole expensive system idle.

The risk of drop out of the total system is also rather high when other parts of the system, e.g. the drive pipe, were not installed very solidly.

Another lesson which could be learned from the total costs overview is the knowledge on the availability of all materials is essential in order to make a realistic estimation of the total costs.

A.1. Operation of hydraulic rams

The ram operates on a flow of water falling under a head (abbreviated Hs) from the supply reservoir down through the drive pipe into the pump chamber. The water escapes through the opened waste valve into the surrounding area. With the acceleration of the water the hydrodynamic drag and pressure on the waste valve will increase. When the flow of water through the waste valve attains sufficient velocity, the upward force on the valve will exceed its weight and the valve will slam shut. (In a good ram design the valve closure is rapid, almost instantaneous.)

fig. 2a

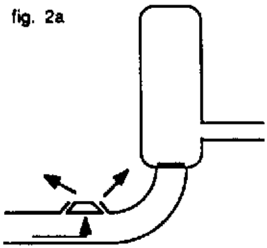
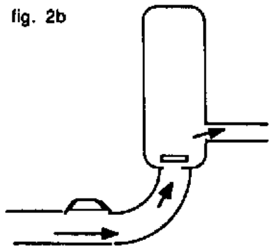


fig. 2b



Thus the flow through the waste valve is abruptly stopped, but since the column of water in the drive pipe still has a considerable velocity a high pressure develops in the ram, locally retarding the flow of water.

If the pressure rise is large enough to overcome the pressure in the air chamber the delivery valve will be forced open, which in turn limits the pressure rise in the ram body to slightly above the delivery pressure. The front of this pressure rise expands upstream, partly reducing the flow velocity in successive cross-sections of the drive pipe as it passes. In the meantime the remainder of the flow passes through the opened delivery valve into the air chamber. The 'air cushion' permits water to be stored temporarily in the air chamber with only a comparatively low rise in local pressure, thus preventing the occurrence of waterhammer (shock waves) in the delivery pipe.

With the propagation of successive pressure surges up and down the drive pipe water continues to flow into the air chamber with step-wise decreasing velocity until the momentum of the water column in the drive pipe is exhausted.

The higher pressure which now exists in the air chamber will initiate a reversal flow in the direction of the supply reservoir. This causes the delivery valve to close, preventing the pumped water from flowing back into the ram body. The 'recoil' of water in the drive pipe produces a slight suction in the ram body, thus creating an underpressure near the waste valve. The underpressure makes it possible for the waste valve to reopen, water begins to flow out again, and a new operating cycle is started.

fig. 2c

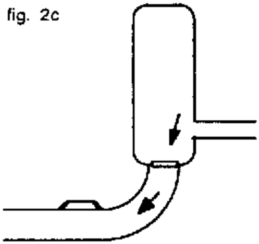
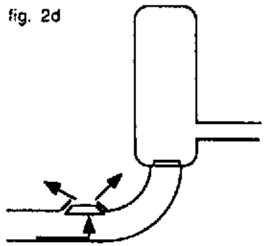


fig. 2d



Meanwhile the water forced into the air chamber, is driven into the delivery pipe to the storage tank at the high level, from which it can be distributed by gravitation as required.
An air valve or snifter valve is mounted into the ram body to allow a small amount of air to be sucked in during the suction part of the ram cycle. This air is carried along with the next surge of water into the air chamber. The air in this chamber is always compressed and needs to be constantly replaced as it becomes mixed with the water and lost to the storage tank. Without a suitable air valve the air chamber would soon be full of water and the hydraulic ram would then cease to function.
Depending on supply head, waste valve adjustment and, to a lesser degree, on drive pipe length and delivery head the cycle is repeated with a frequency of about 30 to 150 times a minute.
Once the adjustment of the waste valve has been set (valve stroke and - if present - tension of the return spring), the hydraulic ram needs almost no attention provided the water flow from the supply source is continuous, at an adequate rate and no foreign matters get into the pump blocking the valves.

A.2. Characteristics

For users of the ram the pumping rate q (output capacity) is the first consideration, since this should meet their demand.
Given an available source supply the pumping rate q of a hydraulic ram is determined by the supply head Hs and the delivery head hd.
An increase of supply head Hs increases the pumping frequency (more beats per minute) and thereby increases the pumping rate q.
Commercially-made hydraulic rams are available in various sizes, covering a wide range of source supplies. The size of the ram (traditionally given in inches) usually denotes the nominal diameter of the drive pipe. The larger the size of the ram the more water is required to operate the ram and the more water can be delivered to a higher level.

Efficiency requires some special attention since different expressions are obtained in product information as well as in literature.
Some give the Rankine equation considering the installation as a whole and taking the head water level as datum. The useful work done in unit time, i.e the net amount of potential energy of the water delivered, is given by $\rho gq(hd - Hs)$. The net amount of energy used by the ram, i.e. the change in potential energy of the driving water is given by $\rho gQHs$.

$$\eta_{rnk} = \frac{\Delta E_{pot} \text{ water delivered}}{\Delta E_{pot} \text{ driving water}} = \frac{q * (h_d - H_s)}{Q * H_s}$$

In product information of hydraulic ram manufacturers, as well as in some other publications, efficiency is often simply defined as

$$\eta_{trd} = \frac{q * h_d}{Q * H_s}$$

The Rankine figure is always the lowest, while the 'trade expression' yields somewhat higher values; especially at low delivery heads the difference is significant.

The efficiency curve is most important when the supply source is limited and waste water must be kept at a minimum. In situations where there is an abundance of supply water the efficiency is a secondary matter. However, efficiency figures give a good indication of the hydraulic performance of the ram. High efficiency machines are hydraulically well- designed, i.e. have fair and smooth waterways and consequently low energy losses.

It should be standard commercial practice that manufacturers of hydraulic rams provide comprehensive and reliable information on the performance characteristics of their rams. Unfortunately this is not always the case.

For example, some ram manufacturers state that the 'output' of their rams can be calculated using the simple formula

$$q = \frac{Q * H_s}{h_d} * 0.6$$

The formula is based merely on the rule of thumb which means that the efficiency of a hydraulic ram is around 60 %. Apart from the fact whether the specific ram is capable of attaining this efficiency, it is unlikely that the use of the formula is correct for all arrangements of supply and delivery heads, since it has been found from experiments that efficiency eventually diminishes as head ratio hd/Hs increases.

A more realistic approach is followed by manufacturers recommending the formula

$$q = \frac{Q * H_s}{h_d} * \eta$$

where numerical values of η are given in relation to head ratio hd/Hs.

Only a few manufacturers provide empirically obtained operating tables.

B. Results of the comparative laboratory and field tests

In the Laboratory at Delft 12 types of hydraulic rams of 6 manufacturers were tested. An important result of this investigation was a sound theoretical description of what is happening inside the ram (litt. #1). This was the basis of this guide and will be a valuable point of departure for further research.

The results are given in the table on the next two pages. Specific remarks and assessments (field tests) are given at the end of this appendix. Figures for efficiency and pumping capacity, are placed next to the price per type.

In the field tests in Rwanda it became clear that hydraulic rams are sensitive to damage and obstruction, and depend strongly on the functioning of the rest of the system (drive and delivery pipe). Maintenance and repair played an important role.

It has to be kept in mind that the rather negative picture has been caused by the field testing procedure. While testing, the output should be watched continuously. In Rwanda however, weekly to monthly checks were carried out and there was not enough time to solve occurring problems immediately. A delay of some weeks in maintenance or repair of a ram is not a characteristic of that particular ram.
Another disadvantage of the procedure followed during the field tests as well as in the laboratory is the use of just one prototype of every model. Yet it is possible that just a good or worse prototype is used.
There seems to be no direct relation between price and efficiency as can be seen in the table on the following pages. Keeping in mind the earlier statements on the total costs of a water supply system and the importance of efficiency, hydraulic rams with an efficiency less then about 55 % are disproportionately expensive.

The schedule on the testing program prevented the investigation of the newly designed rams Mbaraga I and II. These rams were designed after the unsatisfactory experiences (maintenance) in the field test after finishing the laboratory tests.

The locally designed and constructed hydraulic rams (Mbaraga I and II, as well as the ITDG-ram) are, compared to the commercially available rams, still in a too experimental stage to judge their value. Justification for the use of this types could be caused by the specific local situation (availability of other rams and materials, transport problems, construction capacity etc.).

Hydraulic ram	Supply Head Hs	Waste Flow Q (a)	Period Time T (a)	Delivery Head hd [m]	
	[m]	[l/min]	[s]	from	to
Blake Hydram No. 2 (1,5")	1.35	40	1.600	12	112
	2.00	39	1.000	11	130
	3.00	38	0.700	11	140
Blake Hydram No. 3,5 (2,5")	1.35	110	1.600	8	112
	2.00	100	1.000	8	120
	3.00	95	0.700	12	133
Alto J 26-80-8 (1")	1.00	14	1.300	6	19
	2.00	14	0.700	9	33
	3.00	15	0.550	12	42
Alto CH 50-110-18 (2")	1.00	33	1.000	6	40
	2.00	36	0.600	7	60
	3.00	39	0.450	10	66
Vulcan 1" (1")	1.00	15	1.550	4	75
	2.00	17	0.950	8	117
	3.00	16	0.650	13	134
Vulcan 2" (2")	1.00	35	1.150	6	68
	2.00	33	0.600	12	80
	3.00	34	0.450	18	88
SANO No.1-25 mm (1")	1.00	10	1.100	4	67
	2.00	10	0.550	9	81
	3.00	10	0.400	11	93
SANO No.4-50 mm (2")	1.00	60	1.900	4	102
	2.00	55	0.900	8	120
	3.00	60	0.650	12	138
Davey No. 3 (1")	1.00	13	1.900	2	28
	2.00	13	1.000	4	44
	3.00	12	0.750	6	54
Rife 20 HDU (2")	1.25	85	2.500	4	112
	2.00	80	1.300	4	133
	3.00	80	0.900	6	154
Schlumpf 4A5 (1,5")	1.00	25	1.500	4	32
	2.00	32	1.400	6	29
	3.00	30	1.000	9	27
Schlumpf 4A23 (1,5")	1.00	25	1.900	4	40
	2.00	45	1.600	8	78
	3.00	36	1.100	9	73

(a) approx. average value for the whole range of operation

Hydraulic ram	Pumping Rate q [l/min]		Efficiency	Price	Maintenance Durability Reliability
	from	to	% (b)	(c)	(d)
Blake Hydram No. 2	2.00	0	44/42/37		
(1,5")	4.75	0	62/64/60	£ 250	
	7.70	0	67/70/67		
Blake Hydram No. 3,5	9.95	0	51/51/45		-
(2,5")	17.15	0	65/64/57	£ 450	-
	20.30	0	70/73/68		+
Alto J 26-80-8	1.10	0	- / - / -		
(1")	1.75	0	45/ 8/ -	Frs 3550	
	2.20	0	38/ - / -		
Alto CH 50-110-18	1.25	0	37/ - / -		-
(2")	3.05	0	40/36/ 1	Frs 6950	+
	4.45	0	38/41/22		++
Vulcan 1"	1.00	0	36/34/18		
(1")	1.00	0	48/52/51	£ 165	
	2.25	0	52/58/57		
Vulcan 2"	4.25	0	70/63/31		
(2")	5.05	0	75/68/54	£ 365	
	5.40	0	76/71/56		
SANO No.1-25 mm	1.05	0	45/35/11		
(1")	1.50	0	60/59/44	DM 700	
	2.05	0	61/64/54		
SANO No.4-50 mm	4.70	0	38/32/27		-
(2")	8.40	0	63/63/62	DM 1350	-
	10.25	0	65/68/66		-
Davey No. 3	2.67	0	26/ - / -		
(1")	3.77	0	51/16/ -	£ 250	
	4.80	0	59/47/ -		
Rife 20 HDU	3.90	0	26/28/27		-
(2")	8.90	0	42/54/45	$ 800	- -
	12.90	0	45/47/48		-
Schlumpf 4A5	3.85	0	- / - / -		
(1,5")	9.30	0	22/ - / -	SFr 2000	
	10.30	0	38/ - / -		
Schlumpf 4A23	3.70	0	37/ 2/ -		-
(1,5")	7.65	0	44/33/ 8	SFr 3000	-
	11.70	0	53/35/16		-

(b) for resp. h = 20 m, 40 m and 60 m

(c) global prices 1980/1981

(d) according to field tests

Remarks and assessments per ram (field tests)

Blake 3 1/2"
During the 11/2- year testing-period of this ram it has been standing still during most of the time due to external influences (drive and delivery pipes and a flexible joint). The joint between drive pipe and ram body seemed to cause heavy trouble for local maintenance.

SANO 4
With the Sano-ram also external influences played an important role. The delivery valve caused trouble time and again.

Schlumpf No. 4A23
Again external factors were of great influence. After a few days the delivery valve had to be modified fundamentally.

Vulcan 21/2"
After some starting problems this ram worked reasonably although a lot of time was lost due to external factors. Repairing was necessary twice; a new gasket and two rubber delivery valve clacks.

Vulcan 2"
Misjudgement during the installation (wrong interpretation of the pump behaviour due to a leaking drive pipe) of this Vulcan caused its premature removal. So classification is not possible.

Rife # 20 HDU
The Rife could not function under the given conditions, although according to the description of the manufacturer, it should have been possible.

Alto CH No. 50-110-18
With the Alto the installation problems already appearing by the Vulcan 2", showed up again. After repairing the drive pipe and slowing down the waste valve by some modifications, there were no internal break-downs, but the drive pipe broke again, combined with a period with lack of water. After a working period of 16 months the Alto ram was extremily worn down, also as a result of agressive-water.

Mbaraga I & II
Mbaraga I & II are designed locally and constructed hydraulic rams. This was done because of the poor results of the commercially available rams. These rams were not tested in Delft but nevertheless a, not surprising, result can be given: reliability and durability were very poor and access of local maintenance was good

C. Calculation example

Given: a community of 60 persons and some cattle (30)

Water Demand = Population * Capita Consumption

The capita consumption depends on geographic, social and cultural aspects, but most af all on the availability of water. The domestic consumption could be 2 - 5 liters daily, with a population living 15 km from a water source. Having a watertap, shower and adjusted toilet, it could be 60 - 80 litres per day per person.

For this exaple is calculated with 50 litres daily and 20 litres for the local cattle per animal. So,

Water Demand = 60 * 50 + 30 * 20 = 3600 l/day

The pumping rate (continuously pumping) will be

$$\text{Pumping Rate} = \frac{3600}{1440} = 2.5 \text{ l/min}$$

The next figure needed is the delivery head. Herefore is given:

- f = 0.04 (estimation, depending on the pipes available)
- Ld = 1000 m (to be measured in the field)
- d = 0.02 m (a suitable diameter for this pumping rate ? Has to be checked.)
- ξd = 10 (estimation for a long and difficult track)
- v = 0.3 ms^{-1} (estimation, has to be checked)
- g = 9.8 ms^{-2}

Vertcial lift = 40 m (to be measured in the field)

$$h_d = 40 + \left[\frac{0.04 * 1000}{0.02} + 10 \right] \frac{0.3^2}{2 * 9.8} = 49 \text{ m}$$

As shown in the table on page 13 and 14 such a supply could be created with e.g. a Blake Hydram no. 2 or some others, using a supply head of 3.00 m at least and a supply flow around 60 l/min. With a given efficiency of 70 % this will result in

$$q = \frac{60 * 3.00}{49} * 0.70 = 2.57 \text{ l/min}$$

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International Reference Centre, P.O. Box 93190, 2509 AD, The Hague, The Netherlands

#10 A handbook of gravity-flow water systems, 186 pp. + appendixes, 1980
Intermediate Technology Development Group

11. Adresses of hydraulic ram manufacturers

Alta Cabeza "Gaviotas"	Centro Las Gaviotas, Paseo Bolivar no. 20 - 90, Bogota, Columbia
Auto-Lift Pump	Godbole & Sons, New Ramdaspeth, Kachipura, Nagpur - 1, India
Bélier ALTO	J.M. Desclaud, 57, Rue Bertrand-de-Goth, 33800 Bordeaux, France
Billabong	John Danks & Son. Pty Ltd, Doody Street, Alexandria, Sydney, New South Wales, Australia
Blake Hydram	John Blake Ltd, P.O. Box 43, Accrington, Lancashire BB5 5LP, UK
Bomba Hydraulicas Rochfer	Industrias Mecanicas Rochfer Ltda. Avenida Jose de Silva 3765, Jardin Moria Rosa, Caixa Postal 194, Sao Paulo, CEP 14400, Brazil
Briau Hydram	Briau S.A., B.P. 43, 37009 Tours, France
BZH Hydrauliska	Ab Bruzaholms Bruk, 570 34 Bruzaholm, Sweden
CeCoCo Hydro-Hi-Lift Pump	CeCoCo, P.O. Box 8, Ibaraka City, Osaka 567, Japan
Chandra Hydram	Singh Metal Casting Works, 110-D Nirala Nagar, Lucknow, India
Fleming Pump	C.W. Pipe Inc., P.O. Box 678, Amherst, Virginia 24521, USA
Jandu's Hydram	Jandu Plumbers Ltd, P.O. Box 409, Uhuru Road, Arusha, Tanzania
Pompe Pilter	Pilter, 22, Rue Florian, 75020 Paris, France
Premier Hydram	Premier Irrigation Equipment Ltd, 17/1C Alipore Road, Calcutta 700.027, India
Rife Ram Pump	Rife Hydraulic Engine Manufacturing Co., 316 W. Poplar Street, P.O. Box 790, Norristown, PA 19401, USA
SANO Ram Pump	Pfister & Langhanss, Sandstraße 2-8, Postfach 3555, 8500 Nürnberg 1, Federal Republic of Germany

HYDRAULIC RAM PUMPS

A guide to ram pump water supply systems

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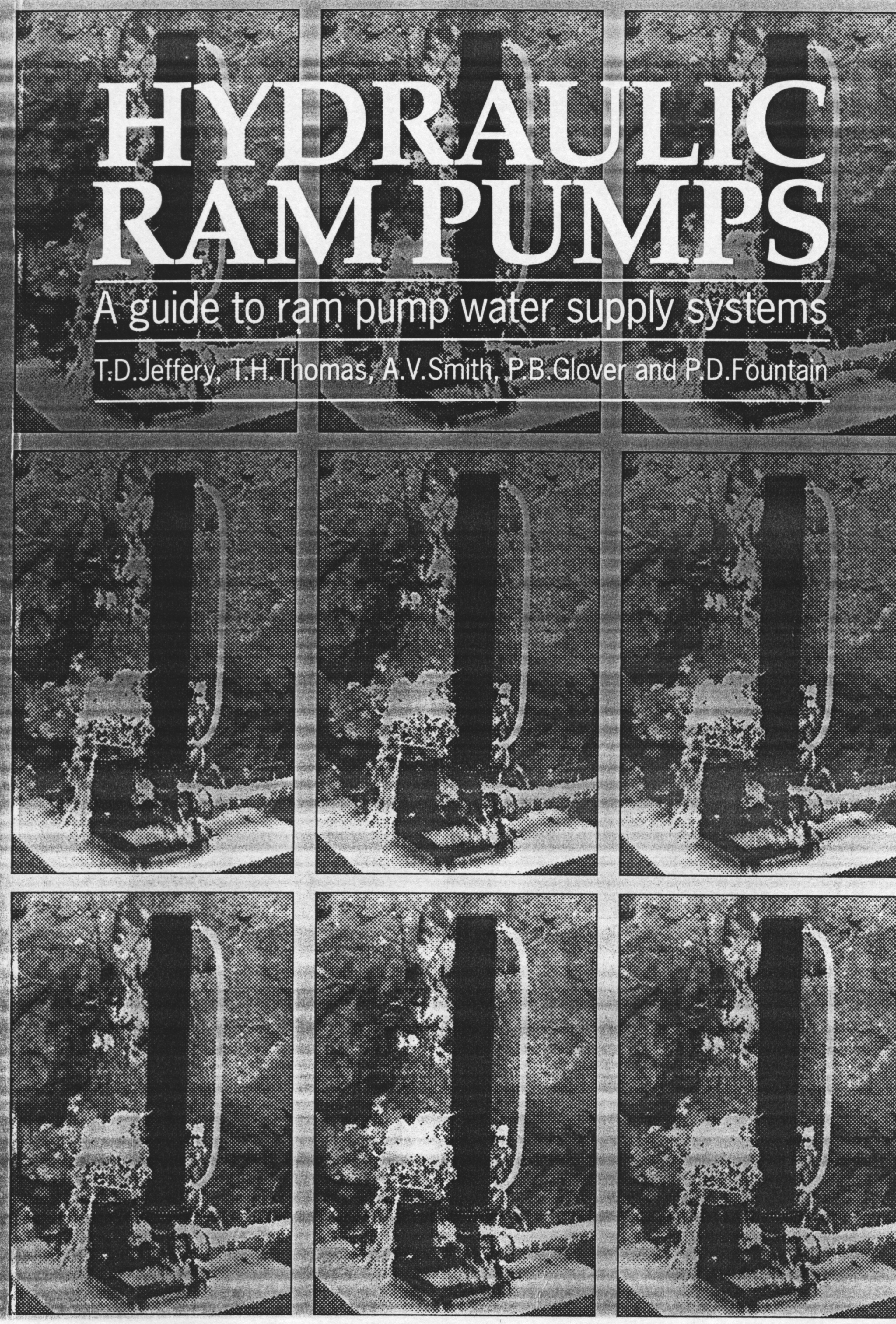

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P. B. GLOVER and P. D. FOUNTAIN

The Development Technology Unit
University of Warwick

About this book

In recent years there has been a revival of interest in the hydraulic ram pump, a renewable energy water-lifting device. This book aims to introduce the reader to all aspects of the use of ram pumps. It should be particularly useful to technicians and engineers involved in rural water supply, whether they are assessing the suitability of ram pumps, installing a system or contemplating local manufacture. It gives practical guidelines for the installation and operation of water supply systems based on such pumps, as well as describing the operation of the pump and the factors affecting its performance.

The reader is taken through the steps involved in designing and installing a complete system, steps applicable to any model of ram pump available. Details of one pump, designed for local manufacture in developing countries, are given along with some notes on ram pump design for those wishing to develop their own models.

A large number of illustrations are used alongside simple text in order to make the information useful to a wide range of non-specialist readers. Readers are welcome to photocopy the diagrams and add labels in other languages for training purposes.

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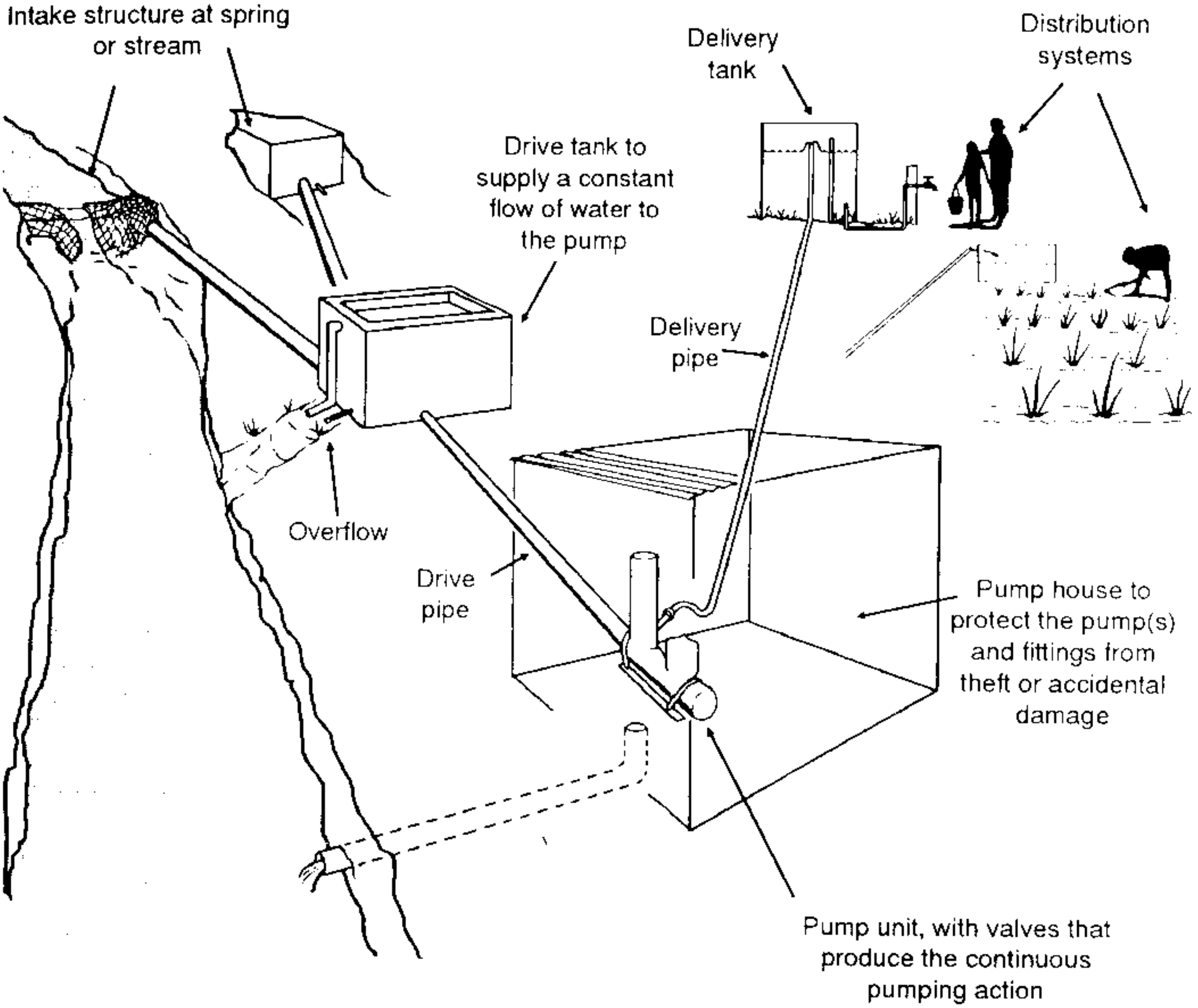
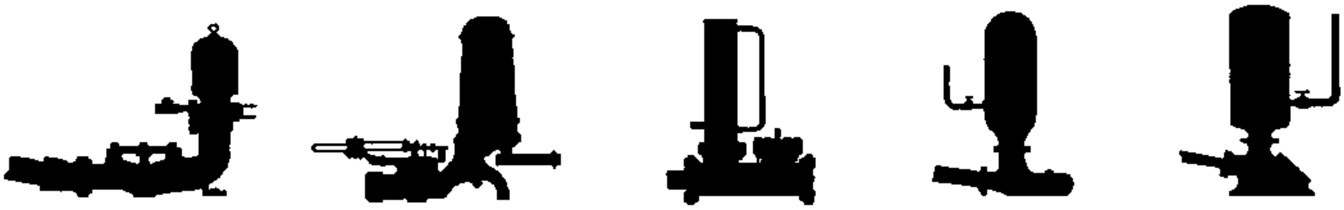
CHAPTER 1: Introduction to the ram pump

Ram pumps are water pumping devices that are powered by falling water. The pump works by using the energy of a large amount of water falling a small height to lift a small amount of that water to a much greater height. In this way, water from a spring or stream in a valley can be pumped to a village or irrigation scheme on the hillside. Wherever a fall of water can be obtained, the ram pump can be used as a comparatively cheap, simple and reliable means of raising water to considerable heights.

Components of a ram pump system

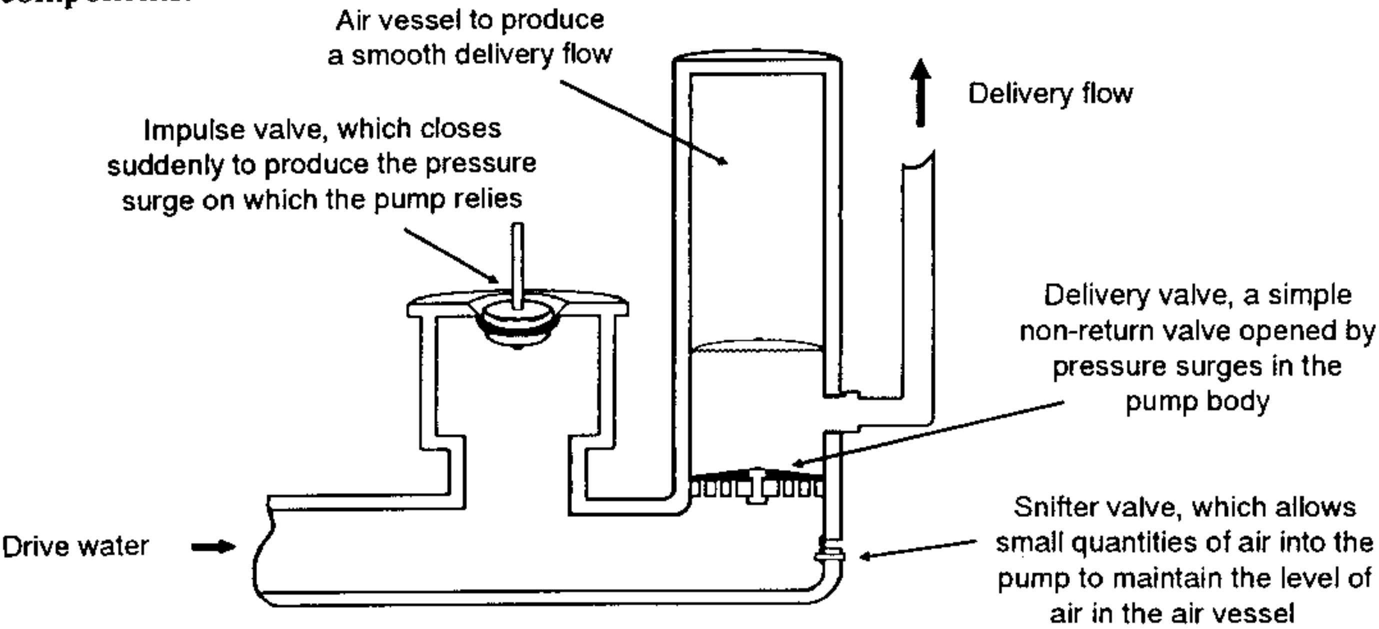
The diagram below shows all the main components of a ram pump system and briefly introduces their various functions.





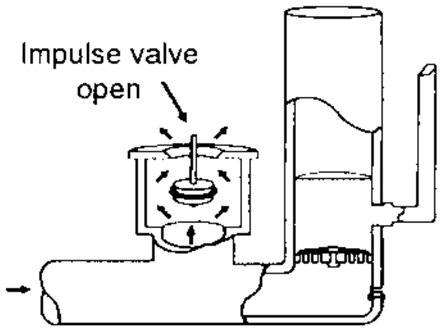
The ram pump

Although ram pumps come in a variety of shapes and sizes they all have the same basic components:

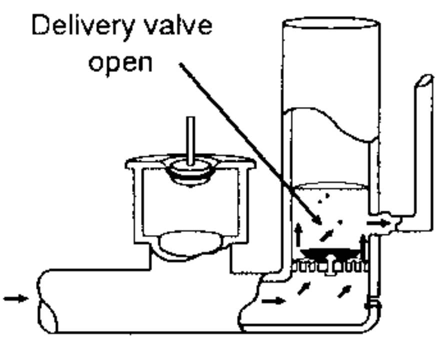


Ram pumps have a cyclic pumping action that produces their characteristic beat during operation. The cycle can be divided into three phases: acceleration, delivery and recoil.

Acceleration When the impulse valve is open, water accelerates down the drive pipe and discharges through the open valve. The friction of the water flowing past the moving parts of the valve causes a force on the valve acting to close it. As the flow increases it reaches a speed where the drag force is sufficient to start closing the valve. Once it has begun to move, the valve closes very quickly.

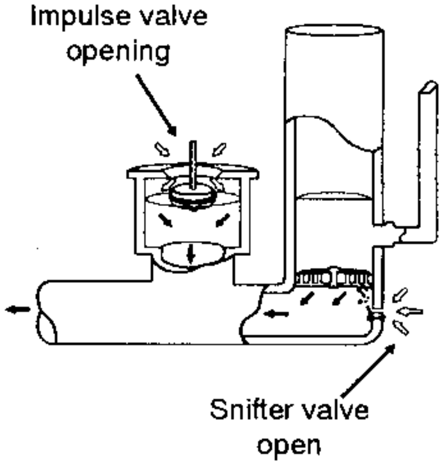


Delivery As the impulse valve slams shut, it stops the flow of water through it. The water that has been flowing in the drive pipe has considerable momentum which has to be dissipated. For a fraction of a second, the water in the body of pump is compressed causing a large surge in pressure. This type of pressure rise is known as water hammer.



As the pressure rises higher than that in the air vessel, it forces water through the delivery valve (a non-return valve). The delivery valve stays open until the water in the drive pipe has almost completely slowed down and the pressure in the pump body drops below the delivery pressure. The delivery valve then closes, stopping any backflow from the air vessel into the pump and drive pipe.

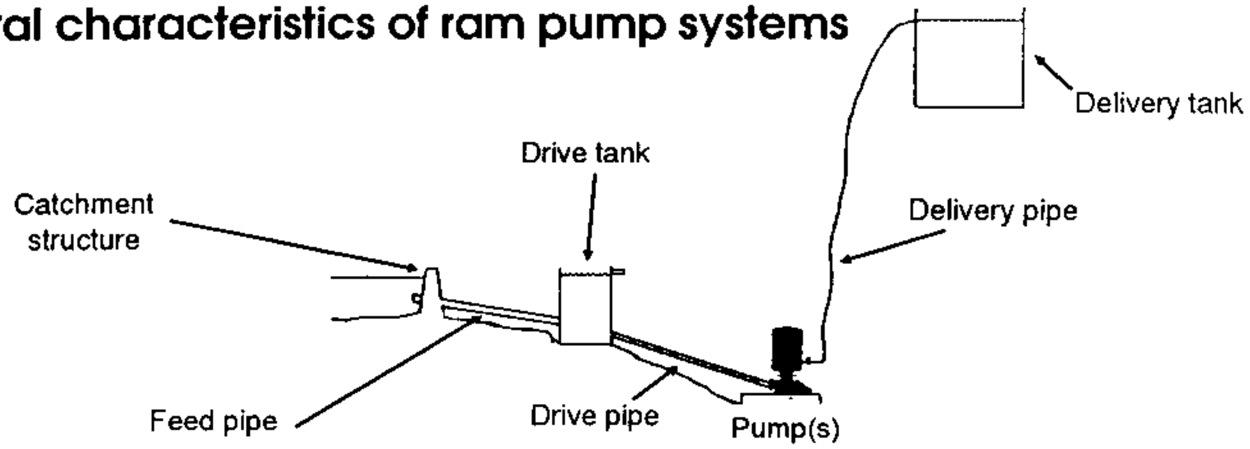
Recoil The remaining flow in the drive pipe recoils against the closed delivery valve — rather like a ball bouncing back. This causes the pressure in the body of the pump to drop low enough for the impulse valve to reopen. The recoil also sucks a small amount of air in through the snifter valve. The air sits under the delivery valve until the next cycle when it is pumped with the delivery water into the air vessel. This ensures that the air vessel stays full of air. When the recoil energy is finished, water begins to accelerate down the drive pipe and out through the open impulse valve, starting the cycle again.



Throughout the cycle the pressure in the air vessel steadily forces water up the delivery pipe. The air vessel smooths the pulsing inflow through the delivery valve into an even outflow up the delivery pipe. The pumping cycle happens very quickly, typically 40 to 120 times per minute. During each pumping cycle only a very small amount of water is pumped. However, with cycle after cycle continuing over 24 hours, a significant amount of water can be lifted.

While the ram pump is operating, the water flowing out of the impulse valve splashes onto the floor of the pump house and is considered 'waste' water. It is this water spraying out, and the repeated donk-donk-donk sound of the impulse valve closing, which observers notice when watching a ram pump in action. The term 'waste' water needs to be understood. Although 'waste' water is not delivered by the ram pump, it is the energy of this water that pumps the water which is delivered. It is not so much 'waste' water as 'used' water.

General characteristics of ram pump systems

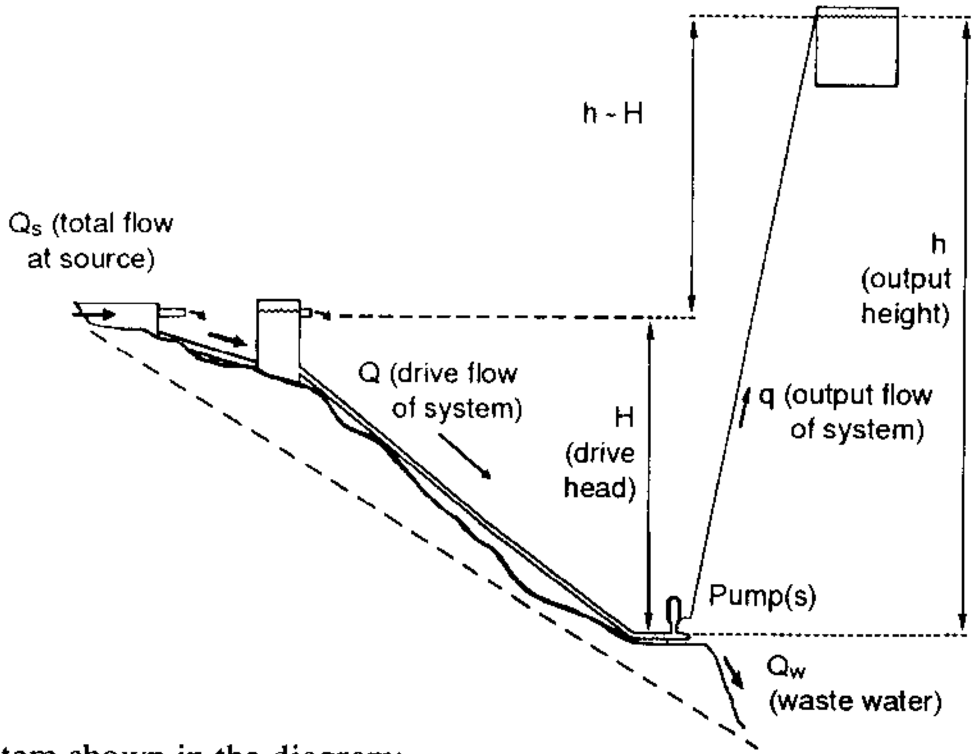


Ram pumps can only be used in situations where falling water is available, which restricts them to use in three main applications:

- lifting drinking water from springs in valleys to settlements on higher ground;
- pumping drinking water from clean streams that have a significant slope;
- lifting irrigation water from streams or raised irrigation channels.

Efficiency and power

The power required to raise water is proportional to the water's flow rate multiplied by the height through which it is lifted (in a ram pump q x h). Similarly, the power available from falling water is proportional to its flow rate multiplied by the distance dropped (Q x H). A ram pump works by transferring the power of a falling drive flow to a rising delivery flow.



For the system shown in the diagram:

Input power is proportional to drive flow (Q) x drive head (H)

Output power is proportional to delivery flow (q) x delivery head (h).

In an ideal system there would be a perfect transfer so that:

$$\text{output power} = \text{input power}$$

$$qh = QH$$

Unfortunately no real system is ideal and some of the input power gets wasted in friction instead of being transferred to the output. The fraction of input power that is used properly, rather than wasted, is called the 'efficiency' ; in textbooks it is often represented by the Greek letter eta (η).

$$\text{Efficiency } (\eta) = \frac{\text{output power}}{\text{input power}} = \frac{qh}{QH}$$

Efficiency is always less than 1. It is useful to know the efficiency because we can use it to predict the delivery flow of a system and to compare two different pumps. Rearranging the equation above gives the formula:

$$\text{Delivery flow } (q) = \frac{QH\eta}{h}$$

To obtain a good delivery flow, the efficiency of the pump should be high, there should be a large drive flow, and the delivery head should not be too many times the drive head. If the delivery head is twenty times the drive head, for instance, even working at 100% efficiency the pump could only deliver one twentieth of the drive flow to the users. *A ram pump system can only lift a fraction of the flow that drives it.* This ratio of delivery head to drive head (h/H) is typically in the range 5 to 25.

The value of system efficiency to put into the formula depends upon many factors including the design of the pump and the system being used. For a well designed system it is normally between 0.5 and 0.8 (50%-80%). For a system with a badly tuned pump, very long drive pipe and a very high ratio of delivery to drive head, the efficiency can drop below 40%. Pump manufacturers often give a guide to the efficiency of systems that use their machines under normal conditions. If the efficiency is not known, it is best to assume a value of 50%-60% in order to calculate the expected delivery flow.

Example

For a particular site the following details were measured:

Q = 100 litres/minute
H = 8 metres
h = 60 metres

Under these conditions the characteristics for a particular pump might predict a system efficiency of 60%, therefore $\eta = 0.60$.

Putting this information into the equation means we can predict what the system should be able to deliver:

$$q = \frac{0.60 \times 100 \text{ litres/minute} \times 8 \text{ metres}}{60 \text{ metres}} = 8 \text{ litres/minute}$$

NOTE: If it is necessary to know the hydraulic power (P) of a ram pump system (measured in Watts), it can be calculated using the formula:

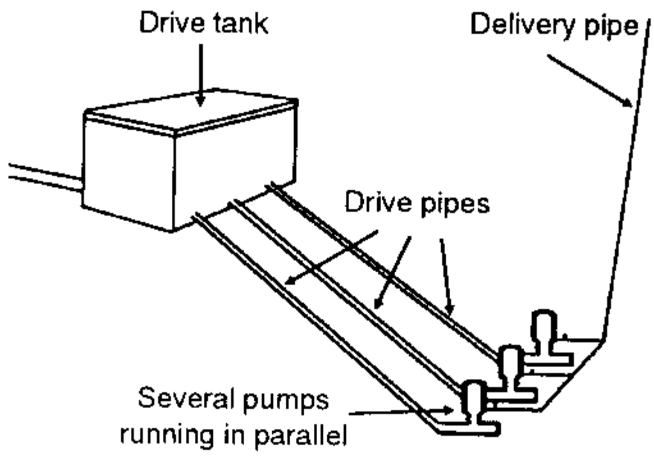
$$P = 9.81 \times \frac{q}{60} \times h$$

Where P is power in Watts
q is the delivery flow in litres/minute
h is the delivery head in metres
9.81 is a constant that accounts for acceleration due to gravity and the density of water.

Pump size

Ram pumps are manufactured in a range of sizes where size normally refers to the diameter of the drive pipe to be used, and sometimes to a dimension of the pump's body. The same pump may be used over a range of drive flows and drive and delivery heads. Ram pumps are not easily classified by their power output as this is dependent on each particular installation. In general ram pumps are low power devices of 10 to 500 watts output. Large machines with drive pipe diameters of 200mm (8") or 300mm (12") on high head sites can deliver several kilowatts of power. Such installations are, however, rare and often require a specially built pump.

Since pumps bigger than 100mm (4") are not normally available, where large flows are required several small ram pumps are run in parallel. Using a number of 50mm (2") ram pumps together usually provides enough pumping power to supply a large village or an institution such as a hospital. Where the population to be served is large, as in a town, ram pumps are not normally suitable and other pump types are preferred. Similarly, for irrigation purposes ram pumps best match the needs of small schemes (up to 5 hectares).



Water quality

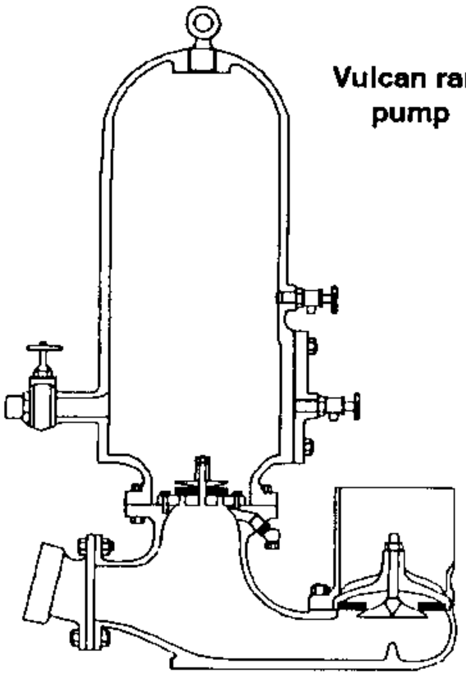
The water pumped by a ram pump is part of the drive water and therefore the water delivered will be of the same quality as the drive water. Special 'double action' ram pumps have been made which use one water source to provide the pumping power and a different source for their delivery. These pumps are much more complex and often less durable than normal ram pumps. In some situations water quality will influence the selection both of pumping technology and the water source to be used.

For irrigation applications, river water is normally of adequate quality unless the method of application (for example drip irrigation) requires very low levels of suspended sediment.

For drinking water, bacterial and other aspects of water quality are more important. It is usually preferable to use a distant source of clean water rather than a more local dirty one. Water treatment using chemicals adds cost and complexity to the system, and is often not practical in rural areas. Simple and effective filtration methods using slow sand filters can be appropriate but these require careful design and a regular maintenance procedure.

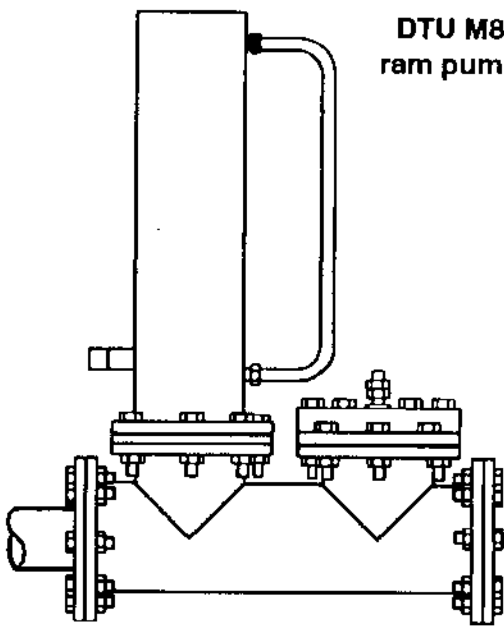
Springs emerging from a hillside can be protected ('capped') to prevent contamination. This makes spring-supplied ram pump systems an excellent option wherever the spring flow and location is adequate. Streams, by contrast, are more likely to be polluted, especially in densely populated areas. In situations where no source of clean water is available and treatment is impractical it is still advantageous to pump the dirty water. The advantages of reduced water collection time will still apply and there should be a decrease in the incidence of water-washed diseases due to more regular washing and general cleanliness.

Life and reliability



Vulcan ram pump

Imported ram pumps operated at fairly low throughput have proved extremely reliable in some developing countries. Some have run without stopping for ten years or more in systems supplied with clean water from a reservoir. This outstanding reliability has had a curious side effect — when such pumps finally stop the beneficiaries have no recall of their source, no knowledge of how to maintain them and no access to spare parts. Failures in ram pump systems often occur outside the pump itself — blockage of filter screens, damage to pipes, sedimentation of pipes and tanks etc. Poorly located drive pipes sometimes show perforation due to a process called cavitation.



DTU M8 ram pump

Pumps made in local workshops are less durable than some of the imported machines made of cast iron, but their lower price usually makes them better value than either imported ram pumps or other pumps of comparable throughput. They also have the advantage of being locally repairable with ready access to spare parts.

Ram pumps run unattended for long periods, so running faults can go unattended for days or weeks. This can lead to expensive failures. For example, blockage of the output for long periods can cause fatigue failure of components (unless a costly pressure relief valve is fitted). The historical high reliability of ram pumps may reflect in part the social circumstances of their traditional use on large farms or mission stations where regular checks are made. The routine supervision of village systems may be much poorer and great care should be taken to ensure adequate caretaking.

Tuning to suit site conditions

Any particular ram pump is normally capable of running under quite a wide range of conditions. Most manufacturers quote operating ranges of drive head (H), drive flow (Q) and delivery head (h) for each pump size and give some indication of expected pump efficiency and delivery flow (q). Most designs of ram pump incorporate a means of adjusting the impulse valve so that the pump can be tuned to suit the conditions at a particular site. In situations where the water source has a larger flow than that required, each pump can be tuned to use as much drive water as possible to ensure minimum capital costs. When there is a limited amount of drive water available, the impulse valve has to be tuned to make the most efficient use of that water to produce the best possible output. At many sites there is a seasonal variation in the drive flow available and this is accommodated by varying the pump tuning or varying the number of pumps in use.

Economic factors

One of the greatest benefits of ram pump systems is that they have extremely low running costs. There is no input of expensive petroleum fuels or electricity, making the systems very inexpensive to operate. The purchase cost of a pump, however, is usually only a fraction of the capital cost of a system: drive and delivery pipework are usually the most expensive parts. Ram pump systems can be subject to economies of scale. For example, where there is enough drive flow, having several pumps at one site gives a lower unit cost then if the same pumps were installed at separate sites. In situations of plentiful drive flow, buying one large pump may be cheaper than buying several smaller ones, although this option does have disadvantages: having a single large pump involves a loss of system flexibility across a range of flows and if the pump needs maintenance or fails, 100% of the delivery is lost. With several smaller pumps, a pump can fail or be stopped for maintenance without stopping the entire delivery flow.

Prices of ram pumps available today vary enormously. If a pump is imported the costs of shipping and customs duty may significantly increase the actual cost of the pump to its users. A ram pump of traditional design with a 2" drive pipe, manufactured in Europe or North America and imported to a developing country, might cost between US$1500 and US$4000. A pump manufactured locally in a developing country using available materials is likely to cost only 20% of this. Costs of complete systems vary widely depending upon the particular site conditions and the number of people to be served. It has been found that for community water supply schemes a cost per person served of between US$5 and US$20 is normal.

Social factors

The significance of social factors to any development project cannot be over-emphasised. This is particularly true of community water supplies, which involve every member of the community on a daily basis. A large amount of written material is available highlighting the importance of community involvement and detailing examples of participation in project initiation, design, management, and finance. It is strongly recommended that anyone exploring the possibility of initiating a community water supply should obtain some of the available literature and give great attention to the social aspects of the project. Good engineering is only one part of a sustainable, economic and equitable water supply system. Without complete community involvement, even a water supply system that is technically perfect is likely to encounter serious problems and may fail altogether.

Adequate community involvement is particularly important during the period of system appraisal and design, and is dependent on good communication. When sufficient time and care is invested in producing a widely acceptable design, ram pump technology can be very appropriate to rural areas and be capable of true village-level operation and maintenance.

CHAPTER 2: Ram pumps in water supply systems

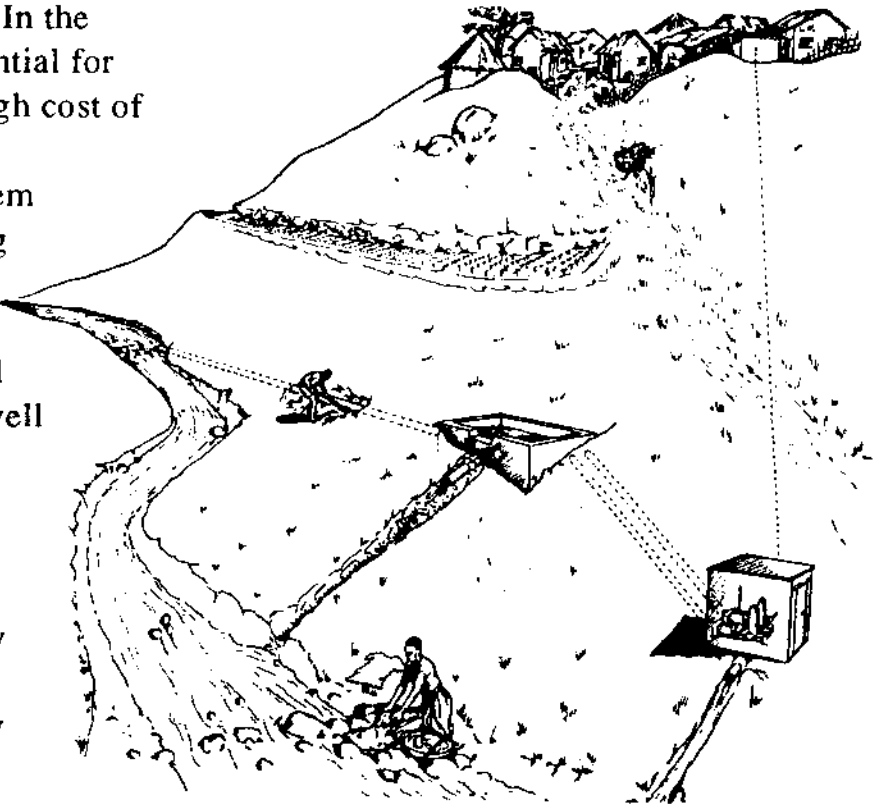
Renewed interest

Ram pumps have been used for over two centuries in many parts of the world. Their simplicity and reliability made them commercially successful, particularly in Europe, in the days before electrical power and the internal combustion engine became widely available. As technology advanced and became increasingly reliant on sources of power derived from fossil fuels, the ram pump was neglected. It was felt to have no relevance in an age of national electricity grids and large-scale water supplies. Big had become beautiful and small-scale ram pump technology was unfashionable.

In recent years an increased interest in renewable energy devices and an awareness of the technological needs of a particular market in developing countries have prompted a reappraisal of ram pumps. In hilly areas with springs and streams the potential for a simple and reliable pumping device is large. Although there are some examples of successful ram pump installations in developing countries, their use to date has merely scratched at the surface of their true potential.

The main reason for their neglect can be found in the design of traditional ram pumps and the lack of a reliable supply of spare parts. During operation, a ram pump is subjected to high stresses and many manufacturers over-designed their pumps to cope with these. To ensure long life and reliability, they used manufacturing methods and components which were stronger and more expensive than necessary and which limited manufacture to developed industrialised areas. In the developing world, where the potential for ram pump usage is highest, the high cost of such machines and the lack of technical advice on how to use them have stopped the technology being used on a wide scale.

The potential for ram pump usage and the problems associated with traditional designs are now well recognised. Many organisations around the world have begun to develop designs more suited to local conditions in rural areas of developing countries. New, locally manufacturable, designs are now becoming available and many of the more traditional manufacturers are updating their own designs.

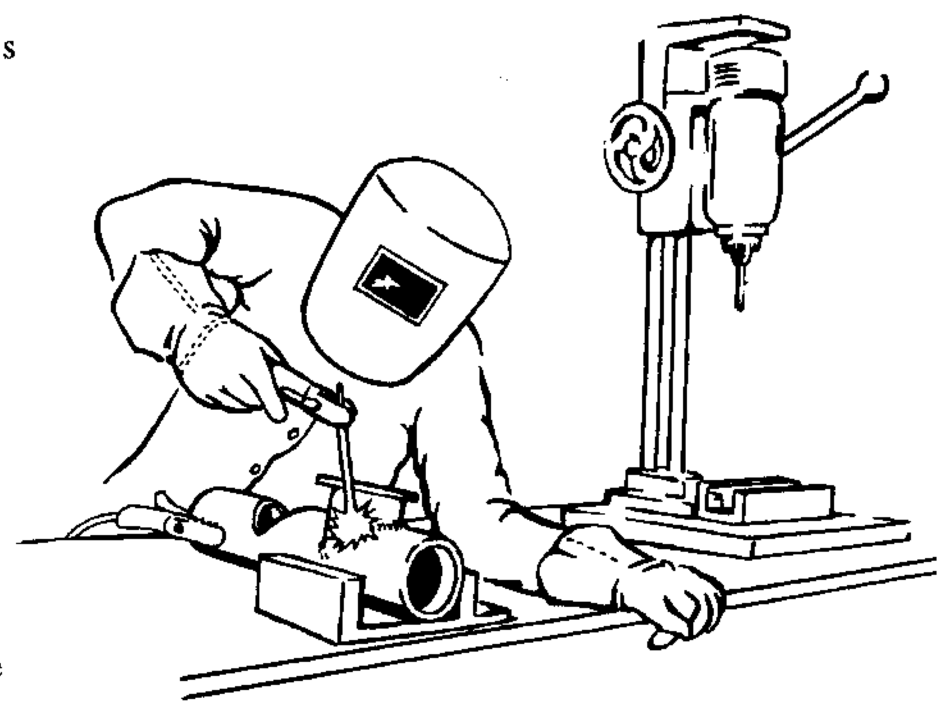


Local manufacture

Pumps manufactured in industrial countries usually perform well. Unfortunately their import into less developed countries has given rise to problems which have significantly restricted their use. They are expensive and require foreign exchange to purchase (often tied to the bureaucracy of import licensing). Spare parts, such as valve components, are often not quickly obtainable. The general agents who handle the sales have no specialised knowledge of ram pumps and cannot help customers to assess their need, design their system or carry out installation. In many developing countries the small volume of ram pump sales has resulted in their becoming uneconomical to stock in provincial towns; in others the small volume of sales has resulted in the retailer's mark-up becoming very high.

The experience of the authors suggests that widespread use of ram pumps will only occur if there is a local manufacturer able to deliver quickly, offer some assistance with system design/installation, and provide an after-sales service of advice and spare parts.

Local manufacture in developing countries requires designs appropriate to local materials and skills. The quality of such designs has considerably improved in recent years and some training in manufacturing them is becoming available. The designs presented in Appendix F have been developed over seven years of research and are believed to be the best (cheapest, best performing, most thoroughly tested) currently available for manufacture in small workshops.



In some situations local manufacture of ram pumps is not viable. Ram pumps can be purchased in many parts of the world, or they can be imported from a chosen manufacturer. Appendix A lists some manufacturers, with addresses and a brief comment about the types of pump produced. Where the potential for installation of many pumps exists, it is preferable to begin local manufacture with all the advantages of cost and spare part availability that this gives. Existing commercial workshops can be used to produce pumps as they are required, or, when the potential market is large, new workshops can be established specifically for pump manufacture.

Other technologies for water supply

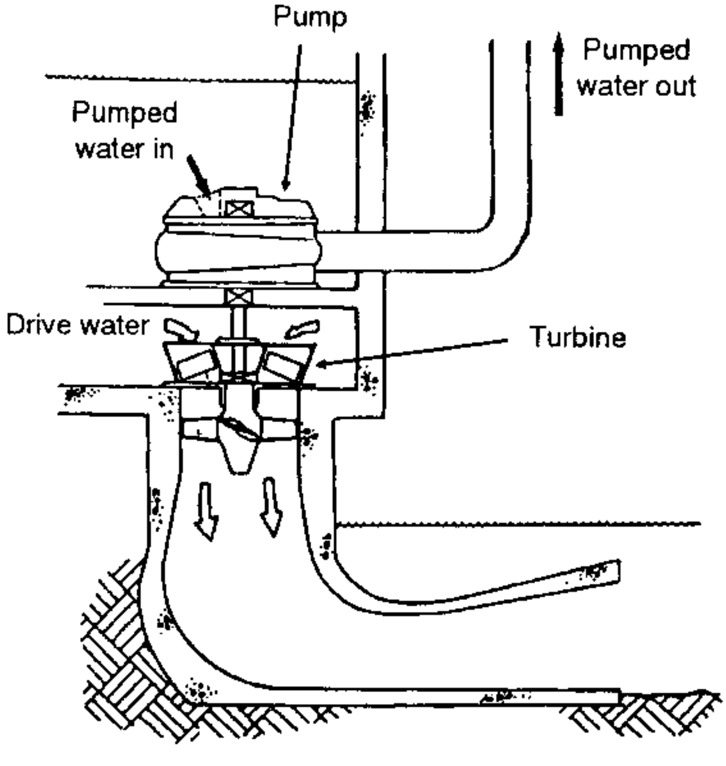
In more developed areas of the world, water-lifting is normally undertaken using motorised or electric pumps. Petrol and diesel-powered water pumps are available in most developing countries and are used to meet a wide range of water pumping requirements. However, their reliance on the supply of fossil fuels, which are expensive and require transportation, usually makes them uneconomic and unattractive for rural areas. Their high requirement for maintenance and spare parts further limits their use.

Electric pumping is convenient and quite cheap provided that mains power is available very close to the desired pump location. The cost of running extra supply cables even over short distances is high. If the pump is more than about 500m from the supply then an expensive weatherproof transformer with switchgear is also required. Electrical pumping is rarely affordable for village water supplies, even where mains electricity has reached the village itself. For irrigation, electric pumps can be economic for plots over about 5 hectares, again provided that the mains supply is close by. A further problem with electrical water pumping in rural areas is that the supply of electricity may be very unreliable, leaving a community without water for long periods.

In recent years many different methods for water-lifting have been developed to suit conditions in rural areas of developing countries. The choice of water-lifting technology is usually made on economic grounds, although other factors such as social control, long term sustainability and ease of maintenance are also important.

Water-powered pumping

Ram pumps offer the simplest and most common form of water-powered pumping device. The only other widely used device for such pumping is the turbine-pump set. This comprises a turbine, designed to capture energy from a large flow of water with a low head, directly connected to a pump delivering a little of the water to a much greater height. To avoid excessive gearing the turbine and pump are usually of very different types. Turbines are usually expensive, but for this constant load application it is often possible to use a much cheaper pump run backwards as a turbine.

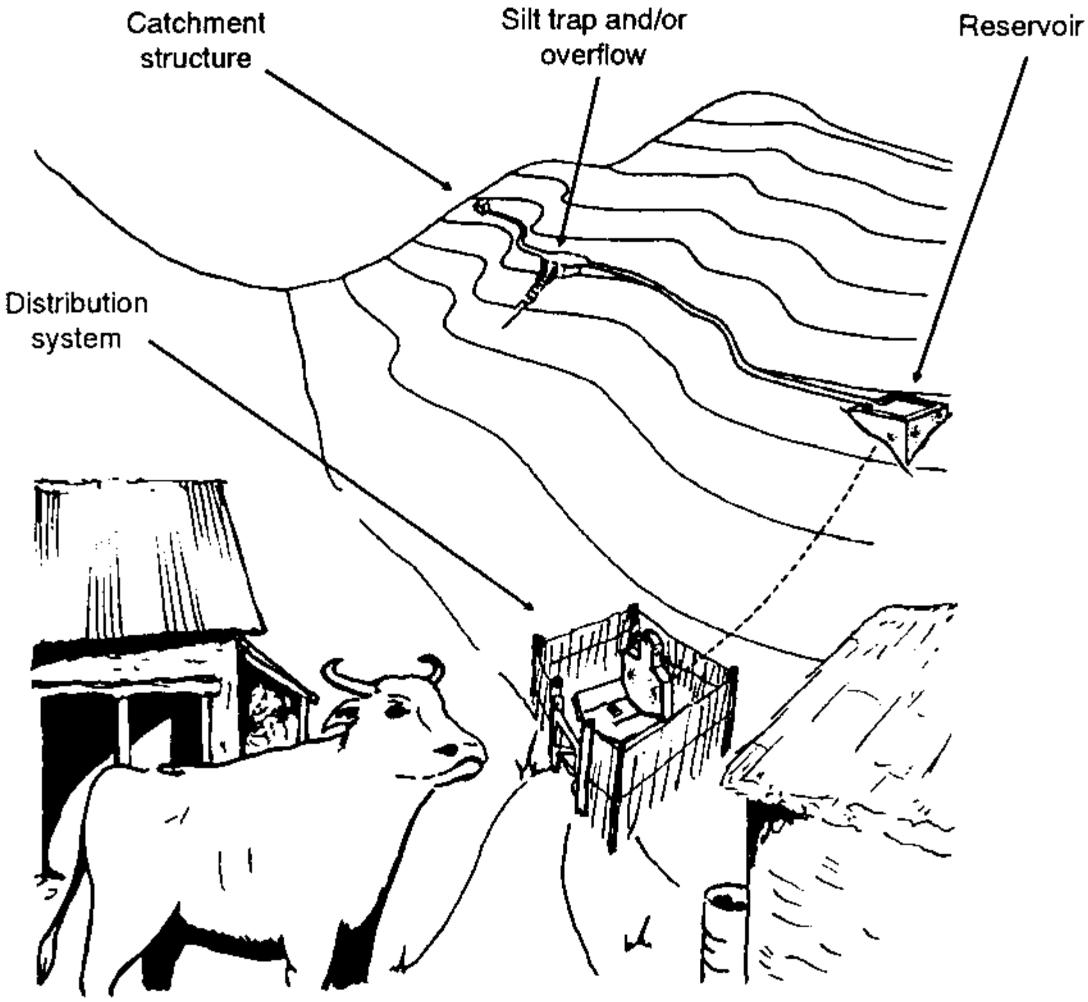


Section through turbine pump

One further water-powered device is the river current turbine. This uses the energy in a very large, fast flowing river to turn a turbine that is connected to a water pump. A similar device on a much smaller scale is a type of turbine placed in an open pipe in rapids. These are simple to install but are susceptible to flood damage.

Gravity feed

An alternative to the use of any water-lifting device is to find a source of water higher than the intended outlet and to let gravity feed the water to the users. This is only a viable option for village water supply or irrigation in mountainous areas. Piping or channels are employed to bring water from the source down a gentle gradient to the outlet. The distances involved can make piping expensive, while open channels require considerable skill to construct and maintain and are not suitable for drinking water.



Rainwater harvesting

The viability of rainwater harvesting depends on the rainfall received and its distribution throughout the year. Where rain falls fairly regularly throughout the year and there are no long dry seasons, the possibility of harvesting rainwater is an option for water supply that should be explored.

The method requires no energy input and no machines. A typical system comprises a collection surface and a storage tank.

Important factors when considering rainwater harvesting are:

- the annual rainfall, which determines how big the collection area will have to be;
- the maximum period of time when there is no rain, which determines how big the water storage facility will have to be;
- the type of collecting surface: although rain is pure water, if the surface used for collecting it is not completely clean the water can be contaminated; it is not, for example, healthy to collect rainwater off a grass, thatch or asbestos roof.

Wind- and solar-powered pumping

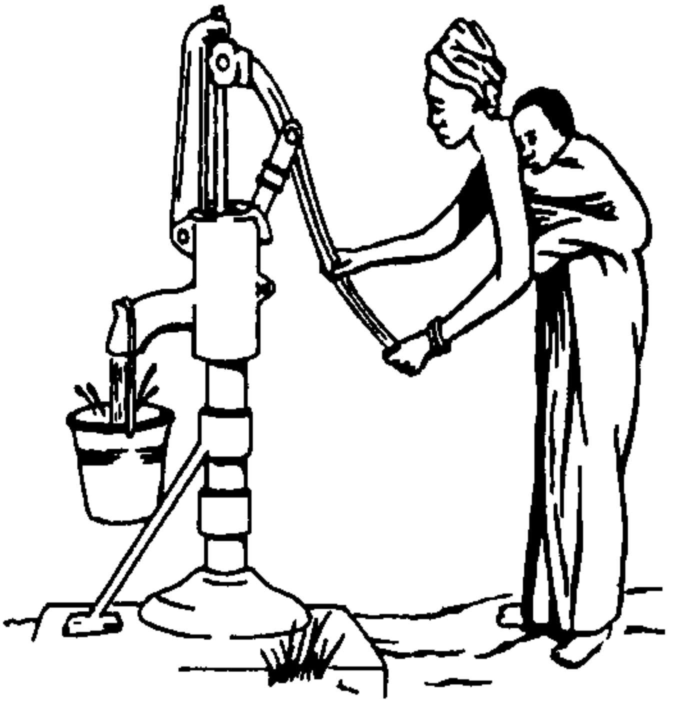
The main renewable energy alternatives are wind pumping and photovoltaic solar powered pumping. Both have been commercially developed and are available in most countries.

Wind turbines generally require high open ground with reliable wind conditions. As it is usually uneconomic to use wind power to lift water from streams in valleys, wind pumping is mainly used to draw water from wells and rivers in plains. Wind pumping is limited to particular sites, has a tendency to be unreliable and requires large water storage facilities for calm periods. Continued development is producing cheaper designs more compatible with manufacture and use in developing countries, but at present high maintenance costs and poor reliability restrict the wider use of the technology.

Photovoltaics (PV) are under intense development in many places and their high cost (up to US$20,000 per continuous equivalent kilowatt) is slowly falling. PV pumps can be used at almost any tropical location to lift both surface and ground waters. They operate for only a part of each day and so must be associated with suitable storage facilities to meet typical demand. PV cells are high technology and are usually imported to developing countries.

Manual and animal-powered pumping

There are numerous devices for lifting water using human power. Some efficiently make use of leg and back muscles, but many are hand operated, employing only the weaker arm muscles. They tend to be cheap to buy but are laborious to use. In countries such as Bangladesh, human-powered pumps are used for irrigation from surface water and shallow wells. In Africa, bucket irrigation from nearby streams is common. In both cases the area that can be irrigated by one fit person is normally only a fraction of a hectare. There is very widespread knowledge of how to manufacture human-powered pumps, often from local materials, making them cheap to install and maintain.



Animals, whose power is up to ten times that of a human being, can be employed to lift water. There are, however, usually technical or organisational difficulties in doing so. Most animal-powered devices are only suitable for vertical lifts from a well or up a river bank.

The place of ram pumps

For any particular site there are usually a number of potential water-lifting options. Choosing between them involves consideration of many different factors. Ram pumps in certain conditions have many advantages over other forms of water-lifting, but in others can be completely inappropriate.

The main advantages of ram pump systems are:

- use of a renewable energy source ensures low running costs;
- pumping only a small proportion of the available flow has little environmental impact;
- simplicity and reliability give a low maintenance requirement;
- there is good potential for local manufacture;
- automatic, continuous operation, requires no supervision or human input.

The main disadvantages of ram pump systems are that they:

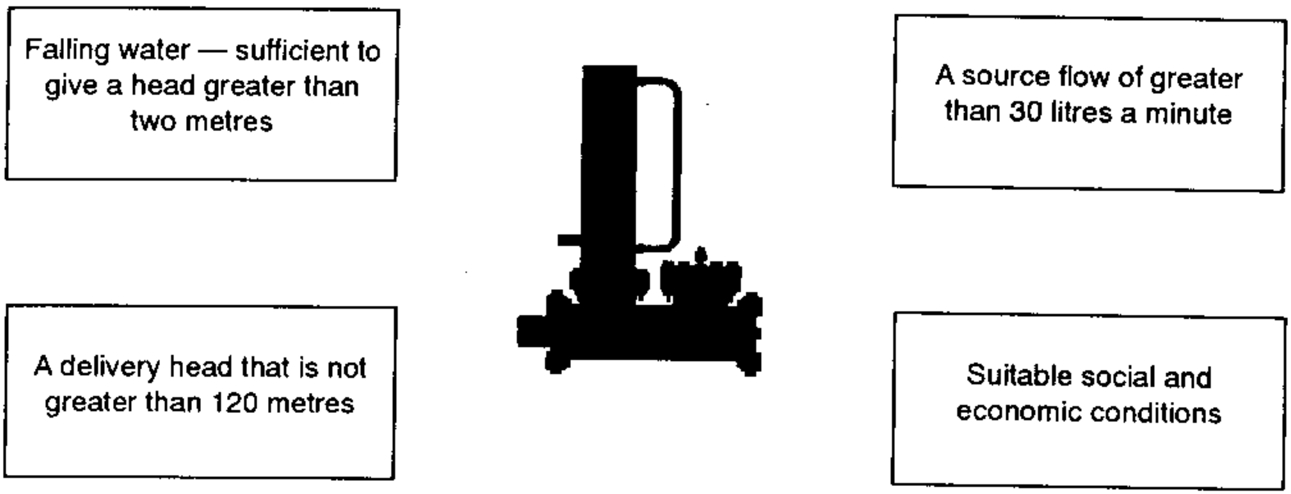
- are limited to use in hilly areas with year-round water sources;
- only pump a small fraction of the available flow and therefore require source flows much larger than actual water delivered;
- can have a high capital cost in relation to some other technologies;
- require some special skills for design and installation of sites;
- are limited to small-scale applications, normally under 1kW output.

In situations where the conditions of water source and landscape are met, ram pumps will normally provide the most economic and appropriate means of water supply. There are, however, a number of specific situations in which other technologies may prove more appropriate. Three important situations are described below.

In terrain where streams are falling very rapidly it may be possible to extract water at a point above the village or irrigation site and feed it through pipes under gravity. If the distance from the source to the point of use is small (or not many times greater than the length of delivery pipe from a ram pump system) then the cost of gravity feed may well be less than that of a ram pump. If gravity feed is an option it should always be examined for its technical and economic viability. Its main advantage is its simplicity and the lack of any form of pump that could break down or require maintenance.

If the water requirement is large (for a small town or large irrigation scheme) and there is a large source of falling water nearby, turbine-pump sets can provide the best solution. Many ram pumps could be used in parallel to give the required output but at powers over about 2kW, turbine-pump systems are normally cheaper. Turbine-pump systems share many of the advantages of ram pumps, although the services of a specialised engineer are often required to choose the right combination of turbine and pump for a given situation. Turbine pump sets can also be used in situations where the delivery head is too high for a ram pump system.

In small-scale domestic water supply, the choice can often be between using a ram pump on a stream or using cleaner groundwater. Surface water will often need to be filtered or treated for human consumption, increasing the cost of a system and requiring regular filter maintenance. If the technology for drilling small boreholes down to the groundwater and supplying human-powered pumps is locally available, these may be preferable to ram pumps. The main drawback is the laborious nature of human pumping and the problems of maintenance. Such pumping is also limited to drawing water from depths of up to 50m, as beyond this the effort required to lift sufficient water becomes too great. Other options for pumping from a borehole include wind and solar devices. The capital and maintenance costs of these options should be carefully considered.



Summary of site requirements for a ram pump system

CHAPTER 3: Preliminary system design

Suitable areas

Although all watercourses slope downwards to some degree, the gradient of many is so shallow that many kilometres of feed pipe or canal would be needed to obtain a fall of water large enough to power a ram pump. Ram pumps can be made to run with drive heads of less than one metre but they are not normally considered viable unless heads of two metres or more are available. If it would take a long length of feed pipe or canal to achieve this head, a ram pump system would be prohibitively expensive. The best geographical area for ram pumps is one which is hilly, with rapidly dropping watercourses and, ideally, springs.

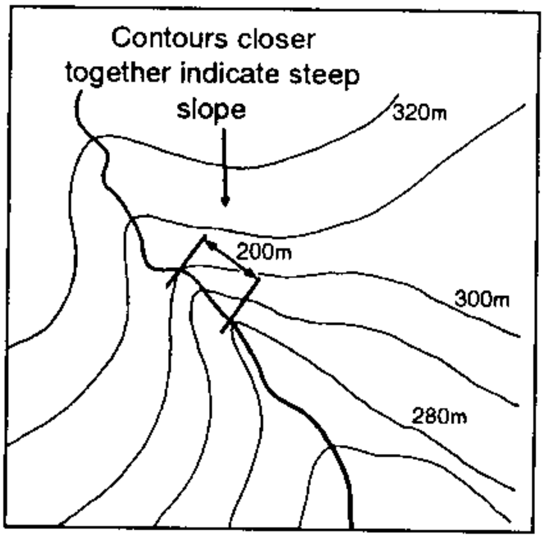
In some areas of the world good regional records of rainfall and flow from springs and in watercourses are kept in government offices and libraries. In others, another agency may have carried out recent relevant studies. If any hydrological studies are available for the region in which you plan to install ram pump systems, you can save time, effort and costly mistakes by consulting the records and using their findings in your site design.

After potential sites have been identified, they must be surveyed. The survey yields information about site dimensions and the materials required to construct the site as well as, when more than one site is surveyed, yielding a cost and performance comparison.

Designing a good drive and pump layout is crucial to achieving good system performance and limiting the amount of maintenance required. The aim is to be able to achieve a large head of water between the drive tank and pump, while using a short drive pipe to connect them. The best and cheapest sites are those where the land falls rapidly, allowing all pipework to be short.

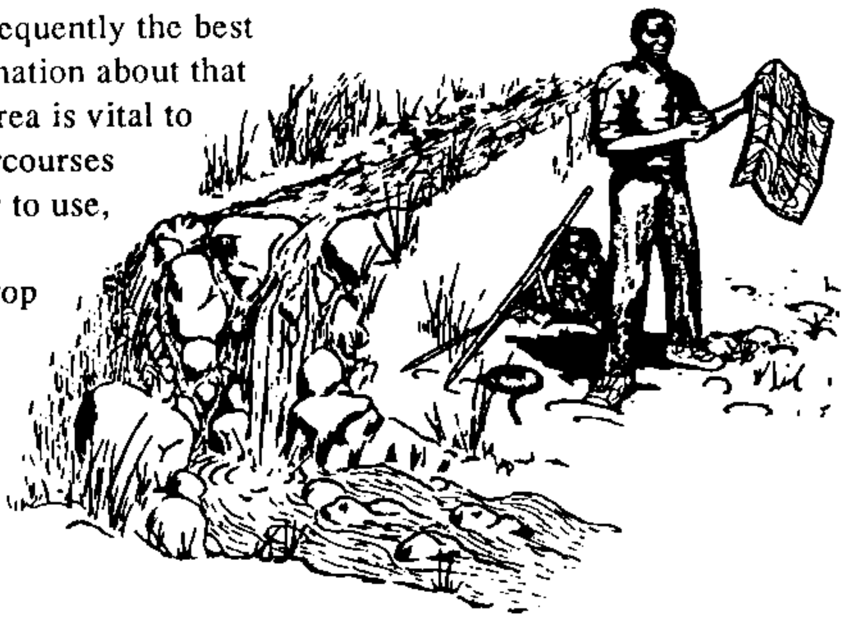
What to look for

Before arriving at a community to survey for a ram pump system, consult any available large-scale contour maps of the area. Look for places near to the community where streams cross contour lines and measure the distance along the stream between two contours. The average stream gradient can be obtained by dividing the height change between contours by this distance. An average gradient of at least 0.02 (0.02 or 2% is the same as 1 in 50) is needed for a water supply ram pump system. The pump will often be installed alongside rapids or a waterfall. If stream flow data for the area is available, look for seasonal variations, particularly during the dry months, and also for any data on the increase of flow during floods.



The section of stream shown in the map alongside falls quite rapidly. Where the contours are closest together on the stream's course, there is a drop of 20m over a distance of 200m, giving an average slope on that section of 10%. This site would be worth looking at.

People living in a community are frequently the best source of reliable, up-to-date information about that particular area. The water in their area is vital to them, so ask them about local watercourses and sources, which ones they prefer to use, and which ones regularly dry up.

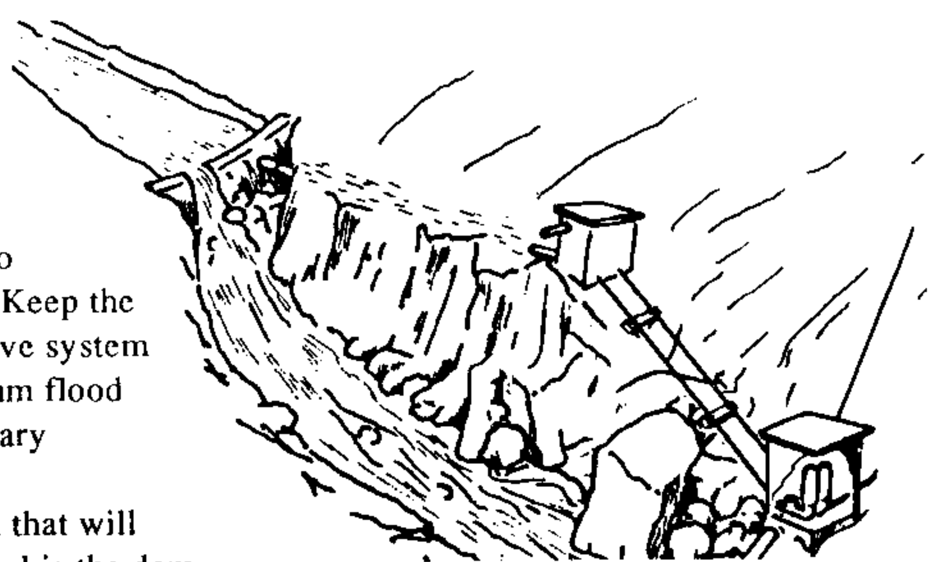


Sound is a good indicator of a drop in water. Where a watercourse is noisy and turbulent it will be dropping rapidly. It can save surveyors a lot of time to ask local people to show them places where the water is noisy, where it falls rapidly, and where there are rocks in the stream bed. Also ask to be shown any springs in the vicinity, particularly any with a source at the side of a valley along which a stream flows.

Allowing for floods

It is important to find out how the watercourse changes during a flood. Although spring-based systems are less susceptible to the extremes of flooding, it is still worth investigating and being aware of flooding as a potential problem when using a spring.

In very heavy rainfall, watercourses can swell to many times their normal flow within a short space of time. Design of a drive system must take account of these worst weather conditions, even if they only last a few hours each year. Ask local people how far the water rises during a big flood and look for evidence such as deposited rocks and stream erosion on the banks to help to confirm their reports. Keep the pumps and as much of the drive system as possible above the maximum flood water level to avoid unnecessary damage.



In the system sketched here, the main flow of flood water and debris is guided past the pumps by the large boulder or outcrop. Whilst the pumps may be submerged in a very high flood they will be protected from damage by most water-borne debris.

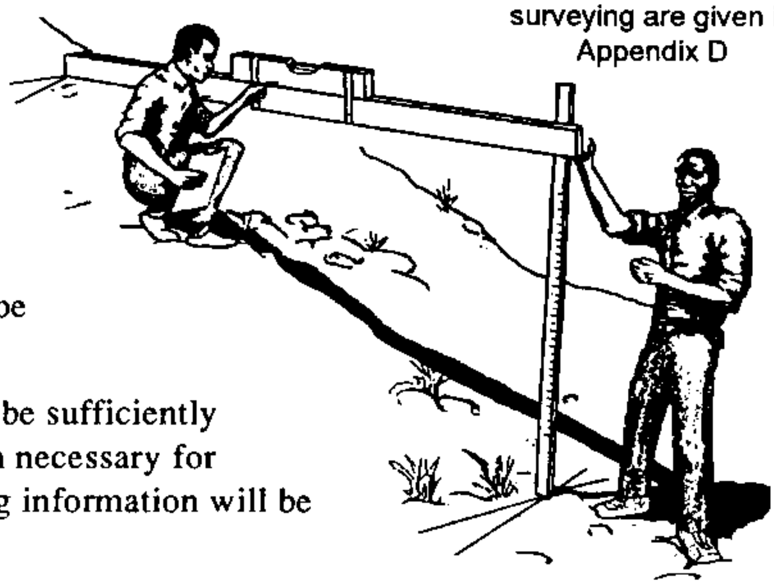
The one part of the system that will always be in the path of a flood is the dam or diversion structure. Bearing the expense in mind, this must either be built to withstand the worst flood conditions or built to be easily repairable. Some protection against the worst damage to a dam should be included in the design, including a cage protection for the system intake, a floodwater overflow in the dam wall and boulders anchored into the stream bed above the dam to reduce the impetus of rolling stones.

Normally the pump(s) should be sited above floodwater level, but in some cases (particularly where the drive head available is marginal) this can be impractical. In these circumstances the pumps need to be sited so that they are protected from any debris in the flood, or so that they can be easily removed when a flood is expected.

Site surveying

Surveying should be in two stages, a preliminary assessment to locate potential sites, and a full survey to select the best option. In brief, the *preliminary survey* will involve the following:

- consulting any relevant maps and hydrology studies;
- travelling to potential sites to make a preliminary assessment and consult local people;
- selecting one or more sites with a high potential that will be surveyed fully.



Several methods of site surveying are given in Appendix D

The *full survey* of selected sites must be sufficiently detailed to provide all the information necessary for accurate system design. The following information will be required:

Water source flow (Qs) This figure must reflect the minimum flow of the water source in a normal year and so the measurements must be taken during the dry season. In order to ensure that the figure represents a typical minimum, local people should be consulted about the flow patterns over recent years. Some indication of maximum expected flows should also be obtained.

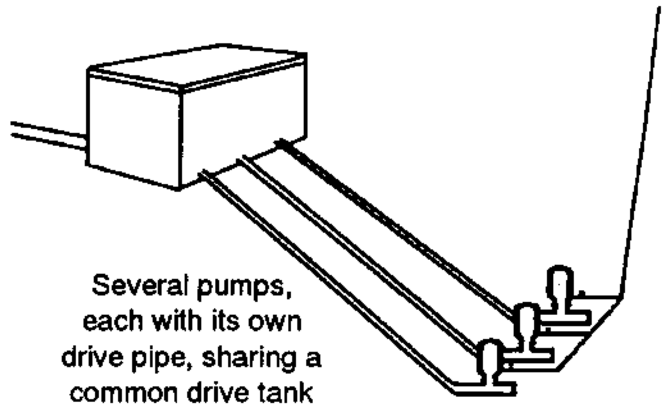
Drive head (H) The maximum possible drive head of the site or the average angle of the slope below the water source should be measured.

Delivery head (h) The height (h^1) from the water source to the expected point of delivery should be measured. This will provide a rough estimate of delivery head but to be accurate the drive head (H) should be added to this figure to give the actual delivery head.

Water requirement (q) This should be estimated with reference to the population to be served (allowing for growth) or the area of land to be irrigated. A table showing various estimated water needs is given in Chapter 4, page 39.

Pump selection

When selecting a ram pump there are often a number of decisions to be made concerning both its type and size. To make these decisions wisely, it is helpful to have some information about the site where the pump will be used. An estimation of the available drive flow and delivery head are needed, along with the anticipated delivery flow requirement. Knowing these will help to ensure that the correct pump is chosen. The main decisions to be made are:



Several pumps, each with its own drive pipe, sharing a common drive tank

- whether to buy an imported pump or to manufacture one locally (see Chapter 2);
- the size and number of pumps to be used.

Pumps with drive pipes of between ¾" and 4" are often commercially available or can be imported fairly quickly from manufacturers in Europe, N. America, etc. Larger models, with up to 12" drive pipes are also obtainable but usually have to be manufactured to order. Choosing between pumps from different manufacturers is not always straightforward. Comparisons of flow and efficiency can be made if the data is available. Cost, however, is normally very important, and varies considerably from pump to pump and manufacturer to manufacturer. The need to import spare parts and their cost should also be carefully considered. Where the source flow is large the choice is often between using one large pump or a number of smaller ones to meet the required delivery. Each model of ram pump with its recommended drive pipe will operate over a specified range of drive flows. In general, pumps are more efficient towards the lower limit of their drive flow, but produce a greater power output with large flows. A number of pumps can be used in parallel sharing a single drive tank and delivery pipe, but they must have separate drive pipes.

Using several small pumps rather than one large one can have the following advantages:

- each pump can be set for high efficiency;
- if the source flow falls below the required drive flow one pump can be stopped, allowing a reduced delivery flow to be maintained;
- a single pump can be stopped for maintenance work to be carried out without stopping all delivery flow;
- smaller sizes of pipe are often more readily available, whereas large steel pipe may have to be imported at high cost: it is also harder to work with large diameter pipe and to transport it;
- the maximum delivery head is generally higher on smaller pumps.

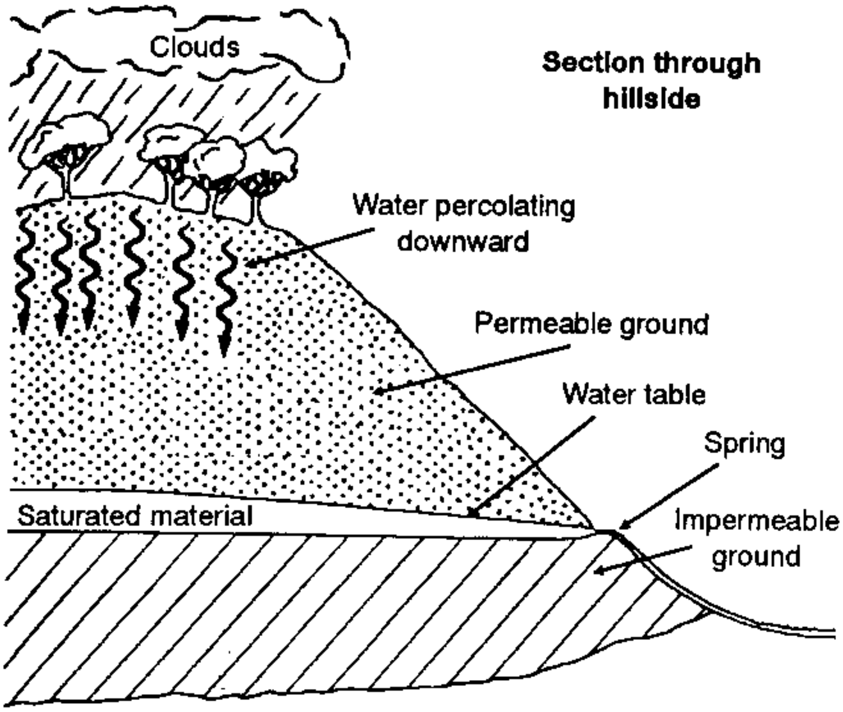
The cost of using a number of smaller pumps may be greater than using one large one but the benefits mentioned above need to be balanced against the extra cost.

Intake design

The drive water for ram pump systems is normally drawn from a spring or a stream and diverted into a feed pipe. An intake structure is required at the chosen water source to collect the water and keep the feed pipe properly supplied.

Spring intakes

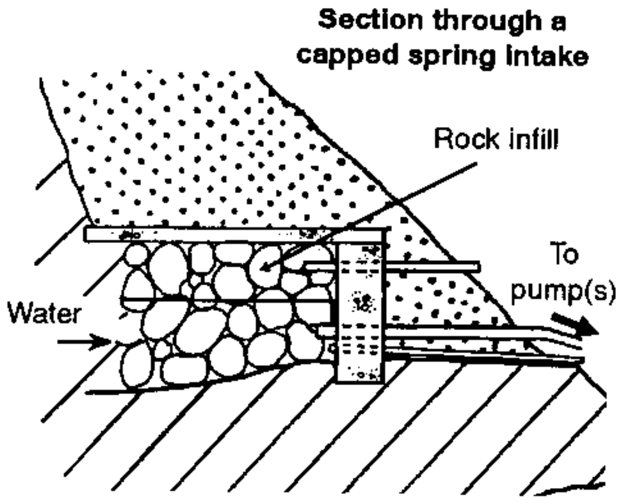
When rain falls on high ground, some of the water soaks into the ground and seeps down through the permeable soil until it reaches an impermeable layer — usually clay or rock. The water collects on this layer, forming a water table of saturated material. The term water table refers to the upper level of the saturated material, and may rise and fall to reflect variations in rainfall throughout the year. As the level of the water table rises, the water spreads out until it reaches the side of the hill, then flows out as a spring.



The nature of the permeable layer influences the kind of spring that occurs. If it is soft, sandy soil through which the water can travel easily, there may be many small springs as the water emerges all along the hillside. If the permeable layer is rock, with cracks through which the water sinks, there is usually one distinct spring.

In most situations water emerging from springs is completely pure and safe for drinking, whereas by the time it flows into a stream or river it has often become contaminated. This is why it is preferable for a ram pump system supplying drinking water to be served directly by a spring.

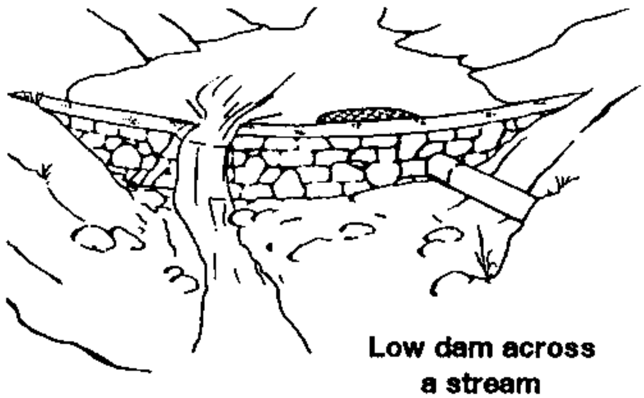
Spring flows are often quite low and in many cases it is necessary to combine the flow from several springs to obtain enough drive flow for a ram pump system. When this is done, the drive head available to the pump(s) is the drop from the lowest of the springs to the pump(s).



Seasonal variations in spring flow must be allowed for. In most cases the users require the same amount of water at all times through the year, so the system must be designed to use the amount of flow available when the springs are at their lowest. If this is not done, there may be times during the year when there is not enough water delivered, or when there is too little water to run the pump(s) at all.

Stream intakes — dams and weirs

On streams and small rivers the feed pipe must draw water from a relatively deep pool to ensure that the end of the pipe remains below water level. To achieve this it is usual to build an obstruction across the stream to raise its level, and to run the feed pipe through it. The obstruction can either be a dam with a specific overflow point (a spillway), or a weir where the water flows over it across its whole length.



Low dam across a stream

The types of dam or weir normally constructed are relatively small and simple as the increase in level needs only to be around 300mm. In situations where the drive head must be increased significantly in order to make a system viable, larger dams may be necessary. In many parts of the world, simple, cheap designs of dam have been developed that suit the local conditions and use readily available materials. Construction details for two types of widely applicable stream intake are given in Chapter 5.

Siting the intake The best site for a dam or weir is where the gradient of the stream is large, such as just above an area of rapids or a waterfall. This enables a high drive head to be obtained within a small distance and so helps to reduce the length of feed and drive pipes. In situations where the gradient of the stream is fairly constant, constraints on siting other components of the system may determine the location of the intake. On streams with a low gradient there are two ways of obtaining a suitable drive head. One is to build a small, cheap dam some distance upstream and run a long and therefore expensive feed pipe to the drive tank. The other is to build a much taller, more expensive and complex dam and run a short length of feed pipe to the drive tank. Siting the dam in a narrow section of stream can greatly reduce the amount of material required in construction, particularly where a taller dam is to be built.

When choosing a site, careful attention must be given to the foundation on which the dam structure will be built. Solid rock foundations ensure a firm base but require the use of cement or concrete to attach the structure securely. If building on loose material, such as soil or gravel, it is necessary to dig a trench across the stream bed to provide a firm anchor for the structure. The foundation should extend well into the banks on either side of the stream, especially where these are soft.

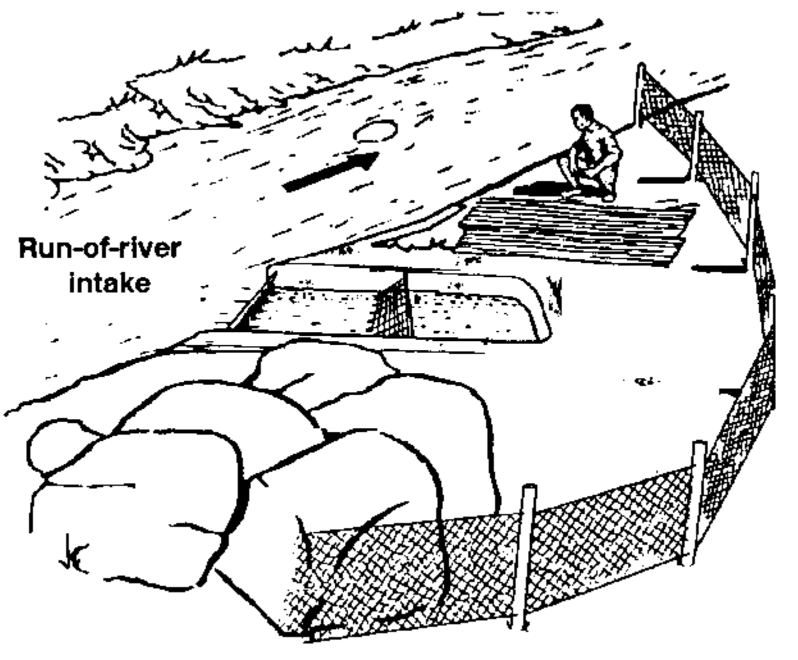
The size of expected floods and the type of debris carried by the floodwater also affects the type and site of the intake structure. A low, well-anchored dam or weir can be designed to allow floodwater to pass straight over it so that, apart from the additional build-up of silt and other debris behind it, the structure is little affected by floods. Larger dams should be built strongly enough to withstand flows much higher than the normal operating levels expected. A spillway will normally take excess water over the dam, but can rarely be large enough to cope with floodwater levels. In some cases a bypass can be built for floodwater but care should be taken to prevent the stream from establishing a new course along the bypass route after the flood.

Components of an intake A number of features should be built into any dam or weir intake:

- Feed pipe socket — a socket built into the structure to enable the end of the feed pipe to be disconnected in case repair or cleaning is required;
- Screen — a coarse wire mesh covering the inlet of the feed pipe to prevent larger debris such as leaves and sticks from entering the system with the drive water;
- De-silting pipe — a small bore steel pipe built into the base of the dam or weir to allow periodic or continuous removal of silt from behind the structure. Silt must be removed before it reaches the level of the feed pipe and starts to enter the system.

Run-of-river intakes

Where the flow of a watercourse is too great to allow construction of a suitable dam or weir, an intake can be built into one of the banks. Such a run-of-river intake diverts a portion of the water from the main flow of the watercourse and channels it into the feed pipe. The intake must be positioned at a site where there is fairly deep water near to the bank. It is also necessary to design and site it so as to prevent excessive silting.



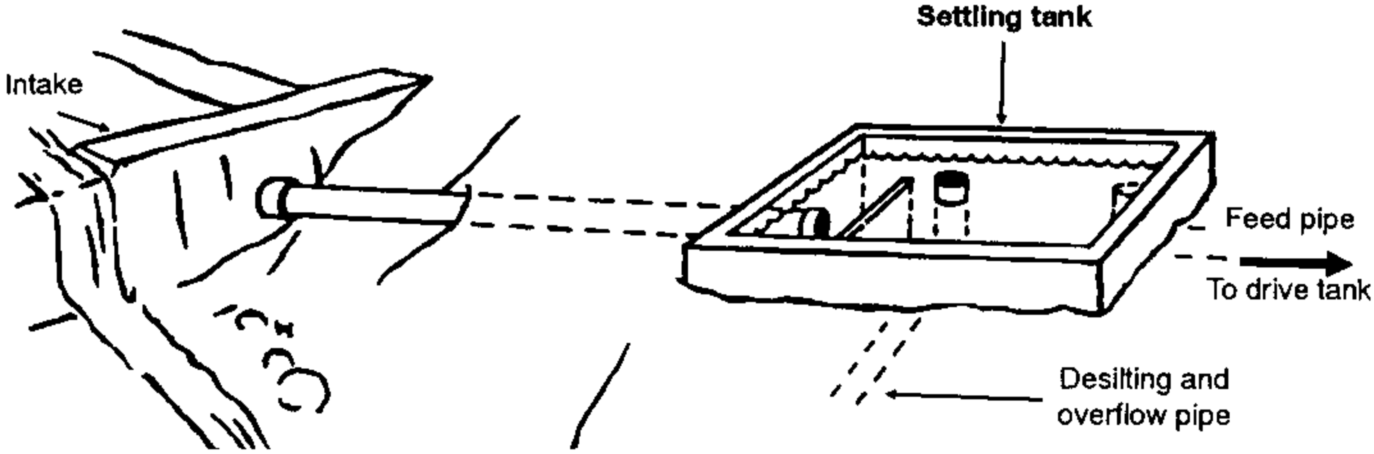
The spiralling flow of water on a bend tends to cause sedimentation on the inside of the curve, so intakes should never be sited in such a position. Siting an intake on the outside of a bend can be advantageous because the water tends to be deeper and silting reduced, but this position can leave it liable to damage by floating debris, especially during floods.

Section through river on a bend

Settling tank

Water, particularly in streams and rivers, can carry a large amount of small pieces of soil and sand — often referred to as silt. The amount of debris carried by water depends upon its velocity and the type of ground over which it has travelled. Silt can cause damage by eroding pipework and pumps as it is forced along by moving water, or by settling and building up to create blockages. When it is planned to use water that has a large silt content for a ram pump system, it is wise to include in the system a means of removing the worst of this debris.

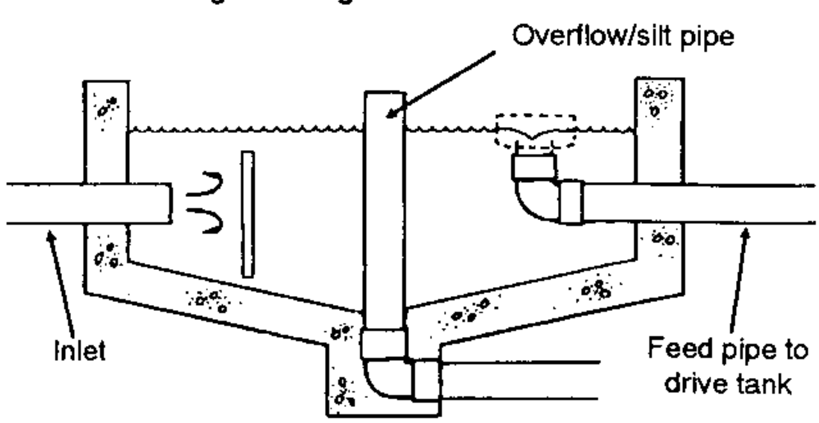
When the velocity of flowing water is reduced, the particles of silt being carried tend to fall slowly and settle out. In some systems, the large pool of water behind a dam or in a spring box can slow down the water sufficiently to allow silt to settle out. A large drive tank will also reduce the velocity of the water sufficiently to allow some settling to occur.



In situations where the source has a particularly high silt content and no large pool of water at the intake, a purpose-built settling tank should be included in the system. The settling tank should be designed to reduce the velocity of the water sufficiently to allow much of the silt to drop to the bottom of the tank rather than being carried with the water further into the feed pipe. The most convenient place to site a settling tank is near to the intake structure. If the system uses several springs, the settling tank can also be the most convenient place to combine the flows from each of the springs.

Settling tanks need regular maintenance. If they are well designed, a large amount of silt will collect very quickly and the tank will need cleaning. A removable overflow that serves as a silt pipe installed as shown can make cleaning fairly simple. Withdrawing the overflow pipe from the elbow in the base of the tank causes a large flow down the silt pipe, removing settled debris from the base of the tank.

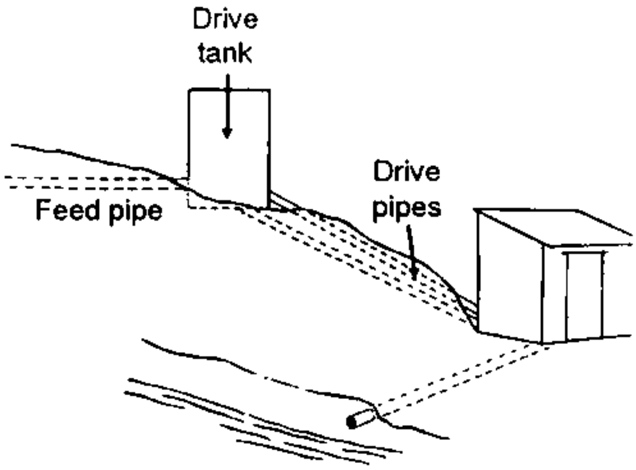
Section through settling tank



Drive system

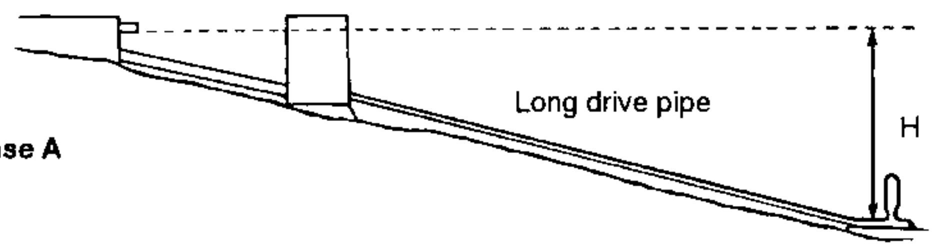
The drive system is the part of a complete ram pump installation that receives water from the intake and feeds it to the pump(s). It normally comprises three main items:

- a feed pipe that carries a constant flow of water from the intake to the drive tank;
- a drive tank that provides a store of water at the top of the drive pipe(s);
- the drive pipe(s) that supply water from the drive tank to the pump(s).



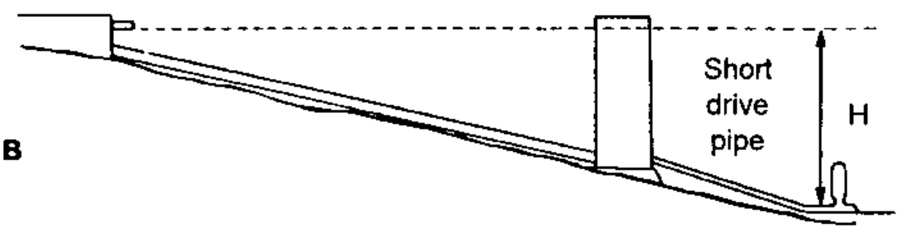
Details of the design and construction of these system components can be found in Chapter 5. However, when first designing a drive system for a ram pump, all three items must be considered together because decisions involving any one of them will affect the design of the other two. In any particular situation there is a balance to be found between each of the items in the drive system. The balance involves the site layout and the relative costs of different types of pipe and of tank construction.

The system sketched below shows how the required drive head can be achieved in two different ways at the same site. Case A shows a small drive tank linked to the source by a short length of feed pipe. To reach the necessary drive head (H) a long drive pipe has to be installed to each pump.



Case A

Case B uses a very tall drive tank being fed from the intake by a long feed pipe and supplying the pump through a much shorter drive pipe.

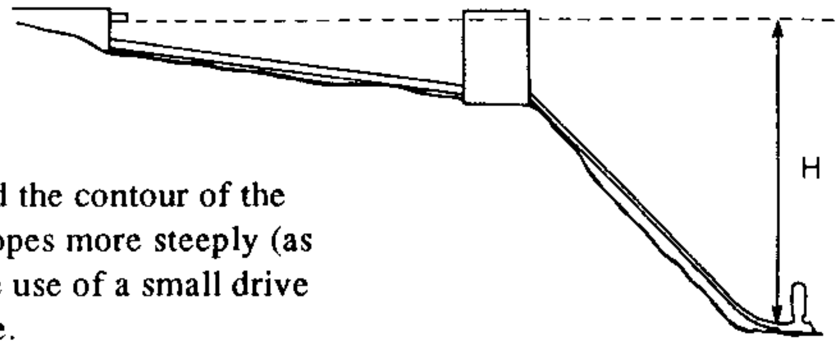


Case B

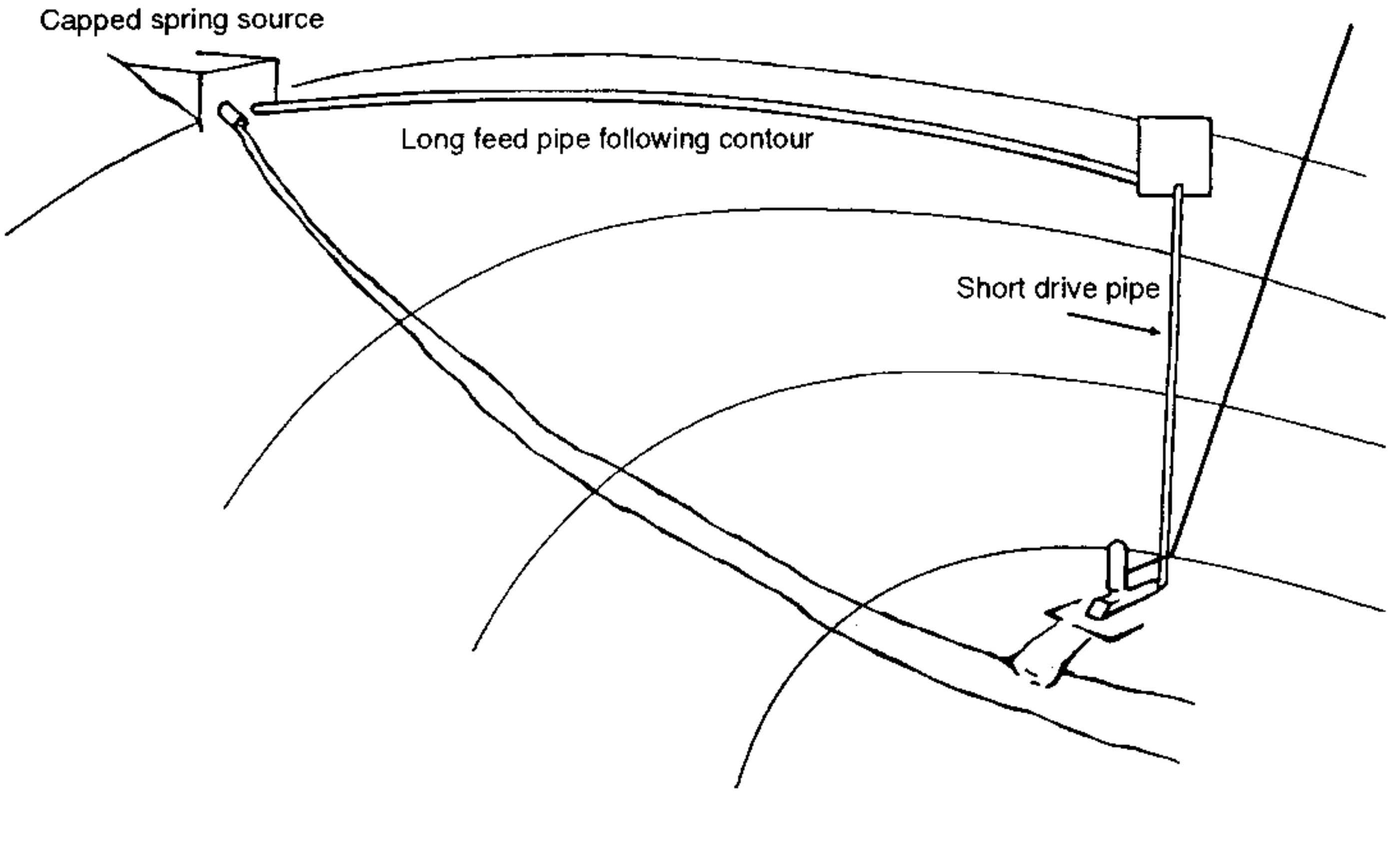
The final design choice in any situation will depend on the cost and the availability of materials and construction techniques.

Small drive tanks are generally cheap and simple to construct whereas tall ones require better foundations, reinforcing and more complicated construction techniques. On the other hand, galvanised steel drive pipe is usually far more expensive than low pressure plastic feed pipe and this cost constraint would often make Case B, using a long feed pipe with a short drive pipe, the more attractive option.

When designing a drive system it is best to look for an area below the proposed intake site which has a particularly steep slope. To obtain a certain drive head (H), the cheapest and most suitable site will be one that allows a small drive tank to be built at the top of a steep slope with a short drive pipe leading to the pump at the bottom as shown below. This will sometimes require a long feed pipe to carry water from the intake to the drive tank.



When using a spring or stream in a valley, the sides of the valley are often much steeper than the slope of the stream itself. Diverting the drive water in the feed pipe around the contour of the valley to a point where the side slopes more steeply (as shown below) can often enable the use of a small drive tank and relatively short drive pipe.

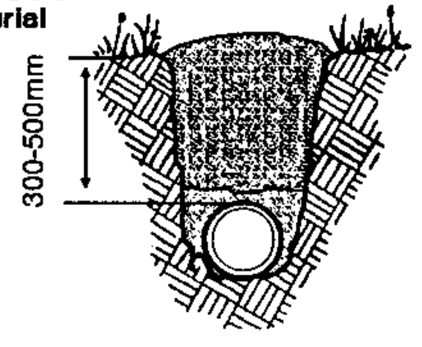


Feed pipe

The feed pipe carries a steady flow of water from the intake to the drive tank. It must supply sufficient water to feed all of the ram pumps running from the drive tank plus a small surplus that will overflow from the tank and ensure that a constant level is maintained inside. In small spring-based systems (or those using very small streams), all of the available source flow may be diverted into the feed pipe and the excess allowed to overflow from the drive tank. All feed pipes must be sized to carry enough water to supply all the pumps installed, plus an allowance for the overflow and any planned expansion of the system at a later date.

The pressure of the water in the feed pipe is generally very low, so cheap, low-pressure plastic pipe is usually adequate. If this type of pipe is used it should be buried or well covered in some way to protect it from damage by animals, farming, or strong sunlight.

Protecting pipe by burial



The water flowing through the feed pipe will experience some friction against the pipe walls. This friction takes up some of the energy of the water and means that the water level in the drive tank under normal operating conditions will be lower than the level at the intake. This head loss caused by the friction of the flowing water must be taken into account when choosing the diameter of the feed pipe. In situations where there is plenty of drive head available a smaller and cheaper pipe size can be used. To achieve the required drive flow, the water in a small pipe will have to flow faster, with more friction and therefore a higher head loss, but when there is plenty of drive head available this will not matter. In situations where the drive head available is very limited, very little head loss in the pipe can be allowed and a larger diameter pipe through which the water flows relatively slowly should be used: the low velocity of the water in a large diameter pipe reduces the friction and therefore reduces the head loss. Appendix D includes methods of determining the amount of head loss that can be expected in various sizes of feed pipes over a wide range of flow rates. When the required flow rate and the acceptable head loss are known, these methods are used to determine the required feed pipe diameter.

Drive tank

The drive tank is an important component in the operation of a ram pump system. It performs the following tasks:

- it keeps a steady water level, ensuring a regular supply to the pumps and a constant drive head;
- it provides a large body of water with an open surface that reflects the pressure waves travelling up the drive pipe when the pump is running;
- it also prevents air from being sucked into the drive pipe.

Very occasionally systems can be sited on a steep slope (more than 30 per cent) directly beneath the water source and can be designed without a drive tank. This can reduce the cost and complexity of the system but extra care must be taken in the design of the water catchment structure, which must then also perform the functions of a drive tank.

One common mistake when designing drive tanks is to have the entrance to the drive pipe too close to the surface of the water. In such cases air is drawn into the drive pipe as the water accelerates down it. This can interrupt the operation of the pump and frequently leads to failure at the top of the drive pipe due to an effect called cavitation. It is recommended that the depth of water above the drive pipe inlet(s) be at least 500mm.

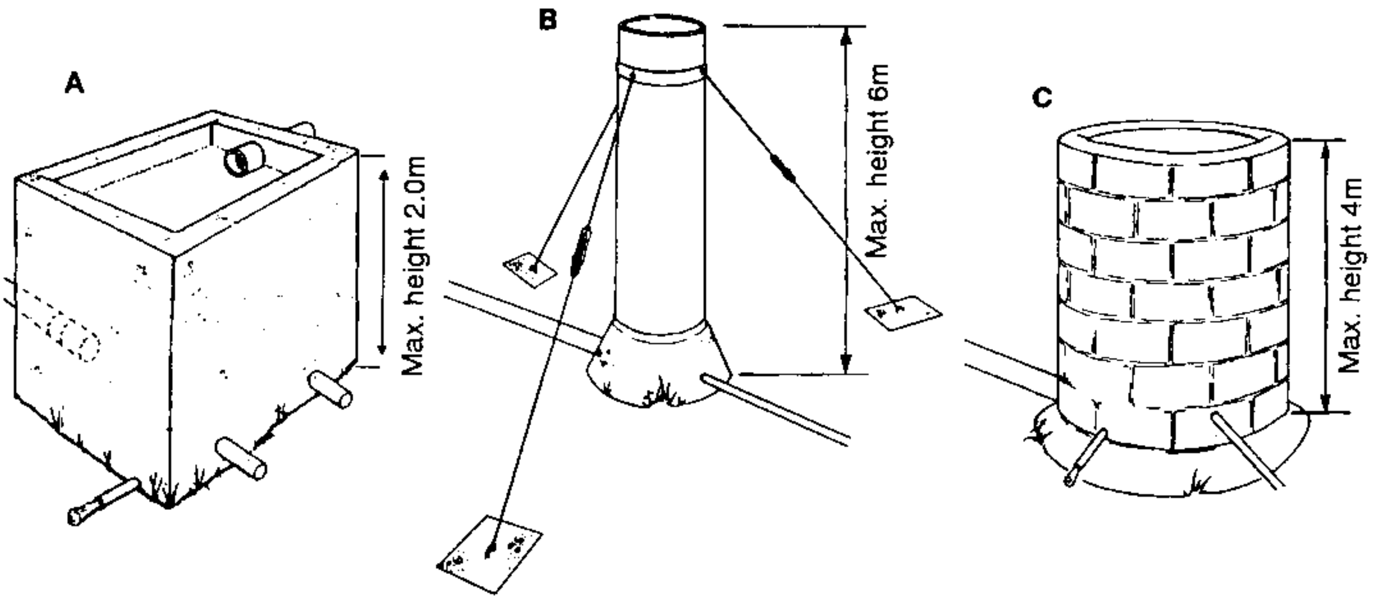
The volume of water in the drive tank, and in particular the cross-sectional area, must be large enough to maintain a steady level in the tank despite the intermittent outflow to the pump(s). As a rough guide, the cross-sectional area should be at least 20 times the total area of the drive pipes being supplied from it.

A number of types of drive tank can be considered. The choice between them depends both upon site conditions and the materials and skills available for their construction. From the authors' experience, three main types are useful, each with its own normal range of use.

[A] A square or rectangular tank made from cement block or fired brick and plastered inside and out. The height of these tanks is usually not greater than 2.0m.

[B] Large diameter PVC pipe set in a concrete base: restraining lines are recommended to ensure stability. These tanks are only appropriate for use in systems with small drive flows — particularly those systems that are spring-based. The height of these tanks is usually not greater than 6m.

[C] Circular tank made of cement blocks with re-bar (reinforcing bar) running vertically and horizontally within it. The height of these tanks is usually between 2 and 4m.



Care must be taken to site the drive tank conveniently for operational reasons and to ensure that it is stable. A large tank full of water is very heavy and the foundations must be strong enough to support this weight without movement. Where possible tanks should be built on a solid rock foundation.

Drive pipes

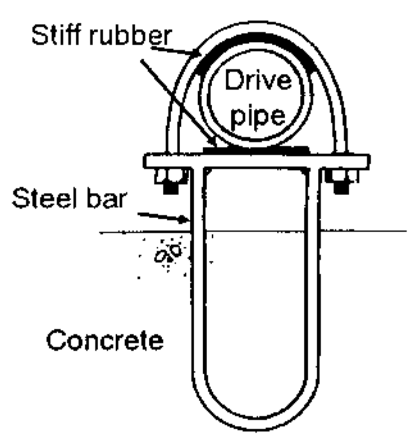
Most pumps are designed for a particular diameter of drive pipe and this recommended size should be used under normal conditions, i.e. in the normal range of drive flows and pipe lengths. Selection of drive pipe diameter is a compromise between having a large diameter to reduce friction losses and a smaller diameter to give adequate water velocity. Never install a pump with a drive pipe diameter larger than the diameter of the drive pipe connection to the pump. Research has shown that many traditional pump designs actually underutilise their drive pipe capacity and so, where drive pipe lengths and drive flows are towards the lower limit of their range, the next standard size of drive pipe below that recommended can be installed. For example, the DTU pumps described in Appendix F are normally driven via a drive pipe in internal diameter 2" (50mm): for drive flows (not delivery flows) of less than 70-80 litres/minutes, a 1½" (38mm) drive pipe can be used instead. Despite its higher friction, the smaller diameter pipe will give better overall efficiency (and output) for the available drive flow because the velocity of the drive water through it is higher. This is especially so when the delivery head is towards the top of the pump's range. It is generally true of all ram pumps that at low flows and high heads reducing the drive pipe diameter leads to an increase in pump efficiency.

There are limits to the length of a drive pipe in a ram pump system. These limits can be calculated by reference to several theories that take account of such factors as the energy available to the pump, the friction in the system and the movement of pressure waves within the pipe. A complete explanation of the theory involved would be too complex to give here, so only some basic guidelines are described.

A short drive pipe, that is, one with a length less than about twice the drive head, will give a very high frequency of operation. This can reduce efficiency and will shorten the life of the pump. The advantage of keeping the drive pipe as short as possible is that its cost is reduced. As a general guide, it is recommended that the length of the drive pipe be kept to between two and four times the drive head, but should never be less than 6m. For example, a system with a drive head of 5m should be designed to keep the length of the drive pipe between 10 and 20m. Systems with drive pipes longer than about five times the drive head may not be able to operate at the optimum efficiency or peak output levels quoted by the manufacturer. Ram pumps with very long drive pipes will operate satisfactorily in many situations but are inefficient and unnecessarily expensive.

The angle of the drive pipe is not a critical factor and will normally be dictated by the particular site conditions. The manufacturer's recommendations for the correct angle for a drive pipe can be ignored provided that the guidelines for pipe length given above are followed. The drive pipe can have gentle bends along its length but it must be very firmly secured near to these points.

Section through simple drive pipe anchor



Drive pipes are normally made from galvanised steel pipe, which is the usually the cheapest and most readily available material with adequate strength and life. Well sealed, threaded joints can be used in most situations, provided that the pipe is properly anchored and cannot vibrate. In systems with very high delivery heads (over 100m), threaded drive pipe connections are sometimes inadequate. In these cases flanges should be welded to the ends of the lengths of drive pipe so that they can be bolted together. The same flanged connections should be used when the threads on the pipe are of poor quality, or when large diameter drive pipe is being used.

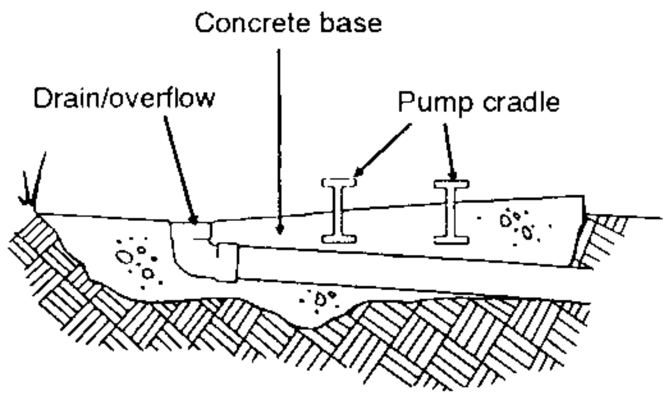
Pump

The pump itself should be considered as one component of the whole system. It needs to be carefully selected and sized in the same way as a tank or pipe, and its installation must be carried out carefully. The section on pump selection earlier in this chapter describes the process of choosing a ram pump or pumps to suit a particular set of conditions. After the particular requirements and constraints of an installation have been identified by the site survey, the pump(s) should be the first component to be selected. When the number and type of pump to be used is known, the sizing of tanks and pipes and the detailed design of the rest of the system can be carried out.

Pump base

It is essential that each pump be held rigidly to prevent it moving and vibrating with each pumping cycle. If a pump is not firmly secured, energy is lost as it moves and pipe joints will quickly break. The best way to secure a pump is to attach it firmly to a large concrete base. Some manufacturers recommend securing their pumps by setting bolts into the concrete but the difficulty of replacing these bolts when their threads rust or become damaged makes this unwise. A better method is to cast a steel frame, referred to as a pump cradle, into the concrete base. There can be either a separate cradle for each pump or a single cradle to support them all. This can be made of angle-iron or other steel section welded together. The top of the cradle is left jutting out of the concrete and has holes pre-drilled through it so that the pump can be bolted down on it. If the securing bolts are damaged, they can be cut off and replaced without the need to recast the concrete base. The shape of the cradle required will be different for each make of pump depending on the fixing methods incorporated by the manufacturer.

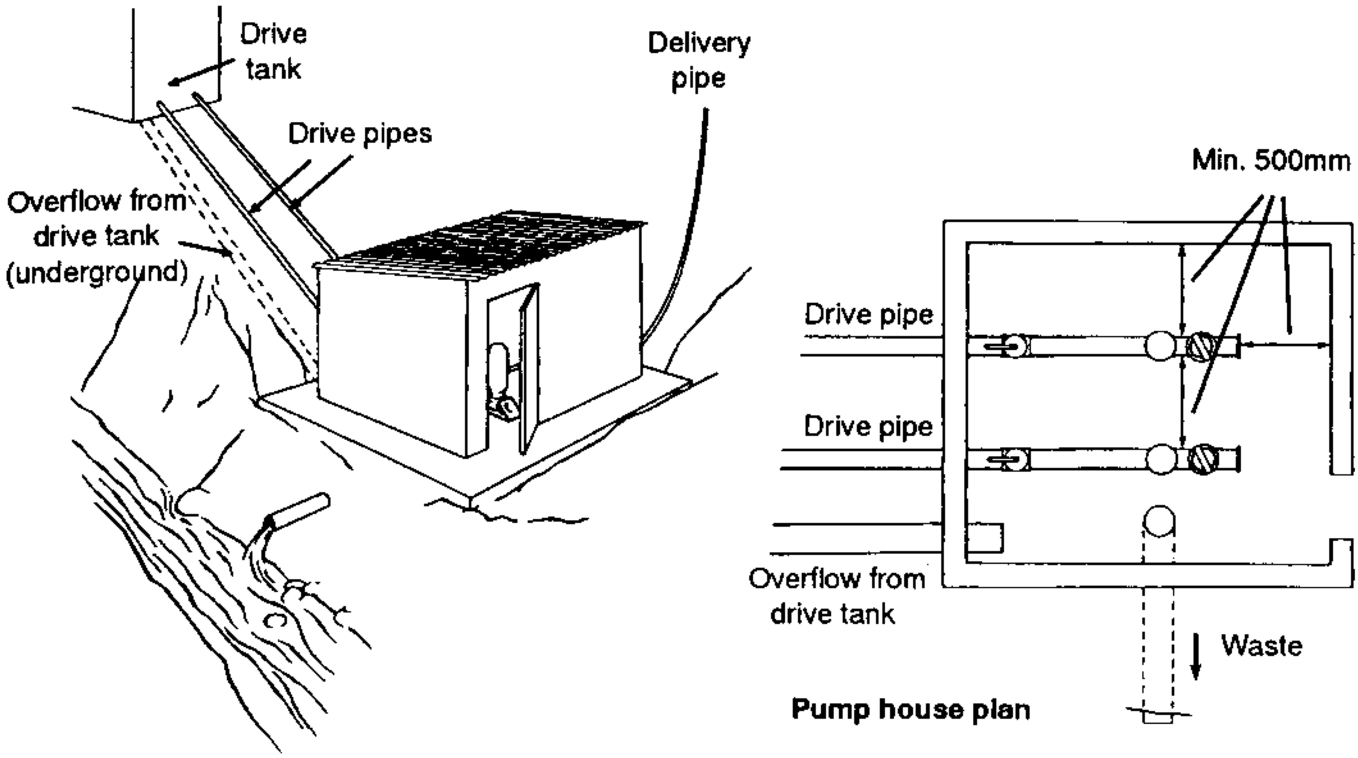
Section through pump base



When designing a drive system, choose a suitable site for casting the pump base. The concrete base must be firmly anchored to prevent the continual vibration of the pump(s) damaging it, or separating the entire base from the material surrounding it. The site must also allow for drainage of the waste water from the pumps to prevent flooding around them.

Pump house

A structure built around the pumps is not essential to the operation of a ram pump system. However, a pump house is recommended to provide security and protection. Curious children can easily damage a ram pump left operating in the open and it also makes an easy target for thieves. The pump house must be made large enough to allow complete access to all parts of the pumps for installation and maintenance. As a general guideline, allow at least 500mm between any part of the pump and the walls of the pump house or another pump.



Delivery manifold

The delivery manifold connects the outlet from one or more ram pump's air vessels to the delivery pipe that carries the water to the point of use. It also traps air and collects silt. The details of building and installing a delivery manifold are covered in Chapter 5.

Delivery pipe

The delivery pipe is an important part of any ram pump system and in many cases its length leads to it being the most expensive item. This is true despite the fact that, unlike drive pipes, many pumps can share the same delivery pipe. The delivery pipe must be sized to suit the expected delivery flow and the cost constraints. The larger the diameter of the delivery pipe, the more expensive it will be, but the lower the friction losses within it. Relatively cheap delivery pipe with a small diameter will impose high friction on the delivery flow, causing a high head loss. The pumps will have to overcome this head loss as well as lifting the water to the point of delivery. Choosing a diameter for the delivery pipe is therefore a balance between having a small diameter pipe to reduce costs or having a large diameter pipe to reduce head loss and maximise delivery flow.

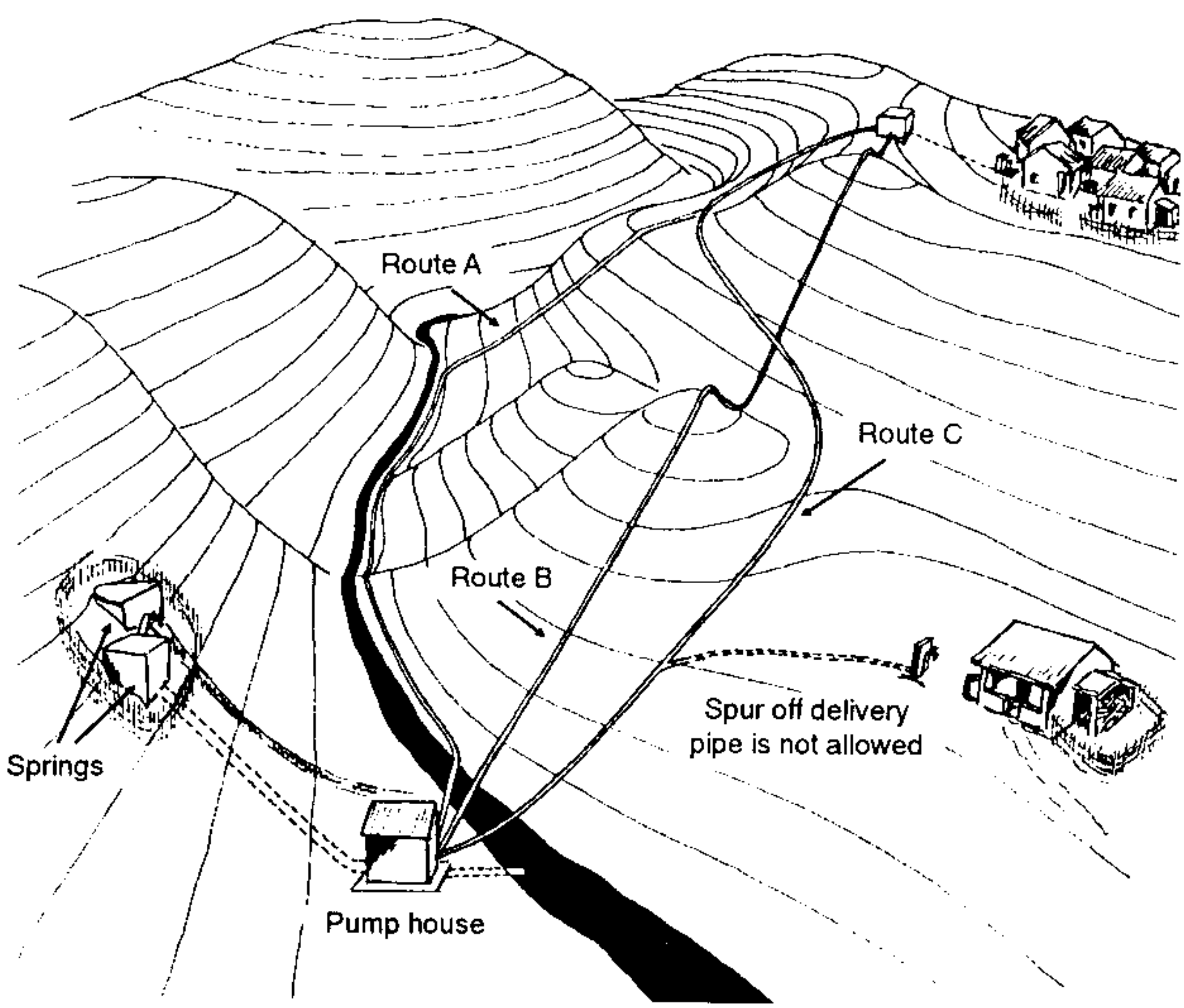
As a rule of thumb, the calculated head loss in the pipe when it is carrying the predicted delivery flow should be between 5 per cent and 10 per cent of the delivery head.

Where there is plenty of delivery water available and low cost is important, a small diameter delivery pipe can be used to reduce cost. If the expected delivery flow is only just sufficient for the users, a larger diameter pipe with a lower head loss should be chosen. Appendix D includes a table and a flow nomograph either of which can be used to determine the head loss in any given situation.

The route chosen for the delivery pipe should be as short as possible to reduce cost and head loss. However, the shortest route may not be technically feasible or necessarily the cheapest.

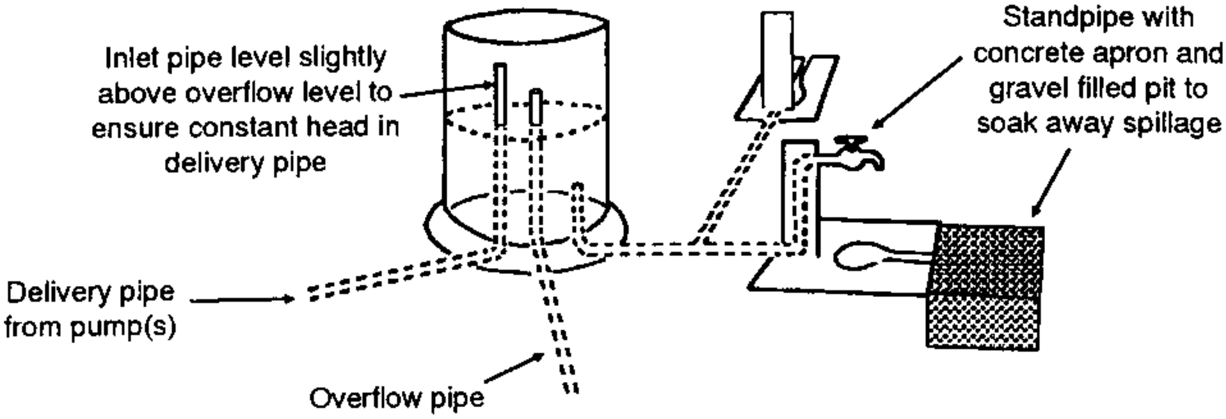
The sketch below shows a system with three possible delivery routes.

- Route A follows the lowest ground for much of its length: it is not recommended because a large section of the pipe is under high pressure and high pressure pipe tends to be more expensive;
- route B takes the most direct line but is not recommended because it has high points in which air would collect, causing air locks and reducing delivery flow;
- route C is the best route, rising quickly from the pump and then following a steady upward incline to the delivery tank. Only a short length of pipe is under high pressure and the line is fairly direct. A spur off the delivery pipe below the delivery tank should never be installed.



Distribution system

After installation and commissioning, most of the components of a ram pump system are forgotten by the users of the water supplied. The water is collected every day from stand pipes and it is the design of this distribution system that will be most relevant to them. It is particularly important to involve the whole community in the design of the distribution system and that the social organisation of water use is planned before construction.



Most ram pump systems for domestic use will require a storage tank at the end of the delivery pipe. A ram pump operates for 24 hours each day, so the water pumped overnight must be stored for use during the times of peak demand. If there is to be more than one storage tank, the water should be pumped to the highest one and then fed by gravity down to the others. Alternatively, if valves are fitted on the inlets to each tank (except the highest one) the flows can be controlled so that all subsidiary tanks fill at the same rate. The total capacity of the delivery tank or tanks in the distribution system must be large enough to hold all of the water pumped overnight. They should therefore be sized to hold at least 12 hours supply and preferably 16 hours supply. The storage requirement can be calculated using the rule:

$$\text{Storage required in litres} = \text{delivery flow in litres/minute} \times 60 \text{ minutes} \times 16 \text{ hours}$$
$$= q \times 960$$

Thus, for each litre per minute of delivery flow, provide about one cubic metre (= 1000 litres) of storage.

The delivery tank should either be conveniently situated for direct use or feed water into a distribution system. In many cases distribution can be directly through stand pipes connected to the delivery tank and fed by gravity. Larger systems serving bigger communities may require a number of distribution points each with a secondary storage tank and stand pipes. These tanks can either be assigned a priority — where the overflow from one tank feeds the next in a chain — or can be fed equally from the main delivery tank.

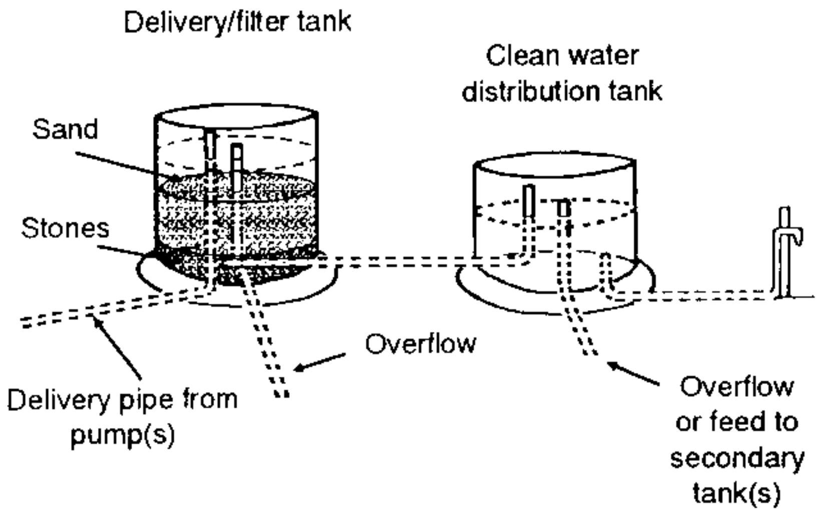
Single and multiple tank delivery systems

Single delivery tank

Priority chain delivery system

Equal priority multiple tank delivery system

Water drawn from springs and high mountain streams is often very clean and can be used without any form of treatment. Where the water to be used in a ram pump system is drawn from a dirty source, filtration of the water delivered may be necessary. Simple sand filters when carefully installed and maintained can be very effective in improving water quality. The details of filter design and construction can be found in many publications and are beyond the scope of this book. From a system design point of view, however, it is worth noting that the delivery tank can itself be a filter tank as shown below. The delivery/filter tank feeds clean water to a second storage tank from which water is drawn for use. The top of the link pipe in the distribution tank should be a few centimetres higher than the level of the sand in the filter tank; this ensures that the sand never dries out.



CHAPTER 4: Design assessment procedure

This chapter describes in detail the process of assessing the site, choosing a pump house location and selecting a suitable pump (or pumps). The actual procedure used by system surveyors and designers varies widely from region to region depending on their experience and the type of system installed. The flow chart on pages 40 and 41 may be used to assess the potential of a site and then to select values for each of the main system variables involved. The design process is broken down here into a series of steps (with questions to be answered and actions to be performed) which cover most practical cases of water lifting using ram pumps.

Each of the steps in the flow chart is explained in detail in the numbered notes. Equations are given for the calculation of system variables where relevant.

The design process is divided into five stages:

- A **collecting the data,** both about the pump to be used and the site being assessed, that will be needed for the calculations that follow;
- B **eliminating unsuitable sites or pumps** to ensure that the pump selected is capable of operating under the limitations of the chosen site;
- C **finding the maximum possible output (delivery flow) of the site** to check whether the site is able to produce the output required by the users;
- D **selecting the optimum drive head, the drive flow and number of pumps;**
- E **finalising design** by choosing a good location for the pump house.

In situations where a range of pump sizes are available, first choose one size of pump to be used in the calculations. If the calculations show that too large a number of pumps of this size would be required at the site (the pump is too small), or that the first choice of pump is too big, choose another size of pump from the available range and work through the calculations again. The process can be carried out for a number of pumps and the costs of each system calculated to enable a comparison to be made.

The notes on Stage A of the design procedure are given on pages 38 and 39, before the flow chart. The notes on Stages B, C, D and E are on the pages following the chart.

Notes on stage A

Data from the pump specification

Every design of ram pump has a range of input and output conditions under which it can operate. In most cases these are quoted by the manufacturer or in the pump designs.

system efficiency, η The efficiency of a pump indicates how much of the power input to the pump is converted into useful power output. The value of efficiency will change depending on the setting of the pump and the site variables. High efficiencies are normally associated with drive flows at the lower end of a pump's range, while lower efficiencies can be expected at high drive flows. Manufacturers will often give a typical value of efficiency for their pump to be used in calculations. To allow for energy losses in the drive and delivery pipes, subtract 6 per cent from the *pump* efficiency to get a *system* efficiency η to use in the design calculations. If no pump efficiency is given, a figure of 50 per cent should be assumed for system efficiency.

drive flow of pump, Q_p There will be a range of drive flows, the minimum being the lowest flow needed to produce the pumping action ($Q_{p,min}$), and the maximum the peak flow of water that can be put through the pump ($Q_{p,max}$). The actual flow conditions will depend on the variables of the site, and also on the tuning of the pump's impulse valve. For design purposes, an average or typical drive flow ($Q_{p,av}$) must be assumed. This is the rate of flow that lies midway between the pump's quoted maximum and minimum drive flows.

minimum drive head, $H_{p,min}$ Ram pumps are capable of operating over a very wide range of drive heads. Manufacturers may recommend a minimum drive head for their pumps. Many pumps will run with drive heads of much less than 1m but, under normal conditions, the minimum for a useful output will be 2m.

maximum delivery head, $h_{p,max}$ All pumps have a recommended maximum delivery head at which they can safely and reliably operate. If this is exceeded, a pump may continue to work, but the high stresses during operation will lead to rapid failure. When the maximum delivery head for a particular pump is not known, it can be assumed to be 100m for a steel pump.

Data from the site survey

maximum supply flow, Q_{max} The flow in most springs and streams has a seasonal variation that reflects the rainfall pattern of the region. Whenever possible measurements of source flow should be made during the dry season when the flow is at a minimum. The maximum available source flow for reliable use in a ram pump system should be taken to be 90% of the lowest flow experienced during the year. This makes an allowance for more extreme conditions and any unexpected seasonal or temporary variations. The maximum supply flow available, Q_{max}, is the same as the maximum available source flow. Q is the total source flow actually used.

maximum supply head, H_{max} The maximum possible supply head (H_{max}) of a system is defined as the head available to a ram pump when the feed and drive pipes are as long as is operationally and economically possible. Most ram pump sites are limited by the gradient of the watercourse or valley to a maximum drive head that it is practical to achieve. Pump manufacturers usually specify a maximum drive head from which their pumps can be safely operated but if none is given, assume a maximum of 30m. At sites where it is possible to achieve very large drive heads, the maximum drive head must be limited to that of the pump. For design purposes, the drive head (H) of a ram pump is taken as the height from the top of the pump's impulse valve to the water level at the *intake*. In practice there will be some friction in the feed pipe which will cause a small head loss between the intake and the drive tank, so the actual drive head during operation is the height difference between the top of the pump's impulse valve and the water level in the *drive tank*.

delivery flow required, q_{req} The water requirements of the users should be accurately assessed during the site survey. The assessment should be based on the number of people and animals that will use the delivered water. The table below gives some typical figures for water requirement.

TYPE OF USER		LITRES OF WATER PER PERSON/ANIMAL EACH DAY
Domestic use		
Rural village	with no distribution system	7-10
	with communal standpipes	20-25
	with standpipes in each property	50-100
	with water to each property but without flush toilets	100-200
	with water to each property with flush toilets	200-350
For schools, per pupil		10-15
For hospitals, per patient bed		100-400
Animal use		
Small livestock (rabbits, chicken, ducks)		2-5
Medium livestock (goats, sheep, pigs)		10-20
Large livestock (cattle, donkeys, horses)		20-50

The total requirement can be converted from litres per day to litres per minute using the following equation:

$$\text{Litres per minute} = \frac{\text{litres per day}}{1440}$$

as there are 1440 minutes in a day.

When designing for a village water supply an allowance should be made for a growth in population. The total delivery flow (q_{req}) needed from the ram pump system is therefore the total current water requirement plus an allowance for growth (e.g. 20%). An additional allowance may also be included as a safety factor.

height from intake to delivery, h^1 During the site survey the location of a spring or potential small dam will have been identified. h^1 is the measured rise in height from the water level at this system intake to the (highest) point at which water is to be delivered.

Flow chart of system design process (see notes on each stage)

A COLLECT THE DATA NEEDED FOR THE CALCULATIONS

From the **pump specification** get

- system efficiency, η
- minimum drive flow, $Q_{p,min}$
- average drive flow, $Q_{p,av}$
- maximum delivery head, $h_{p,max}$
- minimum drive head, $H_{p,min}$

From the **site survey** get

- maximum supply flow available, Q_{max}
- maximum supply head available, H_{max}
- delivery flow required, q_{req}
- height from intake to delivery, h^1

B ELIMINATE UNSUITABLE SITES OR PUMPS

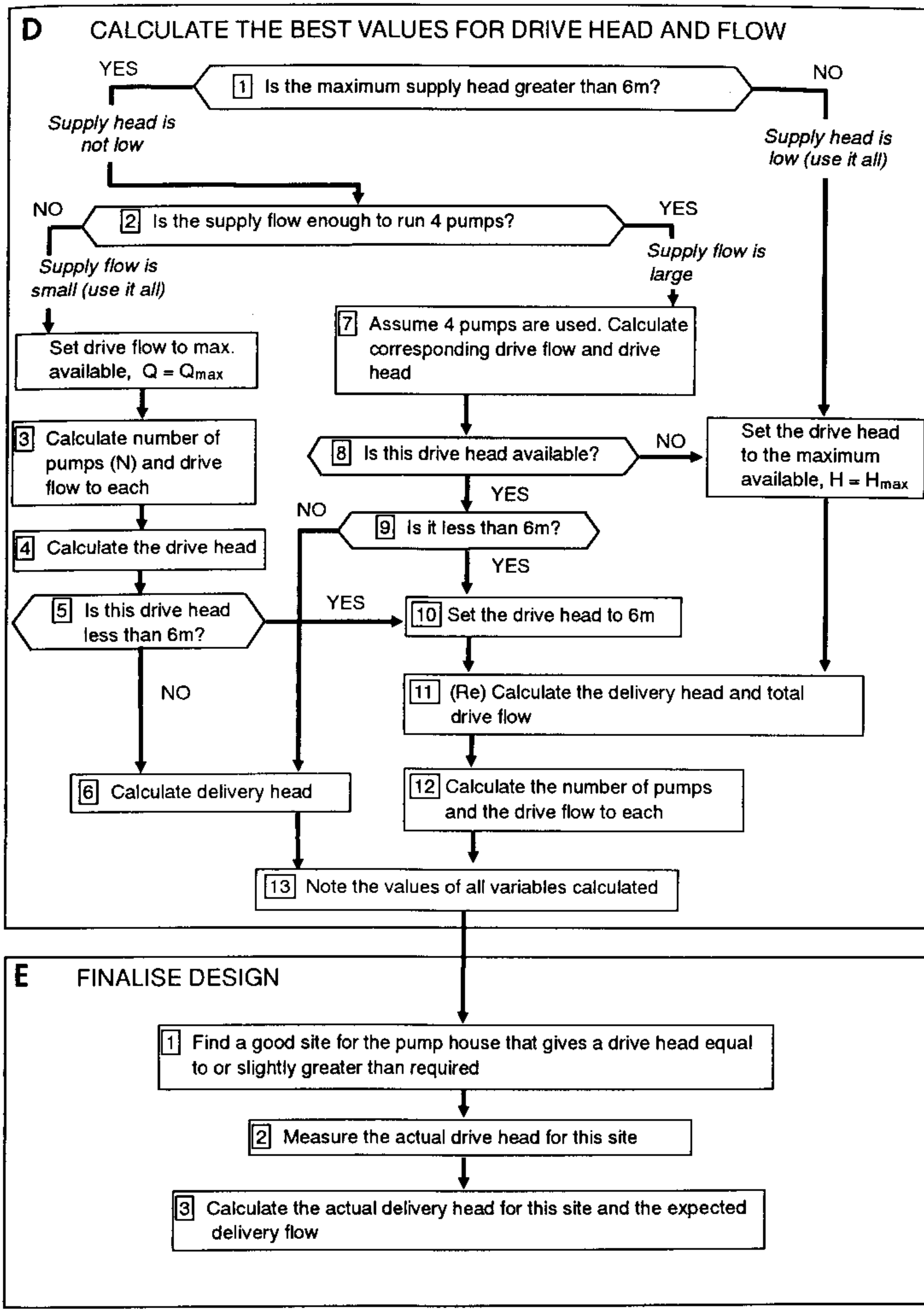
1. Is the maximum delivery head of the pump sufficient? — NO → STOP; YES ↓
2. Is the site's maximum supply head greater than the minimum drive head of the pump? — NO → STOP; YES ↓
3. Is the maximum supply flow reliably available at the site greater than the minimum drive flow of one pump? — NO → STOP; YES ↓

The chosen pump will work at this site

C CHECK THAT THE SITE WILL GIVE THE REQUIRED FLOW

1. Set the system drive head and drive flow to their maximum possible values for this site
2. Calculate the static delivery head for the site
3. Calculate the maximum delivery flow that could be pumped
4. Is this flow greater than the delivery flow required? — NO → STOP; YES ↓

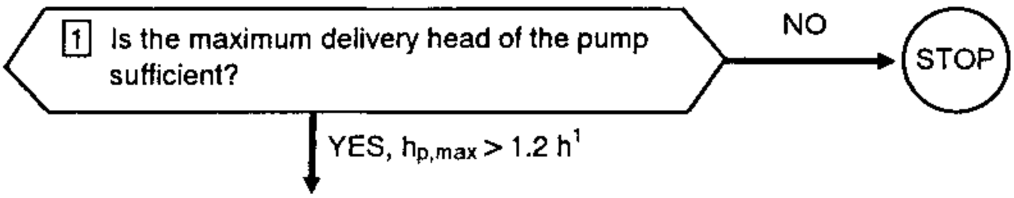
The site is capable of meeting the need — GO TO STAGE D


D CALCULATE THE BEST VALUES FOR DRIVE HEAD AND FLOW
1 Is the maximum supply head greater than 6m?
YES
Supply head is not low
NO
Supply head is low (use it all)
2 Is the supply flow enough to run 4 pumps?
NO
Supply flow is small (use it all)
YES
Supply flow is large
Set drive flow to max. available, Q = Qmax
3 Calculate number of pumps (N) and drive flow to each
4 Calculate the drive head
5 Is this drive head less than 6m?
YES
NO
6 Calculate delivery head
7 Assume 4 pumps are used. Calculate corresponding drive flow and drive head
8 Is this drive head available?
NO
Set the drive head to the maximum available, H = Hmax
YES
9 Is it less than 6m?
NO
YES
10 Set the drive head to 6m
11 (Re) Calculate the delivery head and total drive flow
12 Calculate the number of pumps and the drive flow to each
13 Note the values of all variables calculated
E FINALISE DESIGN
1 Find a good site for the pump house that gives a drive head equal to or slightly greater than required
2 Measure the actual drive head for this site
3 Calculate the actual delivery head for this site and the expected delivery flow

Notes on stage B: Eliminate unsuitable sites

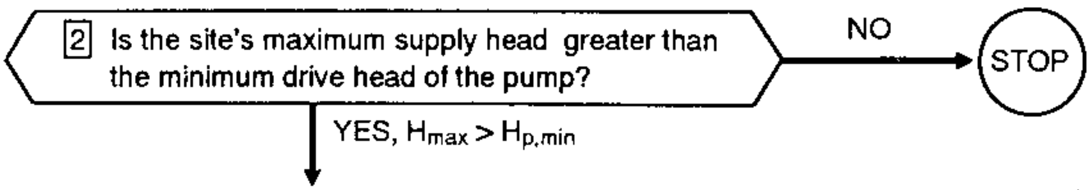
The measured variables of a site must first be checked against the particular limitations of the pump being used. Three steps are necessary.

Step 1



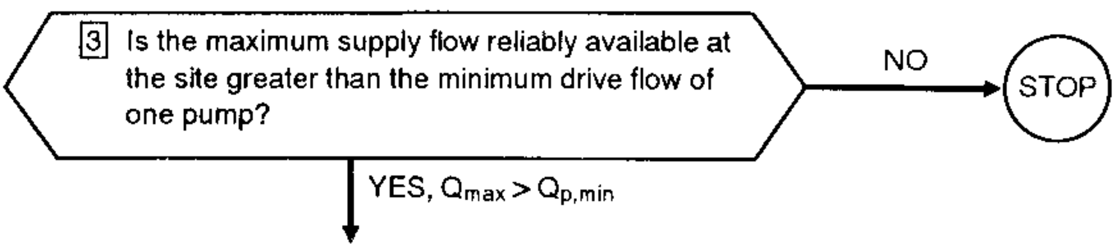
To test whether the pump is strong enough we need to compare the maximum head to which it can reliably deliver with the delivery head it will experience on this site. The dynamic delivery head (experienced when the system is running) is the delivery head h, plus the friction head loss in the delivery pipe. From the geometry of the site, $h = h^1 + H$, where H is the drive head and h^1 the rise from the system intake to the system delivery. At this stage in the calculations we have not yet decided what value H should have, and we do not know the delivery head loss. So, as a convenient and reasonable approximation, we use 1.2 times h^1 instead of the unknown dynamic head for the purposes of this test. If $h_{p,max}$ is less than 1.2 times h^1, the pump is not strong enough and either a stronger pump or a site with a smaller delivery head must be chosen.

Step 2



If only a very small supply head is available (H_{max}), check that it is larger than the minimum ($H_{p,min}$) from which the pump can operate with a reasonable output. If the available head is too low it may be possible to select a different pump that is capable of using the low head, but a site with a higher head will probably be required.

Step 3



Check that the maximum supply flow available (Q_{max}) at the site is greater than the minimum drive flow ($Q_{p,min}$) required by one pump. If there is not enough water to run the pump, a smaller pump may be used, or a site with a greater supply flow must be found.

Notes on stage C: Check that the site will give the required flow

This stage aims to establish the maximum possible delivery flow (q) from the site if all the available supply flow (Q_{max}) and drive head (H_{max}) are used.

Step 1

[1] Set the system drive head and drive flow to their maximum possible values for this site

$Q = Q_{max}$
$H = H_{max}$

Assume that the flow to be used by the system will be the maximum supply flow available (Q_{max}) and that the drive head will be the maximum possible for the site (H_{max}).

Step 2

[2] Calculate the static delivery head for the site

$h = H_{max} + h^1$

The static delivery head (h) to which the pump must lift water can be calculated now that a value for the drive head has been chosen.

Step 3

[3] Calculate the maximum delivery flow that could be pumped

With the optimum site variables known, the maximum delivery flow possible using the selected pump at the particular site can be calculated.

The basic system efficiency equation: $\eta = \frac{qh}{QH}$ can be rearranged to give: $q = \frac{QH\eta}{h}$

Substitute the values for Q_{max}, H_{max} and h for the site and η for the chosen pump, in order to calculate the maximum delivery flow, q_{max}.

Step 4

[4] Is this flow greater than the delivery flow required?

NO → STOP

YES, $q_{max} > q_{req}$ ↓

The calculated maximum delivery flow (q_{max}) that can be produced by the site and chosen pump should be greater than the delivery flow required (q_{req}) to meet the users' anticipated needs. If the maximum delivery flow is greater than required, the system is viable and further design (see Section D) can be undertaken. If the maximum delivery flow is less than required, another pump with a higher efficiency must be used, an alternative site with greater potential must be found, or the requirement for water must be reduced.

Notes on stage D: Calculate the best values for drive head and flow

The site surveyed can produce sufficient water to meet the users' requirements. The actual drive head (H) and drive flow (Q) to be used can now be chosen and detailed system design carried out.

Step 1

1 Is the maximum supply head greater than 6m?

YES → *Supply head is not low*

NO → *Supply head is low (use it all)*

In situations where the drive head is quite low (under 6m) the maximum drive head available (H_{max}) should be used. Where the drive head available is greater than 6m, a balance between drive head and drive flow must be found in order to give the required delivery flow.

Step 2

2 Is the supply flow enough to run 4 pumps?

NO → *Supply flow is small (use it all)*

YES → *Supply flow is large*

In theory it is possible to have however many pumps are needed to produce the required delivery flow, but system layout and cost impose some practical limitations. In most circumstances it is unusual to have more than four ram pumps running in parallel. The normal drive flow ($Q_{p,av}$) required for the chosen pump is already known. If the maximum supply flow (Q_{max}) is less than the flow required to supply four pumps ($4 \times Q_{p,av}$), all the supply flow should be used and the drive head adjusted to achieve sufficient delivery flow. If there is a large supply flow available — that is greater than the drive flow required for four pumps — the total drive flow to be used should be fixed as four times the drive flow for one pump.

Step 3

3 Calculate number of pumps (N) and the drive flow to each

N will rarely be a whole number like 2 or 3. Fortunately most pumps have a range of drive flows within which they can operate. The number of pumps (N) can be calculated using the equation alongside.

$$N = \frac{Q}{Q_{p,av}}$$

Reduce N to the nearest whole number and calculate the drive flow (Q_P) required from each pump using the equation alongside.

$$Q_p = \frac{Q}{N}$$

If the calculated drive flow per pump (Q_P) is within the range of the chosen pump, then N pumps will be enough to use the available supply flow.
If the calculated drive flow per pump (Q_P) is above the range of the chosen pump, increase N by one and use the new figure for N to recalculate the flow ($Q_P = Q/N$) for each pump.

Step 4

[4] Calculate the drive head

$$H = \frac{h^1 q_{req}}{\eta Q - q_{req}}$$

The drive head can be calculated using the equation alongside.

Step 5

[5] Is this drive head less than 6m? — YES → ; NO ↓

The maximum supply head (H_{max}) of this site is greater than 6m (Step 1). Under these circumstances the drive head to be used should be at least 6m. If the drive head calculated in Step 4 is less than 6m, the head to be used should be set at 6m and the number of pumps and the drive flow required recalculated. (Steps 10 to 12.)

Step 6

[6] Calculate delivery head

$$h = H + h^1$$

The total drive flow and drive head required to produce the delivery flow (q) have been determined, as have the number of pumps (N) and the drive flow to each (Q_P). The only remaining system variable, the static delivery head (h), can now be calculated using the formula above.

Step 7

[7] Assume 4 pumps are used. Calculate corresponding drive flow and drive head

$$Q = 4Q_{p,av}$$

$$H = \frac{h^1 q_{req}}{\eta Q - q_{req}}$$

When there is a large supply flow available, set the total drive flow (Q) of the system as four times the average drive flow of one pump. The drive head (H) required can then be calculated.

Step 8

[8] Is this drive head available? — NO → ; YES ↓

If the required drive head (H) calculated in Step 7 is less than the maximum supply head (H_{max}) available on the site, four pumps should be used. If the required drive head is greater, the maximum available drive head must be used ($H = H_{max}$) and the number of pumps required to give the necessary delivery flow recalculated (see Step 12).

Step 9

[9] Is it (the drive head) less than 6m — NO ← ; YES, H < 6m ↓

The maximum supply head (H_{max}) of this site is greater than 6m (from Step 1). If the drive head calculated in Step 8 is less than the minimum value of 6m, it should be increased (Step 10).

Step 10

[10] Set the drive head to 6m

$H = 6$

When the calculated delivery head (H) is lower than the minimum of 6m it should be set at this minimum level.

Step 11

[11] (Re)calculate the total drive flow

$h = H + h^1$

$H = 6$

$$Q = \frac{q_{req}\, h}{H_{max}\, \eta}$$

The delivery head (h) can now be calculated, as can the total drive flow (Q) necessary under these conditions of drive and delivery head to give the delivery flow required, q_{req}.

Step 12

[12] Calculate the number of pumps and the drive flow to each

Using the value of total drive flow (Q) just calculated, follow the procedure in Step 3, page 44 to get the number of pumps (N) and the drive flow to each (Q_p).

Step 13

[13] Note the values of all variables calculated

All the necessary variables have been calculated. Make a list of the actual values to be used in the final design: drive head H, total drive flow Q, number of pumps N, drive flow per pump Q_p and delivery head h.

Notes on stage E: Finalise design

Having chosen the values of drive head and drive flow to be used in the system, the actual site for the pump house must be selected. When this is done the actual drive and delivery heads can be measured and an accurate prediction of the expected delivery flow achieved.

Step 1

> [1] Find a good site for the pump house that gives a drive head equal to or slightly greater than required

Dropping from the proposed intake level by exactly the height calculated for the drive head may not give a site suitable for the pump house. Look for a suitable site that will give a drive head close to, but always greater than, that necessary.

Step 2

> [2] Measure the actual drive head for this site

After the site for the pump house has been chosen, carefully survey the height from it to the level of the proposed intake.

Step 3

> [3] Calculate the actual delivery height for this site and the expected delivery flow

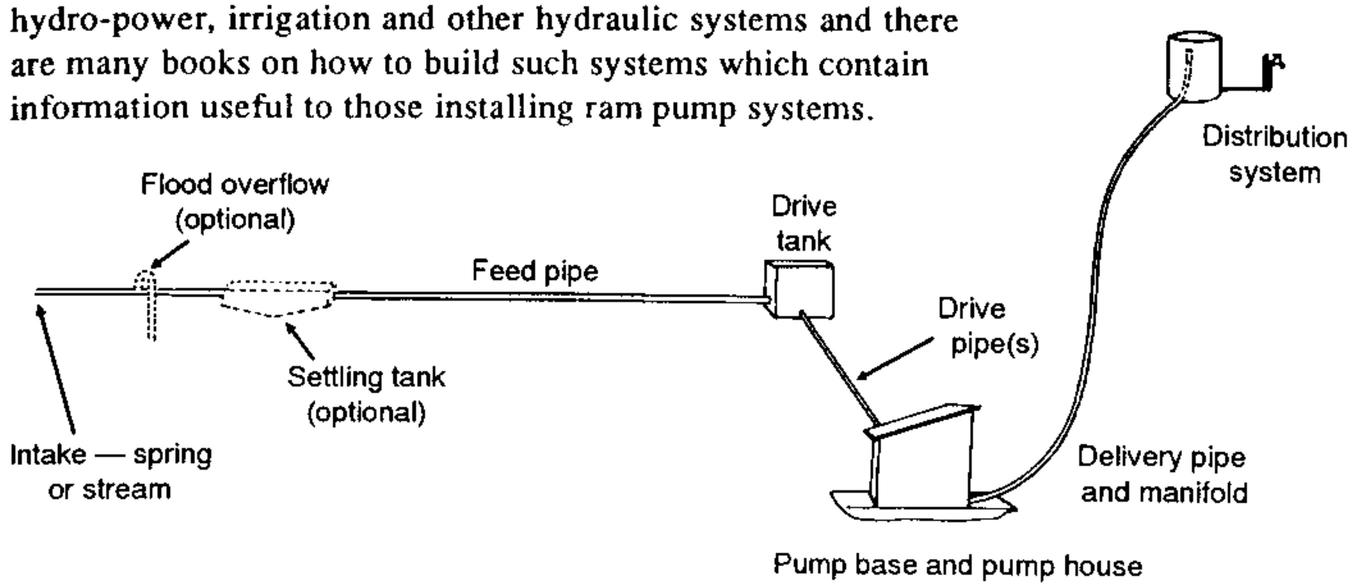
$h = H + h^1$

$q = \frac{QH\eta}{h}$

With the drive head (H) known, the static head against which the pump must deliver can be found. The recalculated delivery flow (q) can be regarded as the expected flow to the users of the system. Check that this flow is greater than that required and that the dynamic delivery head (about 1.1 x h to allow for friction head losses) and drive head (H) are below the maxima for the chosen model of pump.

CHAPTER 5: System construction

This chapter describes in some detail how each component of a ram pump system (except the pumps themselves) can be built. It has, however, been written on the assumption that any system will be constructed by experienced builders, so the basic principles of building are not covered. Moreover, certain components, for example dams, are given only brief descriptions because space does not allow a thorough coverage of the many methods for their construction. Many components of ram pump systems are identical to those in hydro-power, irrigation and other hydraulic systems and there are many books on how to build such systems which contain information useful to those installing ram pump systems.

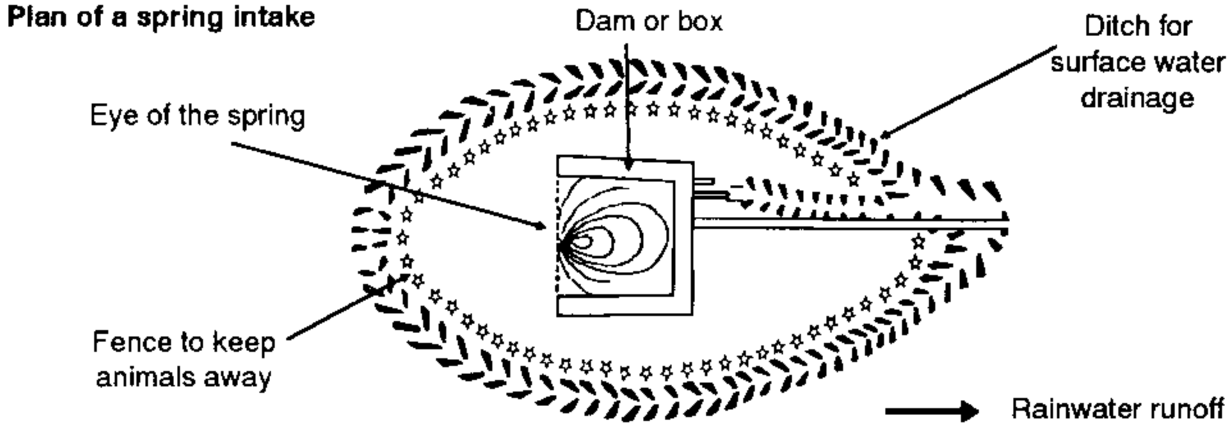


Spring intakes

Although spring intakes are not complicated structures, they do need to be planned and built carefully. Details of the various designs of spring intakes in widespread use can be found among the literature listed for further reading in Appendix C. The common features of all these designs are:

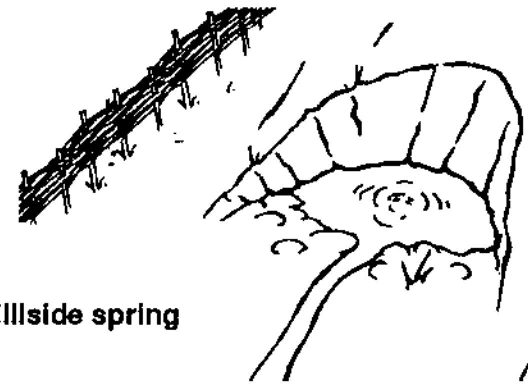
- the construction of a dam or 'box' to collect the spring water;
- the provision of a cover or roof to protect the collected water from contamination;
- the diversion of any water that flows along the ground surface (e.g. during storms) so that it does not mix in with the spring water.

Plan of a spring intake



The nature of a spring is such that it can easily change its course and emerge in a new place. It is essential to avoid disturbing the site more than is necessary during construction, and to avoid raising the level of the water leaving the spring by not building an intake structure that extends high above the existing level. Even a small increase in level can lead to the water finding a lower point at which to emerge and the original spring drying up.

The first step when constructing a spring intake is to remove loose material or earth around the spring and uncover its actual source — known as 'the eye' of the spring. On soft ground, the water often flows from the ground in several places close together rather than at a single point. When the source has been uncovered the intake can be planned so that it traps as much of the flow as possible.


Hillside spring

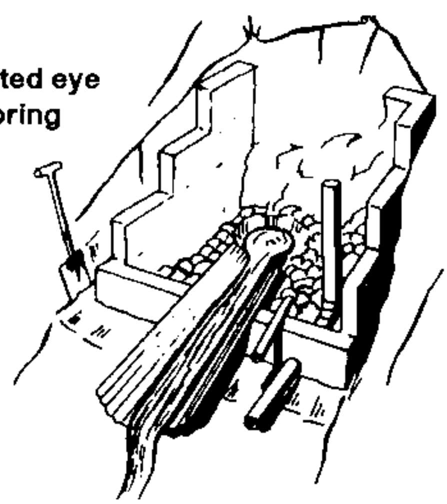
There are three main categories of spring:

Hillside springs — where the water emerges from an earthen hillside. In these cases a low V shaped dam is usually enough to channel the spring flow.
Valley floor springs — where the water emerges on level ground. In these cases the intake structure should be a ring wall encircling the spring.
Rock springs — where the spring emerges in rocky ground. In these cases a simple dam can often be firmly anchored to the surrounding rock.

Foundations

A rocky site is often the easiest to build an intake on. It is usually relatively easy both to locate the eye of a rock spring, and to build a simple intake structure on a foundation that is already secure. The water may have to be temporarily diverted during construction.

Similar diversion methods may have to be employed when building an intake on porous ground. Porous material beneath the planned dam must be excavated until an impervious layer is reached, or until dry material is being removed. Ideally the excavation should be deep enough to reach impervious material, but where this is not possible the porous material should be removed to a depth of at least 500mm so that it will be easier for the water to flow through the outlet pipe than to go around or under the dam.



Flow diverted during construction

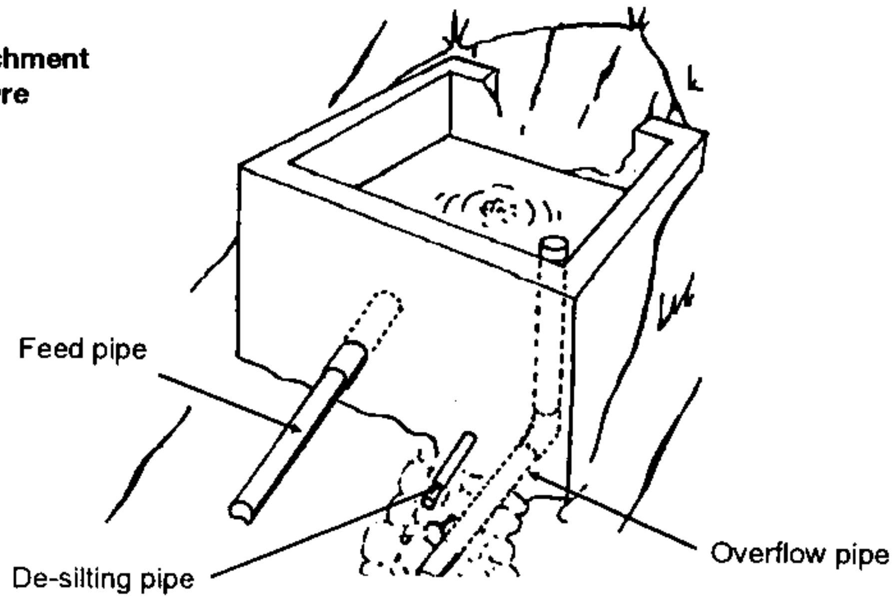
Construction

The intake can be constructed from a wide range of materials, although rock or concrete and cement is often preferred. The walls should be high enough to collect all the water without raising the spring level unduly. Typically a height of 200-400mm is sufficient.

Three pipes should pass through the intake wall:

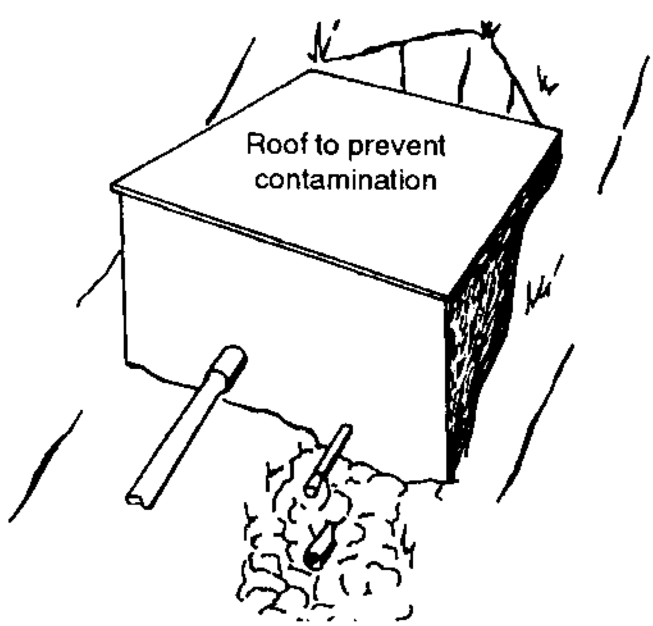
- The de-silting pipe is plugged in normal use and is unplugged to flush silt from within the intake structure. It should be positioned to emerge at ground level inside the dam wall.
- The outlet pipe carries the collected water to a connection with the feed pipe. It should be positioned 50-100mm above the ground level inside the dam wall.
- The overflow pipe carries excess water safely beyond the foundations of the intake structure. It also acts as a relief pipe in the event of the outlet pipe becoming blocked. It should be positioned 50mm above the level of the outlet pipe.

Spring catchment structure



The water should be able to flow freely to collect in the intake structure. Intakes on hills must also be protected from being filled by loose material moving down the hillside. Protection is achieved by filling the area behind the dam with selected rocks (50-100mm diameter). The water flows freely between the rocks, and the earth or large stones that might block the flow are excluded.

To prevent contamination of the water, the intake structure should be covered with a roof, such as a concrete slab. A cheaper alternative is to cover the entire dam and rock infill with a plastic sheet, then bury it under earth. When the latter method is used, the protecting layer of earth should be planted with grass to prevent erosion.

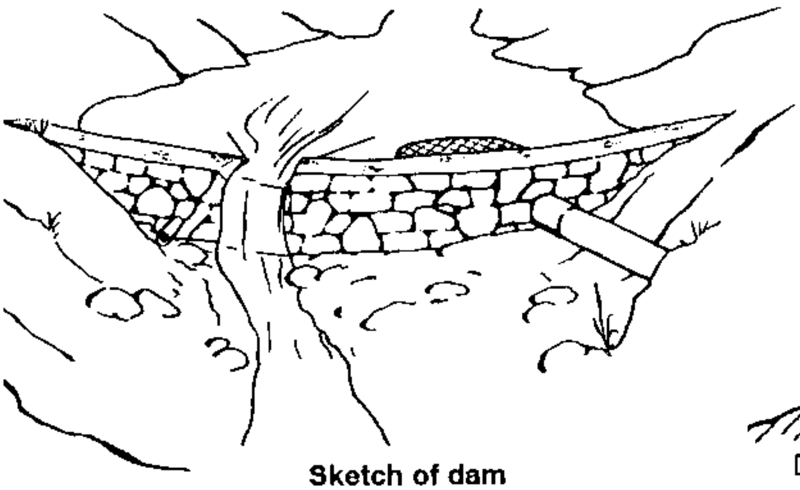


Stream intakes using dams

In systems where the chosen water source is a stream or river, a dam may be constructed to divert some or all of the flow into the feed pipe. Such dams are very small and simple, typically only 600mm high, and may need to be rebuilt after severe floods. Construction is best carried out in the dry season when the flow of water is at a minimum. Some types of dam or weir can be built in the watercourse without having to divert the water around the construction site. In other cases it is necessary to build on a fairly dry site (particularly where cement is used) and so a temporary diversion of the flow is required. This can be achieved by building a temporary dam upstream of the site and diverting the water through a channel or large pipe.

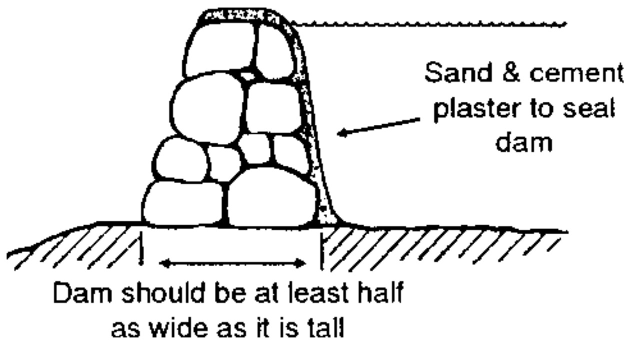
Rock and cement dam

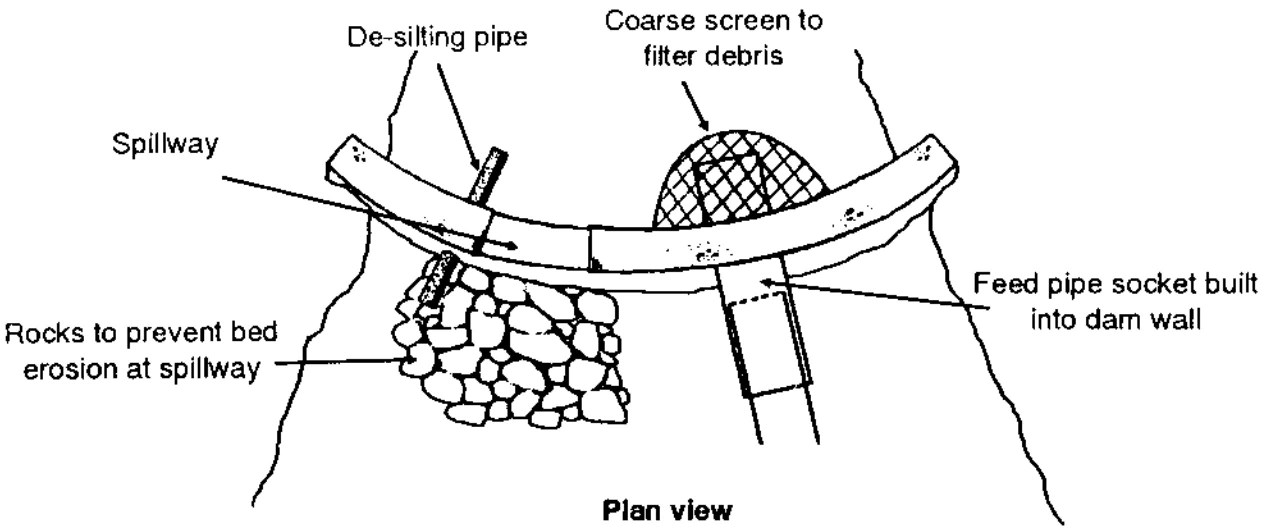
This type of dam is particularly suitable for sites with a foundation of rock on the stream bed. Rocks and stones are cemented together to build a low dam wall extending into the banks of the stream.



Sketch of dam

Section through dam



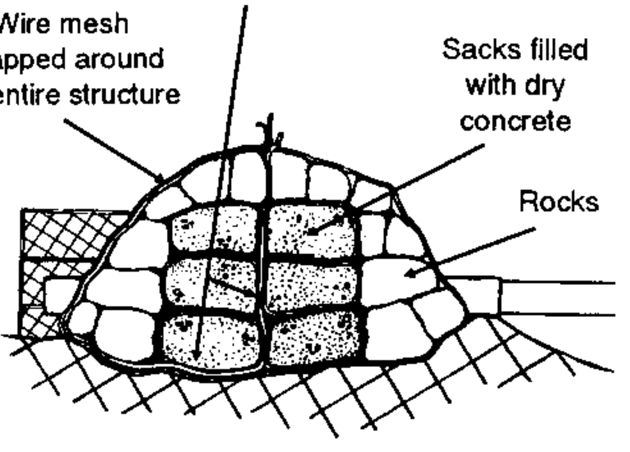


Plan view

Gabion dam

A gabion dam has a central core of sacks that have been filled with dry concrete and then wedged together across the stream. The sacks are protected with loose rocks on both sides, and the whole structure is enclosed in strong wire mesh. (The concrete later gets wet and sets.) This kind of dam is useful where it is not possible to build onto rock foundations or where it is difficult to divert the stream. It is particularly useful for building a low weir across larger streams.

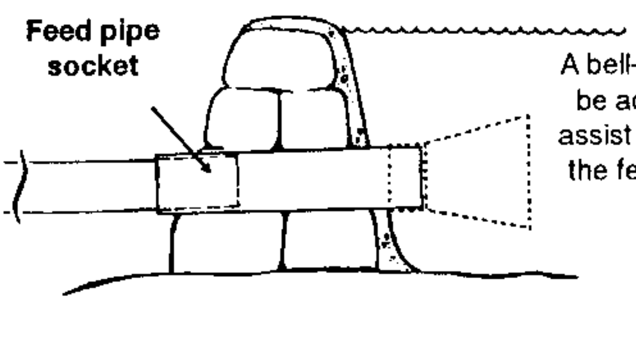
Building a gabion dam



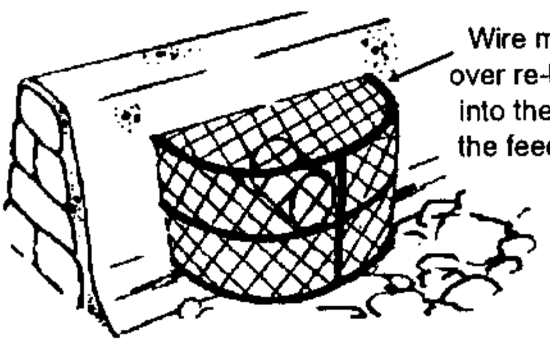
Section through gabion dam

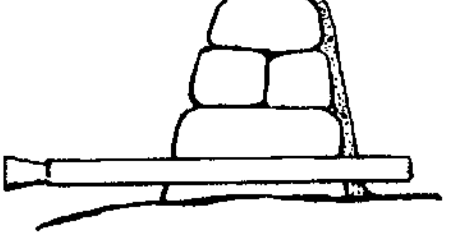
Components of a dam

When constructing a dam a number of components need to be incorporated.



The spillway must direct the overflow away from the feed pipe



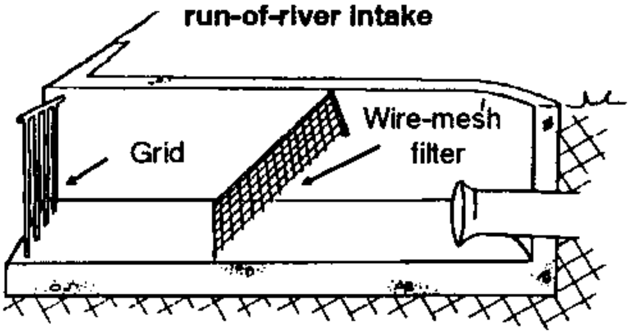


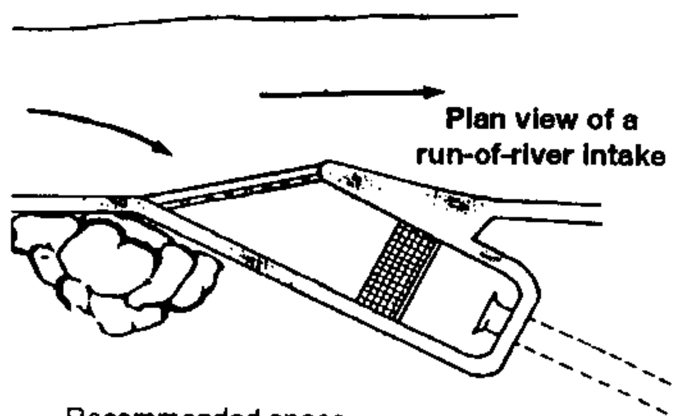
The de-silting pipe must be built into the deepest part of the dam

Run-of-river intake

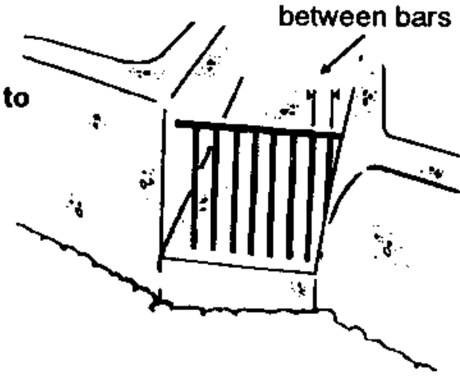
When a suitable site for this type of intake has been selected, the water must be diverted away from the bank to allow construction to be carried out. The intake is built using concrete or stones and mortar, and must be strong enough to withstand the impact of debris carried by the water flowing past it. It can be protected partly from the entry of silt and from debris rolling along the stream bed by raising the base of the intake above bed level. The inclusion of a grill made from welded steel bar across the mouth of the intake ensures that large floating debris and stones carried by floodwater are kept out.

Section through run-of-river intake





Plan view of a run-of-river intake

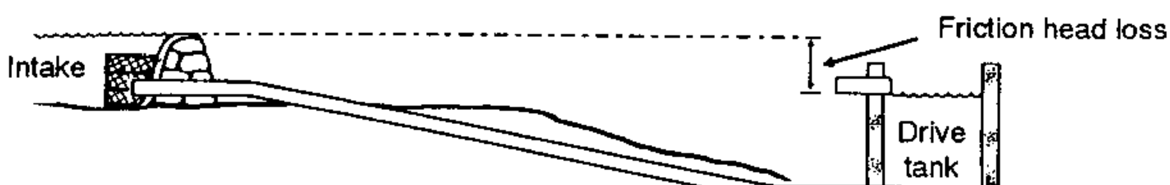


Grill and step-up at entrance to run-of-river intake

Feed pipe

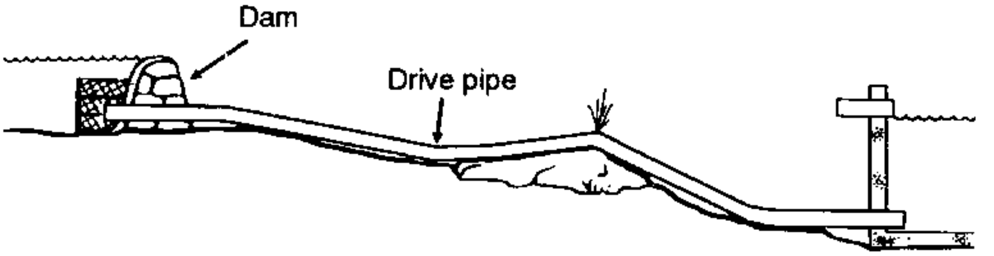
Water is brought from the intake using a feed pipe or a channel. Pipes are preferred because they generally require less skill to install and less maintenance; moreover they protect the water from contamination. Channels are generally used when the flow would be too great for a readily available size of pipe or when the feed pipe would be very expensive and the skills for building a channel are available.

The feed pipe must be big enough to ensure that the pump(s) are adequately supplied. A pipe that is bigger than required is far better than one that may be too small, but restrictions on cost and the need to keep high water velocity make accurate sizing quite important (see Appendix D). Notice that there will be a friction head loss over the length of the pipe. Under flow conditions this will make the level in the drive tank lower than the level in the intake

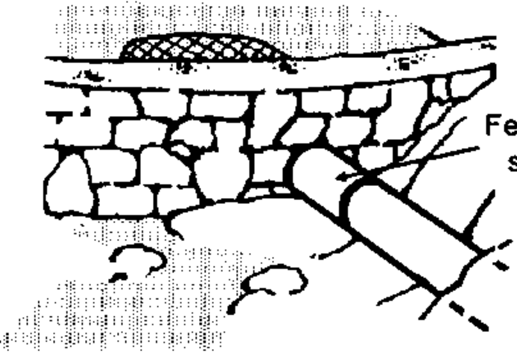


structure. The friction between the water and the pipe increases (for a given diameter and type of pipe) the longer the pipe and the larger the flow through it.

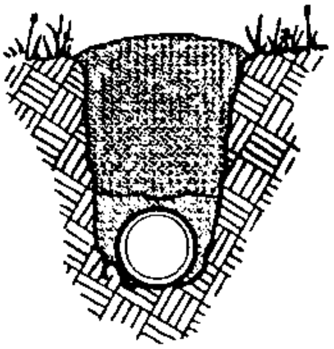
Try to give the pipe a straight run, falling with an even gradient. Avoid putting a rise in the pipe as this may cause an air lock. If there must be a high point, drill a small (eg 3mm) hole to allow the air to escape.



A socket should be built into the catchment structure, into which the feed pipe will fit. When the feed pipe needs to be removed, its first section can be pushed back through the socket to separate the nearest joint.

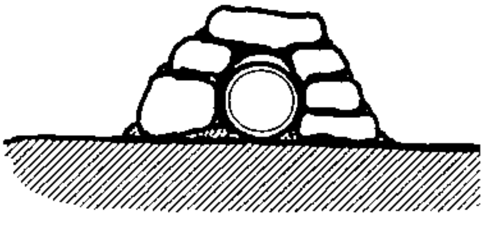


Where possible the feed pipe should be buried for protection. The minimum depth for burial is 300mm. Use sand or fine soil to fill the first 100mm. Coarser material can be used higher up the trench. Finish the infilling with a mound to allow for settling. If the pipe has to run across agricultural land, it should be buried 300mm deeper than the depth of tillage. If the pipe has to run across a road it should be further protected by a layer of flat stones bridging the trench half way up. If the pipe has to run over an area of rock, protect it with a stone and cement cap.



Pipe buried in trench

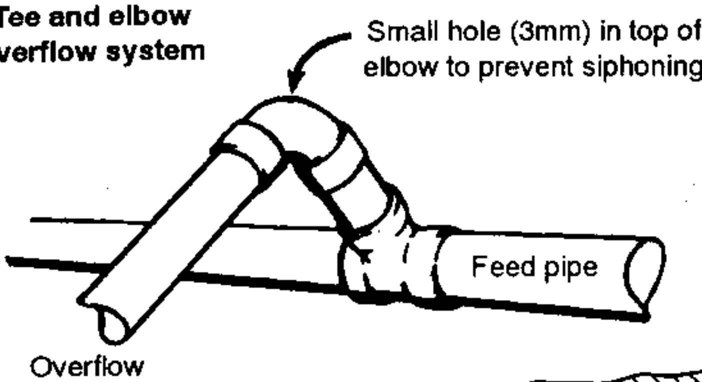
Stone and cement cap over pipe



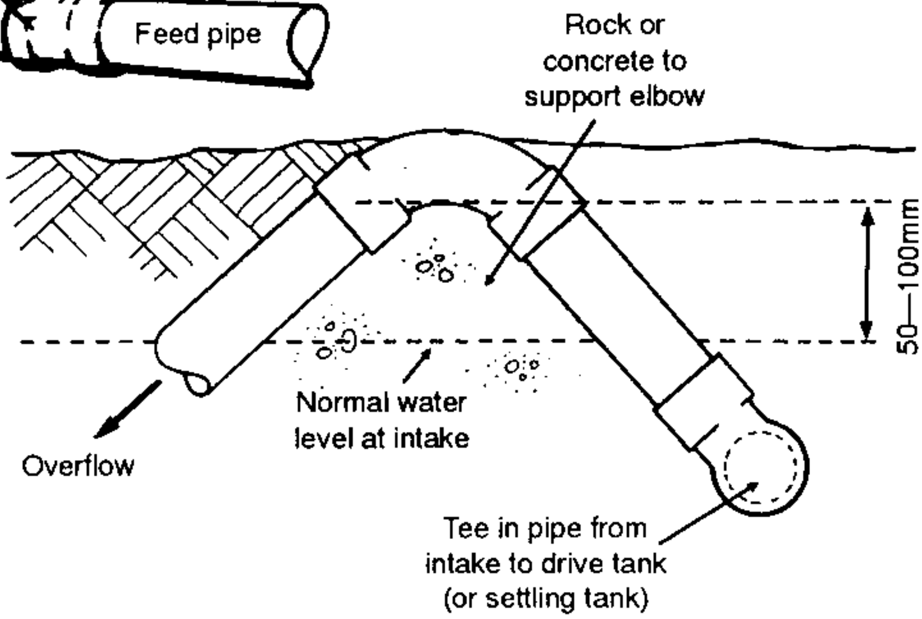
Flood overflow

A water supply system fed from a stream, whether it uses a dam or a 'run-of-river' intake, has to be able to survive flood conditions during which the water is very turbid and its level is high. If no specific flood overflow is provided, there will be large flows along the feed pipe leading to overspill at the drive tank. This will cause problems by introducing large quantities of silt into the drive tank and by making it overflow, which can cause erosion. The best protection is to provide a flood overflow close to the intake, but not so close that it will itself be submerged during floods. One design of flood overflow, using a pipe tee and a pipe elbow, is shown here. A second best alternative is to incorporate a flood overflow in any settling tank.

Tee and elbow overflow system



Section through tee and elbow overflow system



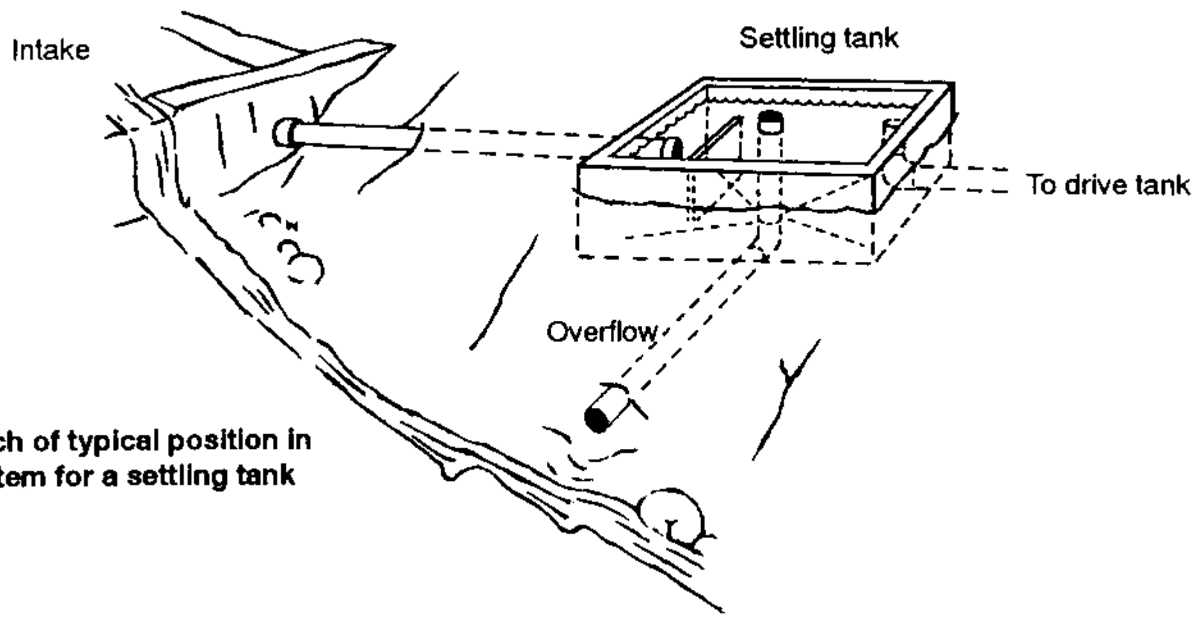
Settling tank

In many systems the source water will contain silt that is too fine to be screened out by the coarse filter inside the intake structure. Large amounts of silt in the system can quickly lead to blocked pipes and the need for regular, time-consuming, maintenance. To help reduce the amount of silt reaching the drive tank, a settling tank can be built between it and the intake. A settling tank allows the water to slow down briefly so that the silt can settle out. To achieve this the tank must, in many cases, be quite big and so can add significantly to the cost of a ram pump system.

Size

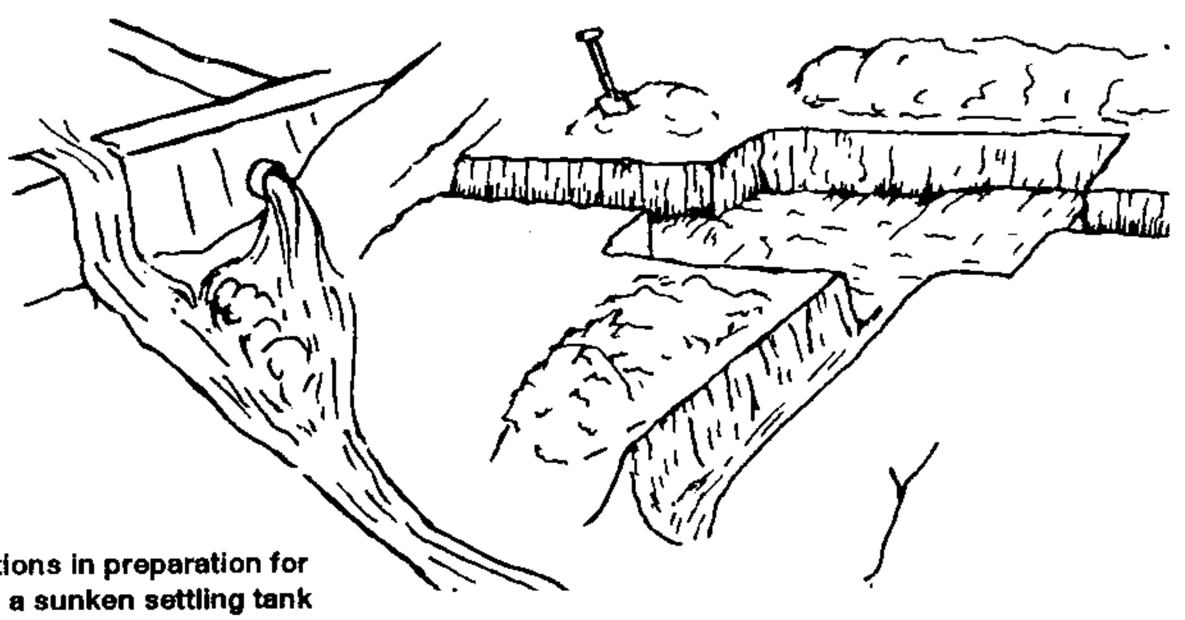
A settling tank should be sized to ensure that the velocity of the water passing through it is much lower than at any other point in the system. If pipes are correctly sized to give velocities adequate to keep silt suspended and the large particles of silt are then removed in a settling tank, there should be no further danger of pipes becoming blocked by silt build-up.

In a system without a settling tank the drive tank will normally have the lowest velocity of water movement. When a settling tank is included *it* should have the lowest such velocity. This is achieved by giving the settling tank a surface area larger than that of the drive tank. For good settling, about one square metre of surface is needed for each 20 litres per minute of drive flow (A = Q/20), but this level of provision is expensive. The depth of a settling tank is not very important: it only determines how often it needs cleaning out. The height of the rim of a settling tank above the normal water level in it should be sufficient to prevent it spilling over during flood conditions. The type of tank to be built and its final dimensions will depend on the building methods and materials available, and the layout of the chosen site.



Sketch of typical position in system for a settling tank

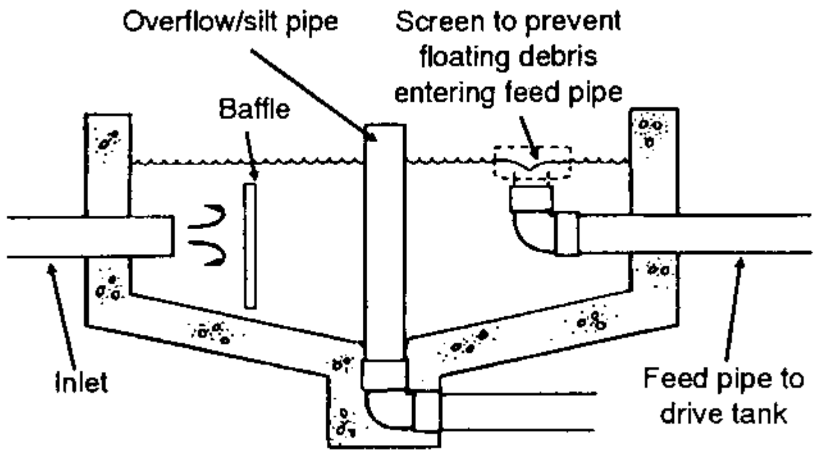
Making a settling tank by digging a pit and lining it with concrete or concrete blocks reduces the forces on the walls of the tank by providing all-around support. This can make the tank much cheaper than an above-ground version.



Excavations in preparation for building a sunken settling tank

Pipe connections to the settling tank

The inlet and outlet of a settling tank should be as far away from each other as possible and the incoming water should be spread out (by hitting a baffle) instead of flowing straight across the tank.



Section through settling tank

The outlet towards the drive tank should be fed like an overflow, taking water from the top of the tank. Although this keeps the outlet away from the settling silt, it makes it vulnerable to floating debris which will be drawn to it. A screen of wire mesh should be fixed to the end of the outlet to keep the debris out. Depending on the cleanliness of the source flow, the screen on the settling tank outlet may require frequent cleaning. A de-silting pipe should be included in the base of the tank and positioned to direct flushing water back into the watercourse. The inclusion of a de-silting pipe makes cleaning the tank much easier. Two kinds of de-silting pipe are introduced in this book. If the tank is built on soft ground, the larger diameter drain in the centre of the tank should be preferred (described under 'Drain overflow' on page 59). By removing the upright length of pipe the tank is rapidly flushed, drawing much of the silt out automatically. When a smaller de-silting pipe in the side of the tank is used, it is often necessary to sweep the silt towards it in order to flush it away.

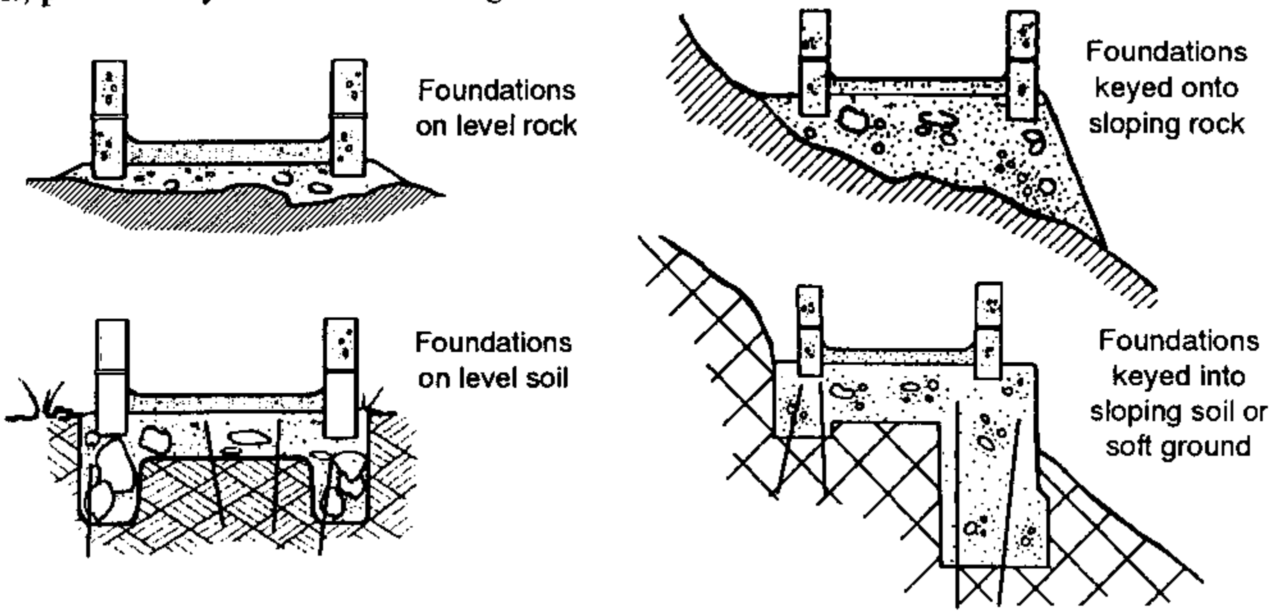
If there is no flood overflow in the pipe feeding into the settling tank, then the de-silting pipe may also have to serve as a flood overflow and should be of the drain type. The overflow level should be set 50 to 100mm above the normal water level in the tank. Where flood levels are high, two overflow pipes may be needed or the single one should be of extra large diameter. Note that the baffle mentioned above can be a board attached to this vertical overflow pipe.

Drive tank construction

The kind of drive tank to be built will depend on both the requirements of the site and the materials and skills that are available. There are a number of characteristics that must be incorporated into the finished tank whatever it is built from, and wherever it is situated.

Foundations of the drive tank

When designing and constructing a drive tank the foundations must be given careful consideration because the total weight of a drive tank full of water can be many tonnes. When available, a rock base should be used because it offers complete stability. If the rock surface is sloping, care must be taken to ensure that the foundation is properly keyed into the rock. When the drive tank has to be built on loose material, a deep, well-reinforced foundation is essential to prevent the tank settling and cracking under the weight of water inside it. If building on a slope, special care should be taken to key the foundation into the soil, particularly on the bottom edge.



It is also important to protect the area around the base of the tank from water erosion such as rainwater run-off from the hillside, or the drive tank overflowing. Both can rapidly wash away any loose material around the tank's foundation and reduce its stability. Stones around the tank or a concrete apron can help reduce the problem of rainwater run-off, and a properly designed overflow from the drive tank should prevent overflow damage.

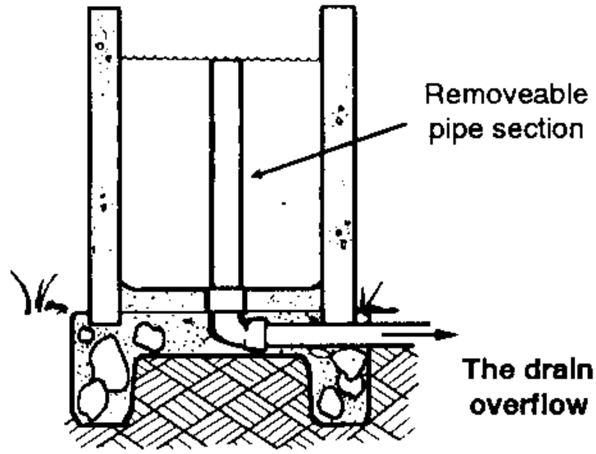
The overflow of the drive tank

The overflow pipe must be capable of carrying the full supply flow if necessary — if all the pumps are turned off, for example. To ensure this, it must be the same diameter as the feed pipe (or greater). Water passing through the overflow should be directed away from the tank and its foundations. In many cases overflow water is returned to the source watercourse directly, although it can be useful to pipe it into the pump house so that the level of overflow is easily seen when tuning the pumps. There are two main designs of overflow, one built into the base of the tank and one which passes through the tank wall at overflow height. These are referred to as the 'drain overflow' and the 'level overflow'.

Drain overflow This is made using PVC pipe and an elbow joint. The elbow joint and a section of pipe are set into the tank base during construction. A removable pipe section is then pushed into the elbow joint and stands up from the base of the tank to the desired overflow level.

The drain overflow has two main advantages:

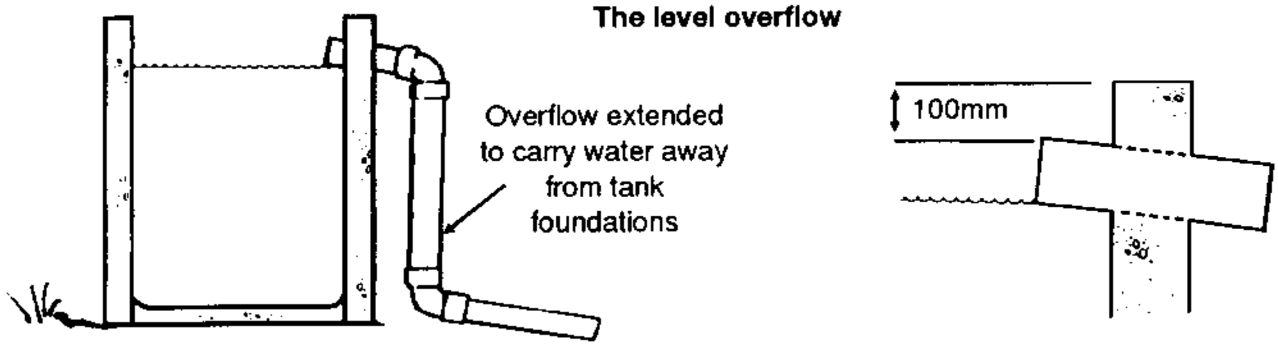
- the overflow height can be readily adjusted by cutting the removable pipe section to a new length;
- the pipe can be removed to drain and flush the tank, and therefore the overflow can also act as a de-silting pipe.



The drain overflow

Level overflow This passes through the wall of the tank at the desired water level. An overflow extension should be added to prevent overflow water causing erosion around the tank foundation.

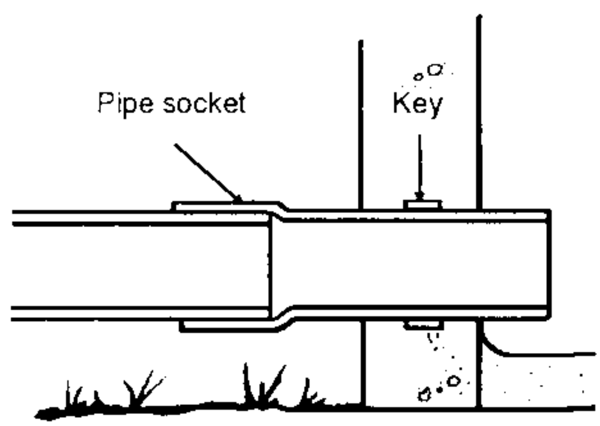
The level overflow



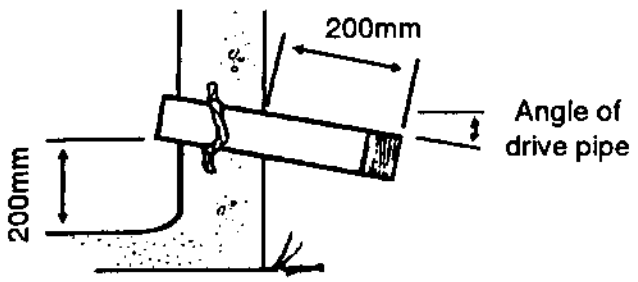
The overflow pipe should pass through the wall not less than 100mm from the top. It can be keyed into the wall in the same way as described below for the feed pipe connection.

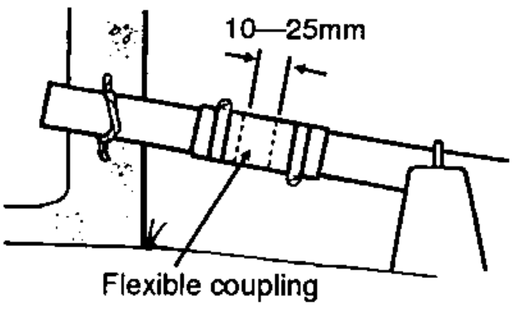
Pipe connections to the drive tank

Feed pipe connection A socket to receive the feed pipe should be set into the tank wall at a low height. The feed pipe is often PVC and a rubber sealed socket generally makes a good connection to the feed pipe. PVC cement may be used to make the connection permanent. To help prevent leaks where the socket passes through the tank wall, it can be keyed into place using a ring of plastic pipe glued over the top of it. When steel pipe is used, it can be keyed into the tank wall using a short section of steel bar welded to it or a jubilee clip.



Drive pipe connection A short length of drive pipe should be keyed into the tank wall.

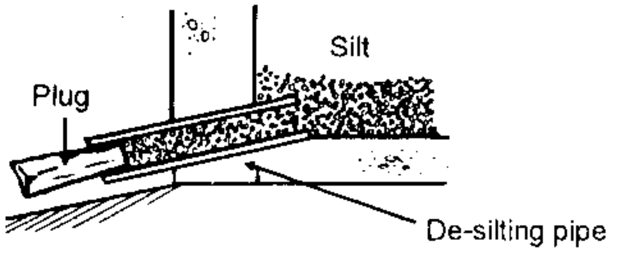


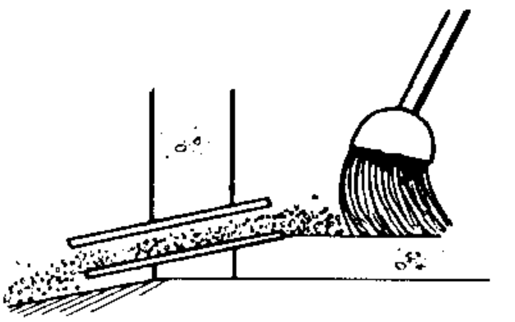


The length of pipe protruding from the wall is important, as is the angle of descent. 200mm of drive pipe should protrude from the drive tank before the first connection. The angle of this pipe should be the same as the angle of descent of the rest of the drive pipe, in this way keeping the drive as straight as possible.

Although a rigid connection can be made at the top of the drive pipe, a flexible connection is recommended so that vibration in the pipe can be absorbed before reaching the drive tank. A flexible joint can be fabricated using strong rubber pipe and jubilee clips. The rubber pipe bridges a gap of between 10 and 25mm. The protruding pipe is supported by the tank on the upper side of the joint and the top of the rest of the drive pipe must be firmly supported a short distance below the joint.

De-silting pipe This pipe will not be necessary if a drain overflow pipe is fitted to the tank.



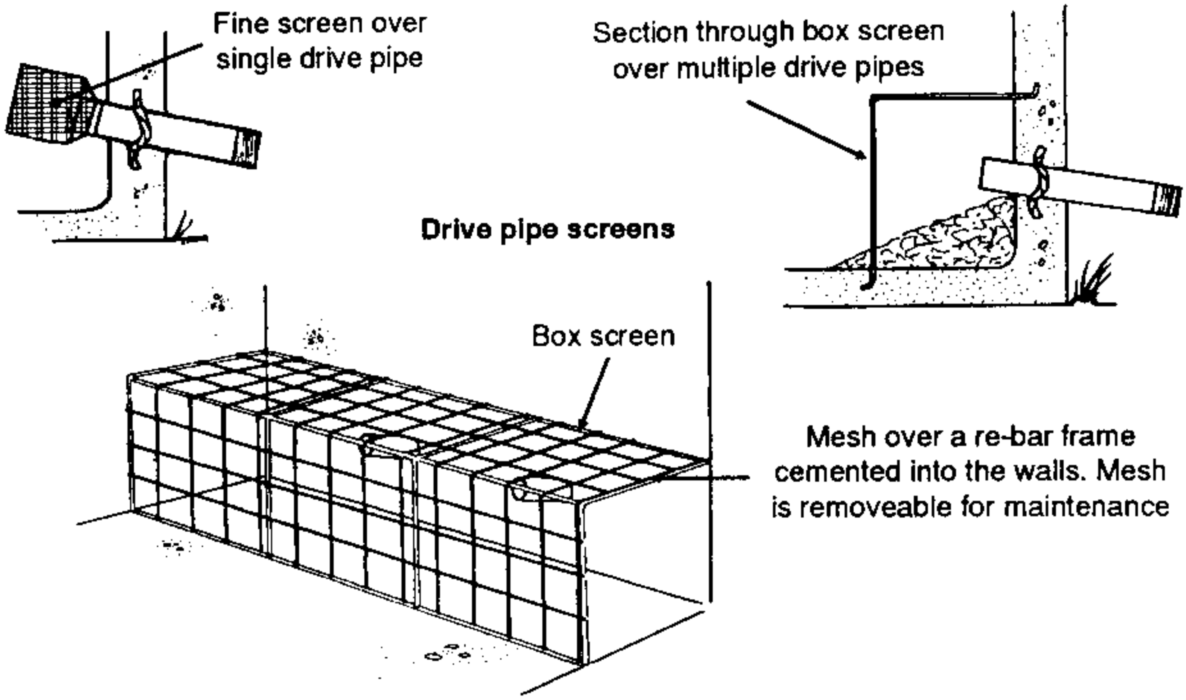


When a level overflow pipe is being used, a separate small diameter steel de-silting pipe should be set into the base of the tank and plugged. A shaped piece of wood can make a suitable plug. The plug is then removed to drain and de-silt the tank. Accumulated silt may need to be brushed towards the pipe to speed its removal.

Screens and covers

Keeping the drive water as clean as possible is essential. Where the source water is captured immediately from a spring, screens are not as important as they are in systems using water drawn from rivers and streams. Even in spring-based systems, sedimentation can cause a problem and a settling tank may be necessary.

With stream-based supplies, although large debris and much of the silt may be removed by a coarse screen at the intake and by a settling tank, small leaves, twigs, frogs and other objects can still enter the drive tank. A fine screen should be installed over the drive pipe(s) to prevent any such debris from entering a drive pipe and possibly stopping a pump.



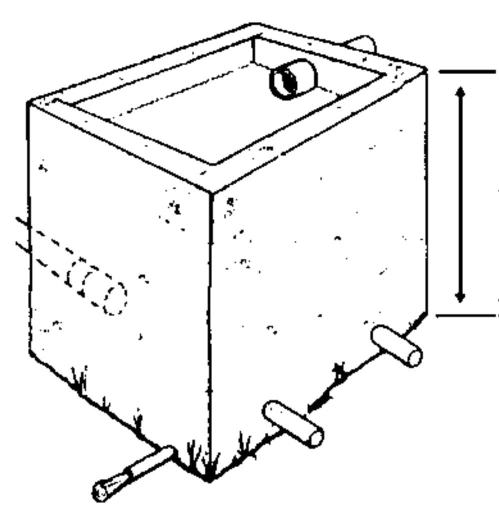
Drive pipe screens

To prevent leaves, animals or curious children getting into the drive tank, a cover should be made to fit securely over the top.

Types of tank

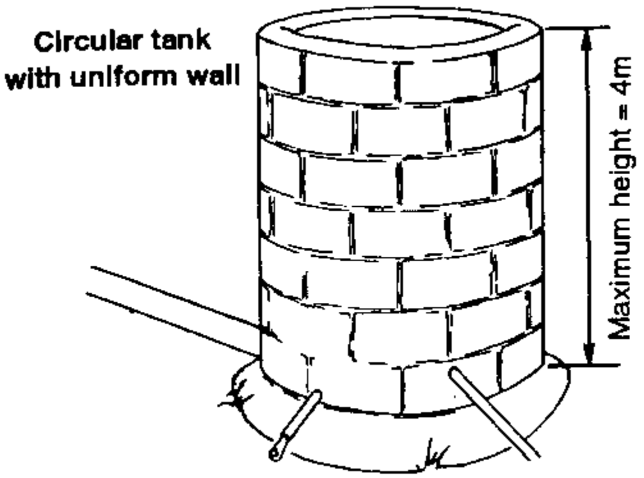
In Chapter 3, various kinds of drive tank were recommended depending on the height required. The height of the tank is the most significant factor determining tank shape and the construction material and methods used. A few important tips on constructing these tanks are given below.

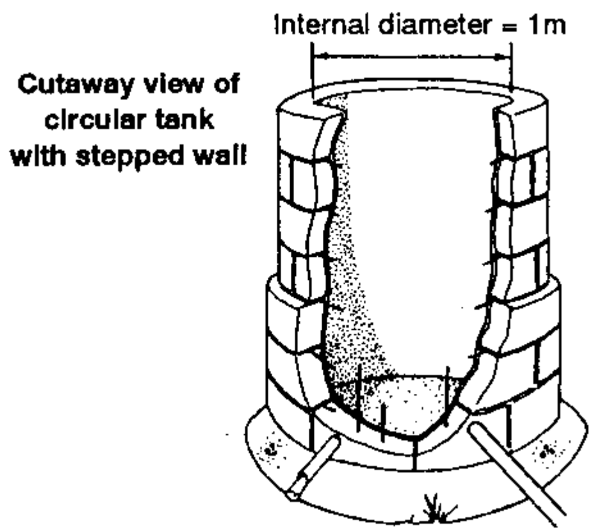
Rectangular tank of concrete block or brick Concrete block or brick is usually the cheapest and most appropriate material to use for a drive tank that is to be up to 4m high. Rectangular tanks are recommended for heights up to 2m as they are the most straight-forward to build. Corners should be overlapped in the normal way and re-bar can be used in the mortar joints to help prevent the spread of cracks. Solid concrete blocks (or hollow ones filled with concrete during construction) should be used. For tanks less than 1.5m tall, fired bricks can be used instead.



The inside of the tank should be plastered in two stages. The first plaster coat should be a strong mix of sand and cement (one part cement to three parts of sand). The second coat should be of cement and water only. Extending the plaster to the outside of the tank can help to protect it, but is not essential.

Circular tanks of concrete block Circular tanks are more complicated to construct than rectangular ones but can be built up to 4m in height. An internal tank diameter of 1m is usually sufficient to permit access during construction and for maintenance. Hollow concrete blocks should be used, with the hollows filled with concrete (around the reinforcement) during construction. Thick concrete blocks (6" or 150mm) can be used at the base, while thinner blocks (4" or 100mm) will give sufficient strength nearer the top. Rings of re-bar should be used to reinforce the lateral joints and straight lengths of re-bar passed vertically through the holes in the concrete blocks before they are filled.

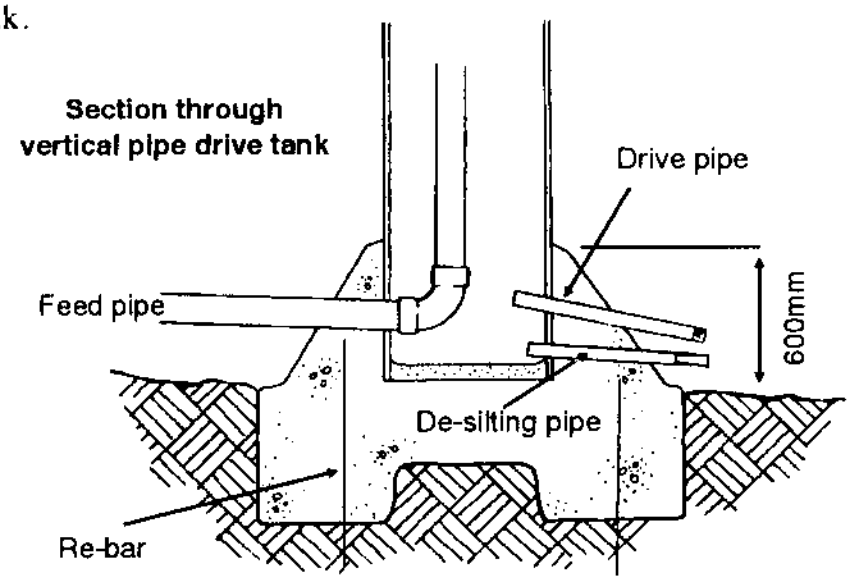




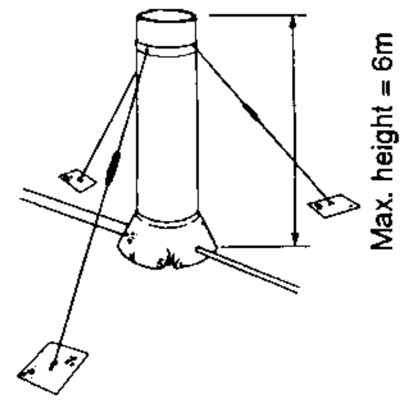
The inside of the tank should be plastered using the same materials described for plastering rectangular tanks.

Large diameter pipe set vertically This kind of drive tank is sometimes referred to as a 'break-pipe' and can be particularly useful in small, spring-based systems. It provides a cheap method of building a very tall drive tank — when the right kind of pipe is available. PVC pipes with diameters from 4" to 12" are typically used, with the choice of size depending on the drive flow required by the size of the pump to be used. For example, one pump with a 1" drive pipe will require a 4" diameter tank and one or two 2" pumps will require an 8" or 10" diameter tank.

As with all drive tanks, a firm foundation is essential. To help to keep the tank upright and stable, a concrete surround should be built around the bottom of the tank and firmly connected to the foundation using re-bar.

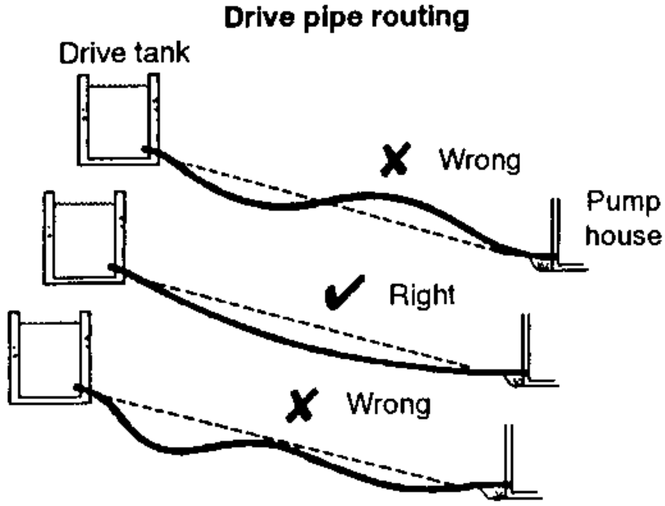


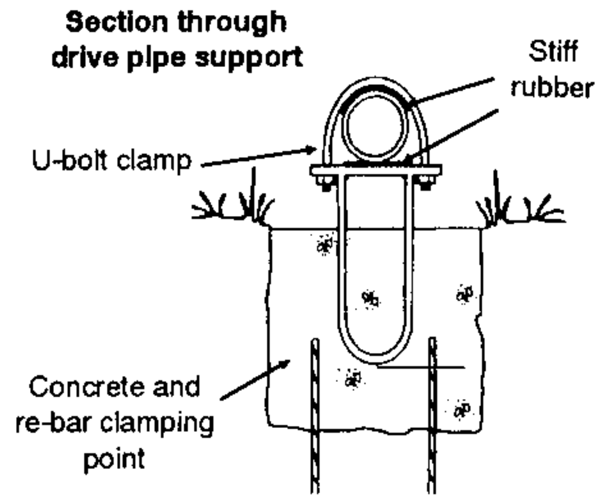
The tank may also require guy lines to keep it upright, particularly at sites which may experience high winds.



Drive pipes

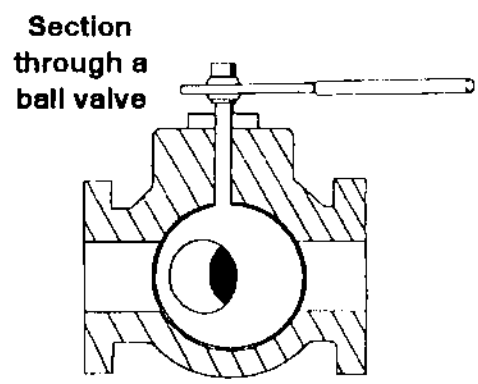
The drive pipe must never rise, and ideally will fall steadily along its length.

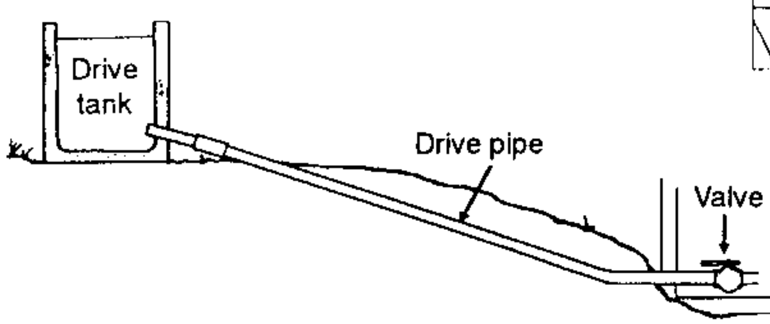




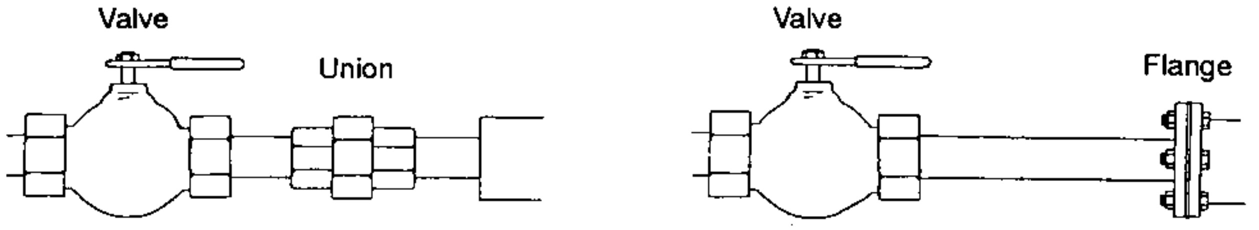
Where possible the drive pipe should be buried for protection. If the pipe has to run over an area of rock, protect it with a stone and cement cap. When the drive pipe cannot be buried it can be anchored by casting concrete blocks into the ground and setting in steel clamping points as shown above. U-bolts can then be used to clamp the pipe to the blocks. An unburied drive pipe should be anchored at each end, and at least every 3m along its length. A flexible coupling should be used to attach the drive pipe at the drive tank end.

Near the pump house, and preferably inside it, a valve should be fitted to each drive pipe. This allows the drive flow to be turned off when necessary. The best type of valve to use is a ball valve, but a gate valve will also work. To prevent anyone tampering with the system, it is recommended that the valve handles be removed while the pump is running.





If the drive pipe connection to the pump is a screw thread joint, a union should be fitted between the drive pipe valve and the pump to allow easy installation and removal of the pump. Where the drive pipe connection to the pump uses a bolted flange, a union is not needed because the flange can be unbolted to give the same ease of pump installation and removal.



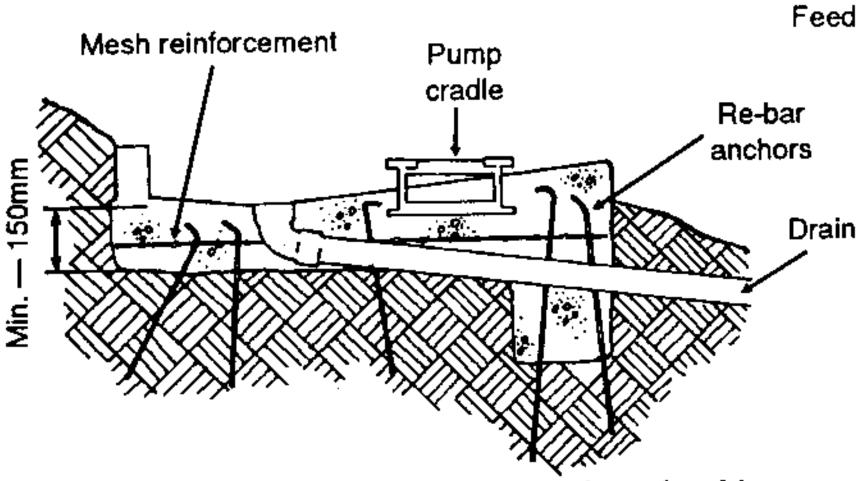
When a number of pumps are to be installed, the drive pipes should leave the drive tank at least 200mm apart. In situations where digging a trench is particularly difficult or where rock has to be broken, the drive pipes can be brought closer together. Gentle bends should be made using a pipe bender or a suitable tree, taking care not to crease the pipe wall and break the galvanised coating.

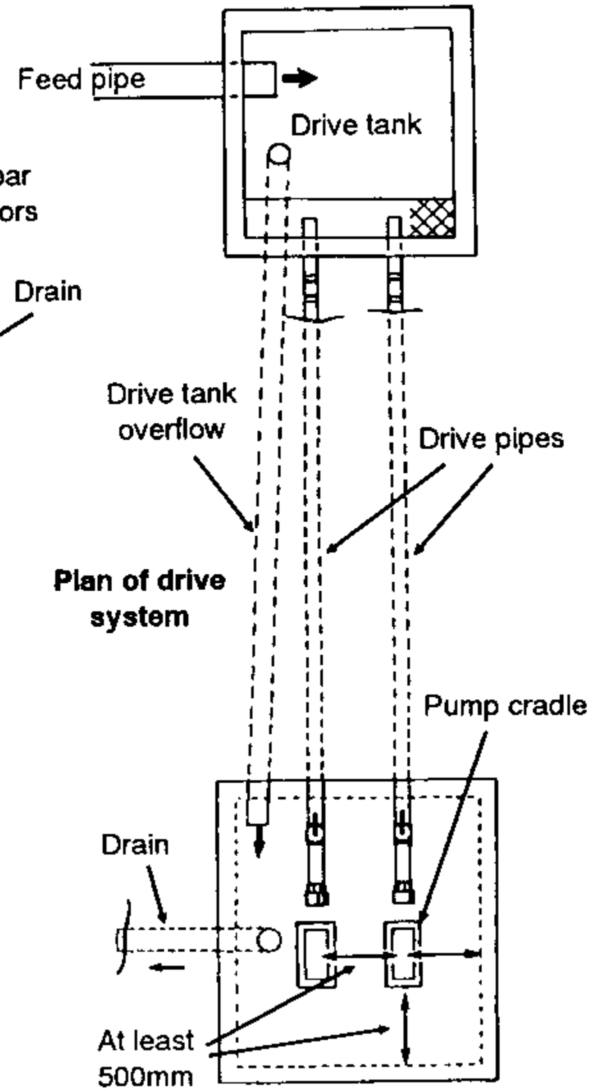
Pump base and pump house

The pump base should incorporate the following features:

- Stability — it should be constructed on firm ground that will not move or settle under the repeated vibrations of the pump(s) operation. When loose ground or a sloping surface must be used, the base should be anchored or pinned using steel rods (re-bar) driven into the ground, or it should be wedged against a large boulder.
- Size — the base should be large enough to accommodate the number of pumps to be used, leaving space to work in around each pump. It should also be large enough to provide a foundation for any pump house that is to be built. The base should be at least 150mm deep.
- Reinforcing — steel reinforcing bar or mesh should be cast into the base to help it to resist cracking and movement.
- Pump cradle — the cradle must be held securely by the base and well keyed into it. The position of the cradle and the space left around it must be designed to ensure sufficient access to the pump(s) after installation.
- Orientation — the pump base, and particularly the cradle, need to be accurately aligned with the drive pipes. Careful marking out of the drive tank site, the planned line of the drive pipe(s) and the pump base will help to reduce errors.
- Drainage — The surface of the pump base should slope gently towards the drain. The drain must be large enough to cope with the full flow of all the pumps installed and will normally be the same size as the feed pipe. A trench should be dug after the site has been prepared and the drain pipe installed before the base is cast over it.

Section through pump base

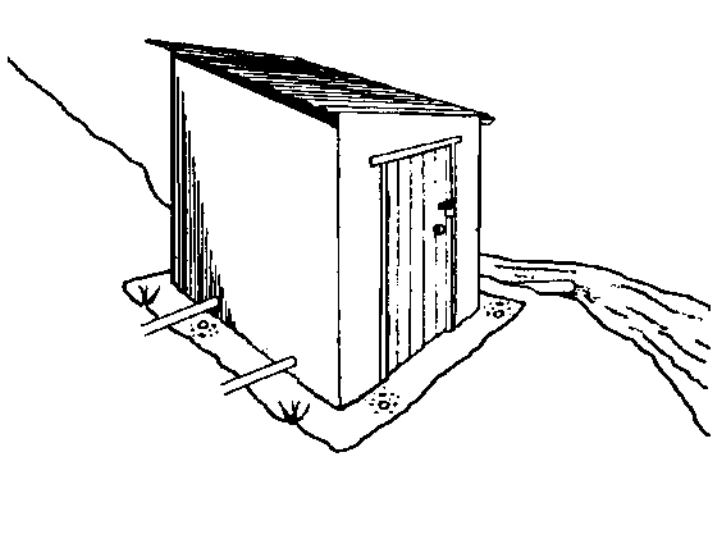




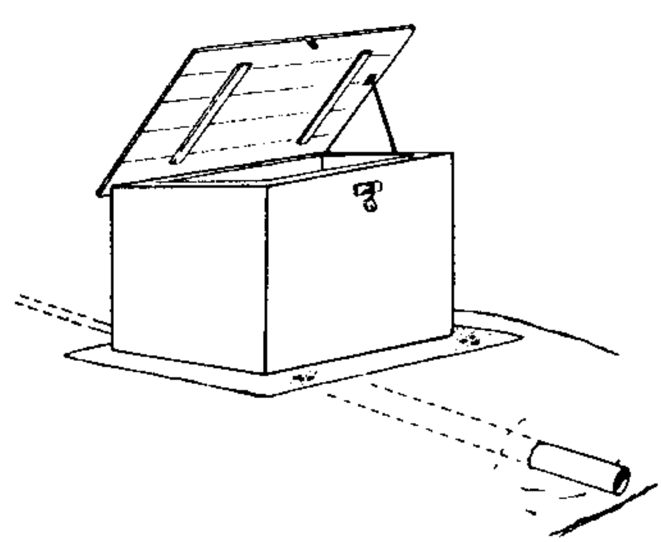
The pump house will often get wet and so should be built using material such as concrete block or stones whenever possible. It should be large enough to give good access to all the pumps and fittings inside it, without making it so large that its cost is prohibitive. Examples of two types of pump house are given below.

The overflow from the drive tank can be brought down into the pump house through a pipe and then share the pump house drain. When tuning a pump on a system with limited drive water available, the presence of the overflow in the pump house makes it easy for the operator to check that there is still an overflow, and so to ensure that the correct amount of water is used by the pump. The pump house walls can also provide a fixing for the delivery manifold (usually the wall through which the drive pipes pass).

Pump house



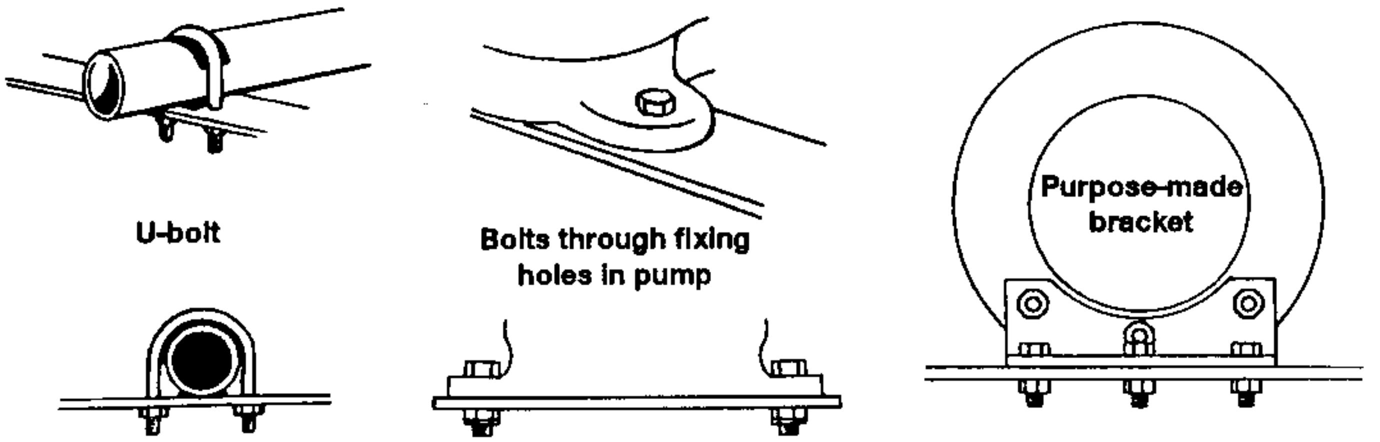
Pump 'box' — a hinged or detachable lid allows access to the pump(s)



Pump installation

Fixing details

A cradle that is designed for the number and type of pumps to be used should be fabricated and cast into the pump base. Ram pumps must be rigidly fixed to their foundation and so the method of clamping to the cradle is important.

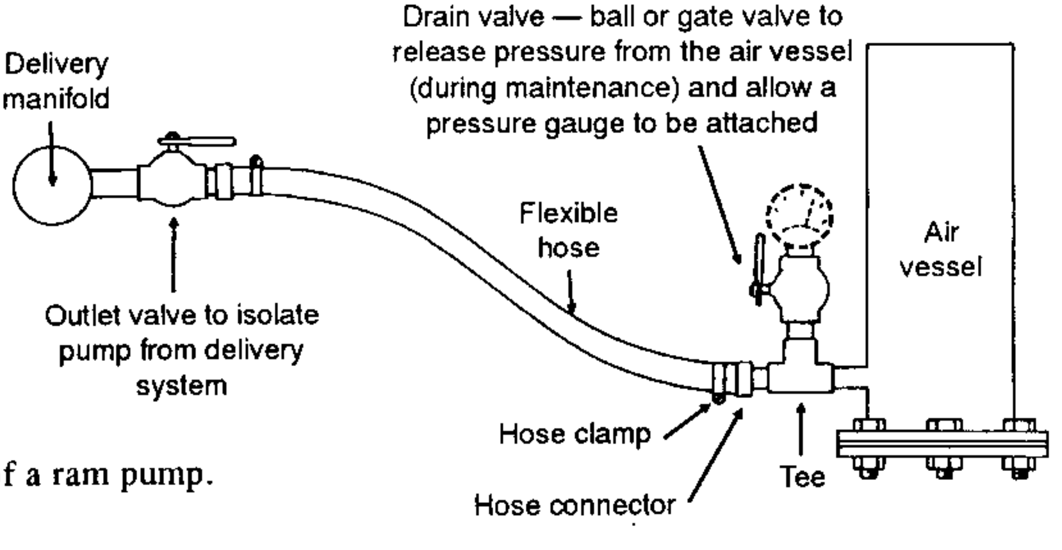


Whenever possible, the threads of fixing bolts should be well greased to help prevent rusting.

Connection to delivery manifold

Even when properly fixed, ram pumps experience some vibration during operation. To prevent this vibration being transmitted into the delivery system, it is recommended that a flexible coupling is used to link the outlet from the air vessel to the delivery manifold. For systems with a delivery head of less than 80m, reinforced PVC hose is usually strong enough to use as a flexible coupling. When the delivery head exceeds 80m, special high pressure flexible pipe such as that used on hydraulic machinery is required. This kind of high pressure pipe can usually be bought or made up to the right length by businesses specialising in the manufacture or maintenance of agricultural machinery. The flexible coupling also acts like a union joint to allow the air vessel to be easily disconnected.

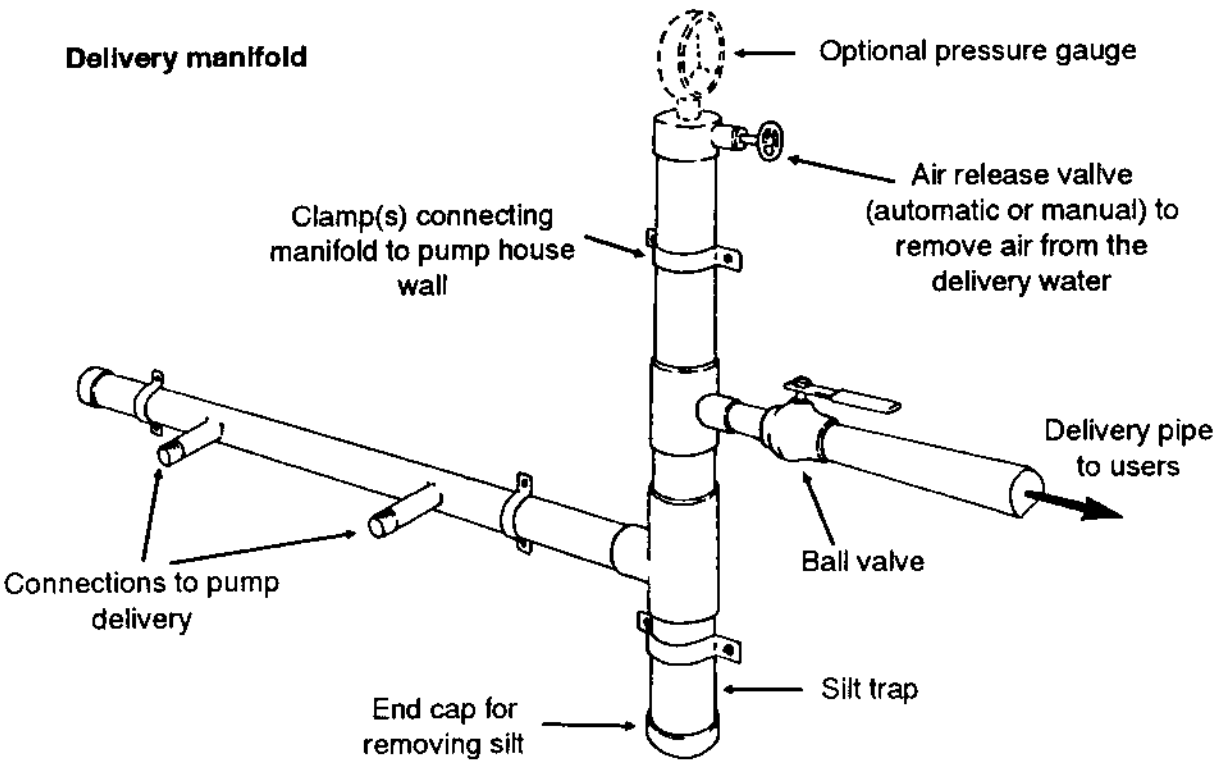
The diagram alongside shows the recommended layout of the air vessel to delivery manifold connection. All the parts detailed perform useful functions but none of them are essential to the successful operation of a ram pump.



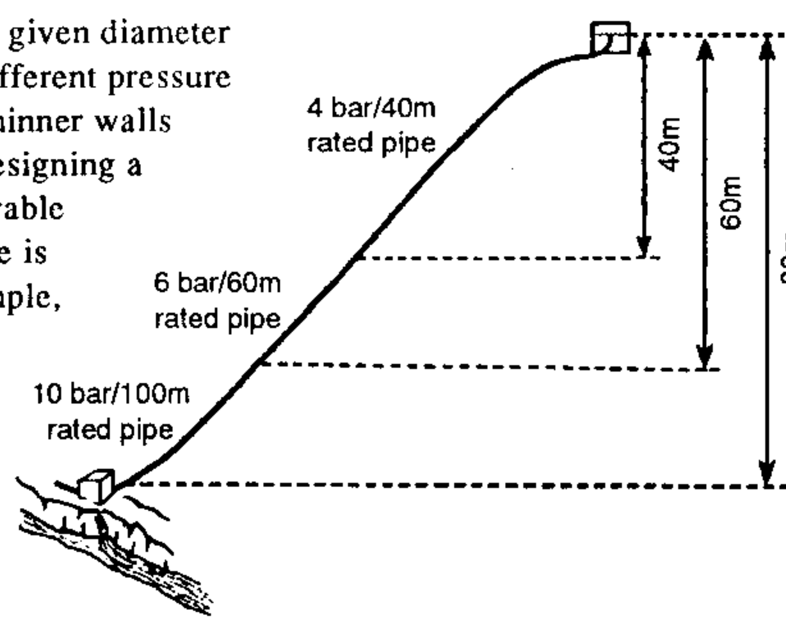
Delivery pipe and manifold

When more than one pump is to be installed it is recommended that a delivery manifold be installed. The delivery manifold connects the pumps to the delivery pipe. The manifold is usually made from steel pipe, welded or screwed together, and includes the features illustrated below.

Delivery manifold



Under normal operating conditions the delivery pipe will have a constant flow through it and should not experience any of the pressure fluctuations occurring within the pump. Because this is the case, the delivery pipe can be rigid plastic pipe which is comparatively cheap, corrosion free, and straightforward to join together. This kind of plastic pipe is usually sold in 6m lengths or in 100m rolls. When the rolls are available, they should be used in preference to the shorter lengths because there will be far fewer joints in the finished system. A given diameter of plastic pipe is often available in different pressure ratings, with lower pressure having thinner walls and therefore being cheaper. When designing a delivery system there can be considerable cost savings if the correctly rated pipe is installed in the right places. For example, on a system with an 80m delivery head a single type of pipe rated to withstand 80m could be used throughout. Alternatively, three ratings of pipe could be used as shown and money saved.



A safety factor should normally be included so that all pipe is only ever used at 80% of its rated pressure.

Particular care is needed when making joints in the high pressure section of systems with delivery heads over 100m. The joints are usually the weakest points and there should be as few as possible. Galvanised steel pipe may also be used in the high pressure section of a delivery system, but it has the disadvantage of being more expensive and of requiring periodic replacement due to rust.

The entire length of the delivery pipe must be protected from damage by people, animals, ploughing, fire, etc. Where possible a trench at least 500mm deep should be dug and the pipe buried. If it is not possible to bury the pipe along its entire length, the exposed section(s) must be protected with a stone cap or by using steel pipe.

Distribution system

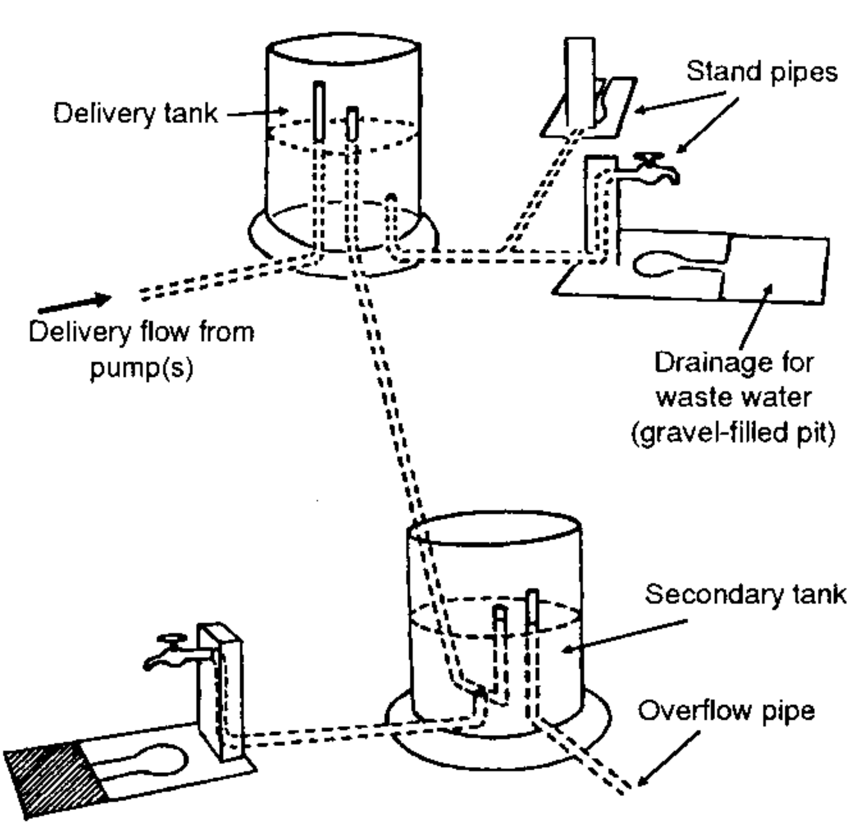
Storage tanks

The delivery and storage tanks in a distribution system can be made using whatever local materials and techniques are traditionally used for water storage. In a big system, a large volume of water may need to be stored overnight and the cost of a tank strong enough to do this can be high. Ferrocement tanks often provide a suitable solution and the techniques involved in their construction are becoming widely known. Where a delivery tank is to be built a little above the village and feed by gravity to distribution points, it can sometimes be cheaper to use a lined concrete pit. Whatever kind of tank is used, it is strongly recommended that it be covered to prevent contamination of the water — and to stop it being used as a swimming pool!

It is good to maintain a constant head in the delivery system. To achieve this, the delivery pipe must enter near to the top of the tank — above the level of the overflow from that tank. The delivery head is then constant, rather than varying with the level of stored water. This arrangement also prevents pumped water being drawn back into the delivery pipe if there is a leak in it.

Pipework connecting tanks together and standpipes to tanks is under low pressure and plastic pipe is usually strong enough. The pipe should be buried, where possible to a

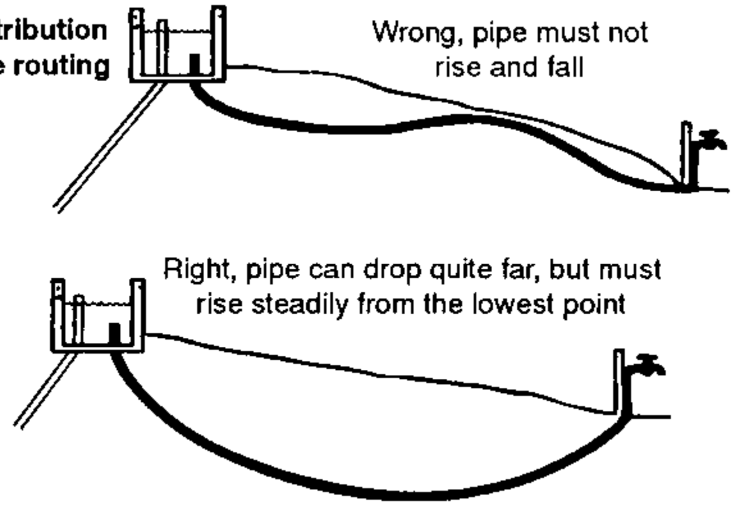
Distribution system



depth of 500mm, to prevent damage.

If a pipe has to cross a road used by vehicles, either bury the pipe at a depth of at least 1m or use a section of steel pipe for the crossing. When laying these pipes, care should be taken to ensure that there are no high points where an airlock might form and cause a blockage.

Distribution pipe routing



Standpipes

One of the best methods of water distribution is through standpipes. These can be made in a variety of ways, with or without taps. If no tap is used a small control valve should be sited in the line feeding the standpipe; this can be opened and closed by the system operator at specific collection times during each day. In order to prevent any pools of dirty water forming and causing a health hazard such as a mosquito breeding site, standpipes should be surrounded by a concrete apron feeding a channel that directs any spilt water to a purpose-made soakaway. Fencing (with a gateway) is sometimes used to keep animals away from standpipes, thereby protecting them from damage and the water from contamination. Another useful feature is a bucket stand.

Pipe joints

Plastic to plastic

To make a good joint in plastic pipe, follow the manufacturer's instruction for both the pipe and the relevant solvent carefully. Usually this will involve thoroughly scraping the inside of the socket and the outside of the pipe to be joined, then spreading the recommended solvent thinly on the prepared surfaces before pushing the pipe into the socket. Leave the pipe to cure for the recommended time before putting water through the pipe.

Steel to steel

Joints in steel pipe are usually made by threading the end of both pipes and using a socket or union joint to make the connection. PTFE tape should be wrapped around the threads to ensure a watertight seal. Flanges can be used in place of the union if preferred. Threaded flanges are available, although welded-on flanges can often be fabricated to save money. Where a joint need not be separated, it can be welded, although care should always be taken not to weld galvanised steel in a confined space because poisonous fumes are given off.

Plastic to steel

When the pipe is under low pressure at the place to be joined, the plastic can often be heated to make it malleable and then pushed over the steel pipe. The steel pipe should be threaded so that as the plastic cools and shrinks it grips the threads and makes a good joint.

When it is necessary to join plastic to steel in a high pressure situation, a commercially available moulded plastic fitting must be used. This is usually a strong plastic socket, one end of which is glued to the plastic pipe and the other end is threaded to screw into the steel pipe.

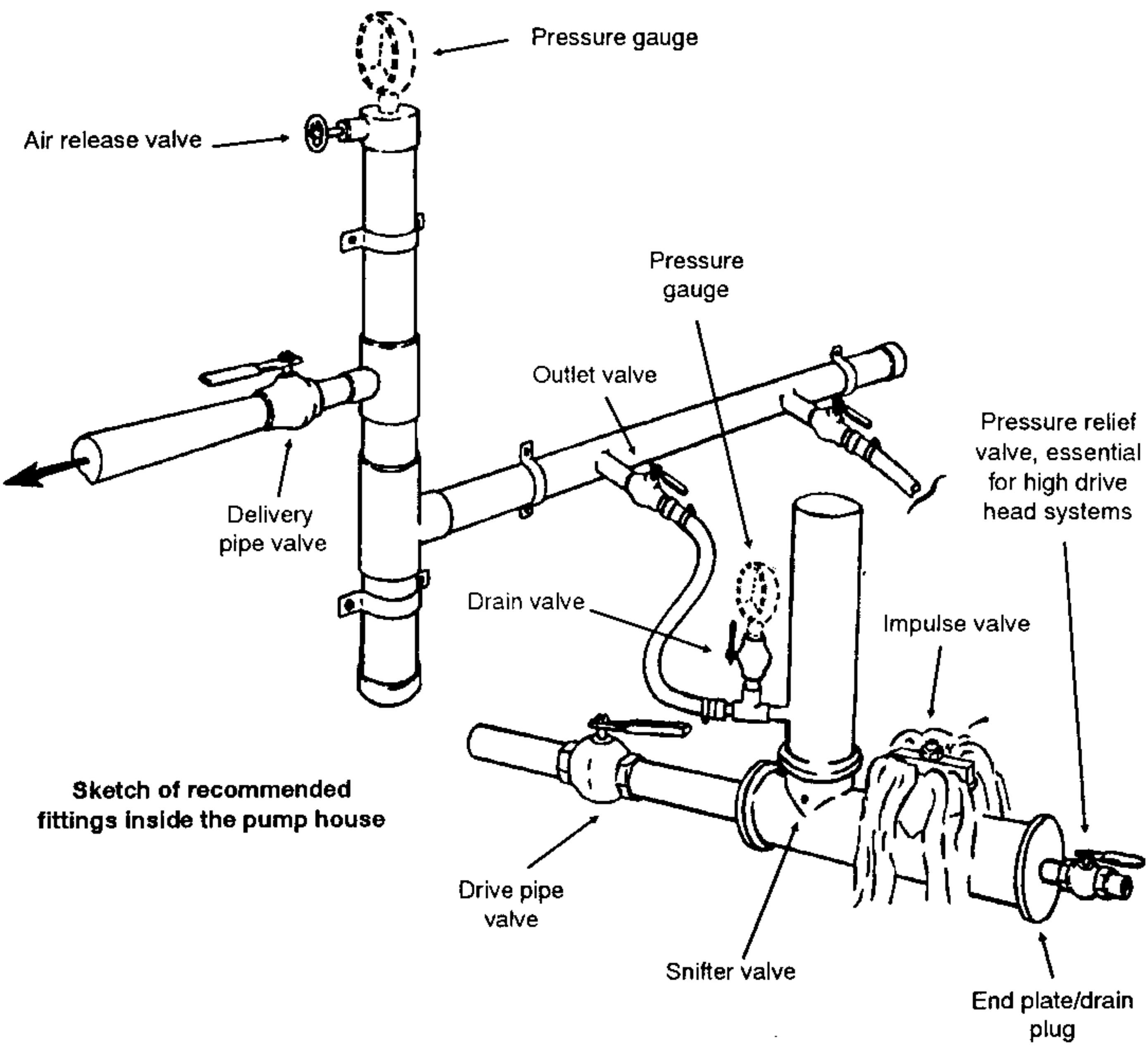
Flexible hose

Flexible hose is usually attached by pushing it over the other pipe and clamping it in place using jubilee clips. The connection can be made more secure by threading the end of the pipe to which the flexible hose it to be attached. The threads then grip the flexible hose when the jubilee clip is tightened.

CHAPTER 6: System commissioning and operation

There are many ram pump designs, some suited to local manufacture and others to commercial manufacture. This chapter describes the procedures typically used in operating a ram pump, measuring its performance, maintaining and repairing it. It is not possible to provide this information in enough depth to cover all the variations of ram pump available, and so some of the information given may have to be adapted by the reader to suit the particular pump in use.

A number of fittings can be added to the system on both the drive and delivery sides of a ram pump to assist in its operation and maintenance. These fittings are shown in the sketch below. All of them are recommended, but some of them are not essential: their purpose is to make operation and maintenance easier.



Sketch of recommended fittings inside the pump house

Before starting a ram pump

Before starting a pump for the first time or after maintenance, carry out the following preparatory steps:

[1] Ensure that all bolts around the pump are tight, that all the parts fit firmly together and that the pump is properly secured to its cradle. Check any lock nuts on the impulse valve.

[2] Check that the flow of water along the feed pipe is steady, that the drive tank is full and its overflow operating.

[3] Check that the pump house drain is clear.

[4] Remove the washout plug or plate at the end of the pump (or hold open the impulse valve if no washout plug or plate is fitted). Gently open the drive pipe valve allowing water from the drive pipe to flush out any debris that has accumulated in the pump body during construction, then close the valve and replace the washout plug or plate.

[5] If possible, wedge the impulse valve open and gently open the drive pipe valve. Allow water to flow quite rapidly through the open valve for at least one minute. This will help to ensure that there is no air in the drive pipe. Close the drive pipe valve slowly and remove the wedge.

[6] Hold the impulse valve closed and gently open the drive pipe valve. Water will fill the pump and begin to find its own level in the delivery system. Check for leaks in the pump and pipework.

[7] Check that the snifter valve is clear of blockages.

Starting a ram pump

Although ram pumps often start very easily, they can require a little coaxing — particularly the first time that they are run. Procedures vary according to the type of pump and the drive head in the system, with large drive heads requiring extra care. To start a pump:

[1] Open the outlet valve slowly and then open the drive pipe valve fairly quickly. Water will flow out through the open impulse valve until it suddenly shuts. If it automatically reopens, the pump should continue to run on its own. If it does not, you must prime the delivery system manually by filling the delivery pipe until sufficient delivery head is available for the pump to operate. Methods for doing this are described in steps 2 and 3 below.

[2] On systems with a low drive head, push down on the impulse valve with your hand or foot to reopen it. Water will flow out of it faster and faster. Keep your hand or foot on the valve (apply no weight) until it shuts by itself. When this happens, push down immediately to re-open the valve. You should feel a point just after closure when the valve is easier to open. This is due to the recoil

reducing pressure under the valve. This recoil will automatically re-open the impulse valve under normal operating conditions. Keep helping the valve to re-open until it will do so by itself.

[3] On systems with a high drive head it is often not possible to re-open the impulse valve manually. In this case a very small (e.g. ½") gate or ball valve should be fitted to the body of the pump to release the pressure in the pump body. Open the drive pipe valve as before until the impulse valve closes, then shut it again. Open the small pressure release valve until the impulse valve reopens and then close the pressure release valve again. Re-open the drive pipe valve and repeat the process until the pump begins to operate automatically.

If starting the pump using either method (2 or 3) takes a long time, then the outlet valve can be used to create a false delivery head.

To create a false delivery head, close the outlet valve and begin to operate the pump manually as described above. As soon as the pump starts running automatically, begin to

WARNING: *be extremely careful if attempting to create a false delivery head! Pressure in the air vessel can rise to dangerous levels in just a few pump cycles, so it is advisable to have a pressure gauge fitted when attempting this.*

open the outlet valve to prevent excessive pressures building up in the air vessel. Steadily continue to open this valve until it is fully open. If the valve is opened too quickly, the pump will falter and may stop. If this happens, close the outlet valve and repeat the starting procedure until the pump begins to operate. This time, partly open the outlet valve immediately, but then continue to open it more slowly preventing the pump from faltering. A pressure gauge, fitted temporarily to the drain valve near the air vessel, is a very useful tool for starting pumps. The outlet valve can be adjusted whilst watching the gauge to ensure that the pressure does not rise too high or fall too low.

If there are a number of pumps sharing the same delivery system, it is much easier to start a second pump when one is already running. Firstly, open the outlet valve to the pump that is not working. The pump's air vessel will fill to the pressure already in the delivery system. Then opening the drive pipe valve should start the new pump operating immediately.

If all else fails....

If you have used the methods described above and are still having trouble starting a pump, work through the following check list before trying to start the pump again:

[1] Check thoroughly for leaks around the pump or drive pipe.

[2] Follow the line of the delivery pipe and check for leaks in the lower section.

[3] Flush the drive pipe through again to check for blockages and remove any air. Quite small pockets of air in the drive pipe can stop the pump working.

[4] Remove the delivery valve and check that it is properly installed.

Stopping a ram pump

When it is necessary to stop the pump:

1. Hold the impulse valve closed or stop the drive flow to the pump. To stop the drive flow, close the drive pipe valve or block the end of the drive pipe inside the drive tank.
2. Close the outlet valve (if fitted) to prevent backflow.

Measuring pump performance

To get a good estimate of pump performance, the following information is needed:

- The drive head (H) — the height from the water surface in the drive tank to the top of the impulse valve.
- The delivery head (h) — the height from the top of the impulse valve to the water level in the highest delivery tank. (If it is known, the head loss in the delivery pipe should be added to the static delivery head measurement to give the total delivery head that must be overcome. If a pressure gauge is fitted, it will indicate the total delivery head.)
- The drive flow (Q) — the total flow of water entering the pump. This can be measured in one of two ways described on the next page.
- The delivery flow (q) — the flow reaching the delivery tank.

These four measured values (H, h, Q and q) can then be used to calculate the efficiency of your system as shown in the two boxes below.

CALCULATING EFFICIENCY AND OUTPUT

System efficiency (%) $= \frac{\text{Output}}{\text{Input}} = \frac{h \times q \times 100}{H \times Q}$

Power Output (W) = q(l/s) x h(m) x 9.81*

9.81* = m/s^2, acceleration due to gravity

Water pumped per day =
q(l/min) x 60 mins x 24 hours = q x 1,440

Note: $Q = Q_W + q$

Example

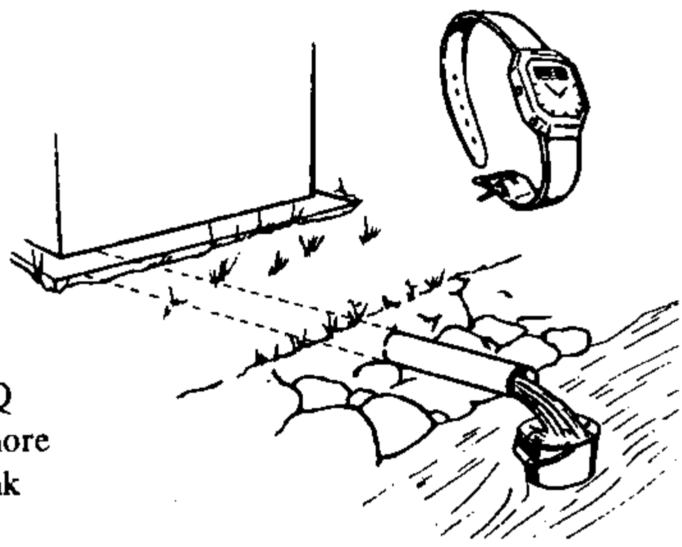
Q_W = 90 l/min q = 6 l/min
$Q = Q_W + q$ so Q = 96 l/min
H = 8m
h = 80m

Efficiency $= \frac{80 \times 6 \times 100}{8 \times 96} = 62.5\%$

Power Output = q x h x g = 0.1 x 80 x 9.81 = 78.5W

Water pumped per day = q x 1,440 = 8,640 litres.

Measuring the drive flow



Use either of the two methods described below.

(a) Collect the water flowing to waste (Q_W) through the pumphouse drain into a container of known volume and measure the time it takes to fill. Convert this into litres per minute. Add on the delivery flow q to give the drive flow Q ($Q = Q_W + q$). This method is not valid if more than one pump is running or if the drive tank overflow discharges into the pump house.

(b) With the pump running, measure the overflow from the drive tank. Stop the pump and remeasure the overflow. The difference between the two measurements is the total drive flow (Q).

Tuning for best performance

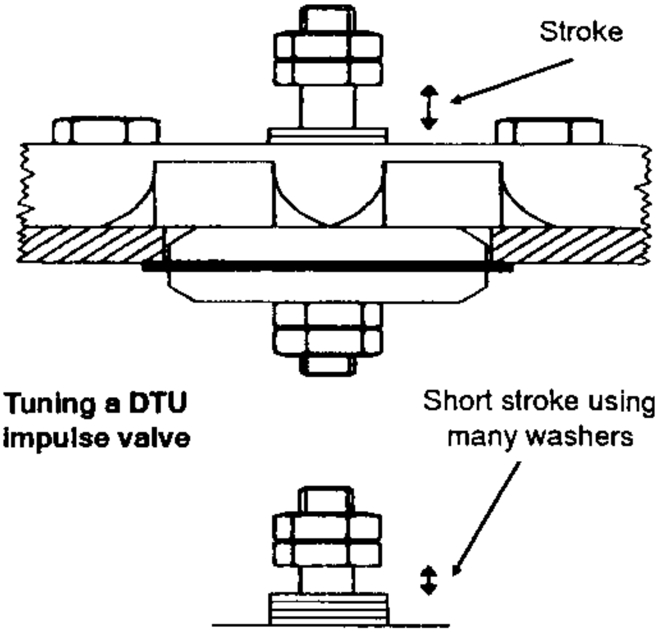
Most ram pumps have impulse valves that are adjustable to allow tuning for optimum performance. Tuning is usually achieved by adjusting the travel of the impulse valve or the tension of a spring. Altering the weight of the impulse valve is also an option in some cases. Adjusting a pump to suit the conditions of any particular site can be a complex process and too great a degree of adjustability can lead to mistakes and damage.

Tuning is usually carried out to try to reach one of two points of optimum performance:

- **Peak output** When there is plenty of drive water available the pump should be tuned for peak output (i.e. the delivery of as much water as possible). This usually coincides with a long impulse valve stroke or high spring tension, allowing the velocity of water in the drive pipe to build up, increasing the energy available for pumping. It should be remembered, however, that tuning for peak output also raises those forces in the pump that accelerate failure. For this reason, never exceed the manufacturer's recommended maximum stroke, spring tension or weight for the valve.
- **Peak efficiency** When there is a limited amount of drive water available, it is important that the pumps installed are tuned to make the most efficient use of it. With one pump, the impulse valve should be tuned down to use 90-95% of the water available from the source (a small overflow must always be left in case the water level drops). If several pumps are operating in parallel they should be tuned so that together they use 90-95% of the available water.

With many pump designs, tuning is easily achieved by altering the impulse valve stroke. In some pumps, the position of lock nuts can be altered to limit the travel of the valve. On others the stroke is changed by using washers as spacers, as shown for a DTU impulse valve in the diagram alongside. The shorter the stroke, the smaller the amount of drive flow needed, and the lower the pump output.

Alternatively a pump's performance can be altered by changing the weight (or adjusting the spring tension) of the impulse valve. Generally, adding weight will increase drive flow and output power, while decreasing weight will reduce drive flow and increase energy efficiency.



Tuning a DTU impulse valve

Routine inspection and maintenance

It is important that the community appoint two or three people who will be responsible for running the system. These people should be involved at all stages of installation and be taught how to operate the system and how to carry out the simple maintenance tasks listed below.

While the pump is running normally, a visit should be made at least once a week to carry out a simple check to ensure that bolts are tight and that there are no leaks from between flanges or through the impulse valve when it is closed. Once a month an inspection of the whole system should be carried out, and once a quarter a detailed inspection of the pump is recommended. The frequency of checks on both the pump and the system can be adjusted as operators become familiar with their system. The recommendations given here are intended to provide an initial guide.

Checking the pump(s) monthly

With the pump running:

[1] Inspect all of the threaded and flanged joints to check for leaks.

[2] If a pressure gauge is fitted check the degree of pressure variation during the cycle. If there is a lot of variation then the air vessel is likely to contain little air, so either the snifter valve is not working properly or there is an air leak near the top of the air vessel. (Some pumps are fitted with air bleed and drain valves on their air vessels: opening the higher air bleed valve will check if there is sufficient air in the air vessel.)

[3] Listen to the pump. If it is much louder than usual, the air vessel is probably nearly empty of air (and therefore too full of water).

Checking the pump(s) quarterly

With the pump stopped:

> **WARNING:** *always release the pressure in the air vessel before starting to remove it. People have been seriously injured by trying to remove a pressurised air vessel.*

1. Remove the air vessel to check the delivery valve rubber for signs of wear or damage and to check for blockage of the valve holes.
2. Check that the snifter valve is clear and, if a rubber flap is fitted, that the rubber is in good condition.
3. Remove the impulse valve and check the condition of any rubber seal or valve seats. Also check any nuts on the valve and look for signs of damage on threads, etc.
4. Remove the end cap or washout plug and open the drive pipe valve for a few seconds to wash through any debris in the pump body.
5. Check that the pump body is firmly bolted down.
6. Reassemble the pump, ensuring that all bolts are properly tightened and protected with grease where necessary.
7. Restart the pump as described above.

Checking the system monthly

Like the pump itself, the whole system requires regular inspection and maintenance. Systems taking their water from a stream or river are likely to need more frequent attention than those supplied by a spring. This is because they are at greater risk from severe weather conditions and variations in water quality.

1. Check the level of silt in the drive tank, in any settling tank and behind the dam or weir (or in the spring catchment box). If it is possible that the next month's accumulation of silt will raise it to a level at which it could foul pipework, remove the existing silt.
2. Clean any filters installed in the system. Filters should also be checked after a flood or heavy rain.
3. Walk along the line of the feed pipe looking for any sign of damage or leaks.
4. Inspect the drive tank for leaks, particularly at pipe joints.
5. Ensure that the overflows from the drive tank and the pump house are clear.
6. Follow the line of the drive pipe to check for any signs of damage or leaks.
7. Walk along the line of the delivery pipe, checking for damage, leaks, or erosion. Certain agricultural techniques, such as burning off brush or digging near the pipeline, should be stopped if they might cause damage to the buried pipe.

[8] Inspect all tanks and pipework in the distribution system. De-silt the tanks when necessary. If a filter is installed, check whether it needs cleaning.

Annual system maintenance

With continuous operation, large amounts of silt can be deposited throughout the system. This build up of silt needs to be removed before it causes a blockage that reduces system efficiency or causes failure. The frequency of de-silting will vary from site to site depending on the quality of the water used and the effectiveness of any silt removal designed into the system.

[1] **Tanks** Flush out silt from all tanks either using de-silting pipes if installed, or manually from inside.

[2] **Feed pipe** Wash large amounts of water through the feed pipe. Dismantle it if there is a large blockage.

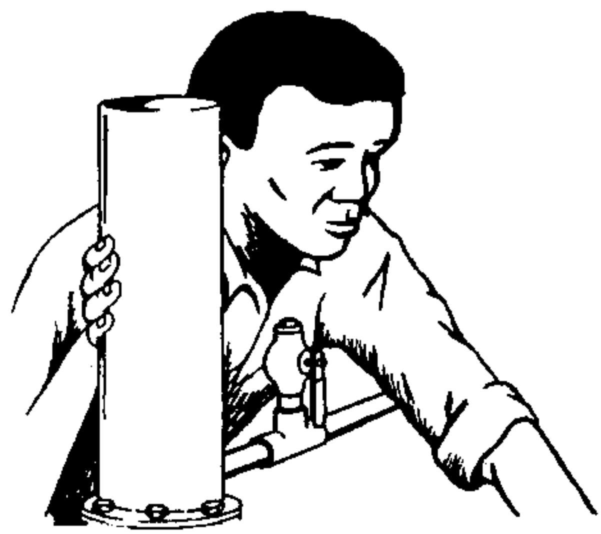
[3] **Drive pipe** With the drive tank full, close the drive pipe valve. Remove the pump from the end of the drive pipe and re-open the drive pipe valve. Water will flow very rapidly through the pipe and should remove any debris.

[4] **Pump** Dismantle the pump completely and thoroughly clean the inside.

[5] **Delivery pipe** Open the drain valve on the pump or in the delivery manifold if fitted and allow the water in the delivery pipe to drain out quickly. *Be careful — the water may be coming out at high pressure!*

Pump repair

If the pump stops or begins to deliver less water than usual, it may require adjustment or repair. Check the pump visually and, if there is no obvious fault, start it again. Then listen for irregular pumping, or unusual noises. A faulty delivery valve, for example, can sometimes be diagnosed by pressing an ear against the air vessel to listen to the valve's operation.

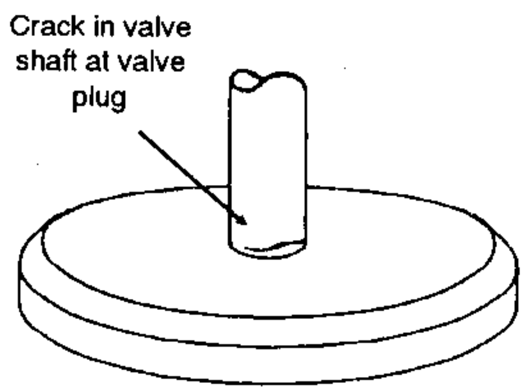


Listening for delivery valve faults. Be prepared to get wet!

When nothing appears to be wrong with the pump, check that the level of water in the drive tank is not dropping as the pump runs. Depending on the size of the tank, it may be necessary to watch for several minutes to determine this. If the level is falling, it is probable that the pump is trying to use more water than is available to it. In this case, either there is something wrong with the feed system or there is simply less water available in the source. If there is too little source water available, the pump must be re-tuned to use the amount that is available. Tuning the pump is described earlier in this chapter. When there is sufficient water in the source, check the entire site for damage, blockages and leaks before assuming that the pump is at fault. Do not neglect to check the delivery side of the system — where a leak can cause the pressure in the air vessel to drop below the level required to keep the pump operating.

Good ram pumps are extremely reliable over long periods of time. There are many examples of traditional pumps operating continuously for years without requiring maintenance or repair. Locally manufactured pumps, using less favourable materials, can still be very reliable but may require more frequent replacement of some components. Some of the repairs likely to be required at variable intervals are listed below.

- The rubber used in the impulse, delivery and snifter valves must be inspected regularly and spares should be kept on site for immediate replacement in case of wear or failure.
- Where the impulse valve has moving parts, these should be checked regularly for signs of wear. On designs where the impulse valve has sliding metal surfaces wear will gradually occur making the hole in the guide bar larger and the shaft smaller. This will eventually lead to unacceptable amounts of lateral movement, allowing the valve to snag as it rises. Spare shafts and stop bars should be available from the manufacturer and it is wise to keep one of each on site when wear is becoming noticeable.



- Valve shafts can break where they join the valve plug. Look for cracks in the shaft and replace it if there is any sign of damage.
- With the continual pulsing of the pump over many years, poor areas of weld in the pump body may fatigue and crack. Take the affected part to a workshop where the old weld can be ground out and a new joint welded.

Problem solving and fault finding

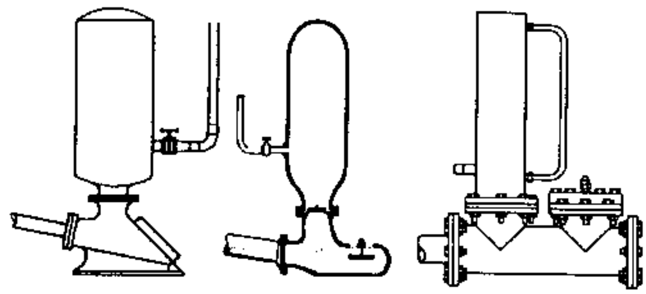
The table on the next page lists some common problems (symptoms), their possible causes and suitable remedies.

Two important features of a working ram pump cannot be readily seen. The first is the delivery valve, which may need to be checked to ensure that it is seating properly. This is achieved by stopping the pump and immediately closing the outlet valve. If the delivery valve is not sealing properly, air will be heard spluttering into the pump body after a minute or two. The other invisible feature is the level of air in the air vessel. Some pumps have sight tubes to display this, some have air bleed valves that can be used to check that the vessel is properly filled with air. Many pumps have neither, in which case the only indications of too little air are unusually loud banging sounds during operation and a pulsing delivery flow.

Problem	Likely causes	Solutions
Pump does not start by itself when impulse valve is opened.	1 Not enough water in delivery pipe to give sufficient delivery pressure to pump against and cause recoil.	1 Manually operate pump until it begins to reopen automatically.
	2 Leak in delivery pipe near the pump house preventing build up of delivery pressure.	2 Repair delivery pipe.
	3 Delivery valve not sealing, thus preventing build up of delivery pressure.	3 Repair delivery valve.
	4 Leak in the drive pipe or from the pump reducing pressure rise and recoil.	4 Repair drive pipe or pump.
Pump starts, makes a few fast beats, then stops.	1 Air in the drive pipe.	1 Flush out drive pipe and wait for remaining air to rise up out of drive pipe.
	2 Incorrect impulse valve setting.	2 Increase impulse valve stroke.
	3 Insufficient delivery pressure to maintain operation.	3 Manually operate pump until it re-opens automatically.
Pump runs, unevenly and slowly, and eventually stops.	1 Large amount of air in the drive pipe.	1 Flush air from drive pipe.
	2 Leak in the drive pipe or pump allowing air to enter during recoil.	2 Repair drive pipe or pump.
Pump runs normally but stops later.	1 Whilst the delivery pipe is filling there can be points at which there is no pump recoil, so the pump does not re-open.	1 Manually operate pump until it re-opens automatically.
	2 Drive flow insufficient so level in drive tank decreases until the pump stops.	2 Reduce impulse valve stroke so that the pump uses less water. Check that the overflow from the drive tank is always running.
	3 Drive tank filter partly blocked.	3 Clean filter.
Pump runs normally but delivers little or no water	1 Delivery valve leaking.	1 Replace or repair the delivery valve.
	2 Air lock in delivery system.	2 Check line of delivery pipe for humps where air could collect. If problem is recurrent, re-route pipe or install air release valve at high point.
	3 Leak in delivery pipe.	3 Find leak and repair pipe.
	4 Leak in drive pipe or pump preventing sufficient pressure rise to open delivery valve.	4 Repair pipe or pump.
	5 No air in air vessel (there will be a loud banging at impulse valve closure).	5 Check and repair snifter valve.

CHAPTER 7: Local pump manufacture

Buy or make?



The choice is not simply between buying ready-made ram pumps or making them, it is also between buying locally made ram pumps or an imported brand. The problems with imported machinery have been discussed before, and it is recommended that locally manufactured ram pumps are used whenever well-made, reliable models are available. If the pumps are not being manufactured locally, and no existing workshop is prepared to make them to order, buy the pumps from an importer who stocks a full range of spares and will continue to do so.

In order to get a steel pump with reasonable performance (i.e. capable of delivering to heads up to 100m and with a life of over 5 years) manufacturing methods must involve the use of some relatively sophisticated tools. Casting (as used by most Northern manufacturers) is not necessary. However, to manufacture a durable steel pump, power-drilling and welding facilities are required, along with hand tools for cutting and filing steel. These are the minimum workshop facilities needed, and on their own they usually restrict economic manufacture to pumps with a maximum delivery head of up to 60m. By adding a lathe for simple turning of steel components, stronger and more reliable designs such as those developed by the DTU can be manufactured. With these tools in the hands of experienced technicians, the manufacturing process is straightforward. (The DTU's plastic irrigation ram under development — see Appendix E — can be made entirely with hand tools but for long-term use it is limited to a delivery head of 15m.)

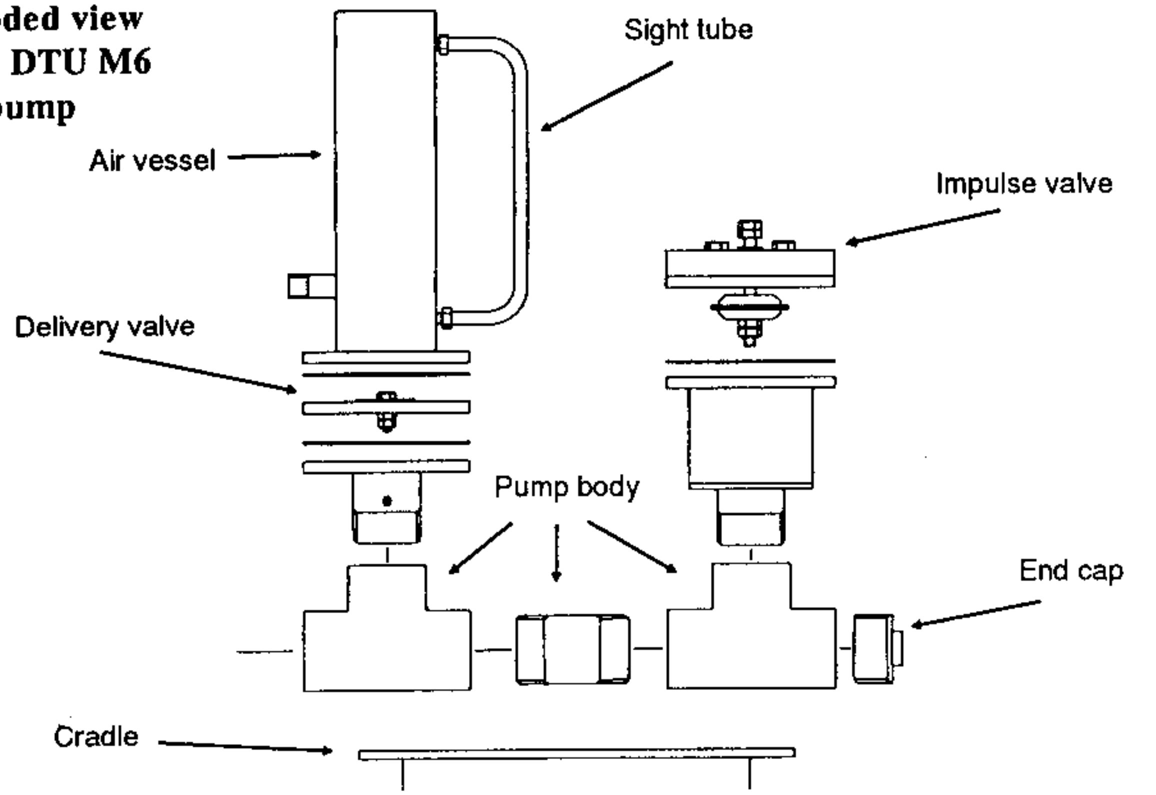
If a programme of ram pump installation is to be initiated in a country with no existing ram pump manufacture, establishing a workshop to make pump components may be appropriate. Where, however, only a few pumps are required, it will be more economic to import pumps from a foreign manufacturer or commission their production by an existing local workshop. The ram pump drawings in Appendix F may be freely copied to aid manufacture.

The manufacture of the DTU steel ram pumps

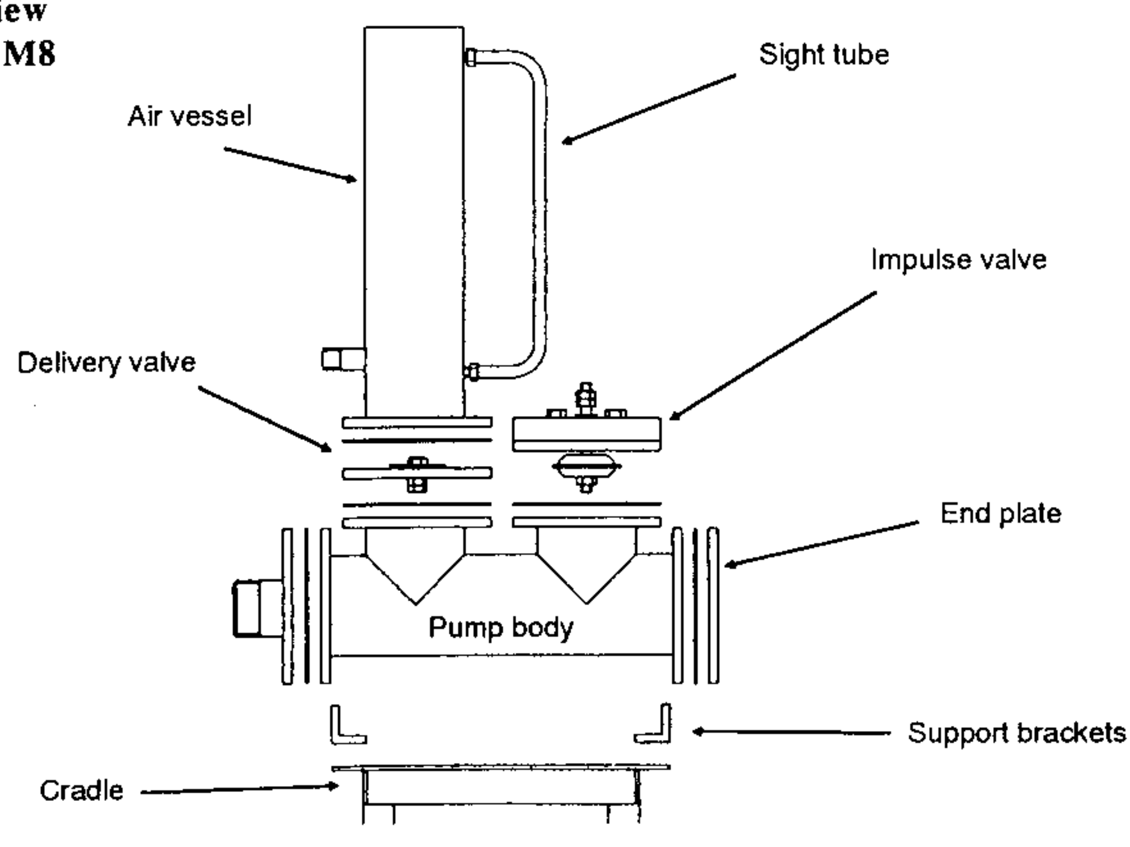
The main DTU pumps are designed to be used with 2" steel drive pipes. This size of pipe is readily available in many developing countries and provides a scale of flow that is compatible with small rural water supply needs. Where necessary a number of these pumps can be used together to give both a larger delivery flow and the flexibility necessary where the source flow varies significantly throughout the year. Pumps designed to suit this size of pipe are also readily manufacturable using equipment usually found in small workshops.

Two designs of pump are detailed in Appendix F — the M6 and the M8. The M8 is the standard design with a large, fabricated pump body that has been found to improve performance characteristics. This design should generally be preferred to the M6. The M6 uses standard 2" pipe fittings for the body of the pump. In situations where such fittings are readily and cheaply available, the M6 is somewhat easier to manufacture.

Exploded view of the DTU M6 ram pump



Exploded view of the DTU M8 ram pump



Workshop facilities

The workshop requirements for DTU ram pump manufacture are:

- a power drill (pillar);
- a welding capability;
- a small lathe;
- miscellaneous hand tools for cutting, threading and filing steel.

Technicians trained to use this equipment are essential to the manufacture of accurate, durable pumps.

Quality control

Achieving an appropriate level of quality control is essential for the success of any manufacturing process. This is because quality control ensures:

- that all parts fit properly together;
- that spare parts fit and that components are interchangeable;
- that badly matched parts do not cause excess wear and poor performance.

Accurate components can be manufactured with careful measurement and machining provided that the required skills and tools are available. While this is an appropriate approach to one-off production, multiple production can be made much easier by taking time to manufacture good quality jigs (templates) at the start. Well-designed jigs remove the need for accurate marking out, provide a guide for machine tools, and make it easy to check component sizes. They save time and allow less experienced technicians to be employed without any loss of product quality.

Most jigs are manufactured with an eye to the situation in which they will be used, and the tools with which they will be used.

Assembly of the DTU pumps

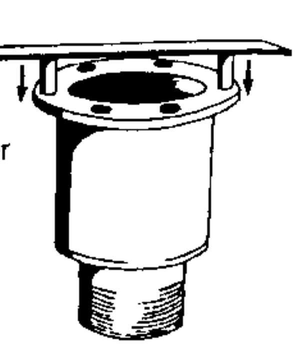
Before assembly check that:

- rubber gaskets have been fabricated to go between all flanged joints. These should have no small cuts or seams that may snag or tear when the pump is operating. A hole punch should have been used to make clean bolt holes through the rubber;
- suitable fittings have been welded or screwed to the air vessel during manufacture if a sight tube is to be used. A sight tube can be an aid to problem solving during commissioning. Jubilee clips are needed to attach the tube, and the tube itself should be clear, reinforced PVC with a bore of around 1/2" (12mm). (This kind of tube is typically capable of holding a pressure of up to 100m for extended periods of time.) A plentiful supply of nuts, bolts and washers for assembly should also be available;
- U-bolts (for the M6) or brackets (for the M8) to attach the pump to its cradle are available.

The tools required for assembly are:

- **M6 & M8** — two spanners to fit the heads of the bolts used. 17mm spanners fit the 10mm bolt heads in the drawings, and although the bolt heads should be approximately this size, a small variation is acceptable. In any case, to keep assembly and maintenance simple, a single size of bolt head should be used throughout.
- **M6 only** — two pipegrip spanners to connect the fittings of the pump body.
- **M6 only** — one flange spanner, fabricated as explained below.

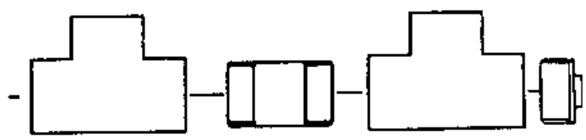
The M6 flange spanner This spanner makes it easy to attach the impulse valve body and the delivery valve adaptor to the pump body. It is made using a 600mm length of flat steel bar with short rods of the same diameter as the holes in the flanges attached as shown. The rods are inserted into the holes and the handle turned to screw the pump part down.



Flange spanner in use

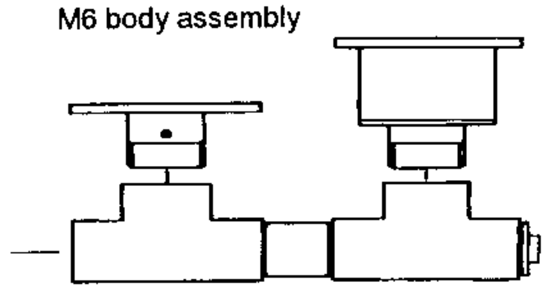
Assembly, step-by-step

[1] Assemble the pump body.
M6 — screw together pipe fittings using PTFE tape on each joint.
M8 — bolt end plate onto pump body.



M6 body assembly

[2] **M6 only** — Attach the impulse valve body and the delivery valve adaptor into the top of the two tee joints. Use PTFE tape on each joint to help sealing.

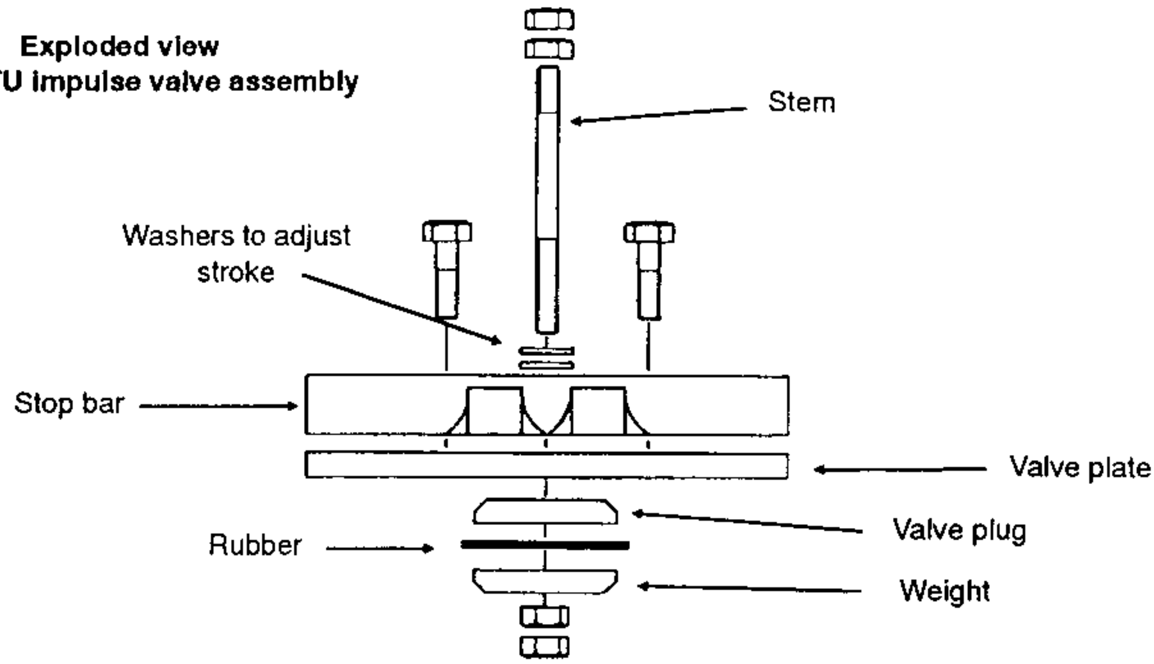


[3] Attach the impulse valve stop bar to the valve plate using the two short bolts. (See the exploded view opposite.)

[4] Assemble the impulse valve stem, taking care not to compress the rubber by over-tightening the lock nuts, as follows. First screw the valve plug onto the valve stem until it reaches the end of the threads. Then push the valve rubber up against the plug. The rubber should be a tight fit over the threads, without being so tight that the rubber is distorted. Next screw on a weight, which can be another valve plug or a large washer, until it sits flat against the valve rubber. Finally, screw on a nut hand tight beneath the weight, then lock a second nut against this. Take care not to compress the rubber by further tightening the first nut while locking the second against it.

5 Push the assembled impulse valve stem up through the stop bar and thread on a single nut by hand. Measure the amount of available up and down movement (the stroke).

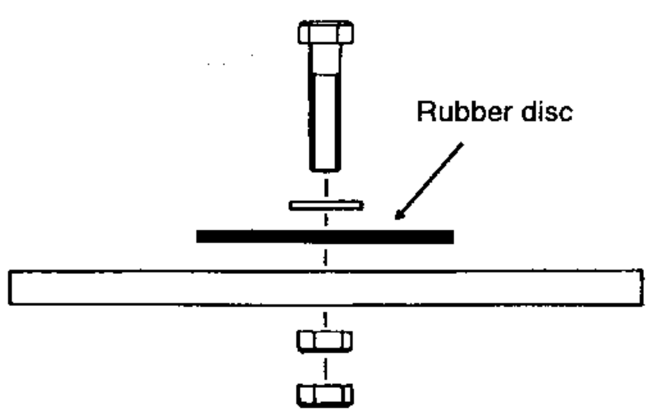
Exploded view of the DTU impulse valve assembly



If the required stroke of the impulse valve has been estimated, remove the top nut and add washers between the stop bar and the top of the valve stem to achieve the required stroke. When the required stroke of the impulse valve has not been estimated, add washers to give about 15mm of valve movement. Replace the top nut, and lock it securely in place with a second nut. Check that when the valve is closed the valve plug hits the stop bar just before the rubber hits the valve plate. If the parts have been accurately manufactured there will be a small gap which helps prevent rapid wearing of the rubber.

6 Attach the assembled valve to the pump body with a rubber gasket between the two flanges. Ensure that the bolts are firmly tightened by holding the bolt head with a spanner and tightening the nut against it.

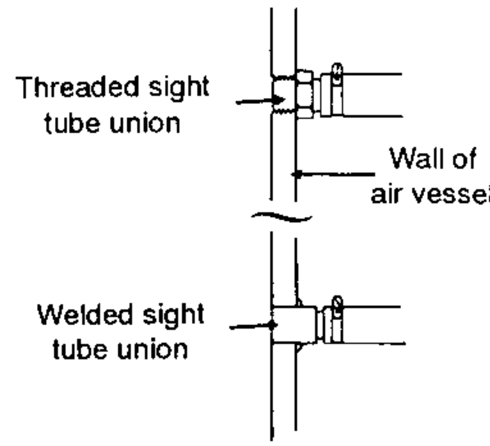
7 Assemble the delivery valve, making sure that the bolt holding the rubber disk is not crushing or distorting it and that the nuts on the delivery valve bolt are locked tight against each other.



Exploded view of the DTU delivery valve assembly

8 Position the delivery valve on the pump body with the rubber uppermost and bolt on the air vessel. Use a rubber gasket between the two flanges. Ensure that the bolts are firmly tightened by holding the bolt head with a spanner and tightening the nut against it.

9 The sight tube on the air vessel is an optional feature that makes it easy during commissioning to see the level of air in the air vessel. When a sight tube is to be used, suitable fittings should have been welded or screwed to the air vessel during manufacture. Attach the sight tube hose using jubilee clips.



10 **M6** Use U-bolts to clamp the pump to the cradle that should have been set into the concrete floor of the pump house in advance. Some rubber may be used as packing between the U-bolt and the pump.
M8 Bolt the pump body to the cradle using the special brackets detailed in Appendix F.

Designing a customised ram pump

Although ram pumps appear to be relatively simple devices, successfully designing them to achieve good performance and durability is surprisingly difficult. The following notes on the design of components are intended to be of use to those wanting to develop a custom ram pump suitable for their particular situation.

The air vessel

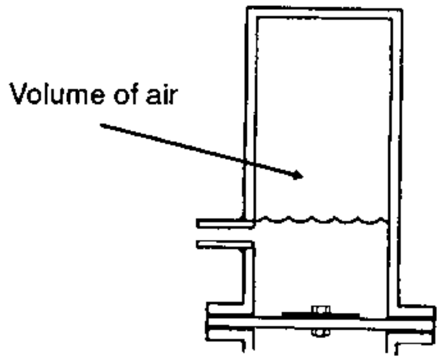
The purpose of the air vessel is to limit the effect of shock waves and produce a smooth delivery flow in the delivery pipe. At each pump cycle a small volume of water passes through the delivery valve into the air vessel in a very short space of time. The air in the air vessel acts like a spring: it is rapidly compressed by each short delivery and slowly expands when the delivery valve closes. This keeps the flow in the delivery pipe constant despite the fact that the pump is actually delivering in pulses. If the volume of air in the air vessel is too small to absorb the sudden impact, the flow in the delivery pipe will be affected. The long column of water in the delivery pipe will be accelerated at every cycle, wasting energy and greatly reducing the amount of water actually delivered. To get good pump performance, it is very important to have enough air in the air vessel at all times. The air vessel should be sized to ensure that the volume of water entering at each cycle is small compared to the volume of air in the air vessel. As a guide, the volume of air should be a minimum of 20 times the maximum expected delivery per cycle, and preferably 50 times as great.

EXAMPLE: at low delivery heads the maximum expected output of a pump is 20 litres/minute and the frequency is 80 cycles per minute, therefore at each cycle the pump delivers $^{20}/_{80} = 0.25$ litres
The *minimum* air vessel size = 20 x 0.25 = 5 litres
The *best* air vessel size = 50 x 0.25 = 12.5 litres

For a particular pump, a large air vessel is required when delivering to a low head because the volume of water entering the air vessel on each cycle is relatively large. The same pump delivering to a high head requires a smaller air vessel because less water enters on each cycle.

Making large air vessels can be expensive, so that the decision on size of air vessel becomes a balance between cost and performance.

NOTE: the water level in an air vessel operating normally will be at the top of the delivery outlet. The air volume is the volume of the vessel above this.



Delivery valve design

The delivery valve acts as a simple one-way valve, allowing water to flow in one direction and preventing it from returning.

The main design criteria of a delivery valve are that it should:

- present low resistance to the delivery flow through it;
- respond very quickly to changes in pressure across it so that it closes and opens rapidly;
- withstand repeated and large changes in pressure;
- seal completely when closed;
- operate over extended periods of time.

When the impulse valve is in the last stages of closure, the pressure in the pump begins to rise in proportion to the reduction in water velocity. The pressure rise is very rapid, and the delivery pressure is reached within a few milliseconds. Ideally the delivery valve needs to then open very quickly with only a very low pressure differential across it. The pressure rise should then stop and the small differential should push water through the delivery valve into the air chamber. If, however, the valve is slow to open or its flow resistance is high, the pressure in the pump body continues to rise considerably above delivery pressure, effectively wasting some of the available pumping energy and therefore reducing efficiency.

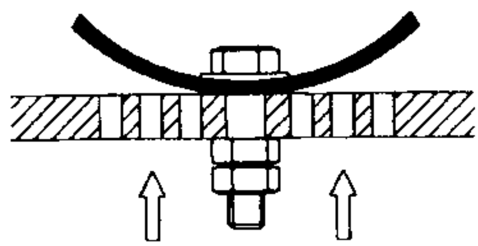
While the valve is open, shock waves travel along the drive pipe. The velocity of the water moving down the pipe and through the delivery valve is reduced by these waves in a series of steps. When there is insufficient velocity left to maintain delivery pressure, the pressure in the pump drops very rapidly and 'recoil' occurs. The delivery valve should close as soon as the pressure in the pump body falls below the pressure above it in the air vessel. In practice the pressure drop is so fast that the valve cannot respond quickly enough and some backflow occurs.

From this description of delivery valve operation, the practical design requirements for a delivery valve can be summarised as follows:

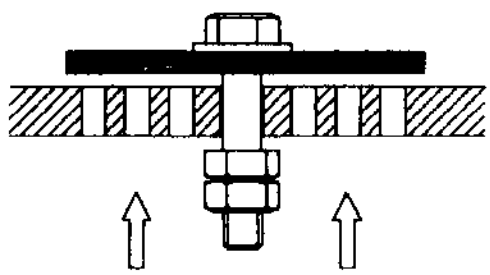
- The valve should move from fully closed to fully open and vice versa as quickly as possible with a minimum pressure differential across it. The movement of the valve and its resistance to moving should therefore be kept as small as possible. As the forward flowrate through the valve falls, it should begin to close rather than stay fully open until the flow reverses.
- The area available for flow through the open valve should be as large as possible, thus giving the smallest possible pressure differential across it.

Types of delivery valve

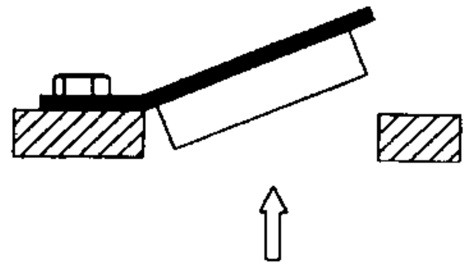
Flap: a simple rubber flap held at the centre against a flat or hollowed plate. Movement is restricted by the type and thickness of rubber used. Flow hole size in the delivery plate is limited by the strength of the rubber and the delivery pressure. The flap valve seals well but is normally limited to low head applications (under 100m). Its low inertia gives it a more rapid response than other valve types.



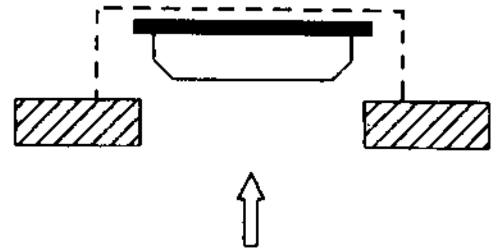
Poppet: the poppet type uses very stiff rubber or an alternative such as shoe sole material rising and falling with a central shaft. This is a good choice at high heads, although it can have sealing problems at low heads. It has the advantage of allowing large diameter holes in the delivery plate to be used. The valve stroke should be kept very short (less than 5mm) to help prevent back flow. The hole in the delivery plate and bolt need careful sizing to ensure ease of movement. Wear can be a problem.



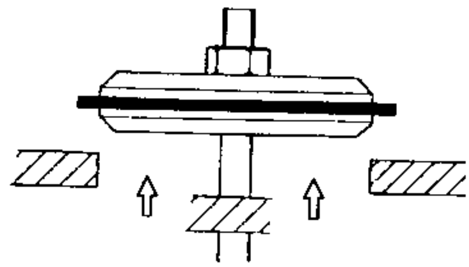
Hinged: a hinged valve allows one large hole to be used in the delivery plate, minimising flow resistance. The materials used for the hinge and the method of fixing are crucial and often cause problems. Back flow due to slow closure can be a problem.



Loose disc: the loose disc delivery valve uses similar material to the Poppet valve for a sealing disk which is restrained by a cage attached to the delivery plate. It is more difficult to fabricate, but has the same characteristics as the Poppet valve.



Plug: the plug valve is effectively an inverted impulse valve with the differential pressure having to overcome the weight of the valve in order to lift it. The large flow area in the delivery plate can be an advantage, but can also lead to a large back flow while the valve closes. A spring can be added to assist rapid closure, but this adds to the differential pressure required to open it.



Impulse valve design

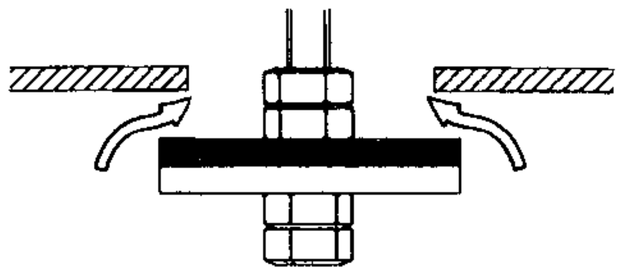
Valve friction Some commercially available ram pumps are oversized in relation to their output potential. Systems using these pumps are unnecessarily expensive because the drive pipes used are bigger than is necessary, and are inefficient because the large drive pipe size leads to low drive water velocity. Their inefficiency is largely due to poor impulse valve design that restricts the amount of water that can flow through the pump. Impulse valves should be designed to make best use of the size of the pump body and drive pipe by balancing the relative amounts of valve and pipe friction. This can be a complex design process but, as a general rule, ensure that the area available for flow at any point in the pump body and through the impulse valve is equal to or greater than the internal area of the drive pipe.

Impulse valve sealing All designs of impulse valve have to ensure a good seal when closed. Some designs rely solely on a metal-to-metal contact which needs to be very precisely made from the right sort of materials. It is easier to use a flexible material such as rubber to provide the sealing required. This is complicated by the fact that in many situations the quality of the flexible material cannot be guaranteed and wear can occur very rapidly.

In Example 1 alongside a material that has great flexibility, resistance to wear and high fatigue tolerance is required. Material with these characteristics is both expensive and rarely available in developing countries.

Impulse valve: example 1

In Example 2 alongside the sealing material is being compressed between the valve plate and the valve plug. It has to be strong enough to withstand the impact and also soft enough to provide efficient sealing. In these conditions rubber will tend to shear and fail very quickly unless it is very hard. Making the edges of the hole and sealing surfaces flat and smooth can help to increase the life of the rubber. One material that is suitable and often available is that used for making shoe soles.



Impulse valve: example 2

In Example 3 the seal takes no impact force and is simply left to seal the small ring between the valve plug and plate. The characteristics of the sealing material is much less critical and a wider range of readily available materials can be used.

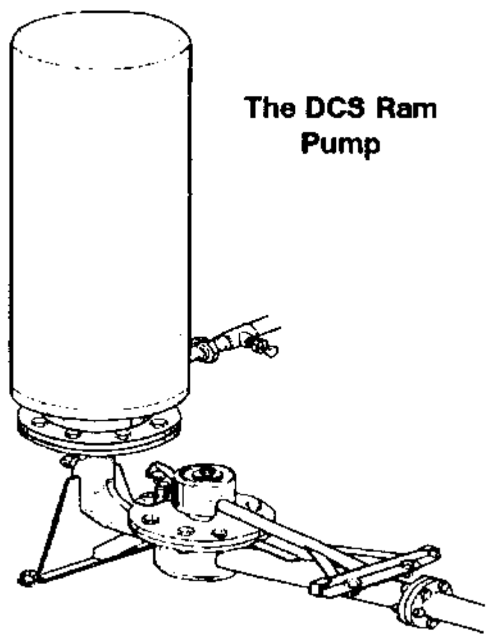
Impulse valve: example 3

CHAPTER 8: Case studies — Nepal and Zaire

Nepal

Set in the Himalayas, Nepal has one of the largest potentials for hydro-power anywhere in the world. Large hydro-electric schemes are being designed to generate tens of thousands of Megawatts of power that will be sold to Nepal's neighbours and bring a considerable foreign exchange income to a very impoverished country. On a scale more appropriate for exploitation by local communities within Nepal, various small-scale, low-cost ways of harnessing the widely available water power are being developed. The United Mission for Nepal established Development and Consultancy Services (DCS) which developed ram pump based water supply schemes during the 1980s. Between 1983 and 1989, sixteen schemes to supply water for domestic use were installed using DCS's own design of locally manufactured ram pump. DCS have built up considerable expertise in both the design of ram pumps for high head applications (100-180m) and the community organisation for their installation, operation and maintenance.

DCS have produced three sizes of pump, 1½", 2" and 4", covering a range of drive pipes from ¾" to 4" with drive flows from 12 - 400 l/min. Pumps are made in a private engineering workshop in Nepal from locally available steel components. The pump design relies upon high quality welding and accurate machining of valve parts. DCS has encountered various problems in the process of developing this high-pressure ram pump, most of which have been related to the very demanding operating conditions. Some of the problems worth noting are:



The DCS Ram Pump

- Threaded joints in the steel drive pipe were found to be of a poor quality that led to leaks and the entrance of air. Pipes with flanges welded to them are now used, bolted together with rubber O-ring seals.
- The original impulse and delivery valve rubbers proved unreliable and have now been replaced by a specially moulded rubber washer that takes no impact.
- At the higher end of the drive head range, the pumps were found to need either a special starting valve or a manual lever on the impulse valve to assist starting.
- The large weight of the moving impulse valve assembly, coupled with its method of alignment, has resulted in the stem bolts either breaking or having their threads stripped. The problem has been lessened by reducing the weight of the valve and paying careful attention to valve assembly.

Organisation and community participation

The organisation of the entire process of system design, installation and operation is a key factor in the success of any community-based water supply scheme. DCS have developed a standard process for interested communities to follow from initial contact to site completion. The initiative to install a ram pump system comes ideally from the community to be served. When the potential of ram pump systems has been recognised in a suitable area, the community groups are encouraged to contact DCS. The community is then asked to complete a detailed Ram Pump Survey Request Form. Questions cover the geographical, social, financial and technical details of the proposed site and community. (The form is reproduced opposite.) A standard payment to cover the costs of the survey is returned to DCS along with the completed form. This process is intended to help communities assess the feasibility of their site, and also to ensure that the whole community is involved and committed to the project.

DCS then arrange for a surveyor to visit the proposed site and undertake a detailed assessment of suitability for a ram pump based water system. Available flows are recorded, heads measured, and a preliminary design carried out. Community meetings are held to which all the users who have rights to the water are invited. The users then have a say in siting the pump and the utilisation of the water. When all the information has been gathered, an estimate of likely water output and the total cost of the proposed system is calculated. If the benefit of the proposed scheme is great enough and the necessary financial arrangements can be made by the community, a detailed system design and costing is undertaken by DCS staff. This is sent to the community for their comment and approval. The community is advised to raise an extra 10% above the estimated cost to place in a bank account for ongoing maintenance and repair of the system. When the community have approved the cost estimate and made the necessary financial arrangements, terms and conditions for the construction work are negotiated with DCS. When the terms are agreed, DCS places orders for the necessary materials and hardware.

DCS supply the drive pipe, ram pump, pipe fittings and special items of hardware such as tank lid frames. DCS do not supply cement, corrugated roofing sheets or pipes for feed and delivery. During construction, the DCS overseer will not take responsibility for building any part of the storage and distribution system within the village.

Community members are expected to dig trenches and bury the major portion of the delivery pipe before the overseer arrives on site and supervises the laying out and construction of the rest of the system. When the system is complete the overseer starts the pump and makes sure that everything is operating smoothly. He then teaches several carefully selected villagers how to start the pump, adjust the flow, and dismantle and reassemble the pump and drive pipe. Care is taken with this training to ensure that a good standard of everyday operation and maintenance is achieved. Spare parts and advice are available from DCS after the system has been commissioned.

Sample DCS (Nepal) Survey Form

RAM PUMP SURVEY REQUEST FORM

1. VILLAGE:... 5. NEAREST ROAD POINT:

2. PANCHAYAT:... ....

3. DISTRICT:... 6. WALKING TIME TO VILLAGE;

4. ZONE:.. ....

SOCIAL

7. PRADHAN PANCH:................................. 11. WATER COMMITTEE MUKHYA:

8. UPPA PRADHAN:.................................. ....

9. ADACHYIA:.. 12. POPULATION REQUIRING LIFTED WATER:

10. SADASYA:... ....

FINANCIAL

13. PROJECT WILL BE PAID FOR BY WHOM?..

14. FULL PAYMENT CAN BE GIVEN BY WHEN?...

15. THE VILLAGE AGREES TO CARRY SAND AND STONES FREE OF CHARGE?..........................

16. THE VILLAGE AGREE TO DIG AND BURY PIPES FREE OF CHARGE?.......................................

TECHNICAL

17. NAME OF WATER SOURCE:..SPRING OR KHOLA?...................

18. DRY SEASON FLOW:..LITRES PER MINUTE

19. WALKING TIME FROM VILLAGE TO WATER SOURCE:...

20. IS THIS WATER USED TO IRRIGATE NEARBY KHET LAND?..

21. IF YES, HOW MANY METRES IN ELEVATION BELOW THE SOURCE?...

WE UNDERSTAND THAT IF THIS SURVEY PROVES TO BE FEASIBLE, THE PIPE AND PUMP(S) WILL BE SENT ONLY AFTER FINANCIAL ARRANGEMENTS WITH DEVELOPMENT AND CONSULTING SERVICES, BUTWAL, HAVE BEEN COMPLETED, THE REQUIRED AMOUNT OF SAND HAS BEEN CARRIED TO THE PUMP SITE, AND THE PLASTIC PIPE FROM THE PUMP SITE TO THE VILLAGE HAS BEEN DUG AND BURIED ALONG THE LINE MARKED BY THE SURVEYOR. WE HAVE INCLUDED WITH THIS REQUEST THE AMOUNT OF RS 400 FOR THE INITIAL SURVEY.

DATE:...SIGNED:...

Zaire

Ram pumps have been used in the Village Water Supply Programme of the Baptist Church of Western Zaire (C.B.Z.O.) for the past three years. The programme arose from a request from villagers to be helped in addressing their drinking needs.

C.B.Z.O. have been actively involved for many years in rural community development, helping to enable villages to collectively address issues in the fields of health, sanitation, agriculture, education, etc. It was within this extensive community work that the Village Water Supply Programme developed. The programme does not install water supplies: its purpose is to train and facilitate the villagers, enabling them to build, install and operate their own water systems. Some villages only want, or are only capable of sustaining, a small-scale project such as protecting their springs. Other villages are much stronger and more dynamic and are able to take on the construction and maintenance of full supply systems that are sometimes of quite elaborate complexity. Whatever the level of the village, it is *their* water supply and the role of the programme is to respond to them with appropriate training and assistance that will enable them to improve their water situation for themselves.

The Bandu and Bas-Zaire regions of Zaire have a high rainfall — on average 1800mm per year. There is plenty of water in the valleys but the villages are on hill tops between 40m and 120m above the valley floors. Because there is a high rainfall and plentiful water there are many hydro-power schemes, most of which are very small-scale and only produce between 50 and 250 Watts. The ram pump is ideally suited to use in areas such as this and, although only one of several water supply technologies currently employed, is widely used.

Each of the village systems is installed as a community-based project initiated by the villagers themselves who request an initial visit from the Village Water Supply team. The purposes of the initial visit are to carry out an initial survey, to assess the various water supply options and their feasibility, to discuss the implications of building a water system and to set out the requirement's necessary for the team's assistance.

These requirements are:

- that the whole village should agree to and be involved in the construction of the water supply. If everyone contributes to the construction, then the water will be freely available to all;
- that the village should pay for the system. Most of the villages are very poor and do not have cash, although they do have agricultural produce. The Programme will help them to market their produce to raise cash;
- that everyone in the village will be prepared to participate in work days and perform the labouring tasks required;
- that the village will provide a small team of people to work on the system from beginning to end. These people will be taught how the system runs, how to maintain it and how to carry out basic repairs.

If the village agrees to these requirements and wishes to go ahead, the Village Water Supply team make a second visit to draw up detailed plans. They explain each of the water supply options, the advantages, disadvantages and costs of the various systems.

A system's cost includes:

- the cost of the materials to be used in the water supply system;
- the cost of transport for agricultural produce going out and the materials coming in;
- an added percentage to cover both some overheads and a two-year complete guarantee on the whole system if any major repairs are required.

The villagers then have time to decide whether they wish to go ahead and, if so, which kind of system they think they could afford. They discuss this with the team and give them an estimate of when the first truck load of their produce will be ready for market. Their contribution usually has to be made in several instalments and can take anything from months to years to complete.

When their first load is ready, the Programme sends out a truck. One or two of the villagers always accompany the truck-load of produce as it goes to the city. The produce is sold and pipes, pumps, cement, etc. are purchased. The purchases are made as quickly as possible to avoid losing because of the very high inflation in Zaire. The materials are then taken to the village where they are stored. The stock of materials serves as a tangible encouragement to the villagers, enabling them to see that their hard work is paying off.

When all the necessary supplies for the system have been purchased, the team returns and lives in the village while it helps the villagers to construct their system. The team's role is to provide instruction so that the villagers can build the system themselves. Clearly, if the villagers are able to construct and install the system themselves, they will be well prepared to operate, maintain and repair it with minimum outside help. Some of the tasks — like laying pipe — are carried out by the whole community, while other more specialised tasks are carried out by smaller groups of technically capable people, including the small team of village 'technicians'. The work is scheduled so that the technicians are included in each aspect of the construction. The technicians also receive training in the operation, maintenance and repair of the pumps themselves.

When the system has been completed and fully commissioned, the Village Water Supply team departs, leaving the system fully with the villagers. Ownership and decision making responsibilities rest with the entire village population. Various tasks are then delegated to particular individuals. Someone living near each standpipe is made responsible for it, holding the key for the control valve and regulating its use in the manner decided. The village selects one of the technicians to take overall responsibility for the system supervision and pump maintenance. This person is given the keys for the pumps, the tools and the spare parts, etc. That person becomes personally responsible for the pumps. When necessary they can call on the other technicians for help, or may call a public work day. Should the selected person fail to do their job or begin to take advantage of their position to gain leverage and influence, then the village can take their responsibility away from them and pass it to one of the other trained technicians.

The Village Water Supply Programme maintains contact with the village and a team member visits, typically at six month intervals, to check the system and ensure that everything is operating correctly. If any further training is required, this can either be carried out during these visits or a special trip can be arranged. If any major problems arise, the Water Supply team will return to the village to help resolve the difficulties.

Appendix A: Some currently available ram pumps

The following is a list of some of the ram pumps currently (1992) available. Brief details and addresses of the manufacturers are given. Where the product range has a distinctive name it is shown under the name of manufacturer. There are a number of other manufacturers in Asia and Latin America catering for local demand in their respective countries. Pipe sizes are given in inches: 1" equals 25mm (internal diameter).

AB HYDRAULISKA VADURAR,
Bruzaholms Bruk,
570 34 Bruzaholm,
SWEDEN

Range (drive pipe size) ½" - 3"

AG MASCHINENFABRIK,
'Schlumpf',
Bahnhofstr. 15,
6312 Steinhausen/Zug,
SWITZERLAND

Made from partly cast iron, partly steel components. Unconventional horizontal axis impulse valve design.
Range (drive pipe size) ¾" - 4"

BRIAU S.A.,
'HYDRAM',
B.P. 0903, 37009 Tours Cedex,
FRANCE

Range (drive pipe size) ¾" - 6"

CECOCO,
'HYDRO HI-LIFT',
P.O. Box 8, Ibaraki City, Osaka 567,
JAPAN

Range (drive pipe size) 1½" - 8"

DCS,
(Development and Consultancy Service of UMN), P.O. Box 8,
Butwal, NEPAL

A fabricated steel design using pipe components.
Range (drive pipe size) ¾" - 4"
Max. lift - 180m

DESCLAUD, J.M.,
'BELIER ALTO'
57 Rue Bertrand-de-Goth,
33800 Bordeaux,
FRANCE

Constructed from steel pipe components with inflatable rubber air compartment to replace air vessel.
Range (drive pipe size) ¾" - 5"
Max. lift - 100m

GREEN & CARTER, **'Vulcan' & 'Easton'** **Vulcan Works, Ashbrittle,** **Wellington, Somerset,** **TA21 0LQ, UK**	Traditional heavy cast design. Range (drive pipe size) 1" - 10" Max. lift - 125m: special pumps to 300m Also specialises in 'compound rams' where the drive water source is other than the delivery water source and a light plastic 2" pump.
IRRIGATION EQUIPMNT. Ltd., **'Premier',** **INDIA**	A cast design with angled impulse valve. Range (drive pipe size) 2" - 4".
JANDU PLUMBERS Ltd., **'Hydram'** **P.O. Box 409, Arusha,** **TANZANIA**	Traditional cast design (Blake's clone) with option of twin impulse valve for improved throughput. Range (drive pipe size) 1½" - 5" (1 impulse valve): 2½" - 8" (twin impulse valve) Max. lift - 110m
JOHN BLAKE LTD., **'HYDRAM',** **P.O. Box 43 Royal Works** **Accrington, Lancs. BB5 5LP** **UK**	Traditional cast design, well proven and widely distributed/copied. Range (drive pipe size) 1¼" - 8" Max. lift - 125m
JOHN DANKS & SON. Pty. Ltd., **'BILLABONG'** **Doody St., Alexandria,** **Sydney, N.S.W.** **AUSTRALIA**	Traditional (1915) cast design. Used extensively in the Solomon Islands for village water supply. Range (drive pipe size) 1" - 4" Max. lift - 60m.
LAS GAVIOTAS, **Calle 18A, No 1E, Apdo 4976,** **Ap.Aereo 18261, Bogotà,** **COLOMBIA**	
RIFE HYDRAULIC ENGINE, Mf. Co., **Box 367, Millburn, New Jersey,** **USA**	Standard but complex cast iron design with steel components. Four models. Range (drive pipe size)¾" - 6". Max. lift - 30 to 150m depending on model.

Some currently available ram pumps

SANO,
Pfister & Langhaas, Apparatebau,
Sandstr. 2-8, 8500 Nürnberg,
GERMANY

Constructed from welded steel components.
Unusual inverted impulse valve design.
Range (drive pipe size) ¾" - 6".

MACHINENBAU MAX WAGNER,
'Wama'
Bergstr. 8, 8018 Grafing,
GERMANY

WARWICK UNIVERSITY,
'DTU Ram Pumps',
Development Technology Unit,
University Of Warwick,
Coventry, CV4 7AL, UK

Designs freely available for self manufacture in small workshops .See other appendices of this book.
Range (drive pipe size) 1" - 2"
Max. lift - 100m

Appendix B: DTU steel pump performance charts

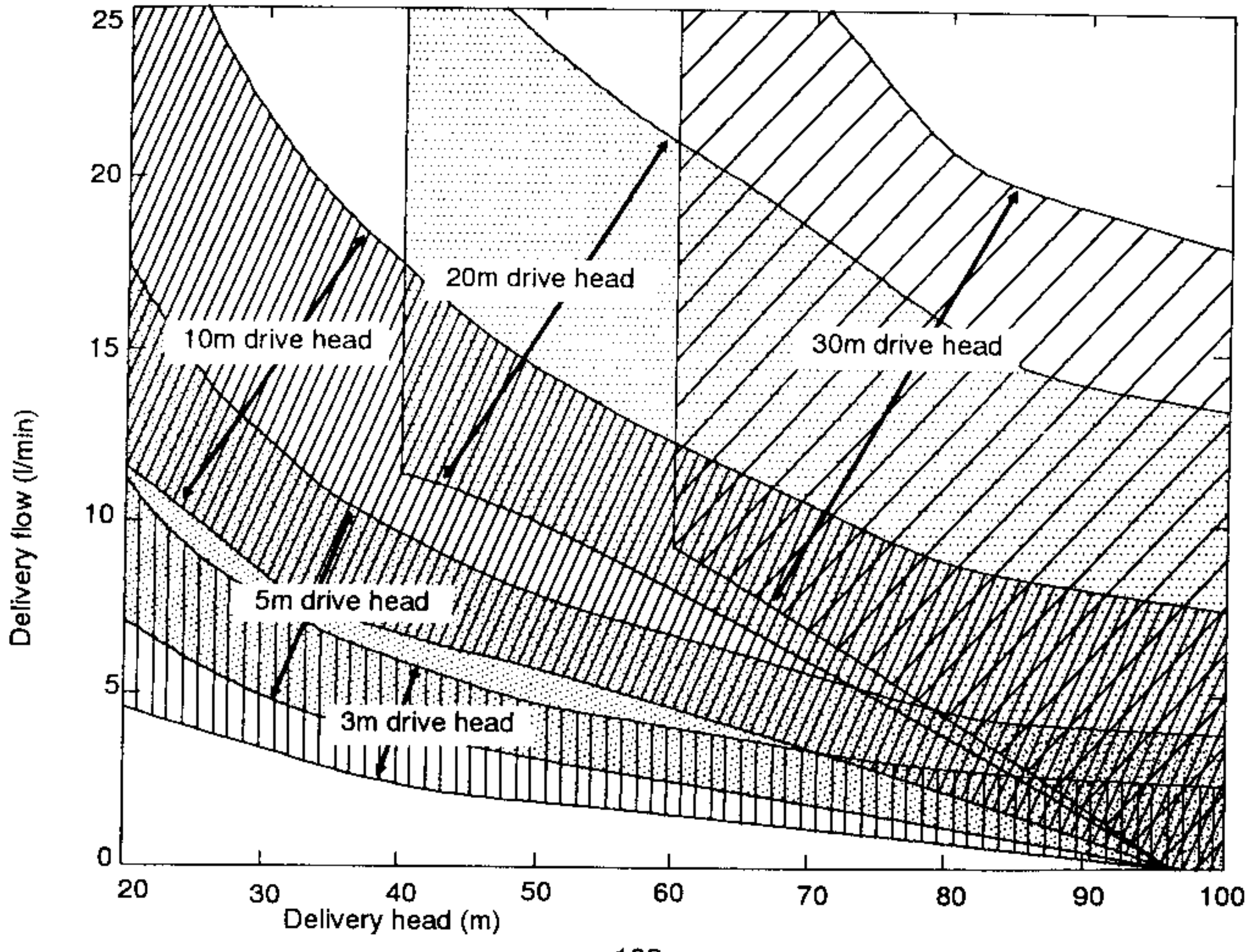
The charts in this appendix are intended to serve as system design aids for use with the DTU 2" pumps (design drawings of these pumps are reproduced in Appendix F).

Chart 1: Estimating pump output

This chart is a guide to 2" DTU steel pump performance and should only be used where the drive pipe length lies in the recommended range as shown in Chart 2.

This chart can be used to estimate the delivery flow of a single pump after other site variables have been found. Each shaded zone represents a particular drive head, the upper boundary indicating the use of the maximum drive flow, the lower boundary representing the use of the minimum.

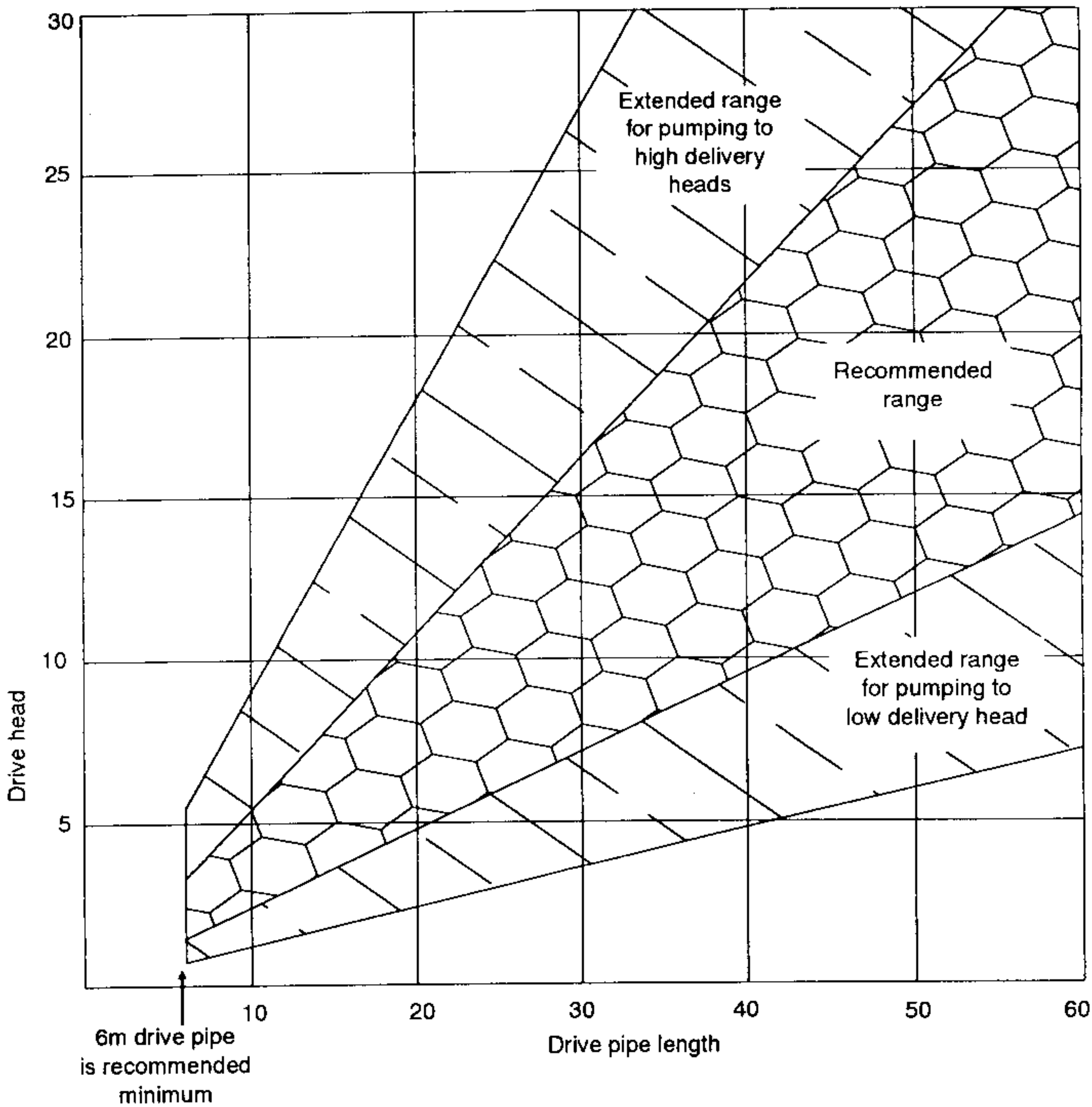
For example: a site has a delivery head of 60m, a drive head of 10m and a drive flow of 90 l/min. On the graph identify the upper and lower boundary of the shaded zone labelled '10 metre drive head'. Draw a line up vertically from 60m on the horizontal (delivery head) axis to cut through the 10m drive head zone. Read off the left hand axis (delivery flow) level with where the line cuts the upper and lower boundary of the 10m drive head zone. In this case the readings are about 5 l/min and 12 l/min. These figures represent the minimum and maximum delivery flows. As the drive flow is about halfway between the minimum (60 l/min) and maximum (120 l/min) recommended for the DTU 2" pump, the delivery flow



will be half way between the minimum and maximum of the 10m zone on the graph — in this case ½ (5 + 12) = 8.5 l/min. If the drive head available (eg 14m) falls between two of the drive heads given on the graph, the above process should be carried out for the drive head zones (eg 10m and 20m) on either side of the actual head. When the values of delivery flow have been obtained for the bordering zones, the actual delivery flow can be estimated from them.

Chart 2: Acceptable drive pipe length

The chart below is an aid to selecting drive pipe length for DTU 2" pumps. The zone marked 'recommended range' can be used to find the normal range of drive pipe length for a given drive head. In some circumstances of particularly high (above 80m) or particularly low (below 30m) delivery head, the range can be broadened as shown.



Appendix C: Sources of further information

The books and articles listed below are believed to be available or 'in print' (in 1992). They give fuller details of water provision, pumping, water treatment and hydraulic construction than is possible in this book.

Archambault, J., *Le Captage des Sources* (trans: Spring Capture), GRET, 213 Rue la Fayette, 75010, Paris, [ISBN 2 86844 016 9], France, 1987.
Practical details of choosing and protecting springs and connecting them to pipes.

Cairncross, (Sandy) & Feacham, (Richard), *Environmental Health Engineering in the Tropics*, Wiley, 1983.

Clark, L., *The Field Guide to Water Wells and Boreholes*, John Wiley, London, 1988.
An introduction to the design and construction of boreholes and wells.

DTU working papers: Development Technology Unit, University of Warwick, UK.

WP 32	Non-motorised Irrigation of Small Farms from streams in Manicaland, Zimbabwe, 1991.
WP 33	Comparison between DTU and Commercial Hydraulic Ram Pump Performances, 1991.
WP 35	Design of DTU PVC Hydraulic Ram Pump, 1992.
WP 36	Analysis of Dynamic Fatigue in uPVC Hydraulic Ram Pumps, 1992.

Fraenkel, (Peter), *Water-pumping Devices, A handbook for Users and Choosers.* IT Publications, London, 1986.
Detailed practical review of the many options available for water lifting on a small scale, including ram pumps.

GRET *La construction des citernes* (trans: construction of tanks), Les dossiers 'le point sur' No. 4, GRET, Paris, 1984.
Covers the catchment and storage of rain water.

Harvey, (Adam) & Brown, (Andy), *Micro Hydro Design Manual*, IT Publications, London, 1992.

Heber, (Gabrielle), *Simple Methods for the Treatment of Drinking Water*, GATE - Vieweg, Frankfurt, Germany, 1986.

Huisman, L. and Wood, W.E., *Slow Sand Filtration*, WHO, 1985.
A description of a cheap and simple biological filtration process.

Inversin, A.R., *Micro-hydropower Source book — a practical guide to design and implementation in Developing Countries*, NRECA International Foundation, 1800 Massachusetts Av N.W., Washington DC, USA, 1986.
Good coverage of flow measurement techniques and design of components of water systems.

Jordan, (Thomas D. Jnr), *A Handbook of Gravity Flow Water Systems*, IT Publications, [ISBN 0 946688 50 8], London, 1984.
A practical guide to gravity fed water systems — useful reference book.

Kenna, J. and Billet, B., *Solar Water Pumping: A Handbook*, IT Publications, [ISBN 0 946688 90 7], London, 1985.
A survey of the field, with costing guides.

Kerr, (Charles) Ed., *Community Water Development*, IT Publications, [ISBN 0 946688 23 0], London, 1989.
Wide ranging collection of articles from *Waterlines* and *Appropriate Technology*, intended as a training guide.

Mann, H.T. and Williamson, D., *Water Treatment and Sanitation*, IT Publications, [ISBN 0 903031 23 X], London, 1982.
A handbook of simple methods for use in rural areas of developing countries.

Meier, (Ueli), *Hydram Information Package*, SKAT (Swiss Centre for Appropriate Technology, University of St. Gall, St. Gallen, Switzerland), WP 01/90, 1990.
A selected and annotated bibliography, list of manufacturers and reprinted articles on ram pumps in German and English.

Morgan, (Peter), *Rural Water Supplies and Sanitation*, Blair Research Bulletin, Macmillan, London, 1988.
Covers how to establish and maintain clean water supplies in rural areas of developing countries.

Muckle, T.B., 'The NDUME turbo-pump - a user experience' *Waterlines*, 10, No. 4, pp 30-1, April 1992.
Describes a small machine widely used in Kenya.

Pacey, A. and Cullis, A., *Rainwater Harvesting*, IT Publications, [ISBN 0 946688 22 2], London, 1986.
This book stresses the importance of social, economic and environmental considerations when planning and implementing projects.

Pickford, (John),(Ed.), *The Worth of Water: Technical Briefs on Health, Water and Sanitation*, IT Publications, [ISBN 1 85339 0690], London, 1991.
Series of short introductions to many areas of community level water supply and sanitation.

Sources of further information

Schiller, E.J. (Ed.), *Proceedings of a Workshop on Hydraulic Ram Pump Technology* held in Arusha, Tanzania, Manuscript report 102eR, IDRC, Ottawa, Canada, 1986.
11 papers including 4 on ram pumps in specific African states, 2 on community participation and recommendations for future programmes.

Stern, (Peter), *Small Scale Irrigation*, IT Publications, [ISBN 0 903031 64 7], London, 1979.
Written for those working with farmers on development and extension in rural areas.

Tacke, J.H.P.M., *Hydraulic Rams — a Comparative Investigation*, Delft University of Technology, Holland, [ISSN 0 169 6548].
A comparison between some of the commercial ram pumps available.

Appendix D: Surveying and pipe sizing

Measuring height/head

There are many ways of measuring height, some involving costly equipment, others requiring no more than a water-filled tube. A rough estimate of the available head on a site can be made from an accurate contour map of the region (when available), but it will always be necessary to survey the actual site to get an accurate figure.

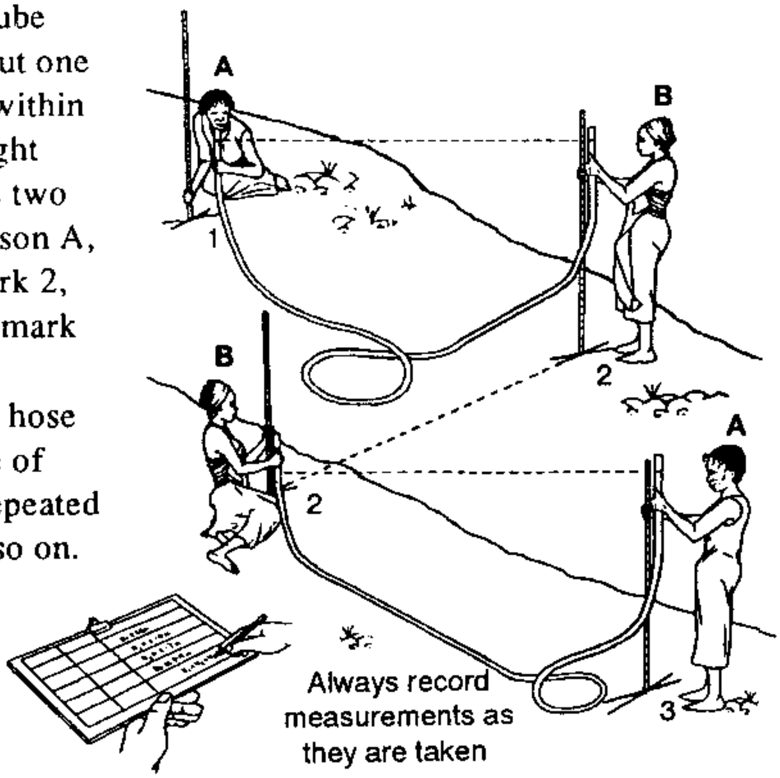
The following methods of measuring head are illustrated here:

- water- filled tube;
- water-filled tube and pressure gauge;
- spirit level and plank;
- sighting meters.

Other methods such as using Dumpy levels and theodolites can give very accurate results but must be used by skilled operators and often involve strings of calculations that are best avoided by the untrained. Generally, accuracy to within a fraction of a centimetre is not required of a ram pump site survey. Where trained surveyors with their own equipment can be hired at an affordable rate it can save trouble and uncertainty to use their services. In most cases, however, adequate results will be obtained by using the methods outlined here.

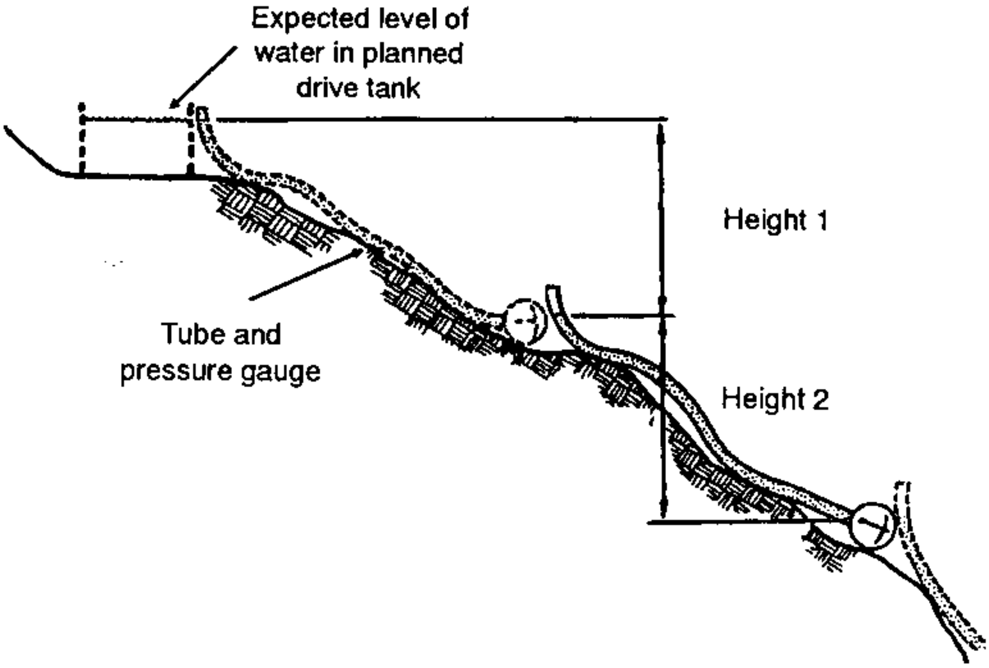
The water-filled tube

The water-filled tube is a cheap and reasonably accurate method of measuring height but is slow to use on slopes with a shallow gradient. In the diagram shown alongside, person A and person B mark two places on the slope, place their respective measuring rods vertically on the marks and drape the tube between them. The second mark is about one metre below the first. The water level within the tube is allowed to settle and its height above each mark is measured using the two rods. The height at mark 1, read by person A, is subtracted from the height above mark 2, read by person B, to give the fall from mark 1 to mark 2. Person B keeps still while person B carries the rod and end of the hose down the hill to mark 3. The procedure of measuring and subtracting heights is repeated to give the fall from 2 to 3, 3 to 4 and so on. A long measuring rod can be made by using a ruler to measure marks onto a stick, or by attaching a tape-measure to a stick.



NOTE: Whenever using the water-filled tube method, make sure that there are no air bubbles in the water: they can cause significant inaccuracies. Always use a clear hose so that bubbles can be seen and allow them to rise before taking measurements. The method can be laborious if a tube with a wide bore is used because it will be very heavy when filled with water. It can also prove difficult to fill a tube with water on site. It is recommended that narrow bore tube (6-10mm) is used, that it be filled off-site and the ends plugged for transport to the site (petrol pipe hose is often 6-8mm and clear). The hose can be filled from a tap or by immersing it in a stream. Water should be allowed to flow through the pipe to drive out bubbles.

Water filled tube and pressure gauge



In this method, the pressure of the water in a water-filled tube is used to give an indication of height. For example, to estimate the drive head of a ram pump. A pressure gauge is attached to one end of a transparent tube which is then laid out down the hill from the water level in the drive tank. The pressure gauge reading is noted and its position marked. The tube is then moved down the hill so that the top water level is aligned with the mark and a second reading and mark is made. This can be repeated as many times as is necessary.

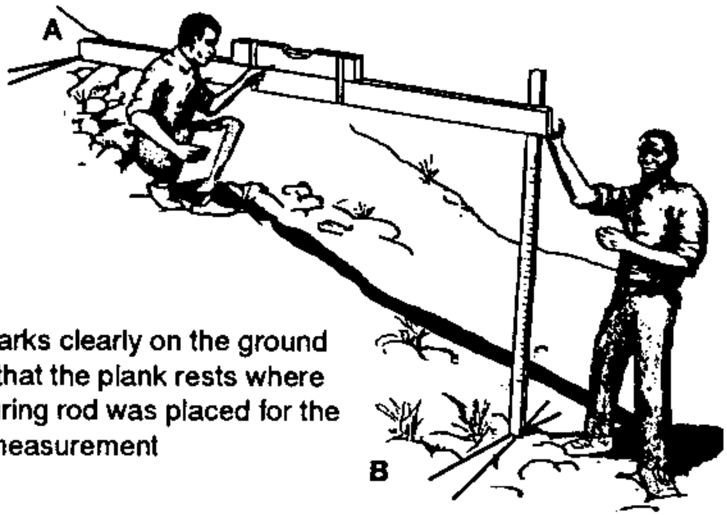
The readings are recorded, converted to metres drop, and added together to give the total head.

This method can be accurate and easy to carry out, but does require that the gauge be calibrated (following the manufacturer's instructions) before each site survey.

Fill the hose before going to site, plug one end and securely attach the gauge to the other. For each measurement, unplug the top of the pipe. It does not matter if a little water is lost, but it is important to keep air bubbles out of it.

Spirit level and plank

In this method a spirit level attached to a reliably straight plank of wood is used, as shown below. Each measurement of height is restricted to the height drop over the length of the plank, so this method can be very slow on gentle slopes. Accuracy can be increased by repeating each measurement after turning the plank around and then taking the average of the two readings. The total drop is then the sum of all the individual height drops obtained by 'stepping' from A to B.

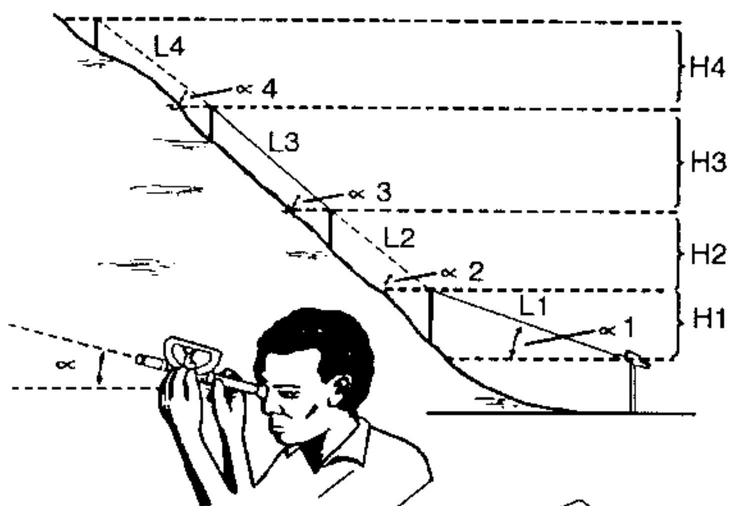


Scratch marks clearly on the ground to ensure that the plank rests where the measuring rod was placed for the previous measurement

Sighting meters

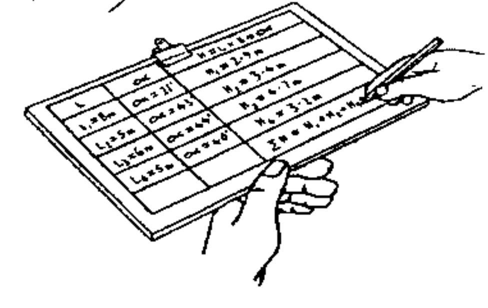
Often called Abney levels or inclinometers, sighting meters measure the angle of incline of a slope. Some include range finders so that it is not necessary to measure the linear distance over which the incline is measured. To use a sighting meter, first position two equal length posts in the ground. The posts can be as far apart as can be easily measured, but must be within visible range of each other. Place the sighting meter on top of one post and record the angle between it and the top of the next post. Move the lower stake above the higher and repeat the measurement. The distances between the posts (L1, L2, L3, L4 on the diagram) and the angles (α1, α2, α3, α4) between post tops are recorded. Each height record is then calculated using:

Height = Length x sin α.



Some sighting meters are actually calibrated directly in slope (Sin α), otherwise, a calculator with a sine function, or a table of 'sines' will be needed to convert each angle (α) into the corresponding slope (Sin α).

The heights are then added up to provide the overall height. The L1, L2, etc lengths can also be added to give the total distance between the two points and therefore gives an indication of the length of pipe required.



Measuring linear distances

The distance between the proposed intake structure, the drive tank, the pump house and the point of delivery must be measured accurately to determine the pipework required. The easiest way to do this is to use a long measuring tape, keeping the tape as straight as possible as it is laid out. It can be useful to mark out the route with sticks before measuring. As an alternative to a long measuring tape, a ball of string, knotted at measured distances, can be used.

Measuring flows

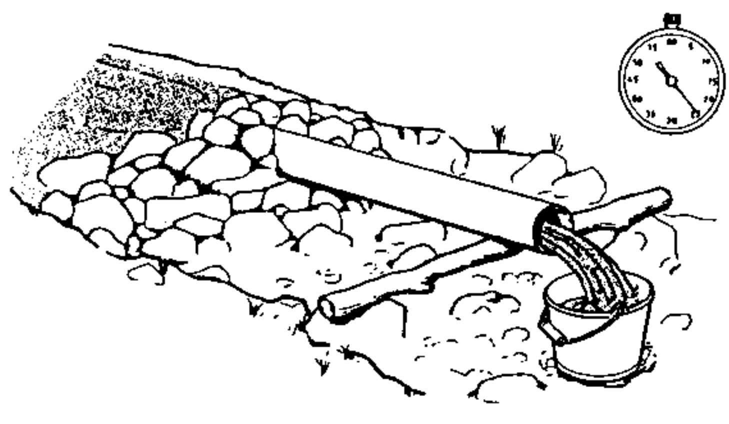
When designing a ram pump system it is useful to know the highest flood level and the minimum normal flow of the source being used. Because of the remote sites in which ram pump systems are often used, there is rarely any accurate record of flows and flow variations in the local water sources. The people living nearby will be able to give information such as whether or not a water source dries up regularly, and roughly how high it rises during floods. Flood debris left by previous high water levels may also provide some clues.

When a source has been identified the actual flow in the source should be assessed. If the source has a large flow, it may be obvious that there is far more than is required, making measurement unnecessary. When the flow is small, it should be measured to ensure that it is sufficient. Ideally the flow should be measured when it is at its maximum and minimum, but this is rarely possible. A rough measurement of typical flow is better than nothing and a method for obtaining this on small streams, using a bucket or barrel, is explained below.

At those ram pump sites where accurate flow measurement is critical, it is recommended that measurements are made using a notched weir. These are relatively complex and expensive semi-permanent structures, the use of which has been extensively documented and is covered in several of the titles suggested as sources of further information in Appendix C.

The bucket/barrel method

The whole flow is diverted into the bucket or barrel and the time it takes to fill is recorded. The bucket or barrel has a known volume and the flow rate is found by dividing the volume by the time it takes to fill. To divert the flow into the container it is often necessary to build a temporary dam (use polythene sheet to help stop leaks) through which a pipe is fixed. This method of flow measurement is susceptible to mistakes and inaccuracies. To provide reliable information, it is worth taking six or more readings and averaging between them to get a mean value. An accuracy of ± 10 per cent is usually considered adequate.

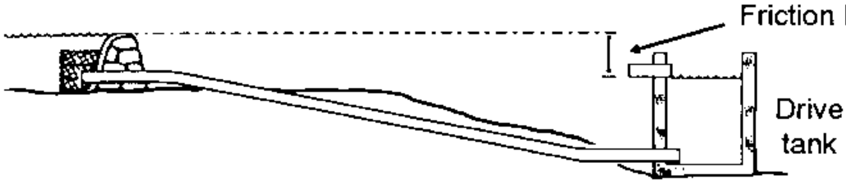


Determining internal pipe diameter/head loss

Friction gradients

In order to select a suitable pipe size for either the delivery or feed pipe, it is necessary to have an understanding of how friction effects the flow of water in pipes. When water flows through a length of pipe, energy in the water is lost to friction, and this causes a pressure drop along the pipe. This pressure drop is often measured as the difference in height between the level of the water at the source, and the level of the water at the point of discharge (see diagram). This level drop is known as 'head loss'. If there is a large flow in the pipe, there is a large head loss, while a smaller flow causes a smaller head loss. Similarly, it is possible to cause a large flow in a pipe by making a large level drop between the water at each end.

The diagram below represents a typical ram pump feed pipe. We need to know how head loss effects the system if we want to select a pipe size, or to decide how much level drop to allow for between the source and the drive tank.



The table below can be used to find the head loss in certain common sizes of PVC pipe for a known flow, or to choose a pipe size to allow a certain (acceptable) head loss for a known flow. For example, a pipe with a diameter of 75mm and a flow of 100 l/min will have a head loss of 3.6m for every kilometre (1000m) of pipe. If the pipe is 100m long, the head loss will be 0.36m.

TABLE 1
Head loss in mm per metre of feed pipe

Flow (l/min)	Diameter (mm) 50	63	75	90	110	125
30	2.9					
35	3.9	1.2				
40	5.0	1.5				
45	6.2	1.9				
50	7.6	2.3				
55	9.1	3.3	1.2			
60	10.7	4.4	1.4			
70	14.4	5.7	1.8			
80	18.7	7.1	2.4			
90	23.4	8.7	2.9	1.2		
100	28.7	10.4	3.6	1.4		
110	34.6	12.3	4.3	1.7		
120	41.0	19.0	5.1	2.0		
150	63.3	27.1	7.8	3.1	1.1	
180	90.5	36.5	11.0	4.4	1.6	
210	122.6	47.5	14.9	5.9	2.1	1.1
240	159.4	59.8	19.3	7.6	2.7	1.4
270	201.1	73.5	24.3	9.6	3.4	1.8
300		105.2	29.8	11.7	4.2	2.2
360		142.7	42.6	16.7	6.0	3.1
420		185.7	57.7	22.6	8.1	4.2
480		234.5	75.0	29.4	10.4	5.4
540			94.6	37.0	13.1	6.8
600			116.4	45.5	16.1	8.3

To find a head loss gradient using Table 1, find the column with a proposed pipe diameter, then find the row with the desired flow. The number given at the point where the column intersects the row is the gradient. The table can therefore be used to find a size of pipe that gives the desired flow with an acceptable level drop (head loss). In addition the table can be used in reverse to calculate the flow that will go through a pipe if the level change and pipe diameters are already fixed.

The table covers the range of flows likely to be experienced in a ram pump system's feed pipe, and the gradient is given as the number of metres head drop needed, or head loss experienced, for every 100m of feed pipe.

On a pump delivery system, the concept of head loss is not straightforward, as the water is actually forced uphill. It is still possible to visualise head loss in such a system if the pressure at the pump discharge is thought of as an equivalent head of water (how high the level of water would reach if there was a vertical pipe rising straight up from the pump. It is now possible to visualise head loss as before (see diagram).

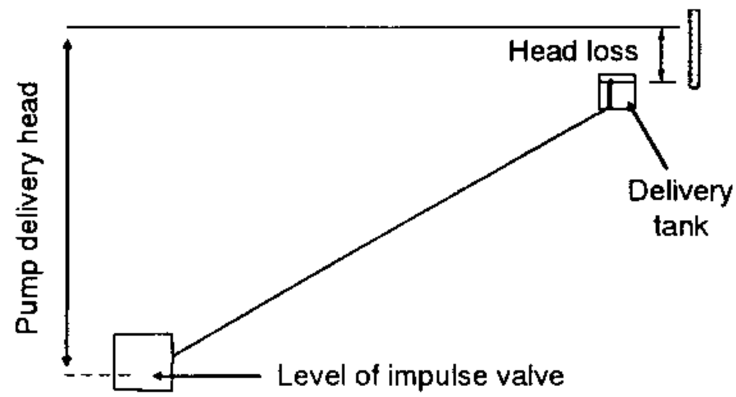


Table 2 below gives gradients for the range of pipe diameters and flows most likely to exist in a ram pump delivery system. It should be noted that the gradient in this diagram is given as the number of metres head loss experienced for every km of delivery pipe.

Table 2 Head loss in metres per km of pipe

Flow (l/min)	Diameter (mm) 20	25	32	40	50
2	3.4				
4	12.0	3.1			
6	25.5	6.5	1.9		
8	44.0	11.1	3.3		
10	67.3	16.8	4.9	1.2	
12	95.5	23.7	6.9	1.7	
14	128.6	31.8	9.2	2.2	
16	166.6	41.0	11.9	2.9	
18	209.5	51.4	14.8	3.5	1.1
20		63.0	18.1	4.3	1.4
22		75.7	21.7	5.2	1.6
24		89.6	25.6	6.1	1.9
26		104.6	29.8	7.1	2.2
28		120.8	34.4	8.1	2.6
30		138.2	39.3	9.2	2.9
35		186.7	52.9	12.4	3.9
40		242.4	68.5	16.0	5.0
45			86.1	20.0	6.2
50			105.7	24.5	7.6
55			127.4	29.4	9.1
60			151.0	34.8	10.7
70			204.3	46.9	14.4
80				60.9	18.7
90				76.6	23.4

Flow nomograph

A flow nomograph can be used to determine the internal pipe diameter needed, the flow rate required or the head loss expected. As long as any two of these are known, the third can be read from the nomograph using a ruler.

To determine the head loss in a pipe when the internal pipe diameter is known and the flow rate required is also known:

1. Place a ruler across the Inner Diameter and Flow Rate scales at the known values.
2. Read the scale for Head Loss where the ruler crosses it. This reading is the head loss in metres for a 100m length of pipe. If the pipe is only 50m long, the head loss will be half this value. If the pipe is 300m long, the head loss will be the value multiplied by three. The scale gives values for both plastic and galvanised pipe.

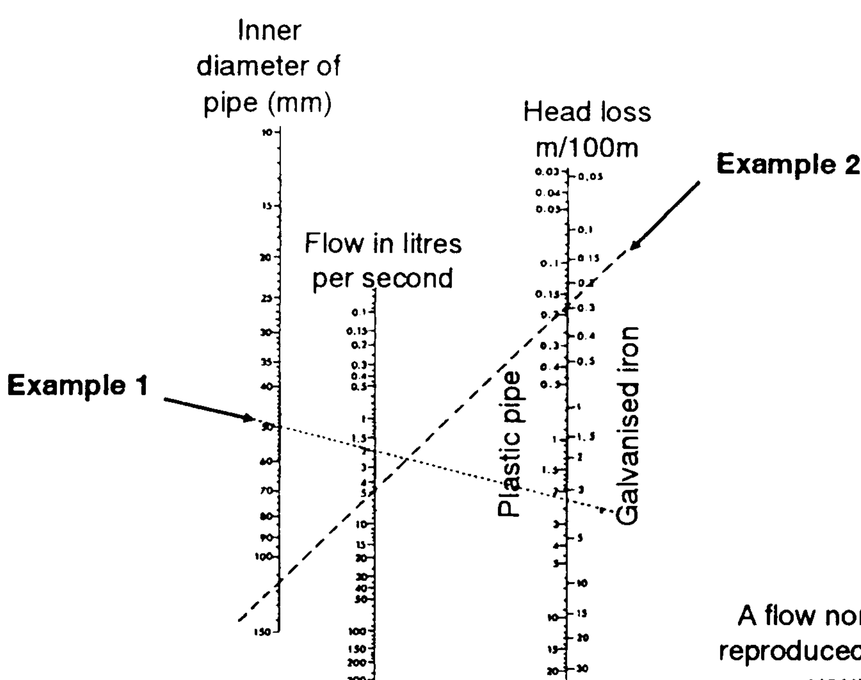
In Example 1 below, a 50mm internal diameter pipe is available and a flow of 2 l/sec (120 l/min) is required. A straight line is drawn through these two points, and on through the Head Loss scale. For plastic pipe the head loss is 2.2m per 100m of pipe and for galvanised pipe the head loss is 3.4m per 100m.

To determine the internal diameter of the pipe required when the head loss and the flow rate required are known:

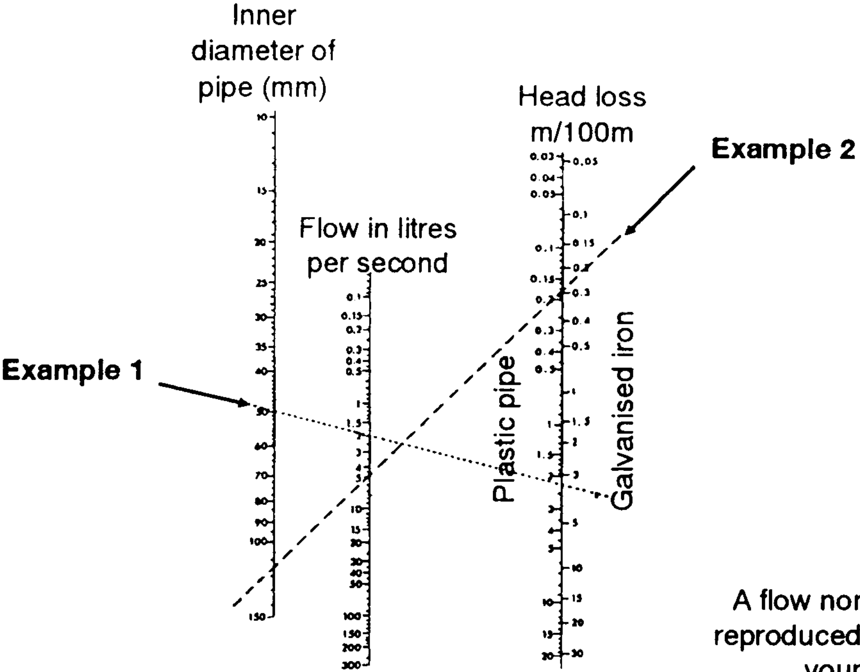
1. Place a ruler across the Head Loss (for the type of pipe used) and Flow Rate scales at the known values.
2. Read the scale for Inner Diameter where the ruler crosses it. This reading assumes that the head loss in metres is for a 100m length of pipe. If the pipe is only 50m long, the head loss used to take this reading must be doubled. For example, if the pipe is only 50m long and a head loss of 2m is acceptable, the head loss must be doubled to 4m to take this reading. This makes the reading on the Inner Diameter scale accurate without further adjustment.

In Example 2 below, a head loss of 0.3m over a 100m length of pipe is acceptable (this is equal to a head loss of 0.15 over 50m of pipe or 1.5m over 500m of pipe, and so on). The flow required is 5 l/sec. The reading for these values indicates that a pipe with an internal diameter of 105mm *or greater* is required.

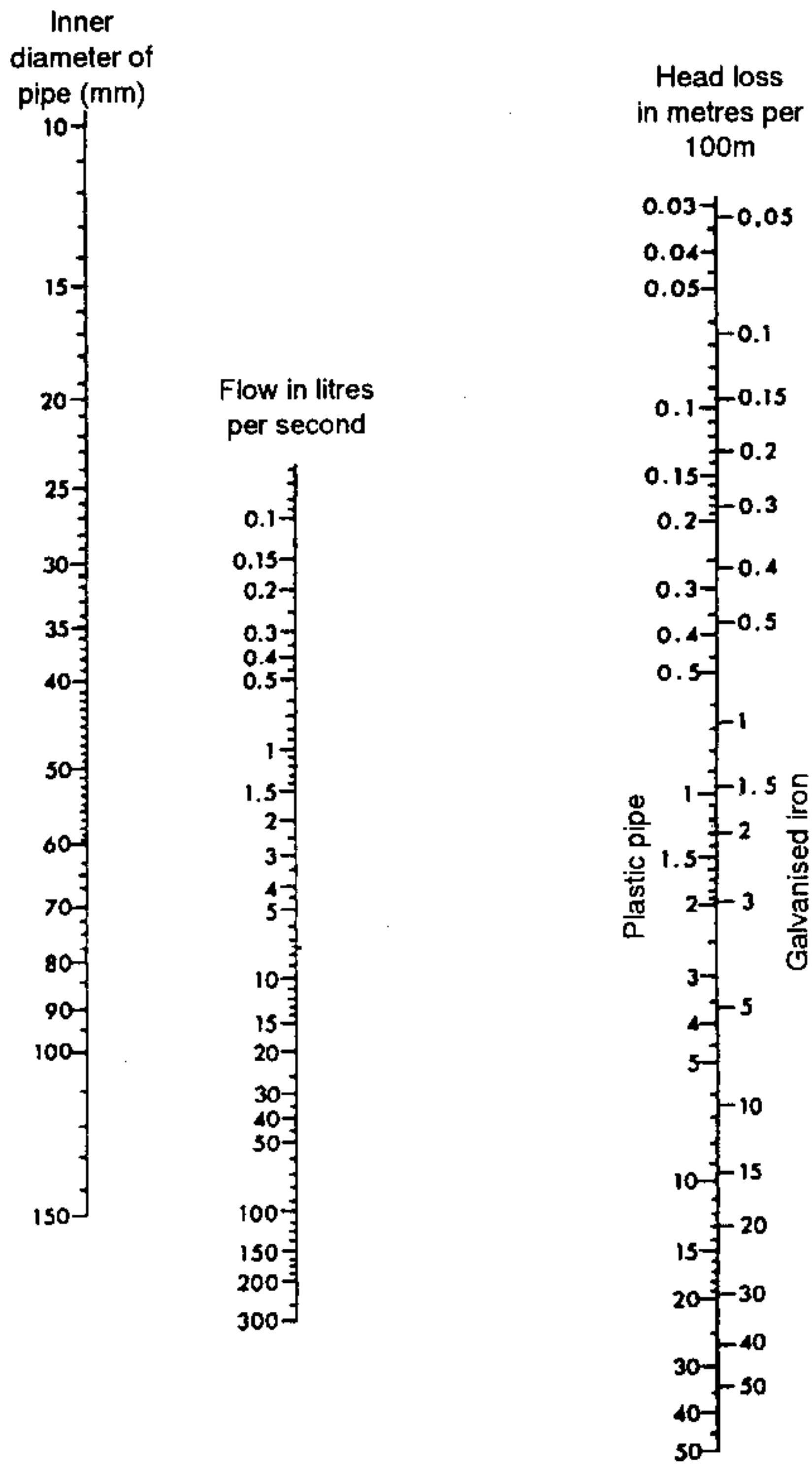
Example



A flow nomograph is reproduced overleaf for your use.



A flow nomograph is reproduced overleaf for your use.

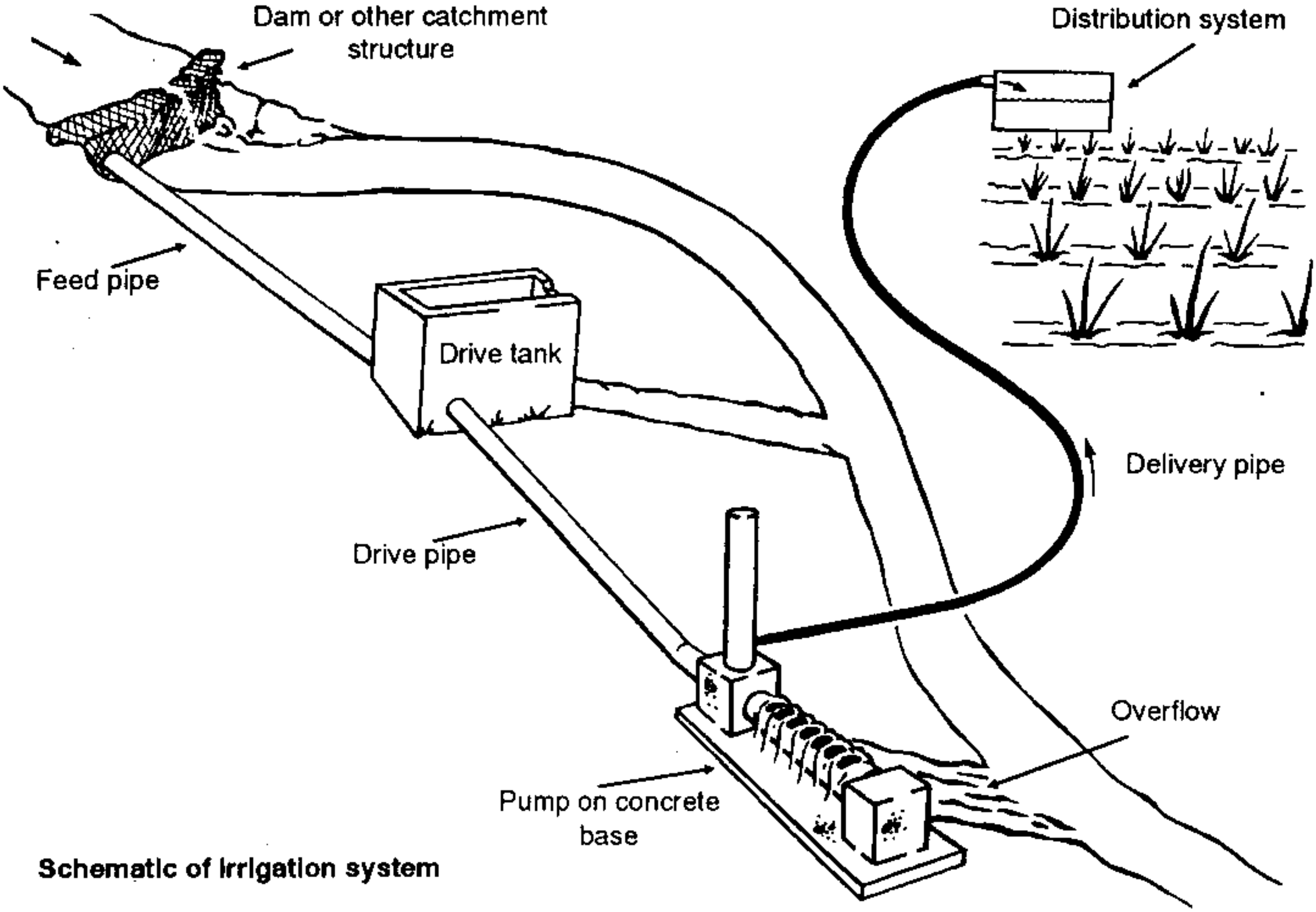


Inner diameter of pipe (mm)
Flow in litres per second
Head loss in metres per 100m
Plastic pipe
Galvanised iron

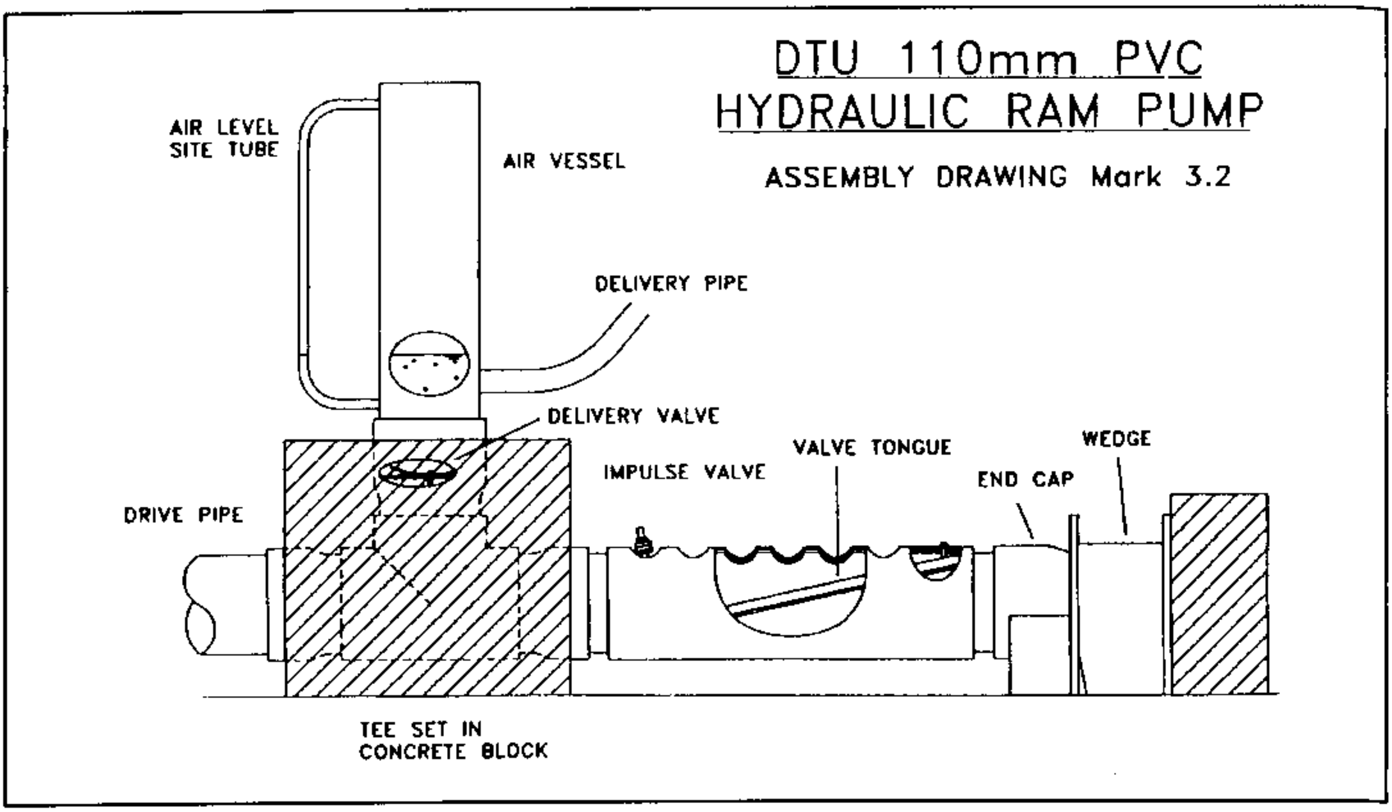
Appendix E: The DTU plastic irrigation pump

Most ram pumps being manufactured are designed to supply water for domestic use because the low flows produced and the costs generally make ram pump systems unsuitable for small-scale crop irrigation. Sufficient water for 1000-1500 people, for example, would only irrigate a plot of around 1 hectare! Some very large bore (12") ram pumps have been built to supply water for irrigation but the capital costs of such schemes restricts their application. In many parts of the world there is a large potential for low-lift, low-cost irrigation of small garden plots to improve yields, allow alternative crops to be grown and increase crop security in unpredictable weather conditions.

The DTU has been involved in a research programme to develop suitable low-lift, low-cost ram pumps and produce designs capable of simple local manufacture.



Schematic of irrigation system



The material selected as the only viable alternative to steel is plastic pipe. PVC 110mm (4") diameter pipe is now widely available in many developing countries and provides the scale of flow necessary for small-scale irrigation. The DTU pump has been developed to the following specification:

- all parts should be manufactured from 110mm pipe with a minimum of other materials such as bolts, rubber, etc.;
- the complete system should be constructed from a minimum amount of pipe and simple building materials;
- all parts should be capable of manufacture using hand tools in small rural workshops;
- the system should be maintained by the user and all parts capable of simple replacement in case of wear, damage or theft;
- designs should be thoroughly tested for performance and endurance (including extensive field tests);
- pumps should be easy to tune to suit a broad range of site conditions.

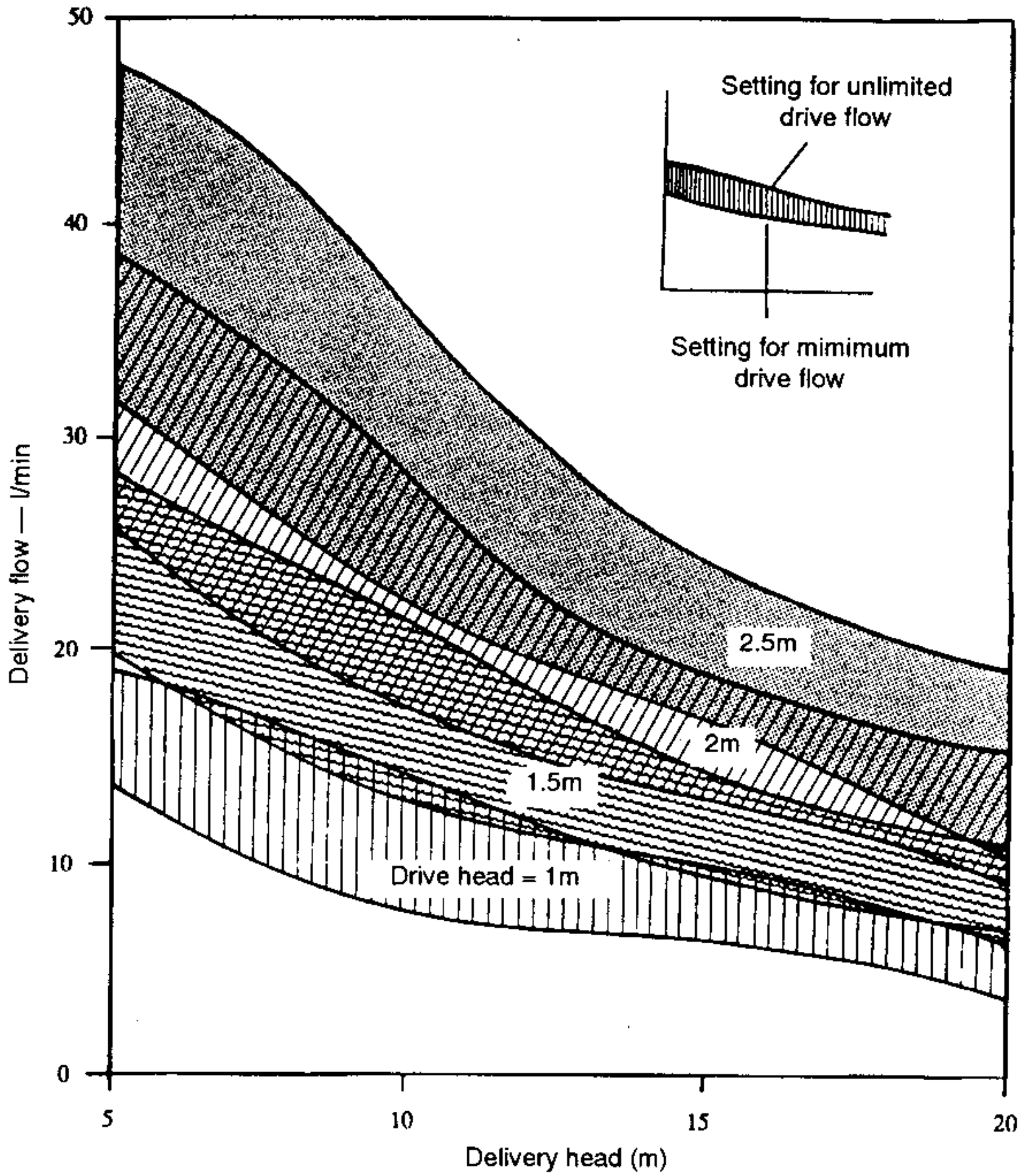
It meets the following specifications:

1. The drive head (fall of water) can be between 1 and 3 metres.
2. The drive flow available can be between 3 and 7 litres/second.
3. The maximum delivery head is 12m.
4. The energy efficiency exceeds 50%.

At 2 metres drive head, maximum delivery to 15 metres is 35,000 litres per day, adequate to irrigate ⅔ of a hectare.

Pump designs have been developed over a number of years with increasing performance and component life. Plastic pipe is more prone to fatigue failure than steel, reducing the life of some components to two years. The current design has been extensively tested in Zimbabwe with promising results but has not been fully proven and should be treated as being still (1992) at the proving stage of development. A full set of design drawings and associated literature can be obtained from the DTU on request.

DTU PVC ram pump
Typical performance data



The shaded areas on the performance data chart above indicate the normal operating range for different values of drive head.

Appendix F: Design drawings for DTU steel pumps

This appendix contains detailed engineering drawings of the DTU M8 and M6 ram pumps. The two pump designs differ only by the method of construction used for the pump body. The reason for producing this variation in body type is to promote ease of manufacture where sophisticated workshop facilities and skills may not be readily available. The M8 pump body is made by welding together cut steel pipe. The M6 pump body is made by screwing together standard pipe fittings that are widely available for purchase. In circumstances when either could be used, the M8 should be preferred because it is slightly more powerful and a little stronger.

The designs of the complete M8 pump, including those parts that both pumps have in common, are shown first. These are followed by drawings of the M6 body. The valves and the air vessel are identical on both the M6 and the M8, so the drawings have not been repeated. The Appendix ends with some construction sketches of pump cradles, the detailed design of which will depend on the particular installation and the materials available.

DTU steel ram pump performance

These are the normal operating ranges of the pumps. In certain circumstances it is possible to operate DTU pumps outside these limits.

drive head range = 2-30m
drive flow range = 60-120 l/min.
delivery head range = 6-100m
typical delivery range = 2-20 l/min.

If further advice about pump suitability is needed, please contact the DTU, giving as much information about the situation and requirements as possible. The address of the DTU is on the reverse of the title page in this book.

Workshop facilities

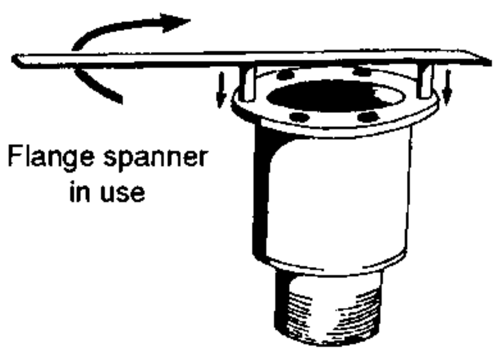
The workshop requirements for DTU ram pump manufacture are:

- a power drill (pillar);
- a welding capability;
- a small lathe;
- miscellaneous hand tools for cutting, threading and filing steel.

The tools required for assembly are:

- **M6 & M8** — two spanners to fit the heads of the bolts used. 17mm spanners fit the 10mm bolt heads in the drawings, and although the bolt heads should be approximately this size, a small variation is acceptable. In any case, to keep assembly and maintenance simple, a single size of bolt head should be used throughout.
- **M6 only** — two pipegrip spanners to connect the fittings of the pump body.
- **M6 only** — one flange spanner, fabricated as explained below.

The M6 flange spanner This spanner makes it easy to attach the impulse valve body and the delivery valve adaptor to the pump body. It is made using a 600mm length of flat steel bar with short rods of the same diameter as the holes in the flanges attached as shown. The rods are inserted into the holes and the handle turned to screw the pump part down.


Flange spanner in use

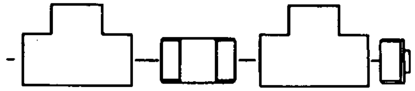
Before assembly check that:

- rubber gaskets have been fabricated to go between all flanged joints. These should have no small cuts or seams that may snag or tear when the pump is operating. A hole punch should have been used to make clean bolt holes through the rubber;
- suitable fittings have been welded or screwed to the air vessel during manufacture if a sight tube is to be used. A sight tube can be an aid to problem solving during commissioning. Jubilee clips are needed to attach the tube, and the tube itself should be clear, reinforced PVC with a bore of around 1/2" (12mm). (This kind of tube is typically capable of holding a pressure of up to 100m for extended periods of time.) A plentiful supply of nuts, bolts and washers for assembly should also be available;
- U-bolts (for the M6) or brackets (for the M8) to attach the pump to its cradle are available.

Assembly of the DTU pumps

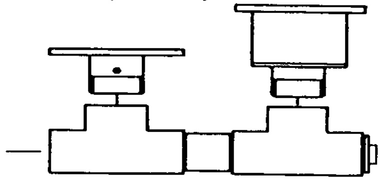
Assembly, step-by-step

1 Assemble the pump body.
M6 — screw together pipe fittings using PTFE tape on each joint.
M8 — bolt end plate onto pump body.



M6 body assembly

2 **M6 only** — Attach the impulse valve body and the delivery valve adaptor into the top of the two tee joints. Use PTFE tape on each joint to help sealing.

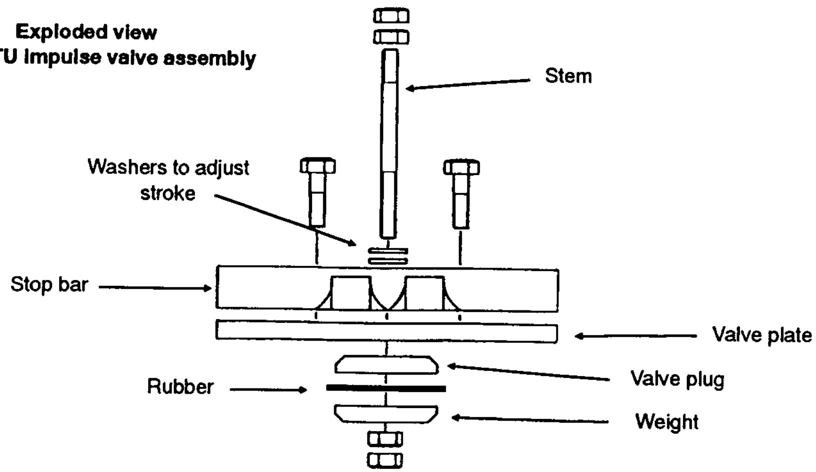


3 Attach the impulse valve stop bar to the valve plate using the two short bolts. (See the exploded view opposite.)

4 Assemble the impulse valve stem, taking care not to compress the rubber by over-tightening the lock nuts, as follows. First screw the valve plug onto the valve stem until it reaches the end of the threads. Then push the valve rubber up against the plug. The rubber should be a tight fit over the threads, without being so tight that the rubber is distorted. Next screw on a weight, which can be another valve plug or a large washer, until it sits flat against the valve rubber. Finally, screw on a nut hand tight beneath the weight, then lock a second nut against this. Take care not to compress the rubber by further tightening the first nut while locking the second against it.

5 Push the assembled impulse valve stem up through the stop bar and thread on a single nut by hand. Measure the amount of available up and down movement (the stroke).

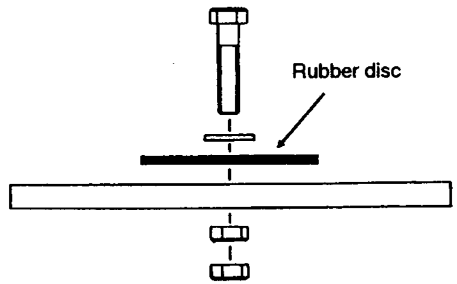
Exploded view of the DTU impulse valve assembly



If the required stroke of the impulse valve has been estimated, remove the top nut and add washers between the stop bar and the top of the valve stem to achieve the required stroke. When the required stroke of the impulse valve has not been estimated, add washers to give about 15mm of valve movement. Replace the top nut, and lock it securely in place with a second nut. Check that when the valve is closed the valve plug hits the stop bar just before the rubber hits the valve plate. If the parts have been accurately manufactured there will be a small gap which helps prevent rapid wearing of the rubber.

6 Attach the assembled valve to the pump body with a rubber gasket between the two flanges. Ensure that the bolts are firmly tightened by holding the bolt head with a spanner and tightening the nut against it.

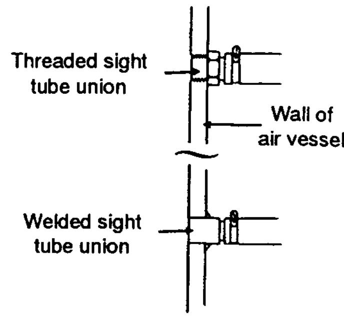
7 Assemble the delivery valve, making sure that the bolt holding the rubber disk is not crushing or distorting it and that the nuts on the delivery valve bolt are locked tight against each other.



Exploded view of the DTU delivery valve assembly

8 Position the delivery valve on the pump body with the rubber uppermost and bolt on the air vessel. Use a rubber gasket between the two flanges. Ensure that the bolts are firmly tightened by holding the bolt head with a spanner and tightening the nut against it.

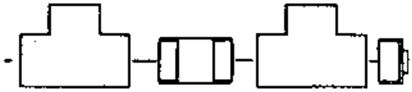
9 The sight tube on the air vessel is an optional feature that makes it easy during commissioning to see the level of air in the air vessel. When a sight tube is to be used, suitable fittings should have been welded or screwed to the air vessel during manufacture. Attach the sight tube hose using jubilee clips.



10 **M6** Use U-bolts to clamp the pump to the cradle that should have been set into the concrete floor of the pump house in advance. Some rubber may be used as packing between the U-bolt and the pump.
M8 Bolt the pump body to the cradle using the special brackets detailed in Appendix F.

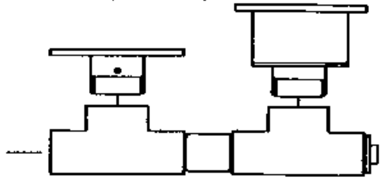
Assembly, step-by-step

1 Assemble the pump body.
M6 — screw together pipe fittings using PTFE tape on each joint.
M8 — bolt end plate onto pump body.



M6 body assembly

2 **M6 only** — Attach the impulse valve body and the delivery valve adaptor into the top of the two tee joints. Use PTFE tape on each joint to help sealing.

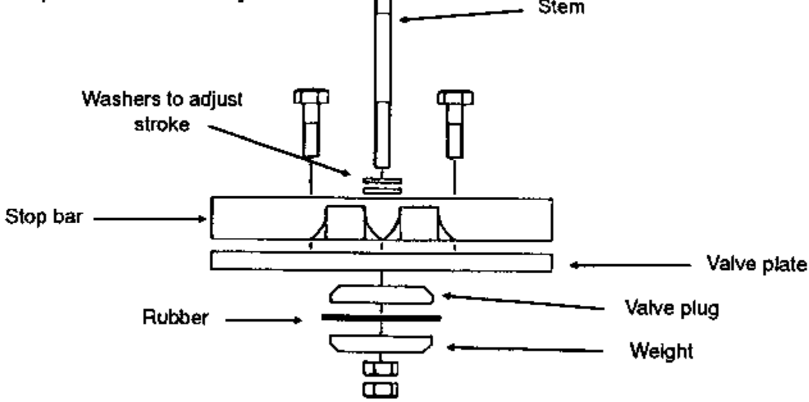


3 Attach the impulse valve stop bar to the valve plate using the two short bolts. (See the exploded view opposite.)

4 Assemble the impulse valve stem, taking care not to compress the rubber by over-tightening the lock nuts, as follows. First screw the valve plug onto the valve stem until it reaches the end of the threads. Then push the valve rubber up against the plug. The rubber should be a tight fit over the threads, without being so tight that the rubber is distorted. Next screw on a weight, which can be another valve plug or a large washer, until it sits flat against the valve rubber. Finally, screw on a nut hand tight beneath the weight, then lock a second nut against this. Take care not to compress the rubber by further tightening the first nut while locking the second against it.

5 Push the assembled impulse valve stem up through the stop bar and thread on a single nut by hand. Measure the amount of available up and down movement (the stroke).

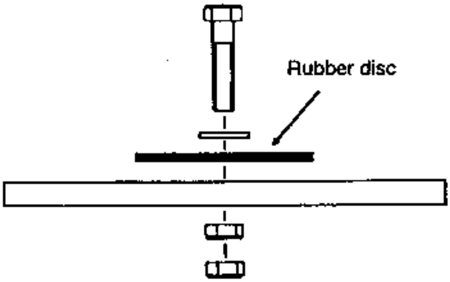
Exploded view of the DTU impulse valve assembly



If the required stroke of the impulse valve has been estimated, remove the top nut and add washers between the stop bar and the top of the valve stem to achieve the required stroke. When the required stroke of the impulse valve has not been estimated, add washers to give about 15mm of valve movement. Replace the top nut, and lock it securely in place with a second nut. Check that when the valve is closed the valve plug hits the stop bar just before the rubber hits the valve plate. If the parts have been accurately manufactured there will be a small gap which helps prevent rapid wearing of the rubber.

6 Attach the assembled valve to the pump body with a rubber gasket between the two flanges. Ensure that the bolts are firmly tightened by holding the bolt head with a spanner and tightening the nut against it.

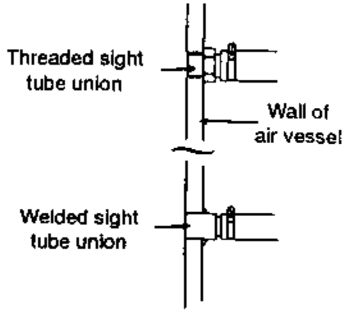
7 Assemble the delivery valve, making sure that the bolt holding the rubber disk is not crushing or distorting it and that the nuts on the delivery valve bolt are locked tight against each other.



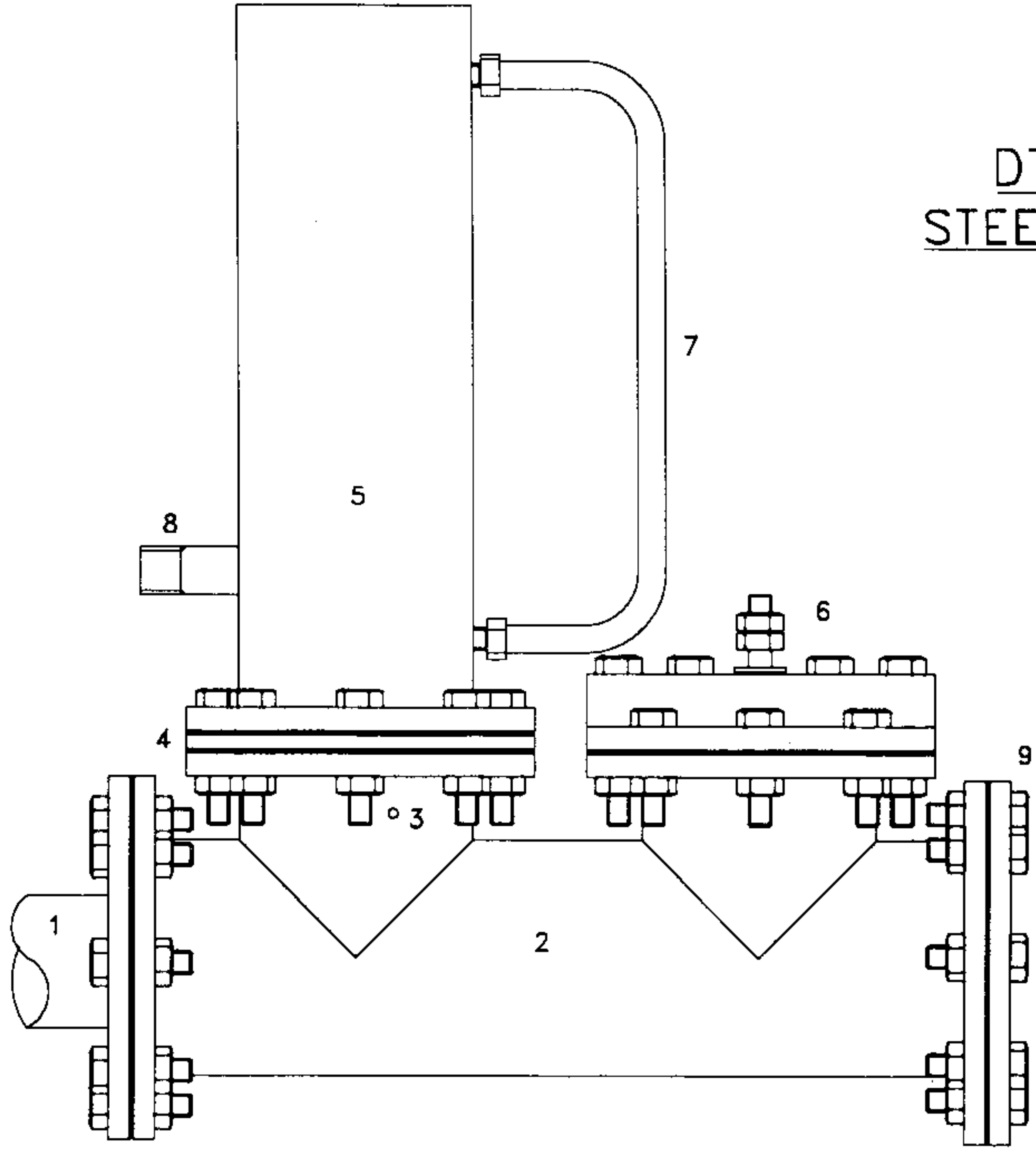
Exploded view of the DTU delivery valve assembly

8 Position the delivery valve on the pump body with the rubber uppermost and bolt on the air vessel. Use a rubber gasket between the two flanges. Ensure that the bolts are firmly tightened by holding the bolt head with a spanner and tightening the nut against it.

9 The sight tube on the air vessel is an optional feature that makes it easy during commissioning to see the level of air in the air vessel. When a sight tube is to be used, suitable fittings should have been welded or screwed to the air vessel during manufacture. Attach the sight tube hose using jubilee clips.



10 **M6** Use U-bolts to clamp the pump to the cradle that should have been set into the concrete floor of the pump house in advance. Some rubber may be used as packing between the U-bolt and the pump.
M8 Bolt the pump body to the cradle using the special brackets detailed in Appendix F.



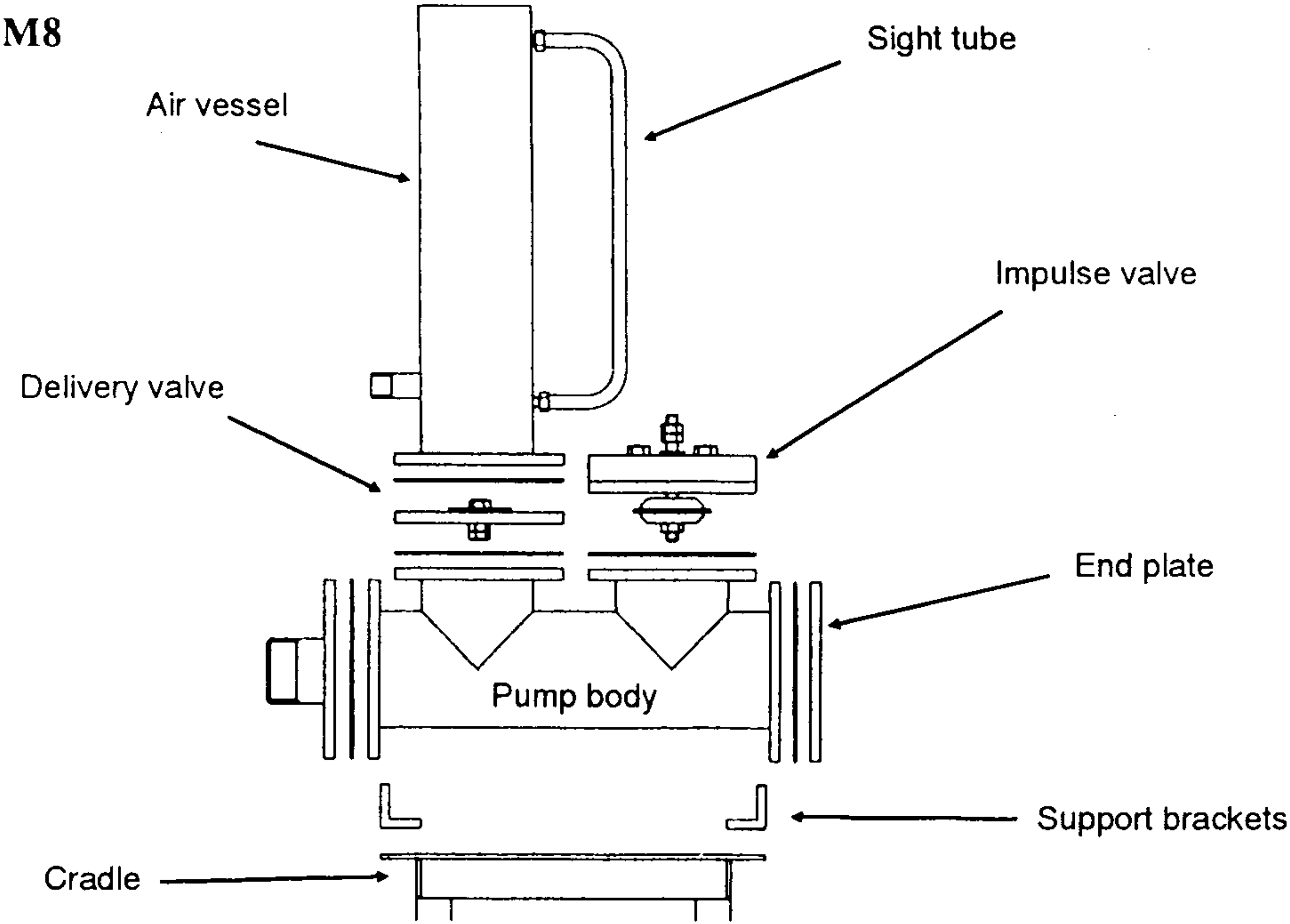
DTU M8 2"
STEEL RAM PUMP

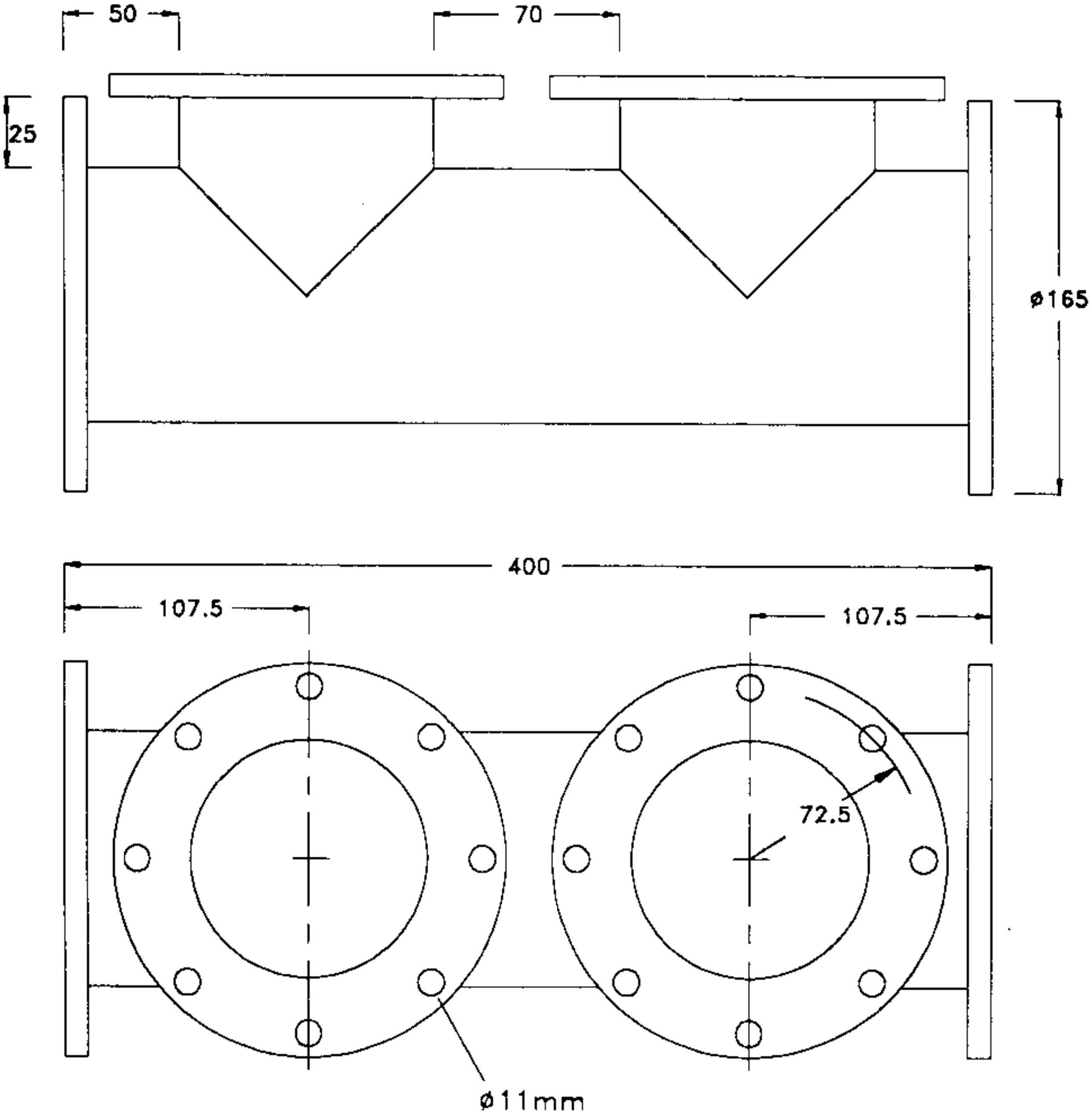
PARTS LIST

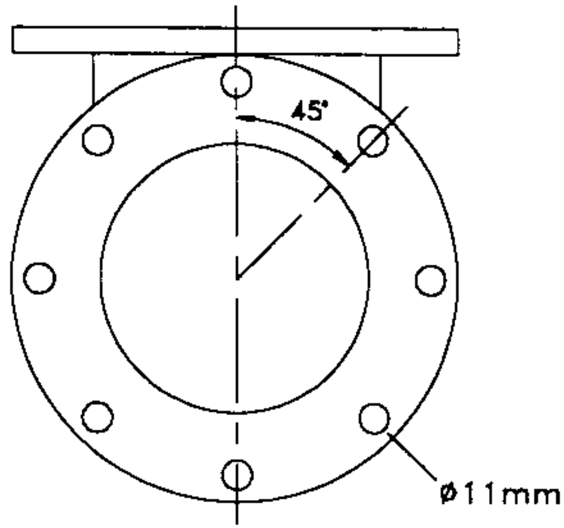
1 DRIVE PIPE
2 PUMP BODY
3 SNIFTER VALVE
4 DELIVERY VALVE
5 AIR VESSEL
6 IMPULSE VALVE ASSEMBLY
7 AIR SIGHT TUBE
8 DELIVERY PIPE
9 END PLATE

M8
ASSEMBLY DRAWING

Exploded view of the DTU M8 ram pump







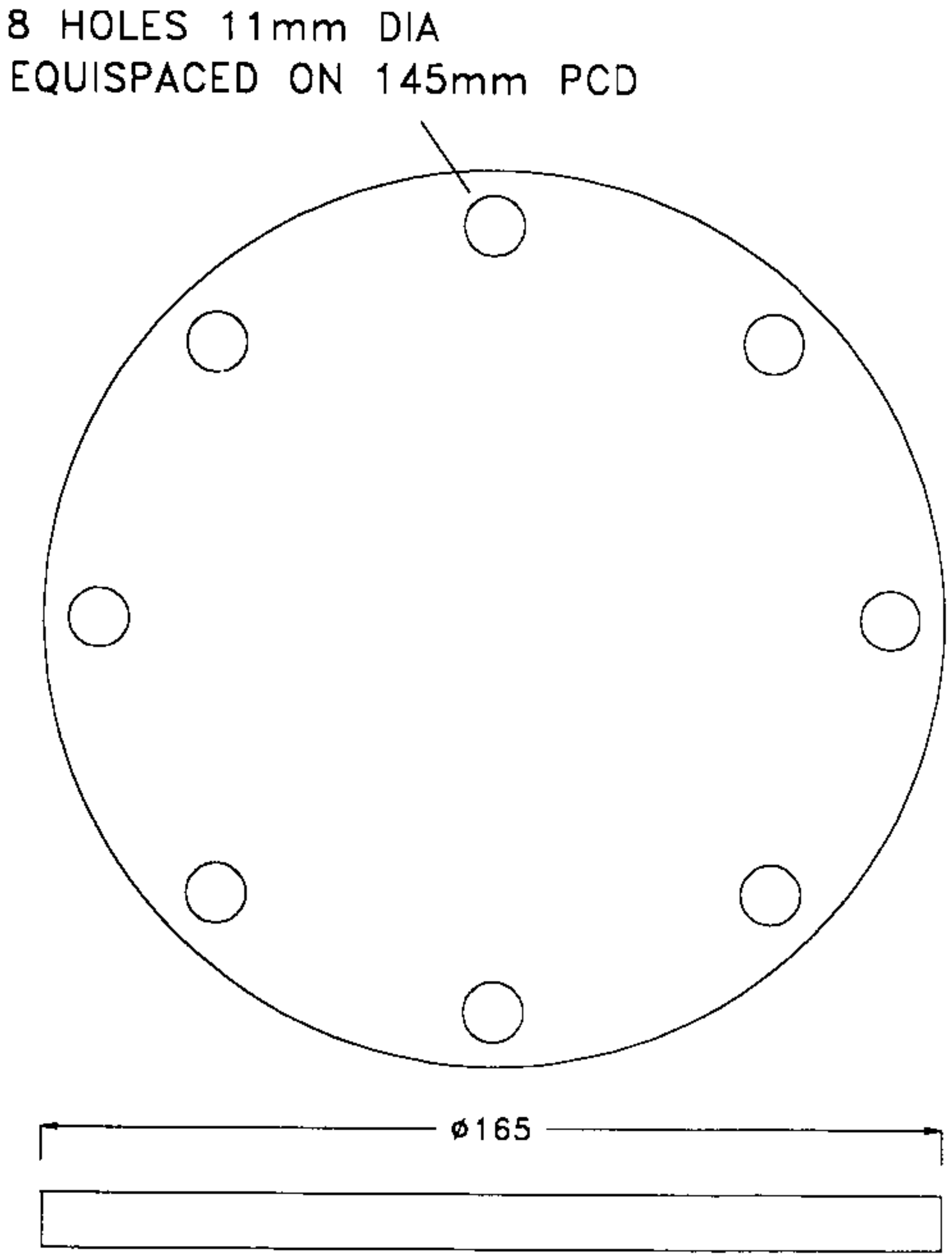
PIPE; MILD STEEL NOMINAL 4"
O/D ø115mm I/D ø105mm

PLATE; MILD STEEL
10 or 12mm THICK

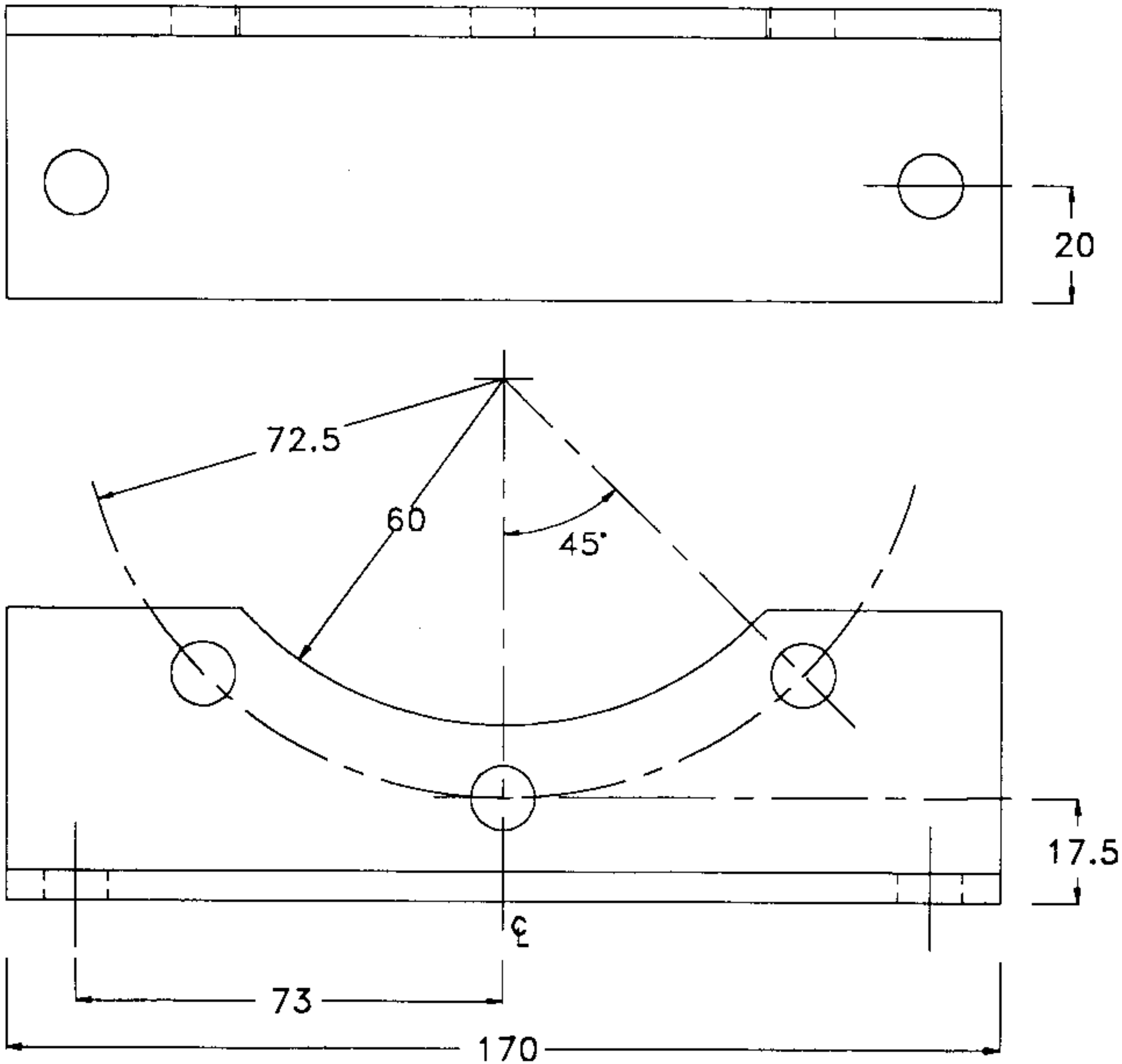
ALL JOINTS WELDED

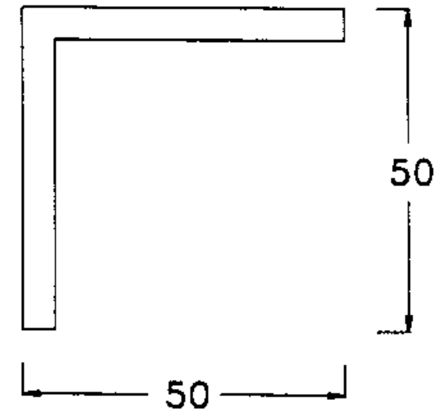
NOT TO SCALE

M8 BODY



M8 END PLATE

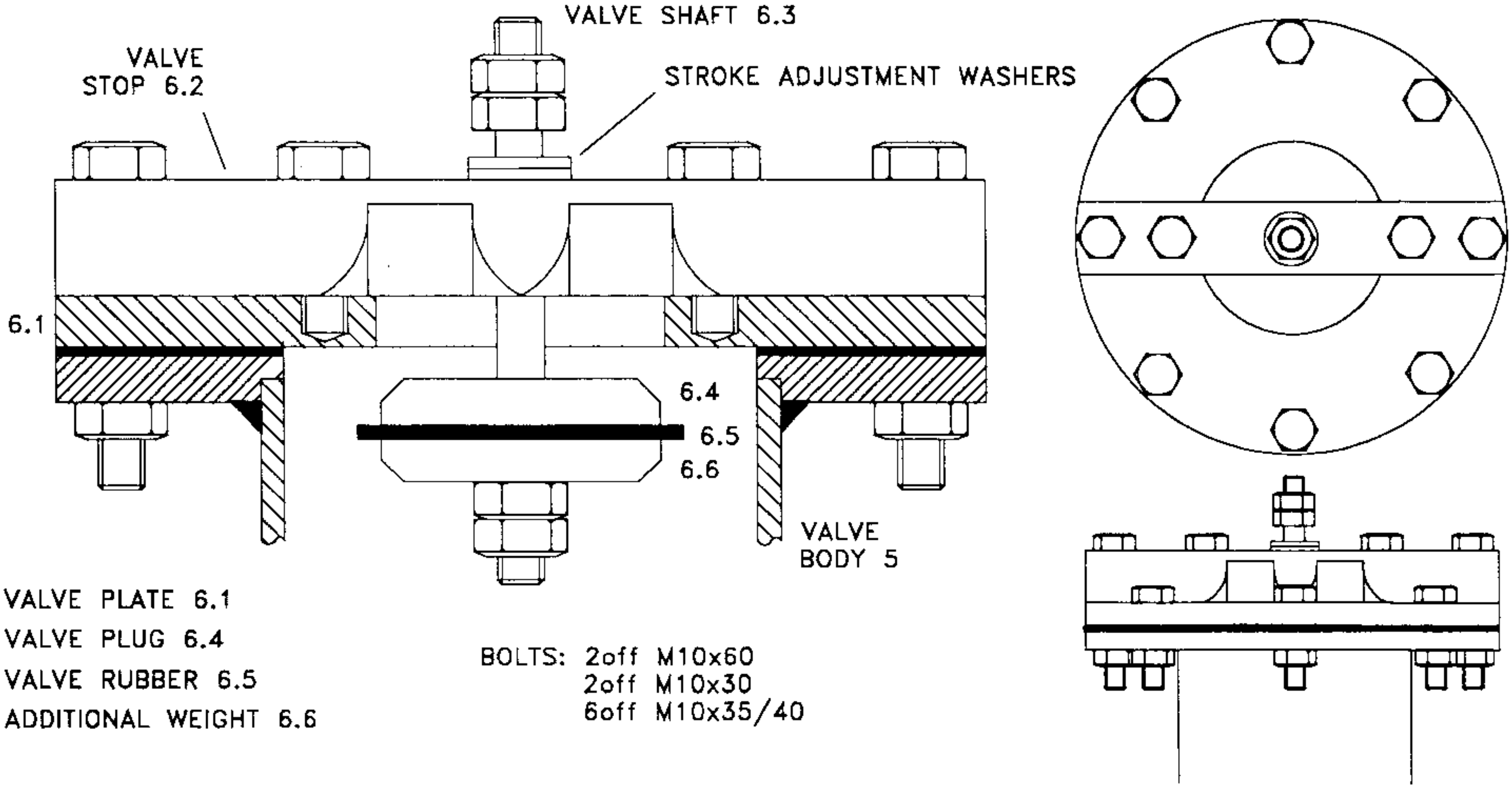




MATERIAL: 50x50 MILD STEEL
ANGLE IRON

PAINT OR GALVANISE TO
PROTECT

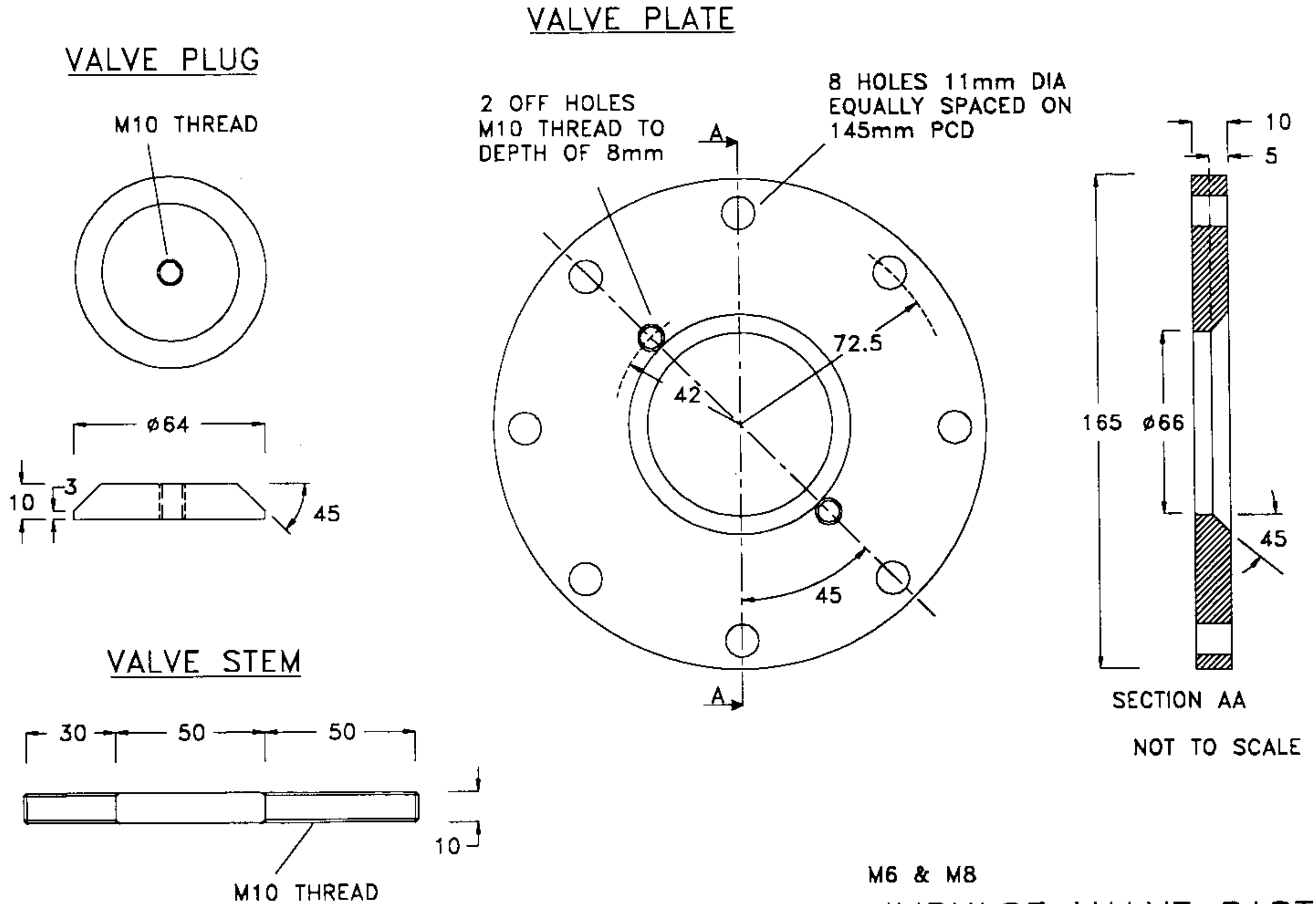
M8 FIXING BRACKET



NOTES

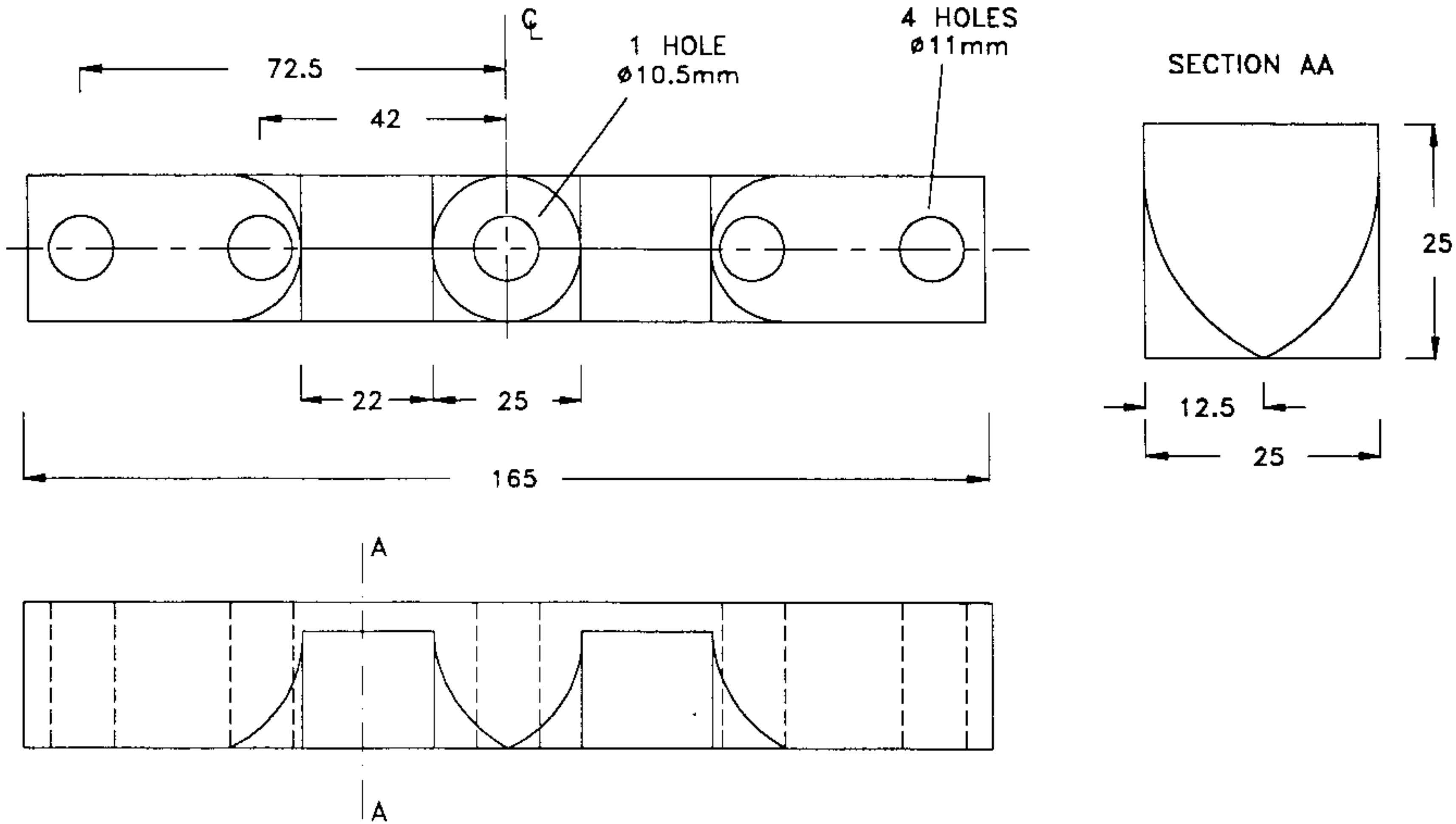
1 VALVE RUBBER (6.5) TO BE MIN 6mm THICKNESS AND Ø76mm
2 VALVE WEIGHTS (6.6) CAN BE ADDED TO ALTER PERFORMANCE
USE STEEL DISCS OF IDENTICAL DIAMETER TO VALVE PLUG (6.4)
3 ALL PARTS PAINTED OR GALVANISED AND THREADS PROTECTED WITH A
HEAVY WATERPROOF GREASE
4 GANLVANISED OR STAINLESS STEEL NUTS AND BOLTS SHOULD BE USED
IF AVAILABLE

M6 & M8 IMPULSE VALVE
ASSEMBLY DRAWING



M6 & M8

IMPULSE VALVE PARTS



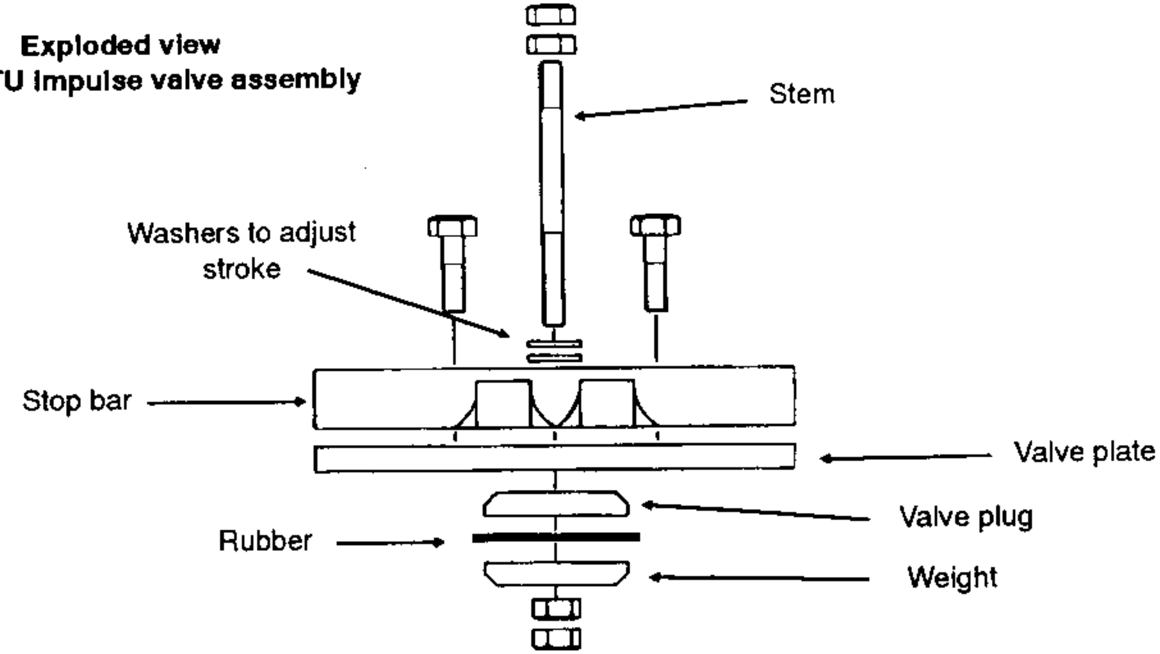
NOT TO SCALE

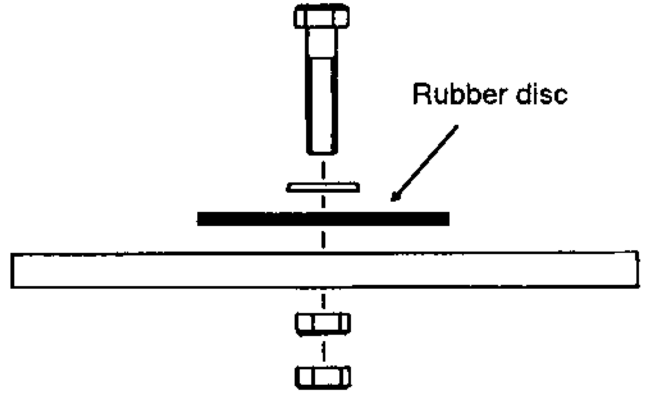
NOTE: 1. STREAMLINING SECTIONS TO BE MANUFACTURED BY FILING
2. MATERIAL: MILD STEEL (OR STAINLESS IF AVAILABLE)

M6 & M8

IMPULSE VALVE STOP

Exploded view
of the DTU impulse valve assembly

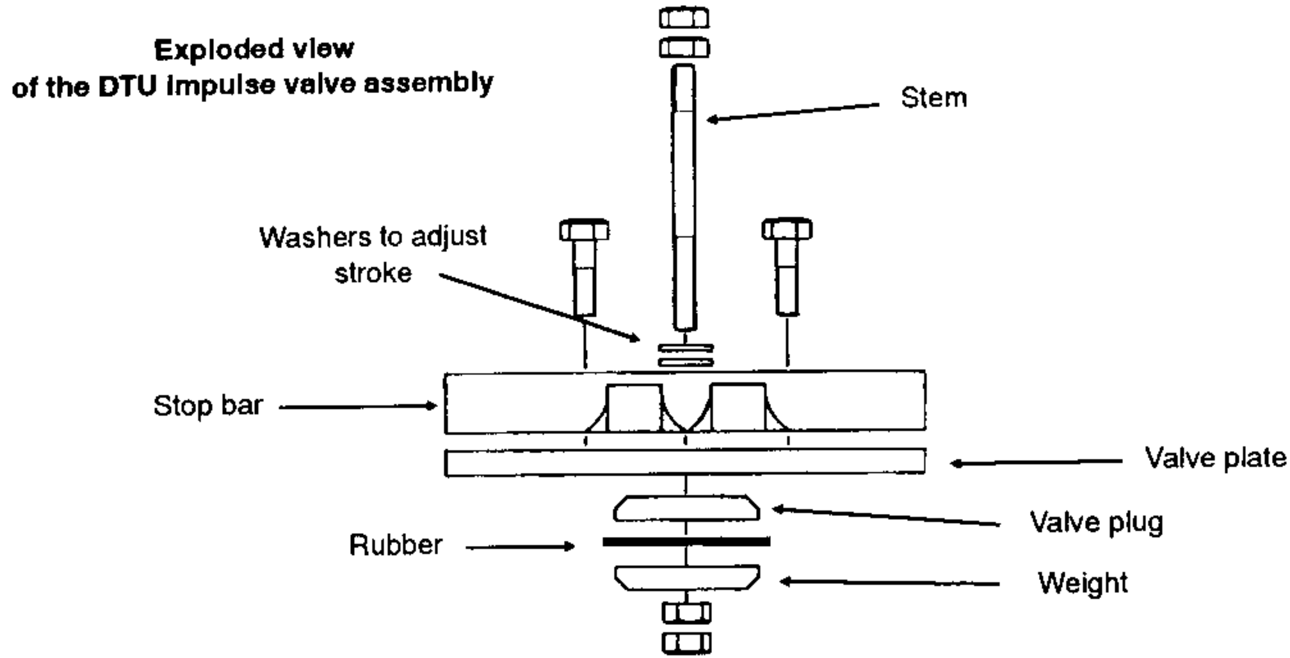




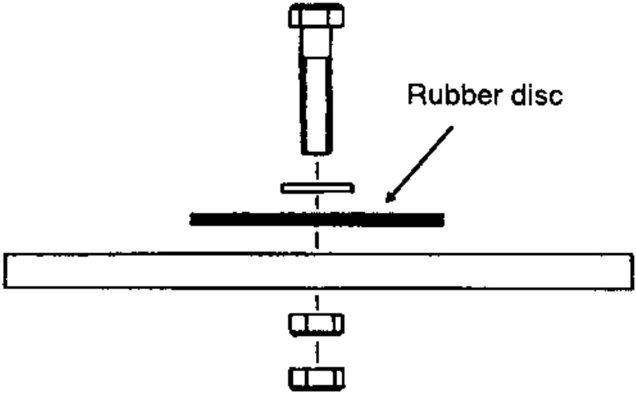
Exploded view
of the DTU delivery valve assembly

Assemble the impulse valve stem, taking care not to compress the rubber by over-tightening the lock nuts, as follows. First screw the valve plug onto the valve stem until it reaches the end of the threads. Then push the valve rubber up against the plug. The rubber should be a tight fit over the threads, without being so tight that the rubber is distorted. Next screw on a weight, which can be another valve plug or a large washer, until it sits flat against the valve rubber. Finally, screw on a nut hand tight beneath the weight, then lock a second nut against this. Take care not to compress the rubber by further tightening the first nut while locking the second against it.

Assemble the delivery valve, making sure that the bolt holding the rubber disk is not crushing or distorting it and that the nuts on the delivery valve bolt are locked tight against each other.



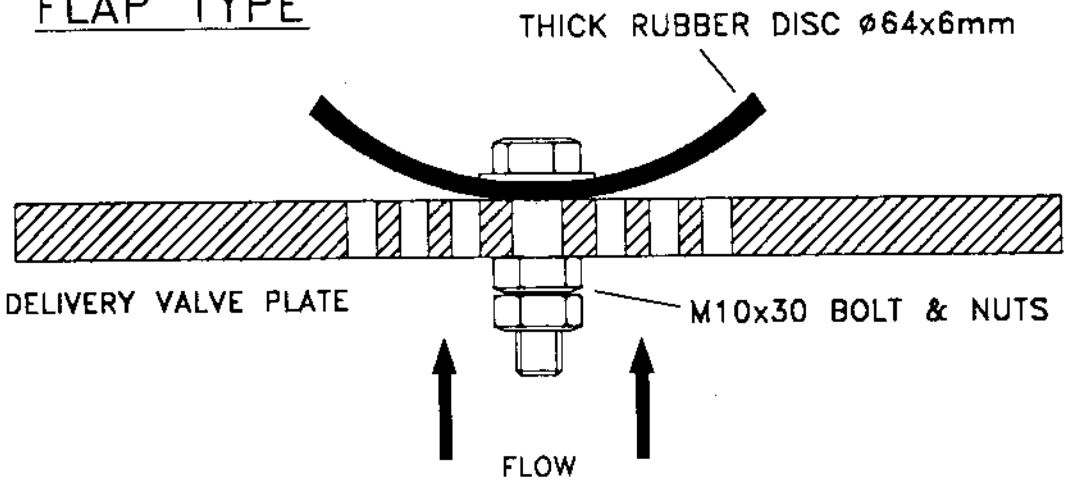
Assemble the impulse valve stem, taking care not to compress the rubber by over-tightening the lock nuts, as follows. First screw the valve plug onto the valve stem until it reaches the end of the threads. Then push the valve rubber up against the plug. The rubber should be a tight fit over the threads, without being so tight that the rubber is distorted. Next screw on a weight, which can be another valve plug or a large washer, until it sits flat against the valve rubber. Finally, screw on a nut hand tight beneath the weight, then lock a second nut against this. Take care not to compress the rubber by further tightening the first nut while locking the second against it.



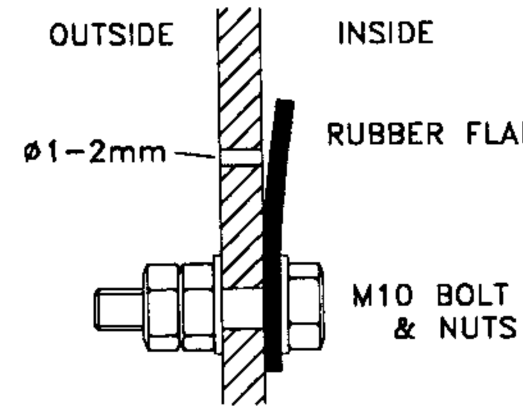
Exploded view of the DTU delivery valve assembly

Assemble the delivery valve, making sure that the bolt holding the rubber disk is not crushing or distorting it and that the nuts on the delivery valve bolt are locked tight against each other.

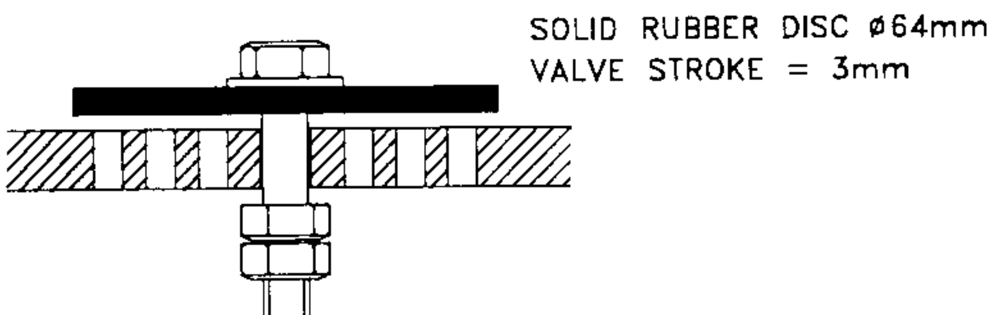
FLAP TYPE



FLAP TYPE SNIFTER



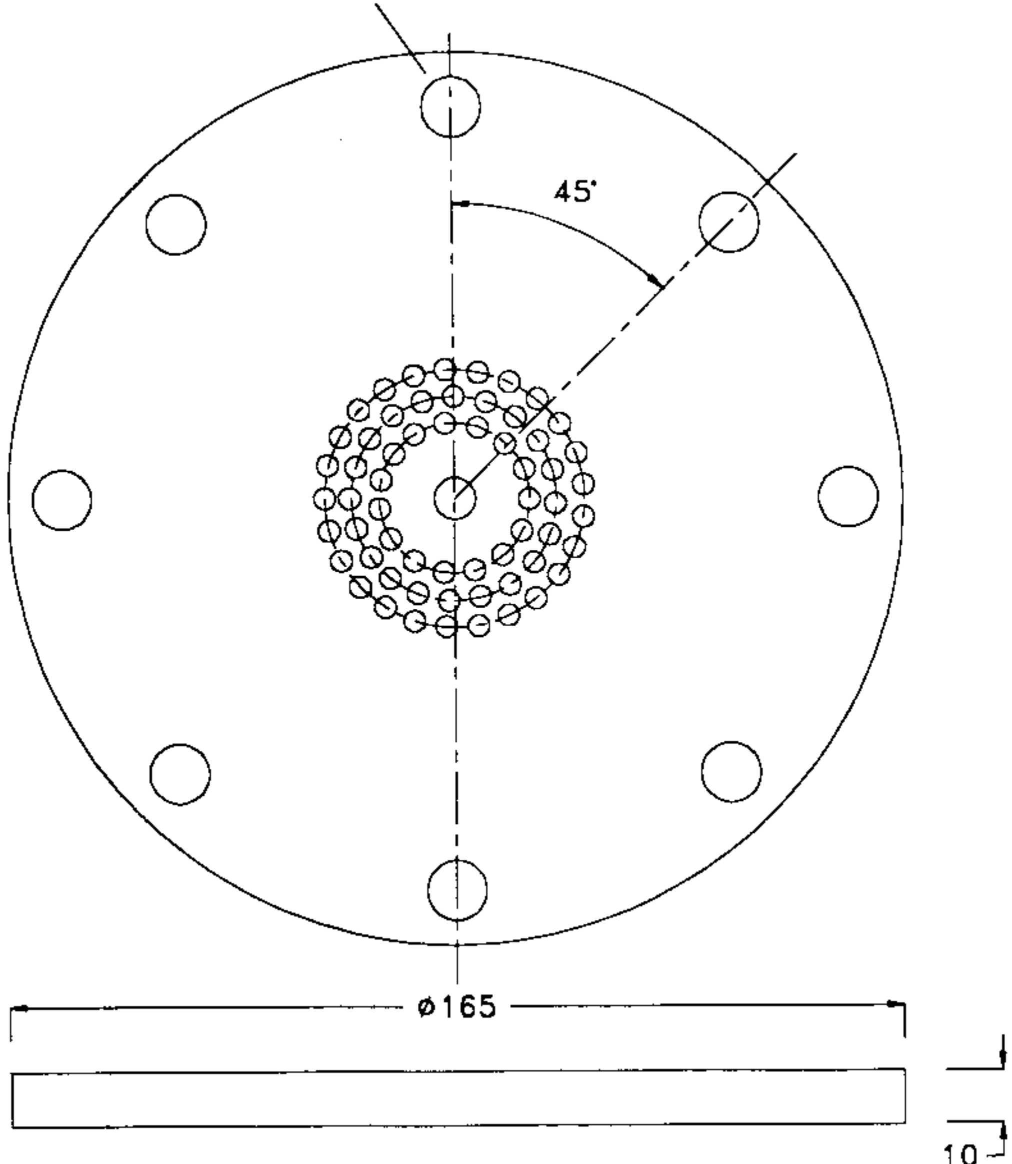
POPPET TYPE



M6 & M8

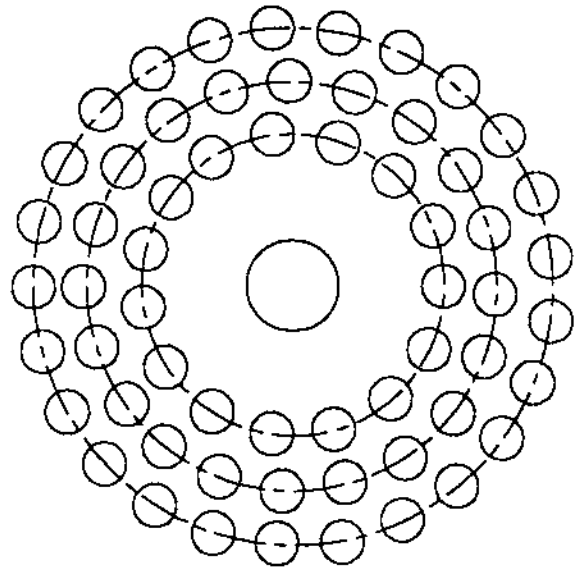
DELIVERY & SNIFTER VALVE ASSEMBLIES

8 HOLES Ø11mm
EQUISPACED ON 145mm PCD



THROUGH HOLES NOT SHOWN

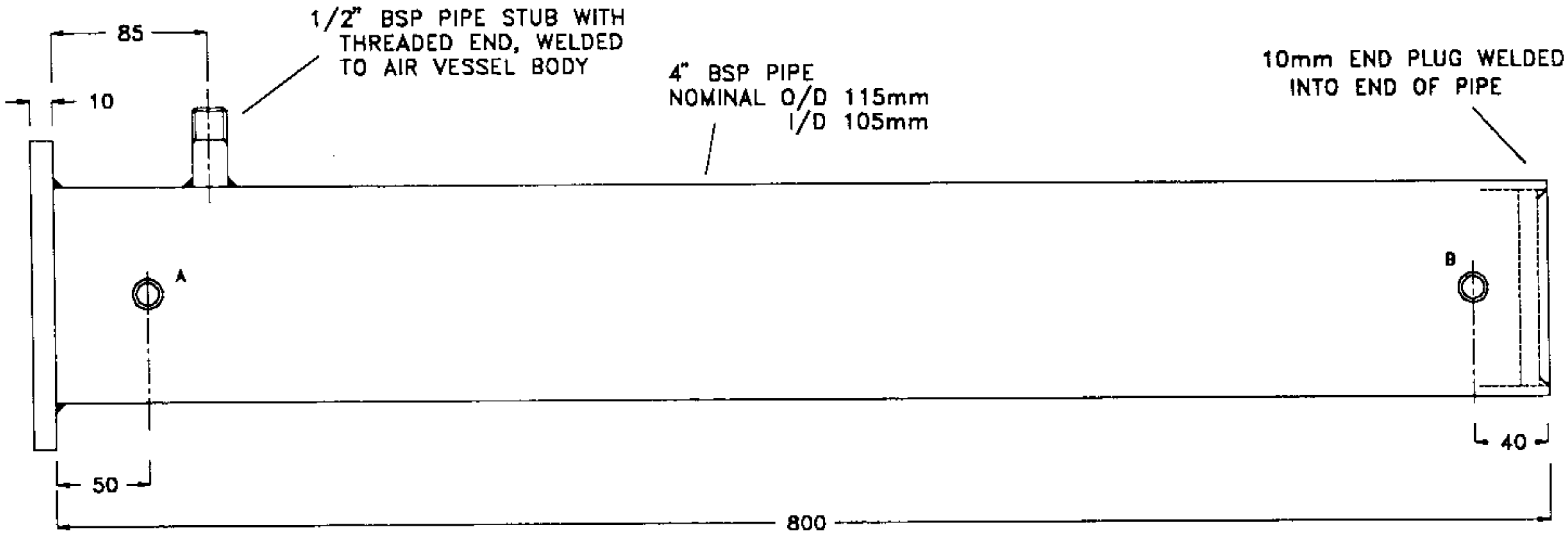
CENTRE HOLE ø10mm
OTHER HOLES ø4MM EQUISPACED ON PCR's OF 14, 19 & 24mm
ALL HOLES DEBURRED AND CHAMFERED ON ONE SIDE ONLY UNTIL HOLES CONNECT
MINIMUM DISTANCE BETWEEN HOLES 1.5mm

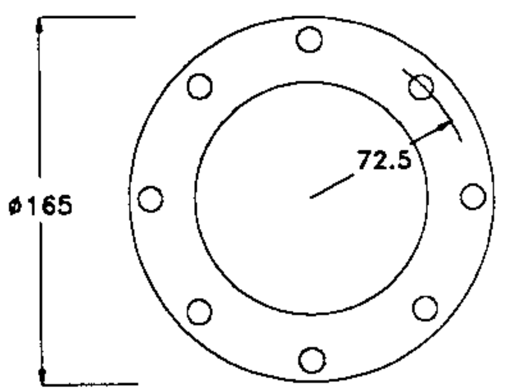


NOT TO SCALE

M6 & M8

DELIVERY VALVE PLATE





NOTE; ALL PARTS TO BE PAINTED WITH UNDERCOAT AND TOPCOAT INSIDE AND OUT AFTER WELDING

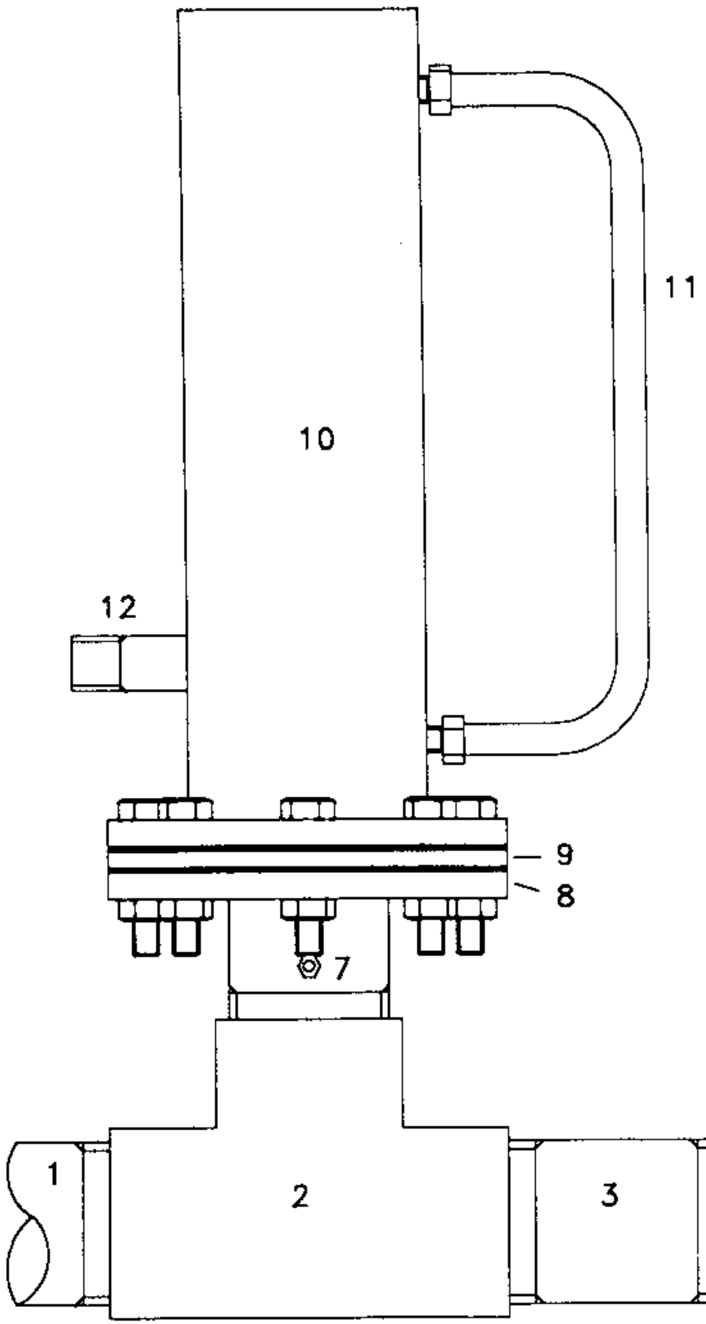
ITEMS MARKED A & B ARE POSITIONS OF CONNECTIONS FOR SIGHT TUBE. IF INCLUDED THESE SHOULD BE MADE TO SUIT TUBE AND FITTINGS AVAILABLE

NOT TO SCALE

FLANGE DETAIL: WELDED TO AIR VESSEL AS SHOWN
8 OFF 11mm DIA HOLES EQUALLY SPACED ON 145mm PCD

M6 & M8

AIR VESSEL



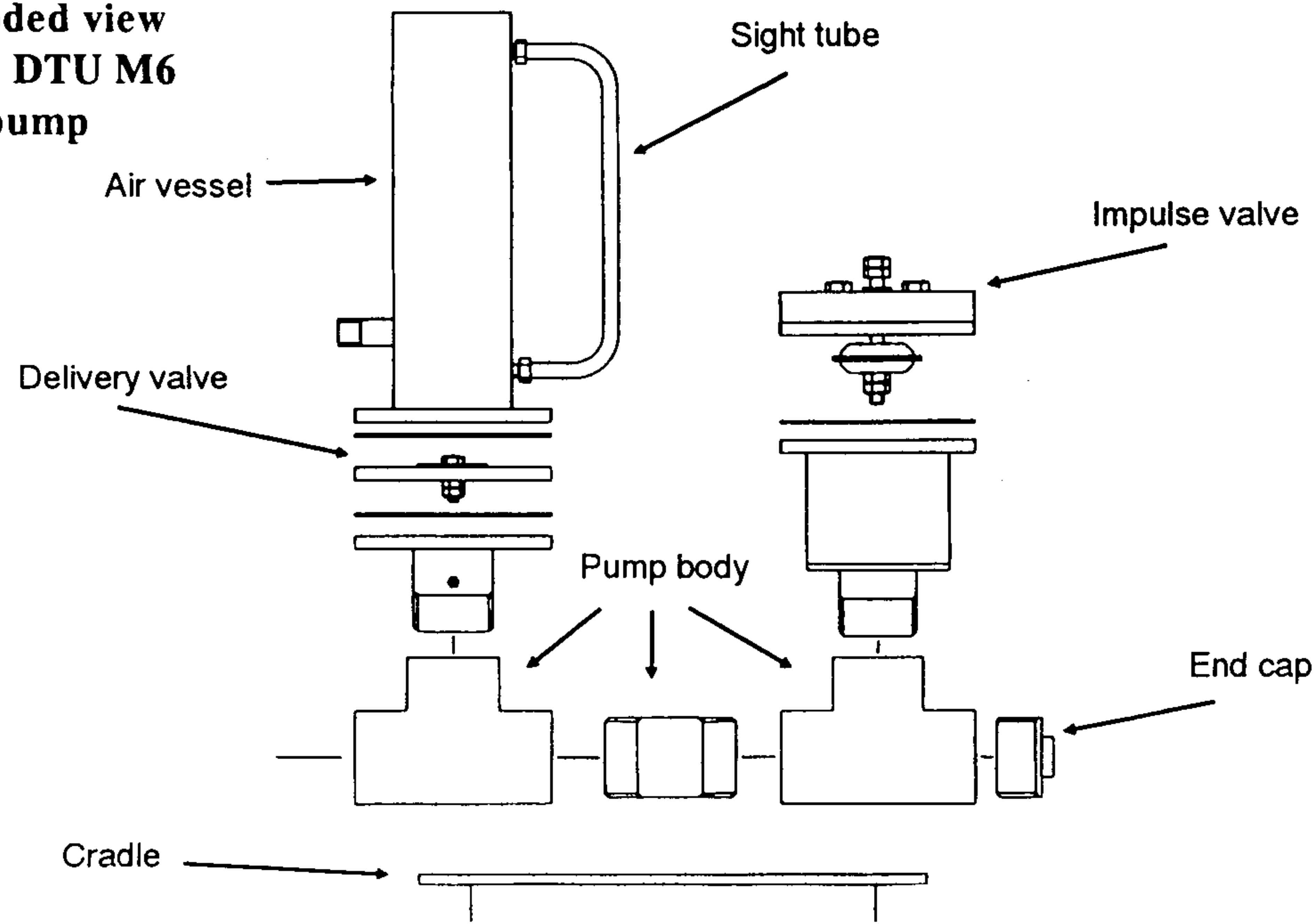
DTU M6 2"
STEEL RAM PUMP

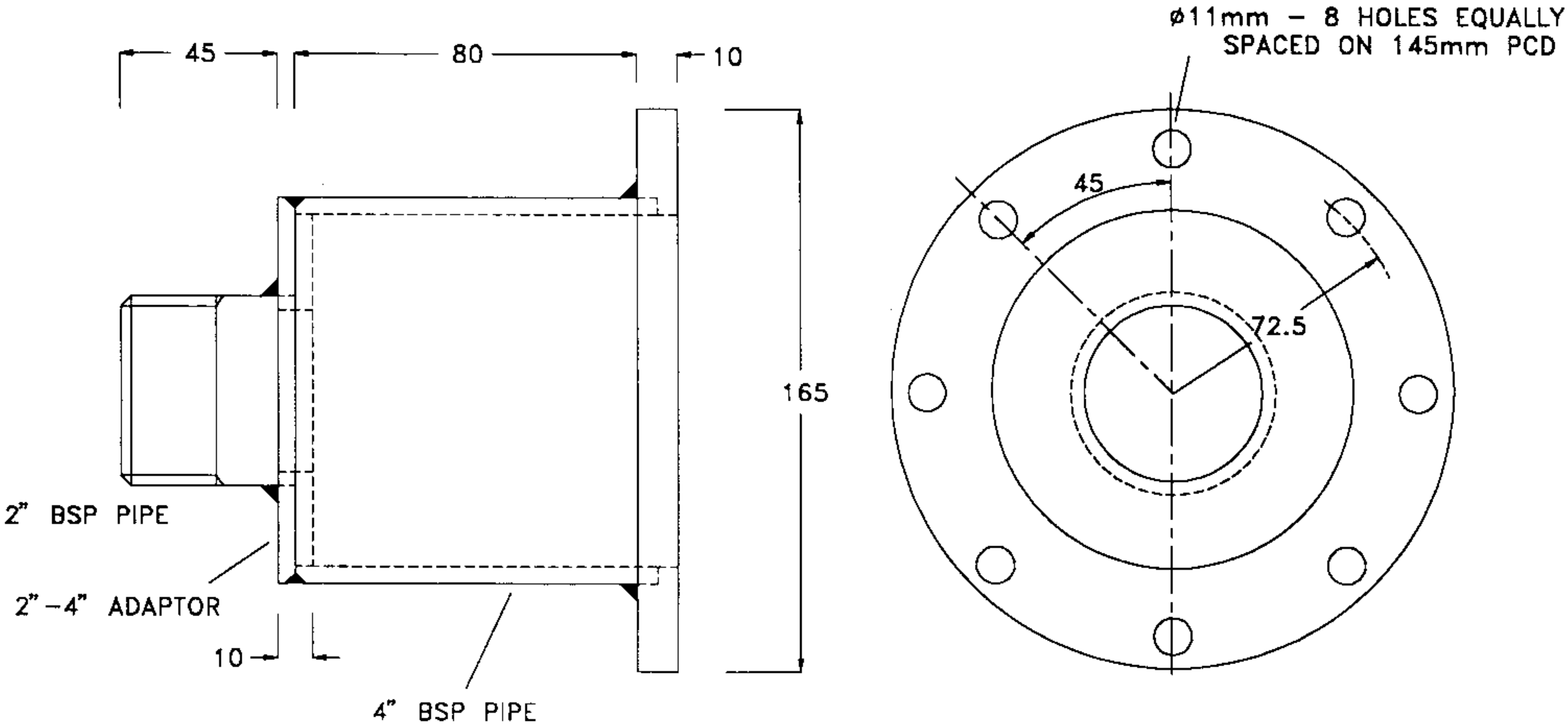
PARTS LIST

1 DRIVE PIPE
2 2" GALV. TEE
3 2" GALV NIPPLE
4 2" GALV PLUG
5 IMPULSE VALVE BODY
6 IMPULSE VALVE ASSEMBLY
7 SNIFTER VALVE
8 SNIFTER HOUSING
9 DELIVERY VALVE
10 AIR VESSEL
11 AIR SIGHT TUBE
12 DELIVERY PIPE

M6
ASSEMBLY DRAWING

Exploded view of the DTU M6 ram pump

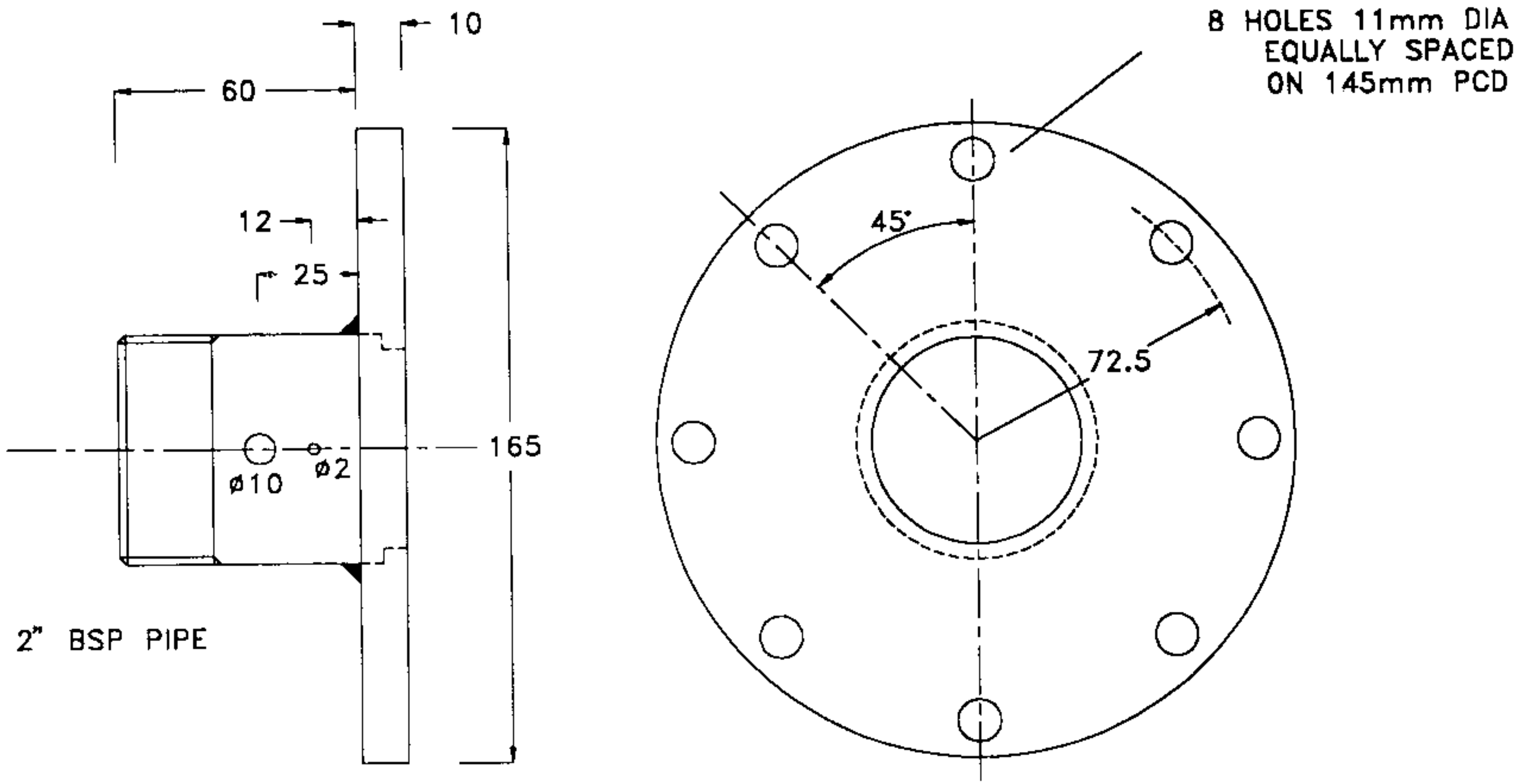




NOTES
1 ALL PARTS MILD STEEL
2 ALL JOINTS WELDED
3 ADAPTOR AND FLANGE CONNECTED TO PIPE USING TOP HAT SECTION
4 ALL TO BE PAINTED — 2 COATS MIN. OR GALVANISED

NOT TO SCALE

M6 IMPULSE VALVE BODY



NOTE: 1. ALL PARTS MILD STEEL
2. ALL JOINTS WELDED

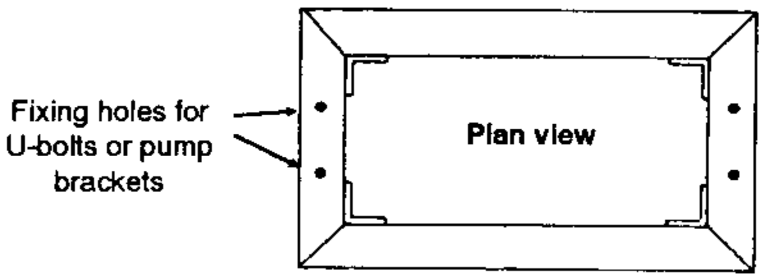
M6

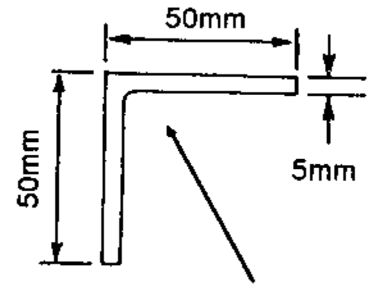
DELIVERY VALVE ADAPTOR

The pump cradle

The design drawing for a fixing bracket to attach the M8 pump to a cradle is on page 125. The M8 pump can be strapped to the cradle using U-bolts with stiff rubber packing.

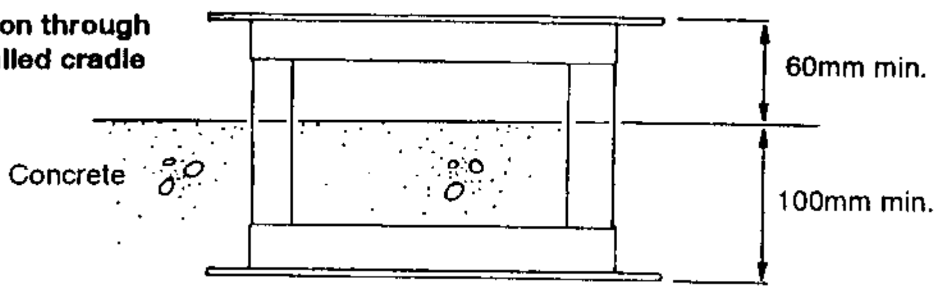
Sketches of cradle design — details will depend on the pump type and number installed



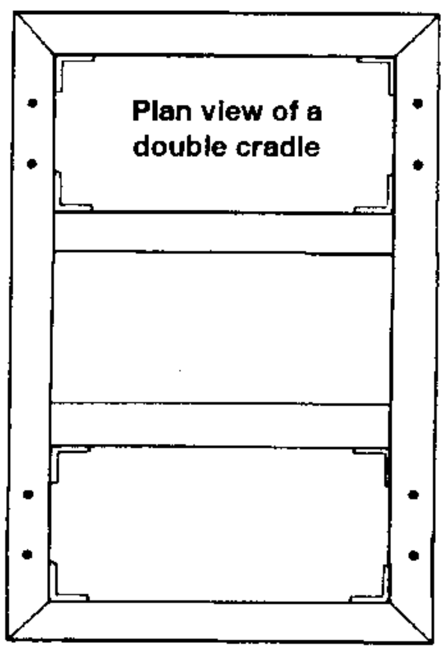


The cradle shown here is made using 50mm angle iron or similar material

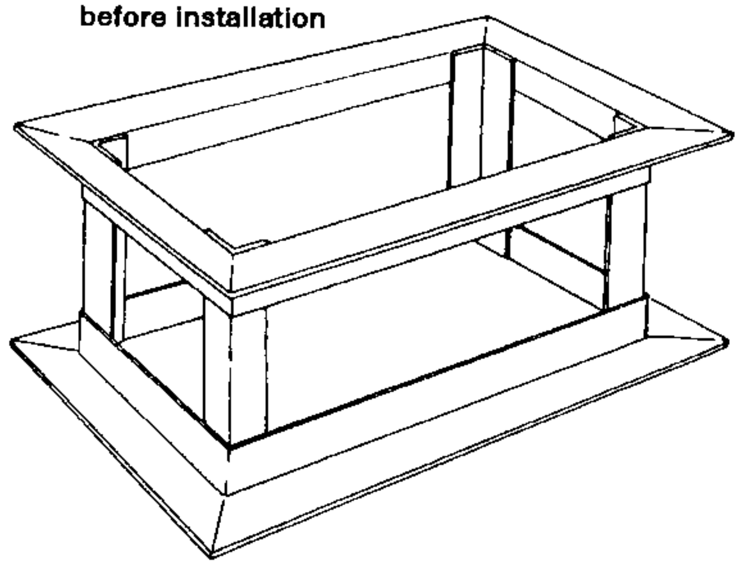
Section through installed cradle



The cradle should be painted or, ideally, galvanised for protection.

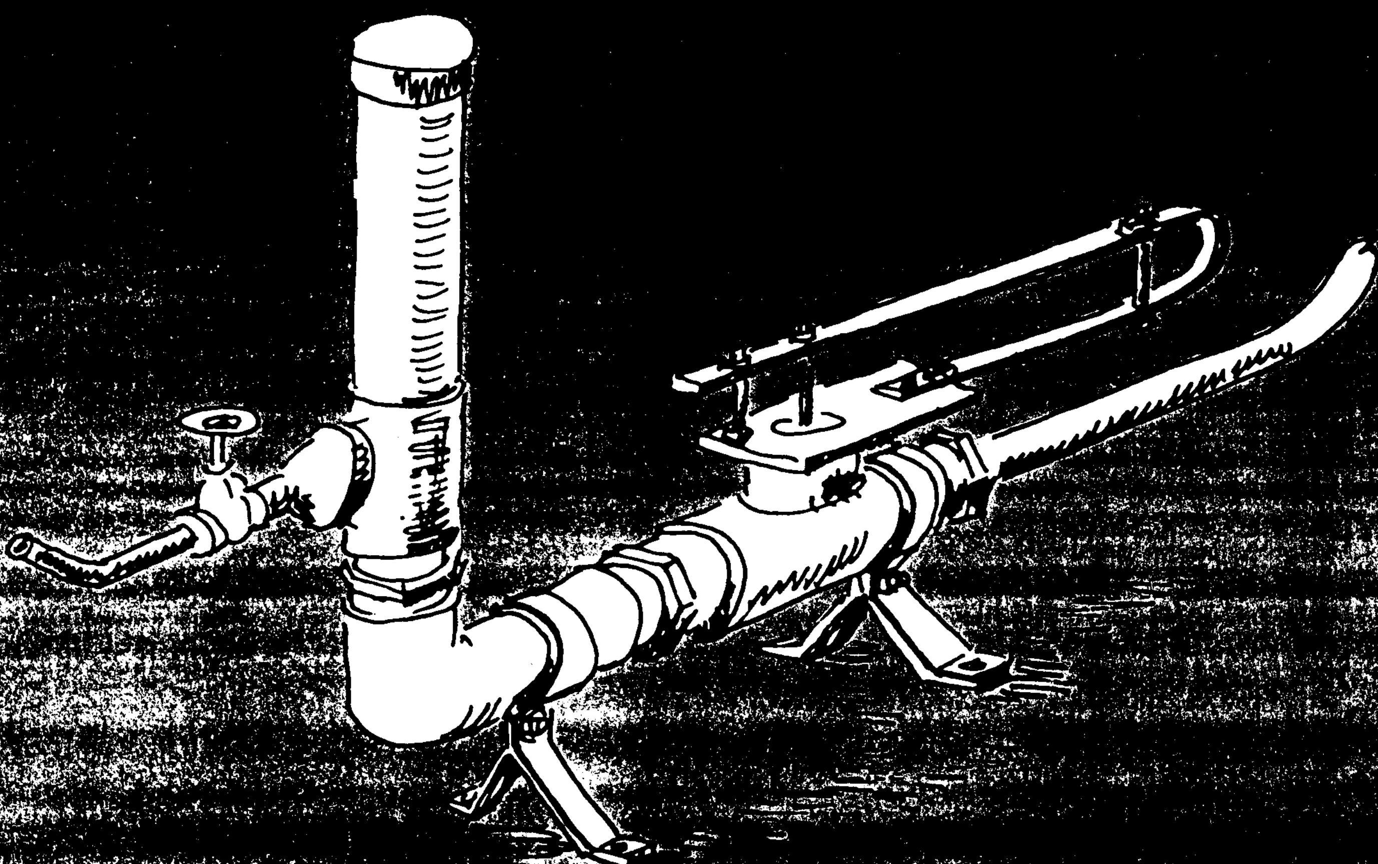


Sketch of cradle before installation



A Manual on the Hydraulic Ram for Pumping Water

S. B. Watt



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Introduction

The automatic hydraulic ram is a pumping device that has been widely used for nearly a century in rural areas, for lifting water to heights of over 100 metres. It is an ideal machine for water pumping if certain conditions are satisfied, because it works solely on the power from falling water carried in a pipe from a spring, stream or river, without any need for an additional power source. It is completely automatic, and has an exceptional record of trouble free operation. It cannot be used everywhere, however. It cannot be used to pump still water from a well, pond or lake, unless there is a separate, flowing water source nearby.

The simple ram pump described in this manual has been made and used since 1948, but we have only limited information on its performance. This has been taken from the VITA publication (Ref. 6.6 in the bibliography) and our own very limited laboratory tests (Section 5). We would welcome information from anyone who has built one of these ram pumps, operated it over a long period, and who has also measured the pumping rate and surveyed the site conditions.

Although this method of making a ram pump has already been published by VITA (6.6.), we have written the manual to do two things. We hope to demonstrate to field workers how they can build the ram and have the confidence to overcome any difficulties in installation and tuning. We also hope to provide information to those with some technical and workshop experience that will enable them to manufacture larger rams.

In Part 1, we describe how a simple ram pump can be made from commercial pipe fittings, how to choose a site for the ram, how to install and adjust the ram, and the sort of maintenance that the ram pump will need during its working life. We have tried to write the manual in non-technical language so that it can be used by people with little or no technical training.

In Part 11, we describe in greater detail the range and limits of operation of ram pumps, and the different materials that have been used to make them. We have taken information given in the trade literature of a commercial ram manufacturer, Blakes Hydrams Ltd., (Ref. 6.9), to describe the simple calculations that you will need to design a different sized ram pump for different site conditions. We also include in Part 11 the results of our limited laboratory tests on the ram, which describes the tuning procedure.

We have not attempted to describe the complex relationship involved in the hydraulic behaviour of the water moving through the ram, this is very difficult to follow unless you have substantial experience of fluid mechanics. An annotated bibliography listing the main sources of information that we used to write this manual is included in the last section of Part 11.

S.B.Watt.

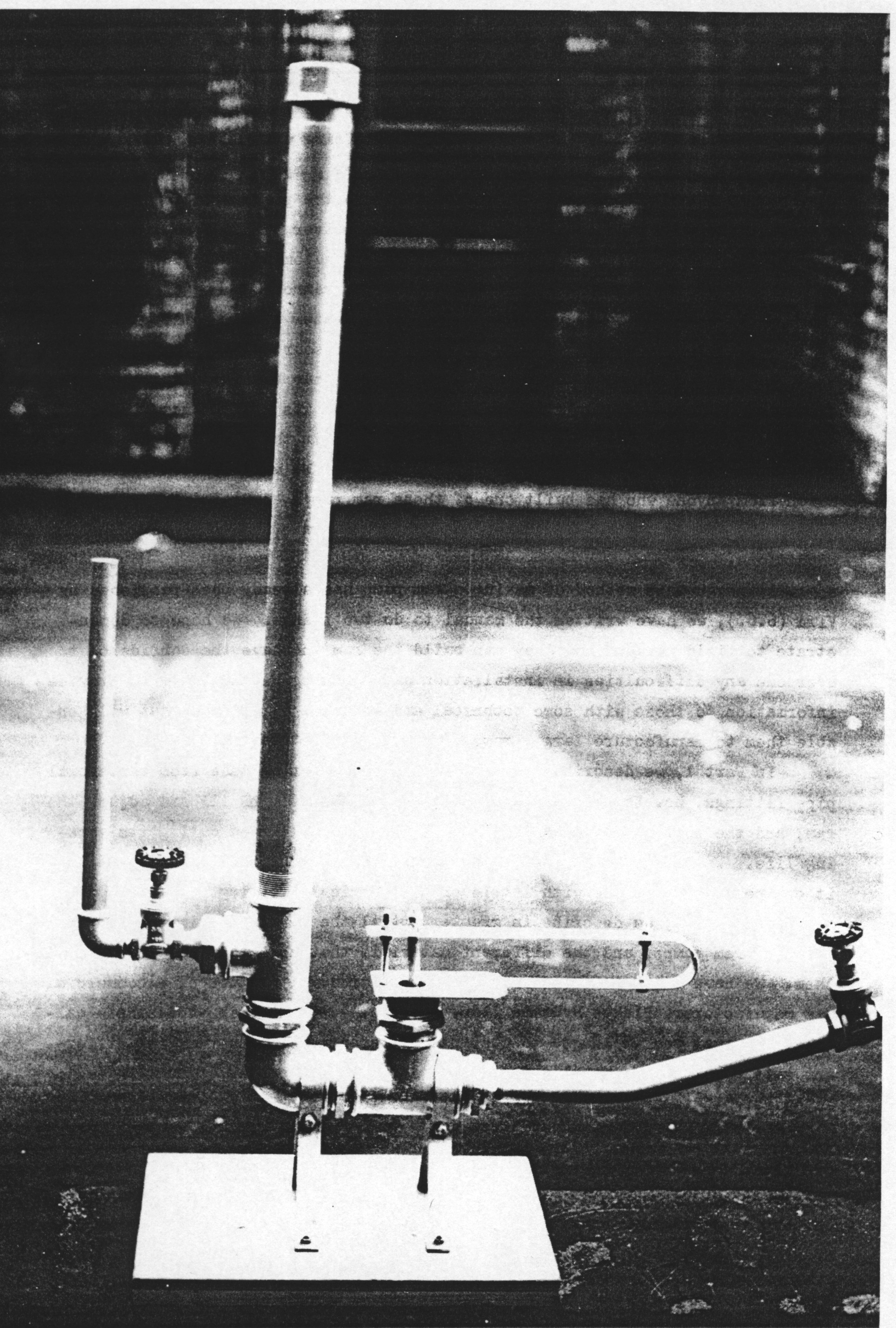
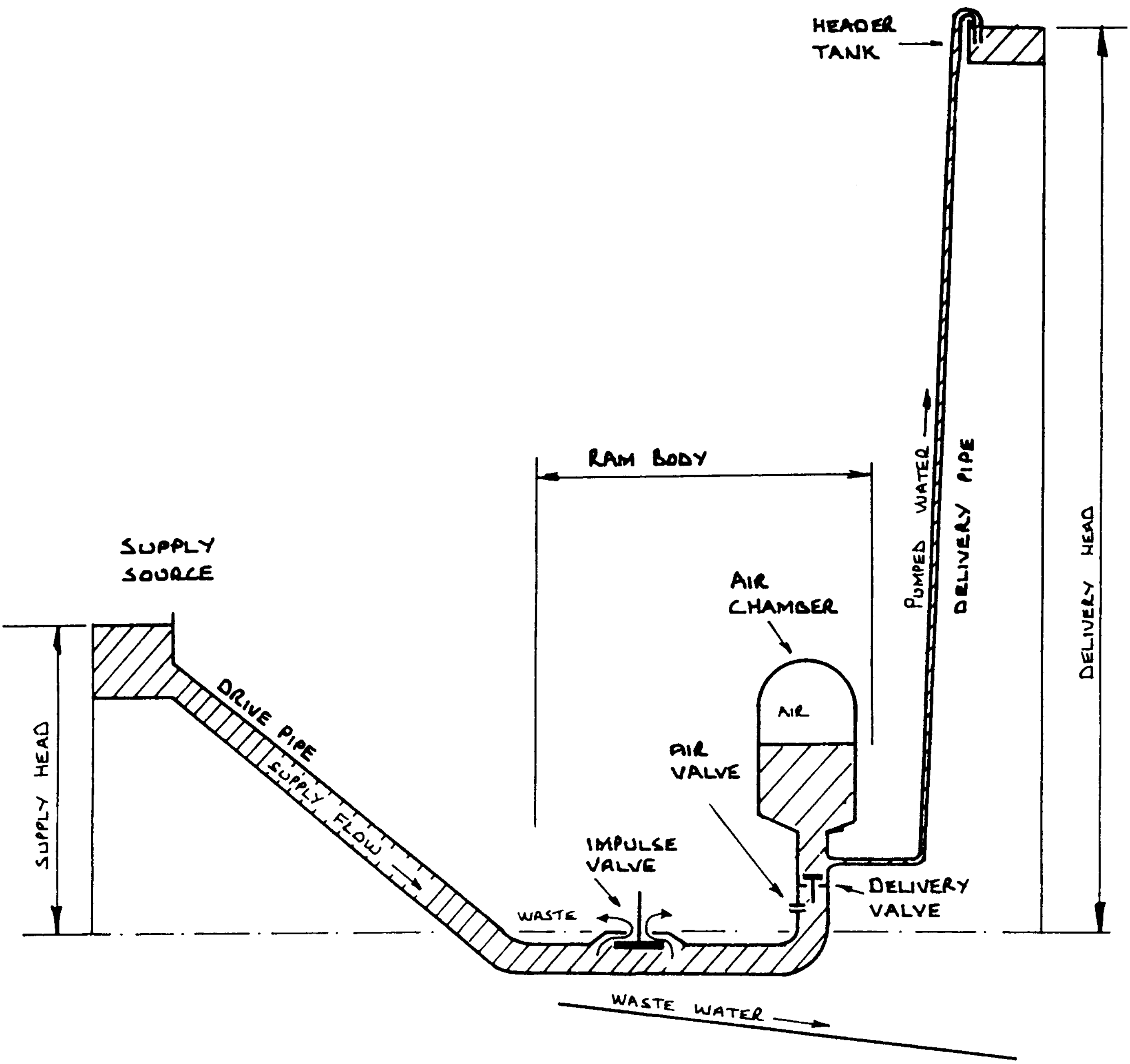


FIG.1 THE ARRANGEMENT OF A TYPICAL RAM ASSEMBLY



The vertical distance between two water levels is known as the 'head' of water available and is a measure of the water pressure. For instance, the pressure in the ram body when it is full of water and not pumping, is known as the supply head; similarly the pressure in the air chamber with the delivery valve closed, is the delivery head.

Part 1 How to make and Install a a Simple Ram Pump Constructed from Water Pipe Fittings

1. A Description

The automatic hydraulic ram is used for pumping water. It works by pumping a small fraction of the water that flows through it from a supply source, to a level that can be much higher than the source. The ram can only be used in places where there is a steady and reliable supply of water, with a fall sufficient to operate the ram.

The ram described in this manual needs to have a fall of at least 1 metre from the source to the ram, and a flow at the source greater than 5 litres per minute. The amount of water that it can pump to different heights is given in Table 1. (Page 7)

In places where this ram can be used, it has many advantages over other pumps powered by hand, animal, wind, or motors, despite the fact that it wastes a lot of water:-

a) it does not need an additional power source and there are no running costs,

b) it has only two moving parts, and these are very simple and cheap to maintain,

c) it works efficiently over a wide range of flows, provided it is tuned in correctly,

d) it can be made using simple work shop equipment.

2. How it works

A labelled diagram of a typical working ram installation is shown in Fig. 1.

Water flows down the drive pipe from the source and escapes out through the impulse valve. When the flow of water past the impulse valve is fast enough, this flow and the upward force on the valve causes the valve to shut suddenly, halting the column of water in the drive pipe. The momentum of the stopped column of water produces a sudden pressure rise in the ram, which will, if it is large enough, overcome the pressure in the air chamber on the delivery valve, allowing water to flow into the air chamber and then up to the header tank.

The pressure surge or hammer in the ram is partly reduced by the escape of water into the air chamber, and the pressure pulse 'rebounds' back up the drive pipe producing a slight suction in the ram body. This causes the delivery valve to close, preventing the pumped water from flowing back into the ram. The impulse valve drops down, water begins to flow out again, and the cycle is repeated.

A small amount of air enters through the air valve during the suction part of the ram cycle, and passes into the air chamber with each surge of water up through the delivery valve. The air chamber is necessary to even out the drastic pressure changes in the ram, allowing a more steady flow of water to the header tank. The air in the chamber is always compressed, and needs to be constantly replaced as it becomes mixed with the water and lost to the header tank.

The ram is 'tuned' to pump the greatest amount of water possible, and this normally occurs when the ram cycle is repeated or 'beats' about 75 times each minute.

3. Is your site suitable for the ram?

You can install this ram at your site without doing any survey work to measure the flow of water at the source, or the supply and delivery heads at the site, and it will probably work perfectly well. However, it is often necessary to know if the ram is capable of pumping the amount of water you need, or whether you need a larger ram. Measuring for this information is not difficult, and is described below.

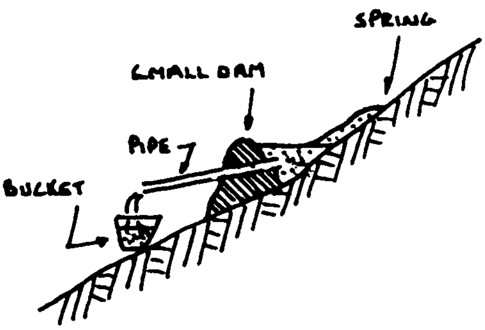
3.1 MEASURING THE FLOW OF WATER AT THE SOURCE.

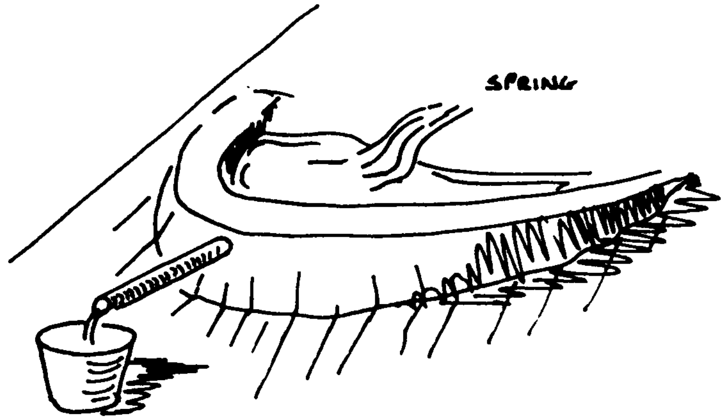
The first thing you must measure, is the flow of water at the source, to see if it is enough to operate the ram; some people with experience can estimate this by eye.

Naturally occuring sources of water tend to dry up during the year, and you must make allowance for this if you use your measurement of water flow to calculate the pumping rate of the ram, otherwise your water supply may be less than you planned for.

a) Measuring a small flow, such as a spring.

When the flow is very small, you can measure it by constructing a temporary dam, and catching the water in a bucket. The amount of water (in litres) that flows into the bucket in one minute can then be measured. The dam may be made from any material, wood, metal sheet, planks etc., but you must make sure that there are no leaks:-



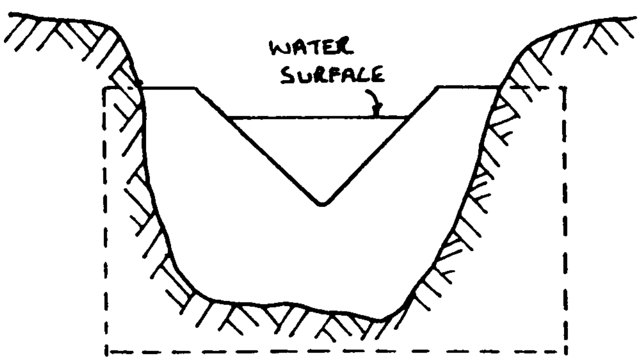


a) MEASURING A SMALL FLOW.

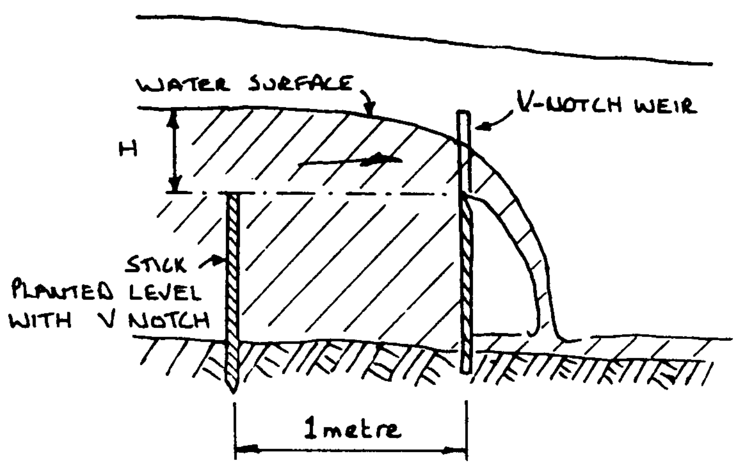
b) Measuring larger flows.

The ram described in this manual requires only a small amount of water to make it work, and often you can see by looking if the flow is large enough. However, if you are going to make or buy an expensive larger ram, it is essential to know how much water there is to be taken from the source.

Larger flows are measured using a timber plank or ply wood weir, with a 90° V-notch cut into the top:-



TEMPORARY DAM WITH V-NOTCH.



MEASUREMENT OF WATER DEPTH H ONE METER UPSTREAM FROM V-NOTCH WEIR.

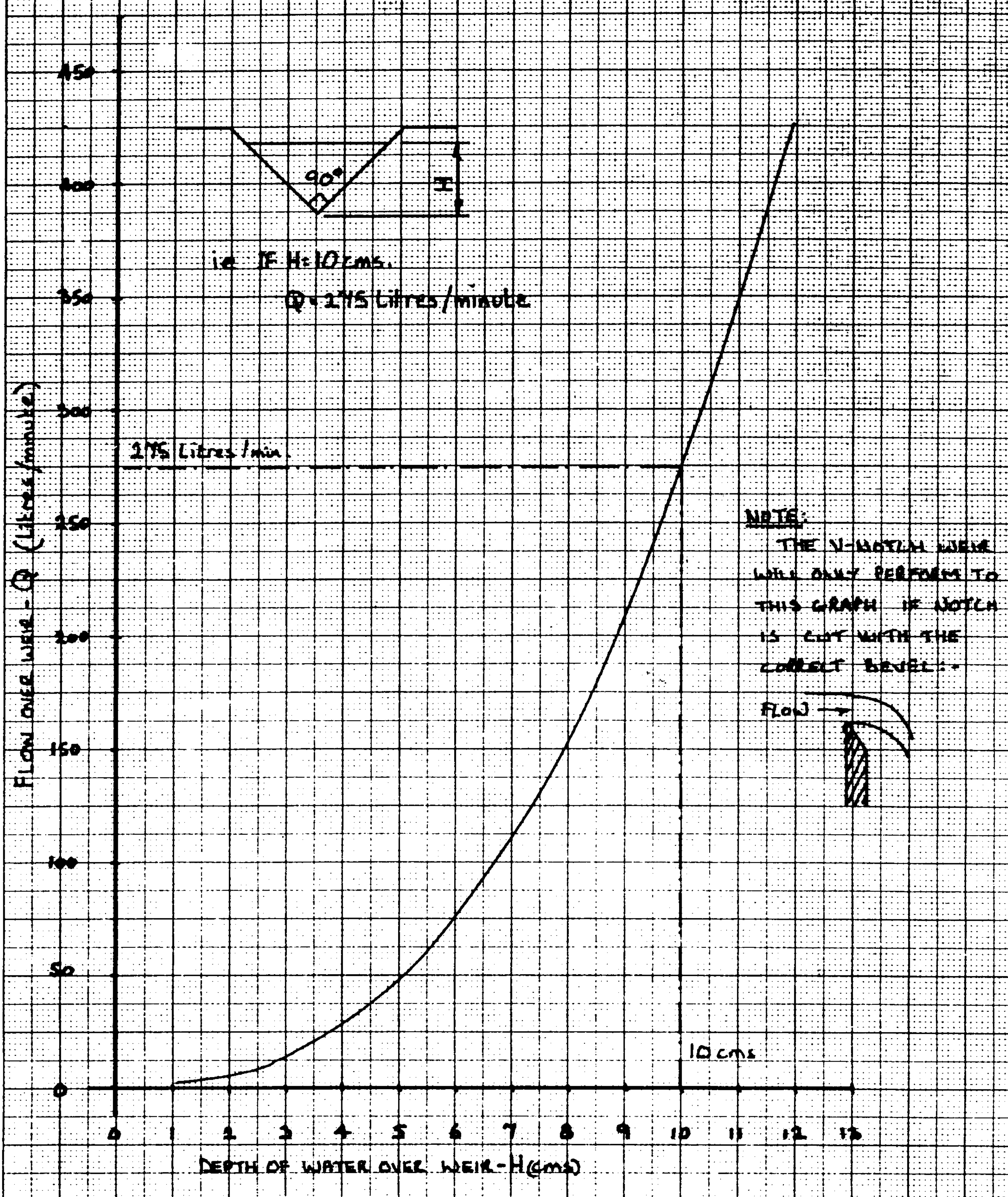
b) MEASURING LARGER FLOWS

The depth of water flowing through the weir is measured about 1 metre upstream of the weir, and you can then use the graph in Figure 2 to read how much water is flowing

Example.

Depth of water measured 1 metre upstream = 10 cms.
From graph, the flow is then read as 275 litres/min.

Fig 2. Flow of water over a triangular V-notch.



GRAPH CONSTRUCTED FROM FORMULA $Q = 0\cdot875 (H)^{5/2}$

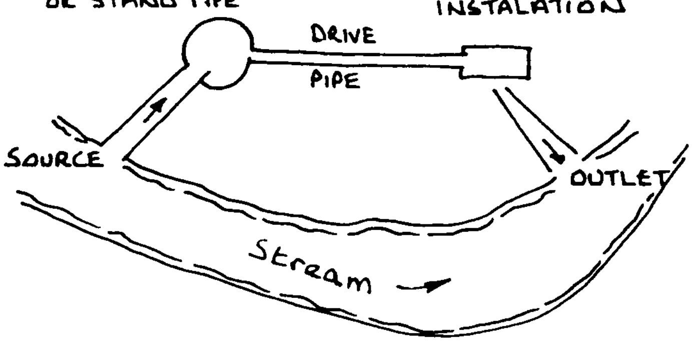
WHERE Q = DISCHARGE (Litres/min)

H = HEAD (cms)

The weir must not leak around its sides, and the graph can only be used if all the water flow is contained within the notch.

3.2 MEASURING THE SUPPLY AND DELIVERY HEADS.

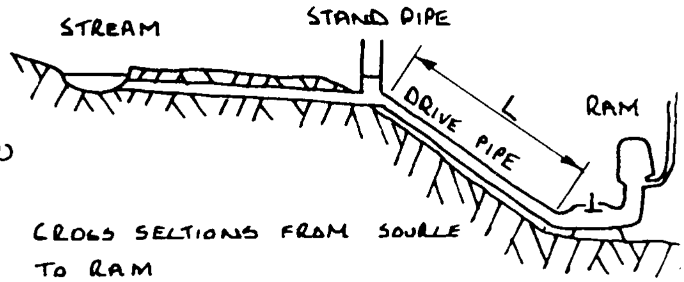
Most rams will work at their best efficiency if the supply head is about one third of the delivery head, but often the site will not allow this, and you must then try to make the supply head as large as possible; this will be necessary if the source is a slow moving stream or river which has a shallow slope. The supply head can be increased by leading the water from the supply source along a feeder canal or pipe to the drive pipe inlet:-



PLAN ON RAM INSTALATION.

INCREASING SUPPLY HEAD OR REDUCING PIPE LENGTH

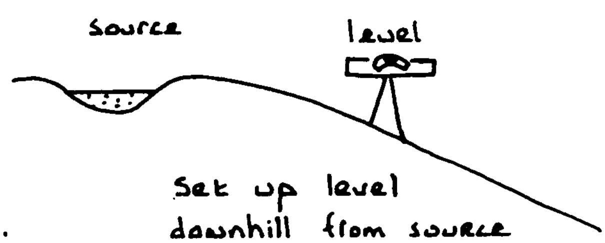
b)



CROSS SECTIONS FROM SOURCE TO RAM

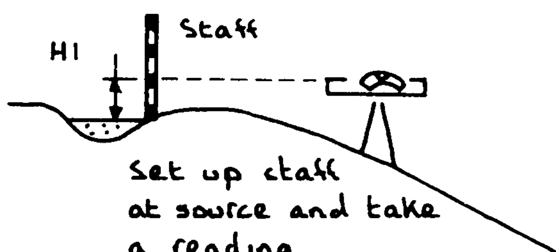
You will only need to measure the supply and delivery heads if you need to make sure that the ram will pump enough water, or if you have to buy a larger ram. The flow at the supply source, and the delivery and supply heads, can be used to calculate how much water this ram will pump. See Table 1. (Page 7)

The differences in level between the source and the ram, and the header tank and the ram, can be measured using a surveyors dumpy level, a clinometer, or even a carpenters spririt level attached to a stick. A method of measuring the supply head is described below:-



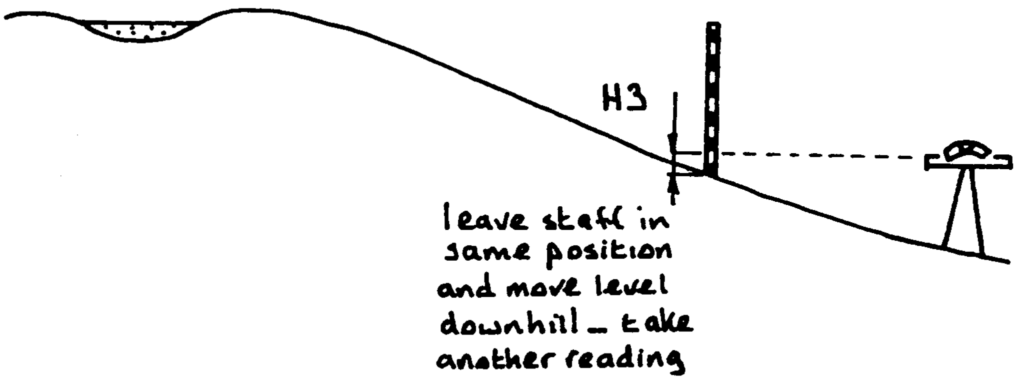
Set up level downhill from source

i)



Set up staff at source and take a reading ii)

iii)



i. Set up the level near the source, and take a reading on a graduated measuring staff held by your assistant on the water surface of the source. Record this reading in a note book. (H1).

ii. Turn the level around on the same spot, and ask your assistant to carry the measuring staff down hill. The staff is held upright, and you take a second reading which you again record. (H2).

iii. Your assistant will stay on the same spot with the measuring staff whilst you carry the level down hill again to a position below your assistant. Set up the level again, and repeate stages i and ii above.

You repeat this process until the ram site is reached, and the supply head can be calculated as follows:-

$$\text{Supply Head} = H_2 - H_1 + H_4 - H_3 + \;..... \text{ etc.}$$

The delivery head is measured in a similar way.

4. Designing the ram.

4.1 HOW MUCH WATER CAN THE RAM PUMP

The simple ram pump made from commercial pipe fittings described in Section 5 of this manual, needs a supply flow of at least 5 litres each minute. Using this supply flow, the smallest amounts of water that this ram may be expected to pump each day for different supply and delivery heads, are given in Table 1.

TABLE 1 DAILY PUMPING RATES FOR RAM PUMP (litres of water)

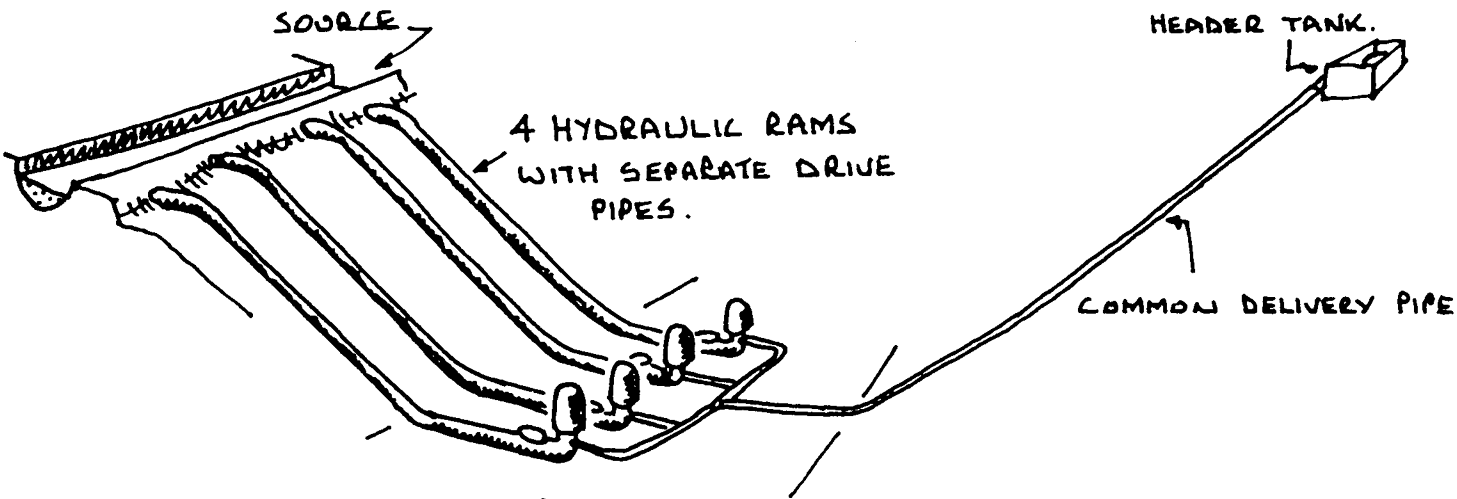
Supply Head (metres)	Delivery Head (metres)										
	5	7.5	10	15	20	30	40	50	60	80	100
1	400	200	150	80	70	50	30	20			
2		550	390	250	200	130	80	60	50	30	
3			650	450	320	220	150	130	100	70	40
4				650	430	300	200	150	130	90	60
5				750	550	370	300	250	200	120	90
6					700	450	350	300	250	150	120
7						550	410	320	270	200	150
8							450	370	300	250	150
10							600	450	400	300	230
12							750	550	470	350	280
14								650	550	400	330
16									620	470	370
18									700	520	420
20										600	450

We have not been able to test the ram pump over this wide range of supply and delivery heads. We have assumed that it will pump at only one half the rate of a comparable commercial ram manufactured by Blakes Hydrams Ltd. (see Table 2, page 30).

The ram will pump at a faster rate if the impulse valve is properly tuned, or if the supply flow is more than 5 litres per minute.If for example, your ram installation can be tuned to allow a flow of 15 litres per minute down the supply pipe, then the ram will pump three times the amount given in Table 1.

The greatest amount of water this ram can use from the source is governed by the size of the ram itself and if the ram installation is to use more water (and therefore be able to pump more water), then a larger ram should be chosen. How to choose the correct ram size is given in Part 11 of this manual.

If you find that your ram installation is not large enough to pump the amount of water you need, you can construct a duplicate ram alongside the original ram. The drive pipes should be separate, but you may use the same delivery pipe. Some installation have batteries of small rams, often 5 or more, next to each other.



A BATTERY OF SEVERAL RAMS

4.2 CHOOSING THE SIZE OF THE DRIVE PIPE.

The drive pipe is really the most important part of the ram installation - it carries the water from the source to the ram, and contains the pressure surge of the water hammer. It must be made from good quality steel or iron water pipe - plastic and concrete pipes are useless for drive pipes.

The diameter and length of the drive pipe is very important, although the ram will work satisfactorily if the ratios of pipe length (L) to diameter (D) are between the limits $\frac{L}{D}$ = 150 to 1000. These are very broad limits. We suggest that you try to install a drive pipe with an $\frac{L}{D}$ ratio of 500, or choose a length that is four (4) times the supply head, whichever is the smaller. The theory behind the drive pipe is described in greater detail in Part 11.

Example

Supply Head	=	4.0 metres
Drive pipe diameter (D)	=	25 mm.

a) Use $\frac{L}{D} = 500$

$L = 500 \times 25 = 12500$ mm or 12.5 metres.

b) Use $L = 4 \times$ Supply head

$L = 4 \times 4.0 = 16.0$ metres.

The ram will work equally well if the drive pipe is cut from 25 mm pipe at either of these lengths, and you should choose the length which is most convenient for your site.

4.3 CHOOSING THE DELIVERY PIPE SIZE

Unlike the drive pipe, you can make the delivery pipe from any material, provided it can stand the pressure of water leading up to the delivery tank. The delivery pipe should have an internal bore of 20 mm; plastic hose pipe is quite satisfactory if it is strong enough.

The water from the ram can be pumped for great distances provided that the delivery head is small enough; in this case, the ram has to spend effort forcing water through the pipe, and you should try to keep the delivery pipe fairly short.

4.4 CHOOSING THE SIZE OF THE HEADER TANK.

One of the great advantages of a ram pump is that it works automatically and continuously, which means that it is always pumping water to the header tank.

If you think about the way that you use water in your household, you will see that during certain periods of the day, you will need a relatively large amount from the header tank. At other times, during the night, for instance, you will most likely use very little water.

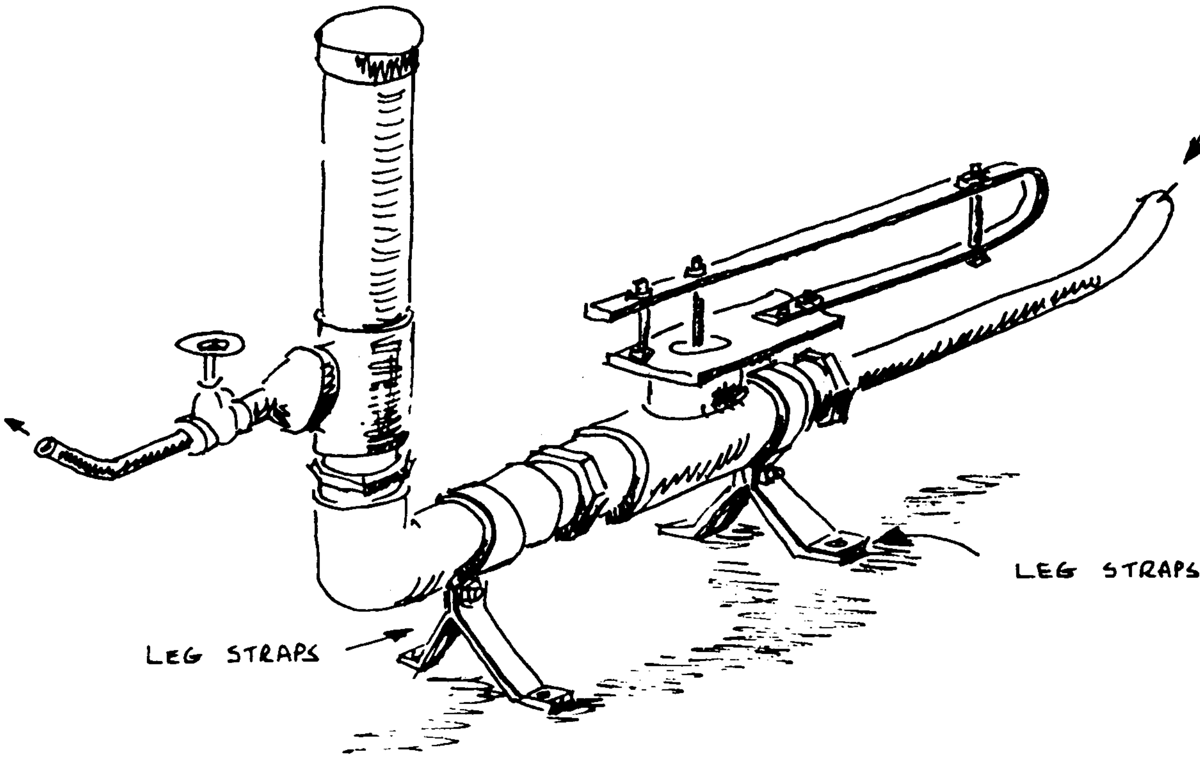
The header tank must therefore be large enough to hold enough water in reserve to supply your needs during periods of peak demand.

Even when you choose a header tank of correct size, there will be times when it overflows. You should therefore fit an overflow pipe to the tank, and lead the waste water to your garden or fish tank.

The way to choose the tank size is to estimate your daily water requirements, and make your tank to contain half this amount. If you find the tank is too small, you can easily add a second tank.

5. Building the ram.

You can build a ram from any size of pipe fittings that you have available, and the way that these will work is described in Part 11. The ram described here has a drive pipe bore of 30 mm. The ram body is made from pipe fittings of 50 mm internal bore, so that the impulse and delivery valves can have large openings: the relatively small sizes of commercial pipe fittings are a major disadvantage for ram construction, and effectively limit the maximum ram size that can be made. The finished ram is shown below and in Fig.3



The main points you should note when you intend to build this ram are:-

a) the capacity of the ram depends on the size of the impulse valve which allows the water to discharge. The pipe fittings are therefore several sizes larger than the drive pipe.

b) the flow of water through the ram should not be restricted by sharp changes of direction of water flow or by the sudden junction of different sized pipes.

c) the ram experiences savage pounding during its working life and all the parts, connections and valves must be strong enough to stand the stresses.

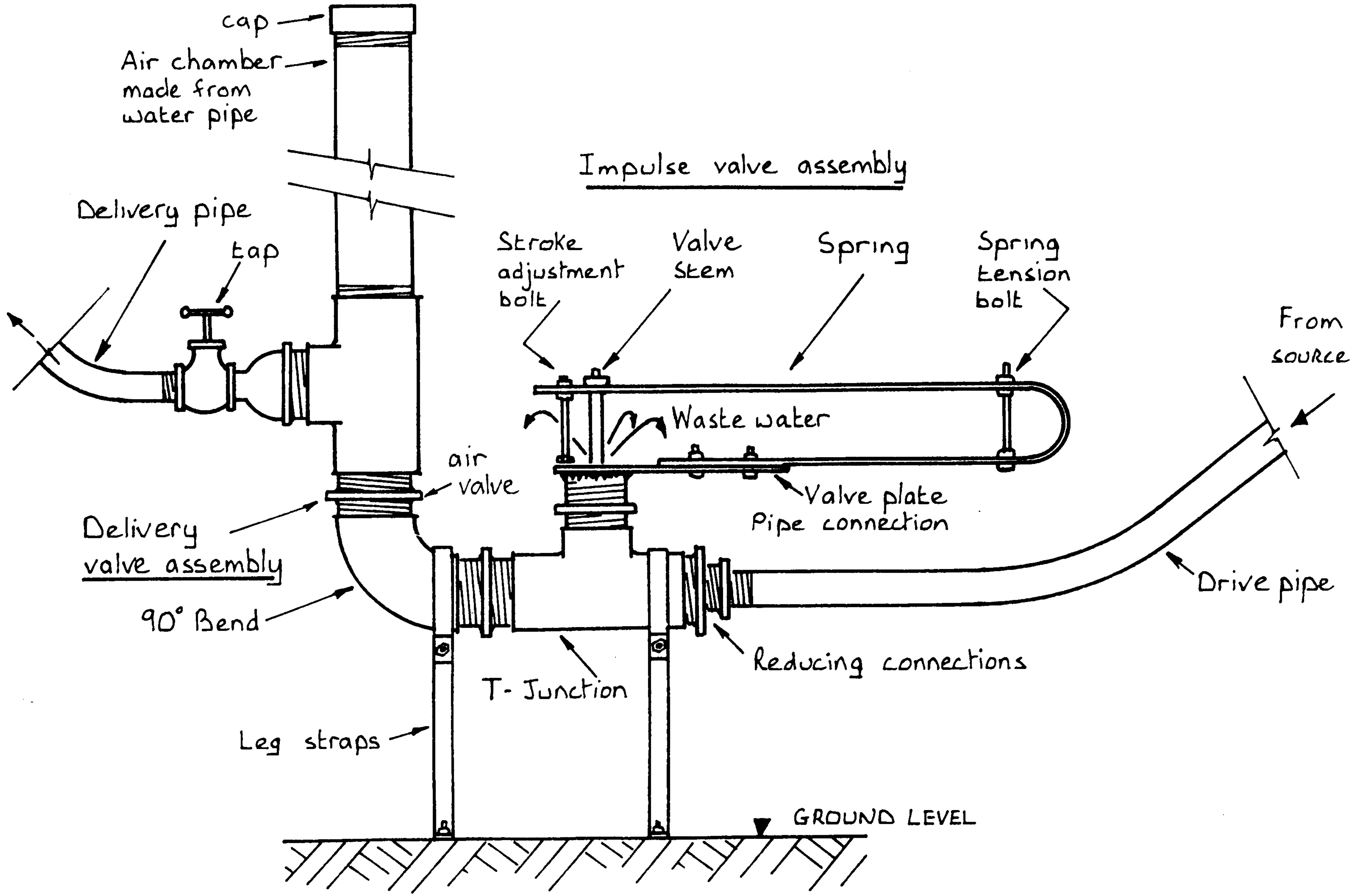
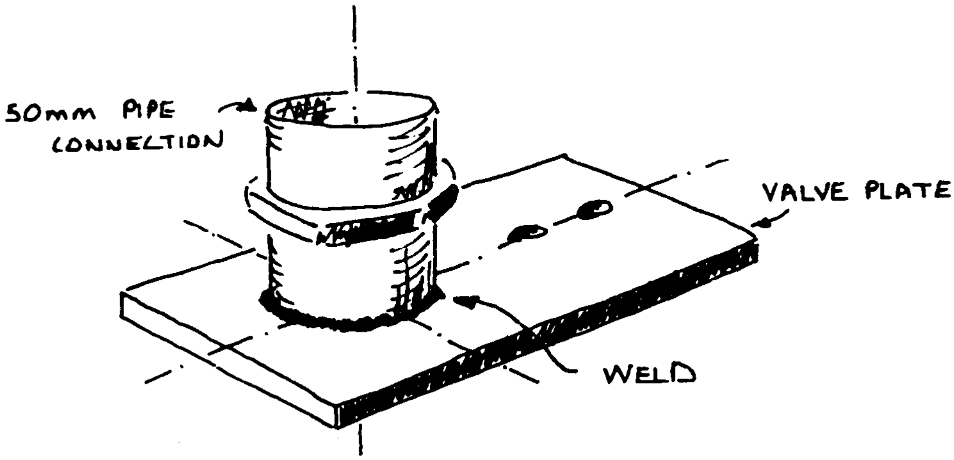


FIG 3 GENERAL ARRANGEMENT OF RAM CONSTRUCTED FROM PIPE FITTINGS

d) there are obviously any number of combinations of pipe fittings which can make up a ram body, and the one described below can be modified to suit available fittings.

5.1 MAKING THE IMPULSE VALVE.

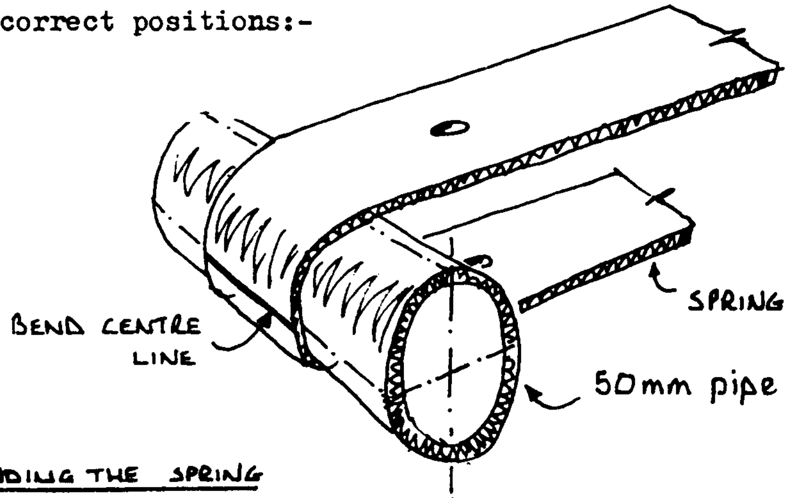
Weld or braze a 50 mm threaded pipe junction onto the valve plate shown in Fig.4.1 centrally over the 30 mm diameter hole:-



WELDING CONNECTOR TO PLATE

This will leave a lip inside the pipe connection about 10 mm wide all round, which will act as a seating for the impulse valve washer. File or rub and smooth the valve plate over the valve seating area to prevent wear on the valve washer. The two elongated holes, each 6 mm diameter on the valve plate, are to hold the valve spring.

The valve spring is made from a strip of mild steel, 650 mm long, 30 x 2 mm in cross section, marked out and drilled as shown in Fig.4.3. Bend the spring to shape around a 50 mm pipe, with the bend centre line on the strip in the position as shown below, this will set the spring with the drilled holes in the correct positions:-

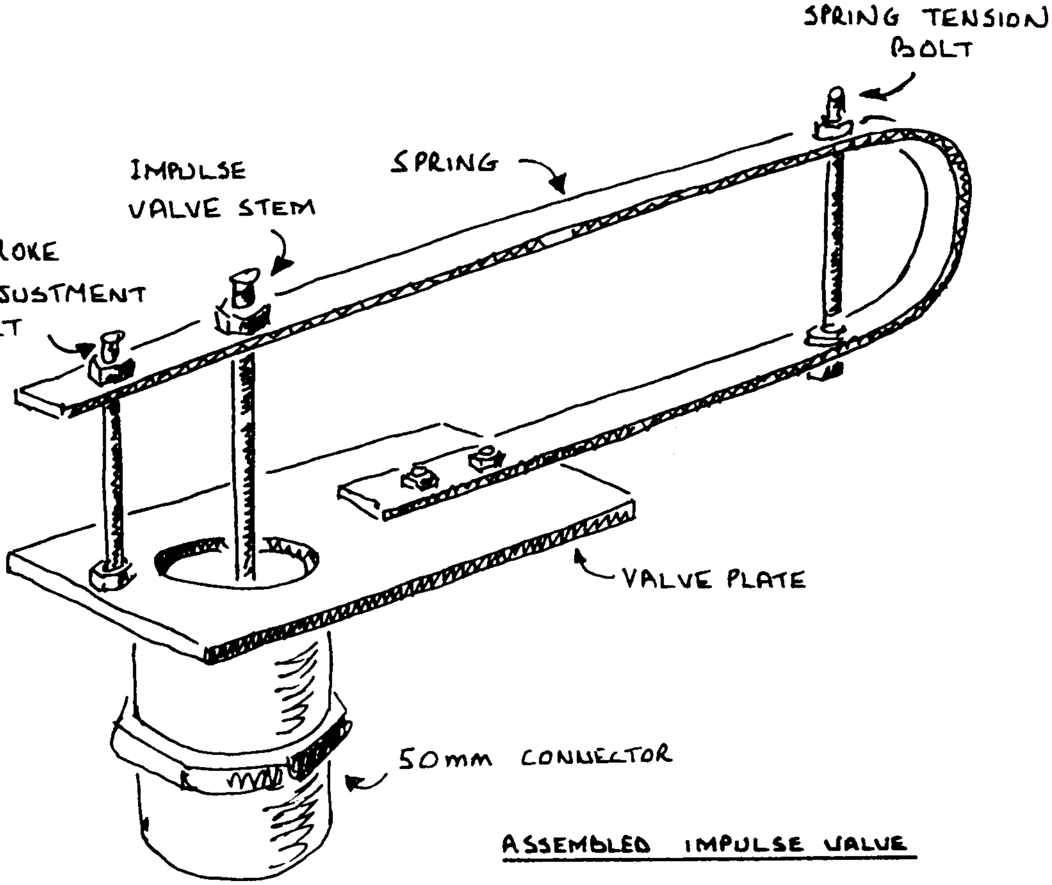


BENDING THE SPRING

Bolt the spring onto the valve plate, which has elongated holes to allow the impulse valve stem to be adjusted for correct seating.

The impulse valve itself is made up from a 6 mm diameter bolt, tube and washers which you assemble through the valve plate to the valve spring, Fig. 4.4

Finally, add spring tension and the valve stroke adjusting bolts. These allow the ram to be tuned for maximum efficiency. You can see that the impulse valve assembly can be removed from the ram for maintenance by just unbolting the spring, then unscrewing the pipe connector and valve plate:-



ASSEMBLED IMPULSE VALVE

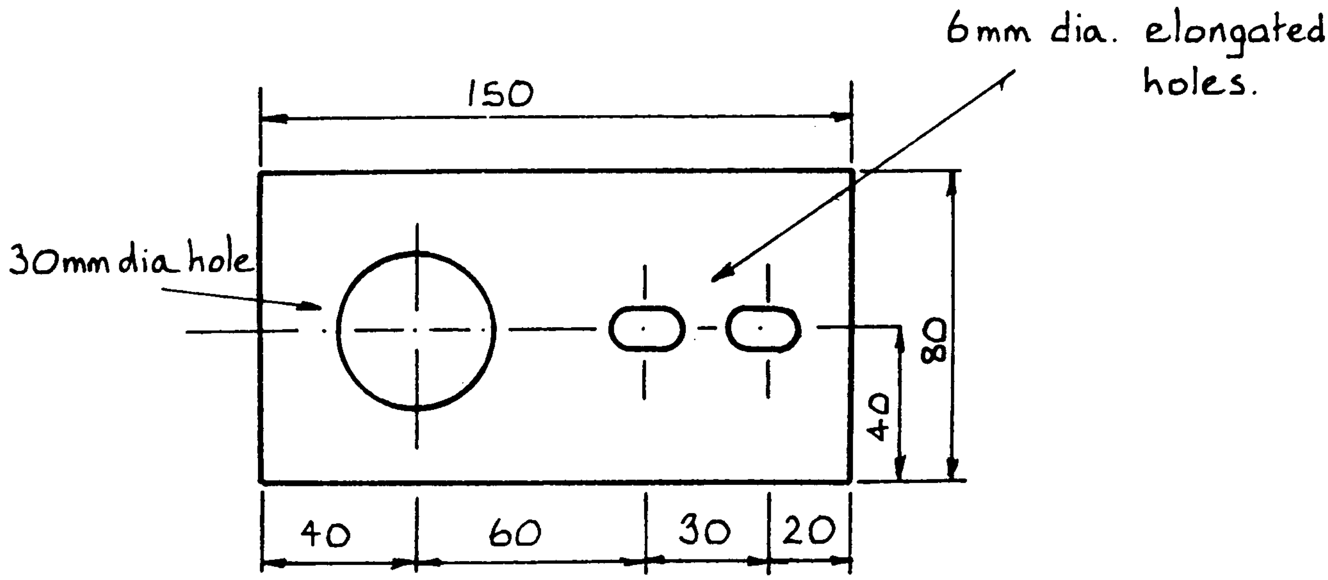
We have chosen this system of impulse valve assembly because it has no wearing parts except for the valve rubber. It is possible that with time, the valve spring will work harden and break; it is also possible that the spring assembly will be damaged during floods if the ram is installed on the side of a stream. An alternative more robust design for the impulse valve assembly is described below.

5.1 B AN ALTERNATIVE IMPULSE VALVE.

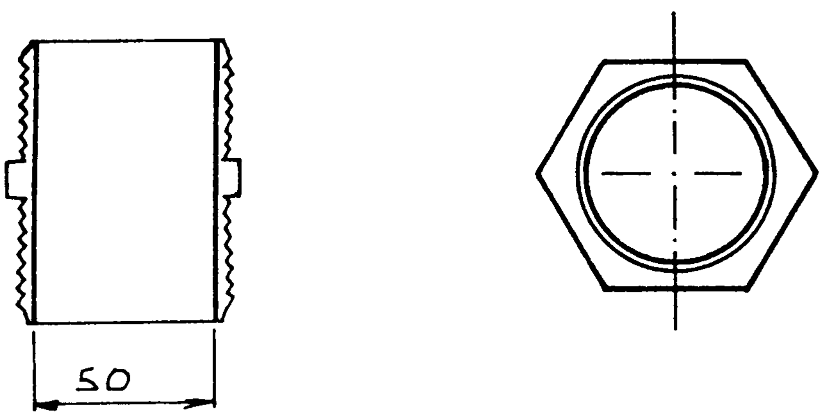
The impulse valve assembly described above has been taken from a design by VITA, and as far as we know, it works quite satisfactorily.

FIG 4 CONSTRUCTION OF IMPULSE VALVE (Dimensions in millimetres)

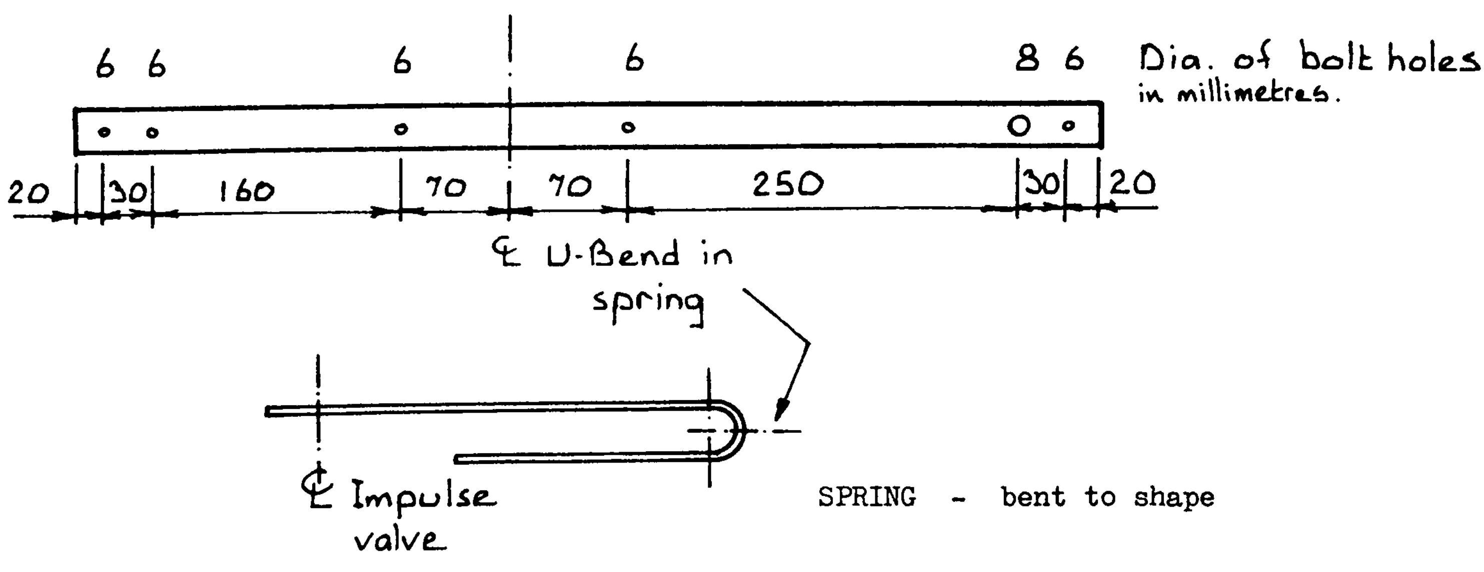
4.1. VALVE PLATE, 150 x 80 x 3 mm Mild steel plate



4.2. PIPE CONNECTION, 50 mm diameter, mole threaded

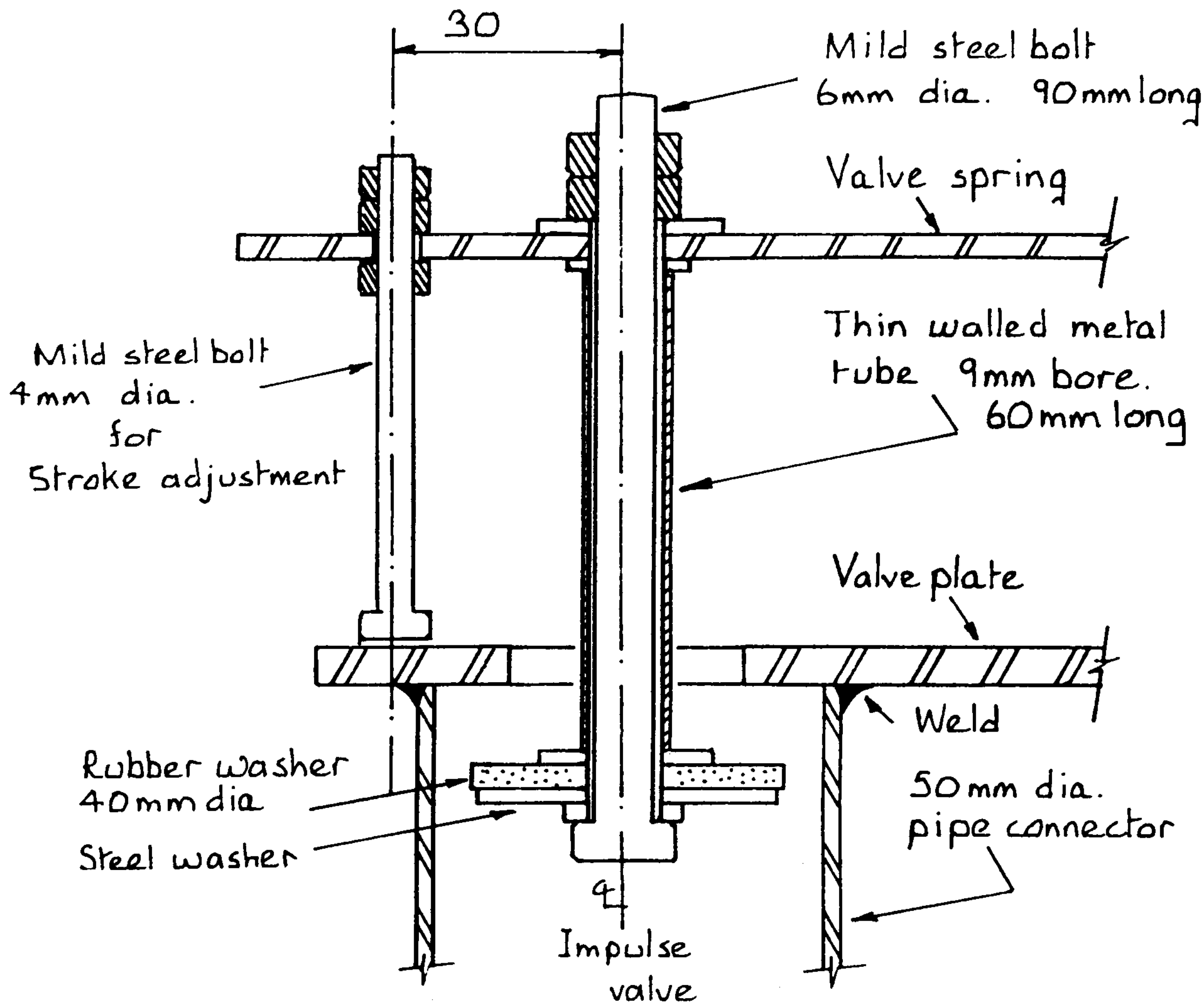


4.3. SPRING, 650 x 30 x 2 mm Mild steel strips

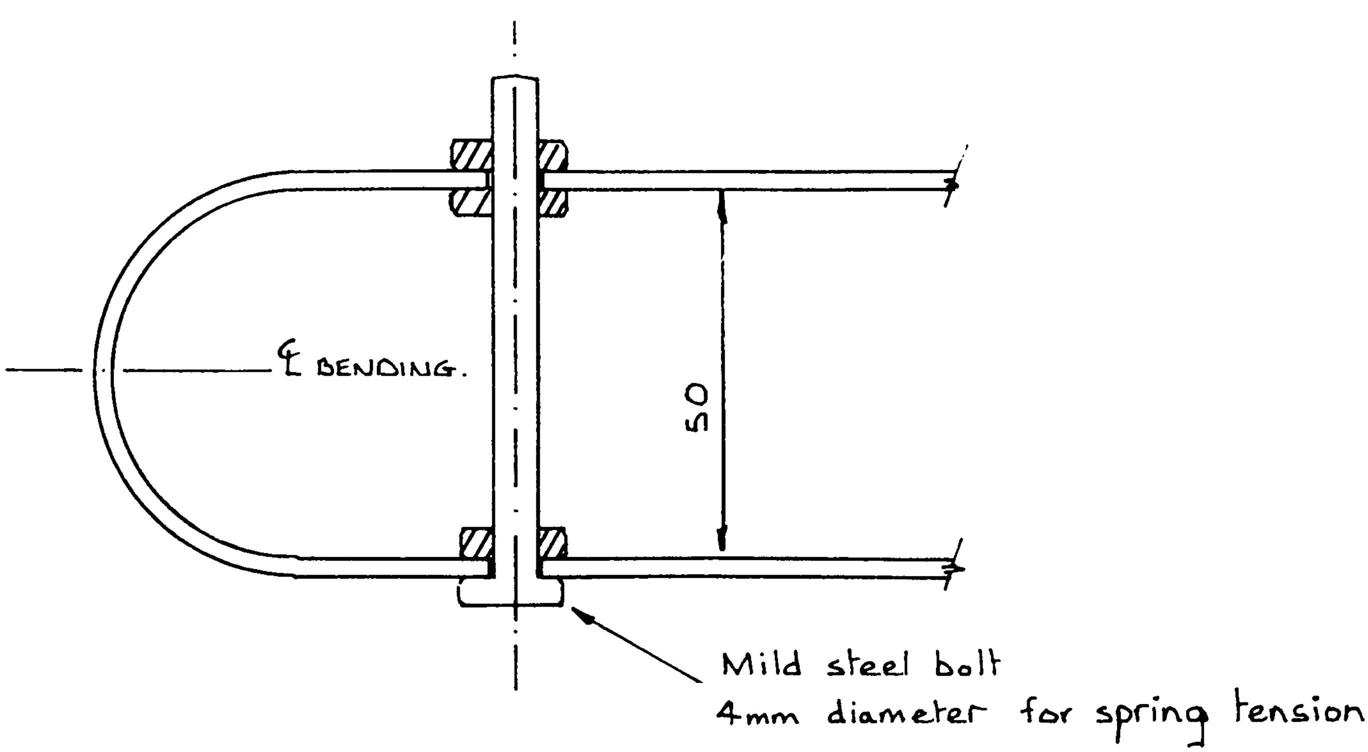


SPRING - bent to shape

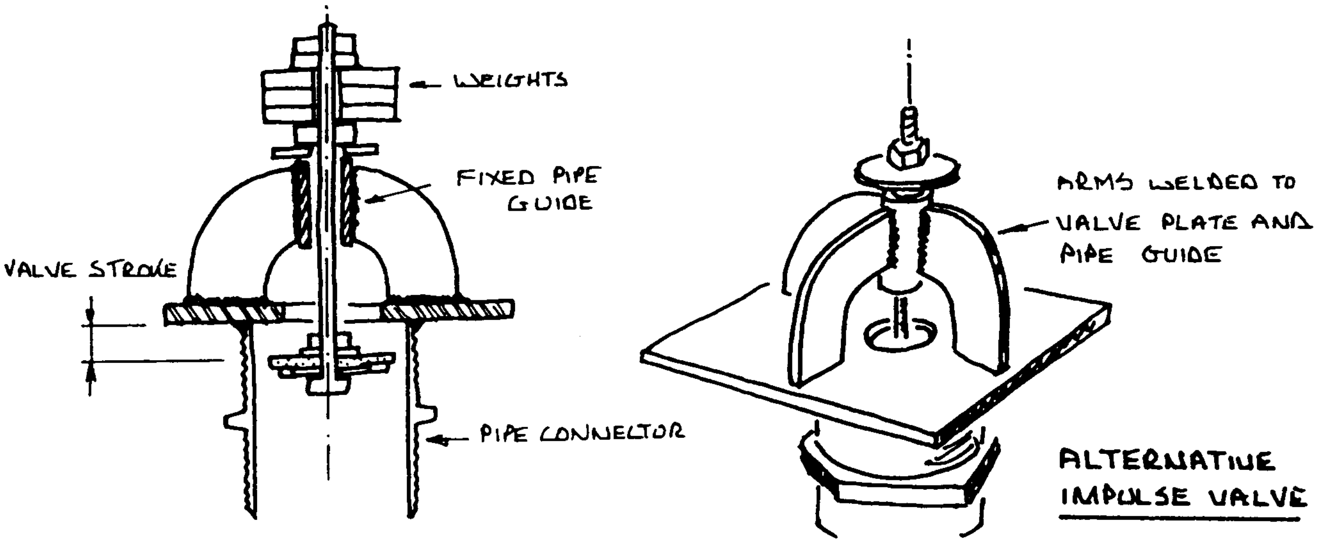
4.4 IMPULSE VALVE STEM



4.5. SPRING TENSION BOLT



We include in this section a more robust impulse valve with a sliding valve which will wear in time. The impulse valve in this case works by falling under its own weight at the finish of each ram cycle:-



The valve stem is fitted through a fixed pipe guide supported above the valve plate by arms welded both to the pipe and valve plate. The pipe connector is welded as before over the centre of the 30 mm diameter hole in the valve plate.

Choose the pipe guide and the valve stem bolt so that they have a close but easy fit. Alternatively, the pipe guide can be chosen to hold a replaceable brass or plastic sleeve which will take the wear from the moving valve stem bolt.

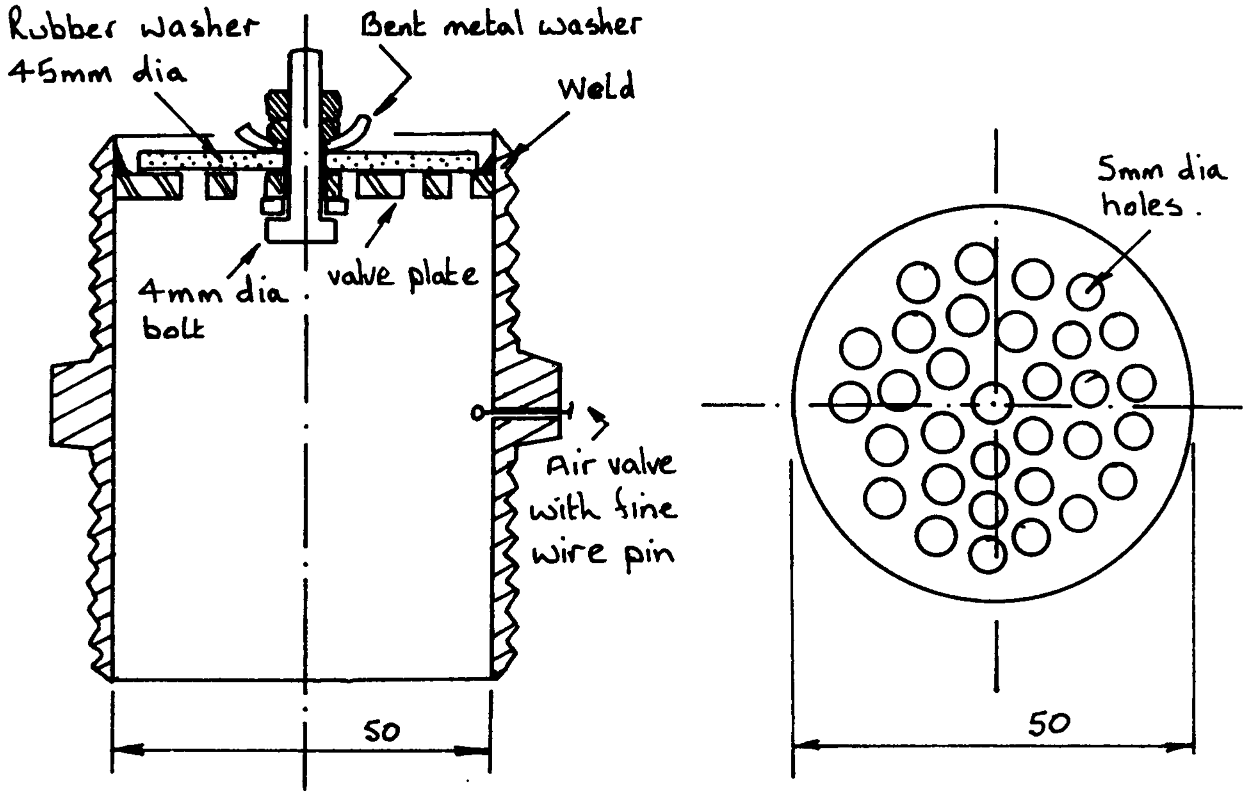
The valve stroke is set by adjusting the nuts on the top of the valve stem bolt, and the weight of the valve can be altered by adding weights onto the bolt.

We have not built or tried this impulse valve assembly, but there is no reason why it should not work. Tuning the ram will be a similar process to that described in Section 7.

5.2 MAKING THE DELIVERY VALVE.

The delivery valve prevents the pumped water from flowing back into the ram after the pressure pulse has been dissipated. It is therefore a non return valve, and you can make it very simply by welding or brazing a cut and drilled piece of 3 mm steel plate into the top of a 50 mm pipe connector:-

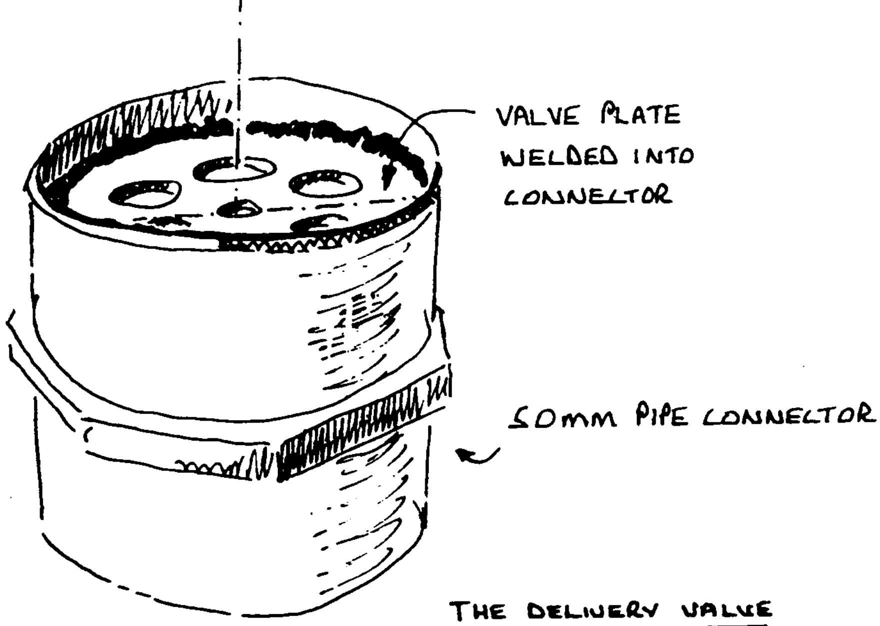
FIG.5 CONSTRUCTION OF DELIVERY VALVE.



Take care when the valve plate is welded or brazed into the pipe connector that the plate remains clean, otherwise the valve rubber will not seat correctly and the valve will Leak.

Non Return valve from 3mm steel plate –

drilled with 5mm dia holes and polished smooth. Larger holes may cause the valve rubber to distort and Leak.



THE DELIVERY VALVE

Cut the plate to shape and file smooth to fit exactly into the end of the pipe connector, and weld or braze it into place. Attach a rubber washer to the plate and bolt it into position; the washer must be flexible enough to allow water to pass easily, but must be firm enough to support the water pressure from the air chamber. The cupped washer above the rubber valve holds the valve in place.

The air valve is made simply by drilling a small hole 1.0 mm in diameter in the side of the pipe connector and below the delivery valve. This is partially blocked by a fine wire split pin which moves with pressure changes in the ram, keeping the hole open and allowing air to enter. Fig.5.

Make sure on assembly that the air valve is placed on the opposite side to the delivery pipe outlet, otherwise the air entering the air chamber is likely to escape into the delivery pipe; it is, of course, essential that the air feeder valve is located below the delivery valve.

5.3 MAKING THE AIR CHAMBER.

Cut a 1 metre length of 50 mm diameter water pipe, and thread each end. Screw one end into the delivery pipe T-junction pipe fitting, and seal the top with a cap.

5.4 MAKING THE MOUNTING LEGS.

Make the mounting legs from any available scrap strip iron, and drill, bend, and bolt these around the ram body. The legs can be bolted to the ground when the ram is assembled at the site if you want the ram to be a permanent fixture.

6. Assembling the ram at the site.

a) Assemble the pipe fittings using plenty of pipe joint compound. Screw these firmly together and adjust them for the correct position in the ram assembly. They must be completely free from leaks.

b) The impulse and delivery valves must move freely and when closed seat evenly on the valve plates.

c) Set the ram level on the mounting legs at the required site, and attach the drive and delivery pipes. Flush these pipes with clean water before connection.

d) The drive pipe should be laid as straight as possible with no sharp bends, and it should have no upward kinks which will trap air.

e) The inlet to the drive pipe must always be submerged, or air will enter the pipe and prevent the ram from working.

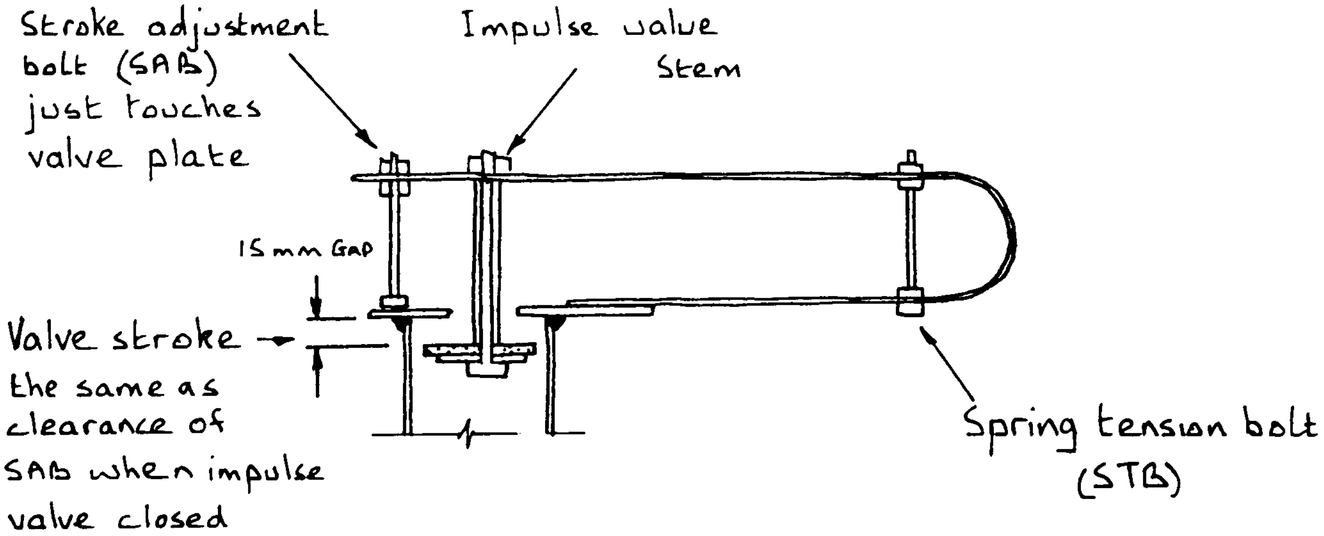
7. Tuning the ram.

The ram should be tuned to pump the greatest amount of water to the delivery tank. Tuning is not difficult, and you will find that the ram will pump some water at most settings of the impulse valve assembly.

The amount of water that the ram will pump, and the number of valve beats each minute, are measured for different valve settings, and the results compared to find the best setting for the ram. You can do this quite easily:-

a) Hold the impulse valve closed, and adjust the 'stroke adjustment bolt' (SAB) until there is a gap of about 15 mm between this bolt and the valve plate. This can most simply be done by slipping a measured pile of steel washers under the bolt and screwing the bolt down onto them.

b) Remove the washers, release the impulse valve, and adjust the 'spring tension bolt' (STB) until the SAB just touches the valve plate. Shortening the STB will bend the spring down.



c) Nip tight the STB and SAB nuts, and allow water to enter the drive pipe. Hold the impulse valve closed until the drive pipe is full of water, then release the valve, moving it up and down by hand several times. The ram should now work by itself.

d) If the valve stays open allowing water to flow out, the spring is too tight, and you should stop the flow of water, and reset the SAB and STB in the way described in a, b, and c, above to give a stroke of 13 mm.

e) When the valve works correctly, repeat a, b, and c, above for valve stroke settings of 13, 11, 9, 7, 5, 3, millimetres, measuring for each setting the amount of water that is pumped and the valve beats each minute.

f) Compare the pumping rates, and reset the STB and SAB as described in a, b, and c, to the stroke setting that gave the best pumping rate. If the pumping rates for several of the valve settings are similar, choose the setting with the smallest stroke - this will mean a smaller spring tension and therefore less wear.

g) The results of our experiments on one of these rams are given in Part 11 of this manual. We obtained the best pumping rate from an initial valve stroke setting giving a valve beat of 100 cycles per minute, by tightening the spring tension bolt until the valve beat was 75 cycles per minute. The ram you make will work in a different way to ours, and you will have to fiddle with the impulse valve to find the best setting.

8. What to do if the ram doesn't work.

There are only two moving parts in an automatic hydraulic ram, and there is very little that can go wrong. However, possible causes of failure are listed below:-

a) Impulse valve does not work.
Check seating of valve washer on valve plate; the valve should not leak when held closed, and should not catch on the side of the pipe connector.
Check to see if there is any debris or obstruction in the drive pipe or ram body.

b) Delivery valve does not operate as a non-return valve.
This can be seen if the water level in the delivery pipe surges during operation, or falls when the ram is not working. The valve should be cleaned and checked for wear.

c) Ram pumps too much air.
Check air feeder valve; if it is too big it will allow large volumes of air to enter the ram, and a larger wire split pin should be used.
Check that air does not enter the ram through loose joints; the joints should be well sealed with pipe compound.
Check that inlet to drive pipe is submerged, otherwise air will enter drive pipe, spoiling the performance of the water hammer.

d) Ram pumps with a loud metallic sound.
Check that air feeder valve is working to allow enough air to enter below the non-return valve; a small spurt of water should come from this valve with each cycle. If there is not enough air entering the ram air chamber, fit a smaller split pin.
Check that air feeder valve is on the opposite side to the delivery pipe, or the air will be pumped with the water directly to the header tank.
Check that there are no air leaks from air chamber due to bad pipe fitting.

9. Maintenance of the ram after installation.

9.1 THE SUPPLY SOURCE

It is obviously essential to prevent dirt from entering the drive pipe or leaves from blocking its entry. So it may be necessary to provide a grating at the off-take from the river or stream supplying the water in order to keep back floating leaves, and a sump should be provided at the feeder tank to collect silt.

9.2 MAINTENANCE TASKS

Maintenance involves keeping gratings and filters clear, and cleaning the feeder tank and sump, as well as caring for the ram itself. The maintenance tasks which you must carry out are likely to be as follows:

(a) dismantling the ram to remove dirt,
(b) clearing air locks in the pipe system,
(c) adjusting the tuning; tightening bolts which work loose,
(d) changing the valve rubber; adjusting the seating of valves,
(e) keeping the inflow to the drive pipe free of debris; clearing filters and gratings.

9.3 FREQUENCY OF MAINTENANCE

Rams have an exceptionally good reputation for trouble-free running, and maintenance will probably not need to be very frequent. The way in which the necessary maintenance is arranged, and the question of whether this type of ram is suitable for a particular application, depends very much on who is available to carry out the maintenance. Is there somebody living locally who can have a look at the ram at least once every week, or is there a technician from somewhere else who can come only at intervals of several weeks?

Tuning, and the adjustment of valves and bolts, may need to be done more frequently with this particular ram than with some commercial models made from purpose-designed alloys and components; and the need for maintenance may become greater as the delivery head becomes greater. On the other hand, specialised tools and spare parts may be needed for the maintenance of a commercially-built pump. So in general, this ram is best suited to a situation where the person responsible for maintenance lives nearby, and where the delivery head is not too great. A commercial pump may be the best choice when maintenance is done at longer intervals by somebody with access to a wide range of tools and components.

Part II A more Technical look at Automatic Hydraulic Rams

1. Introduction

This part of the manual will be of interest to those who have a basic understanding of engineering materials, and fluid mechanics. It will be of use to those who wish to build rams with different sizes to the one described in Part 1.

Commercially available rams have been redesigned and refined by field experience until they work well under all conditions with the minimum of maintenance. They are made from solid iron castings, and are extremely robust - some ram installations have been working for nearly 100 years.

The size of the ram described in Part 1 is necessarily limited by the size of the available pipe fittings. The strength of the pipe fittings also limits the size of the ram, - it is doubtful if pipe fittings would stand up to the savage loads experienced by commercial rams under conditions of high supply heads and supply flows.

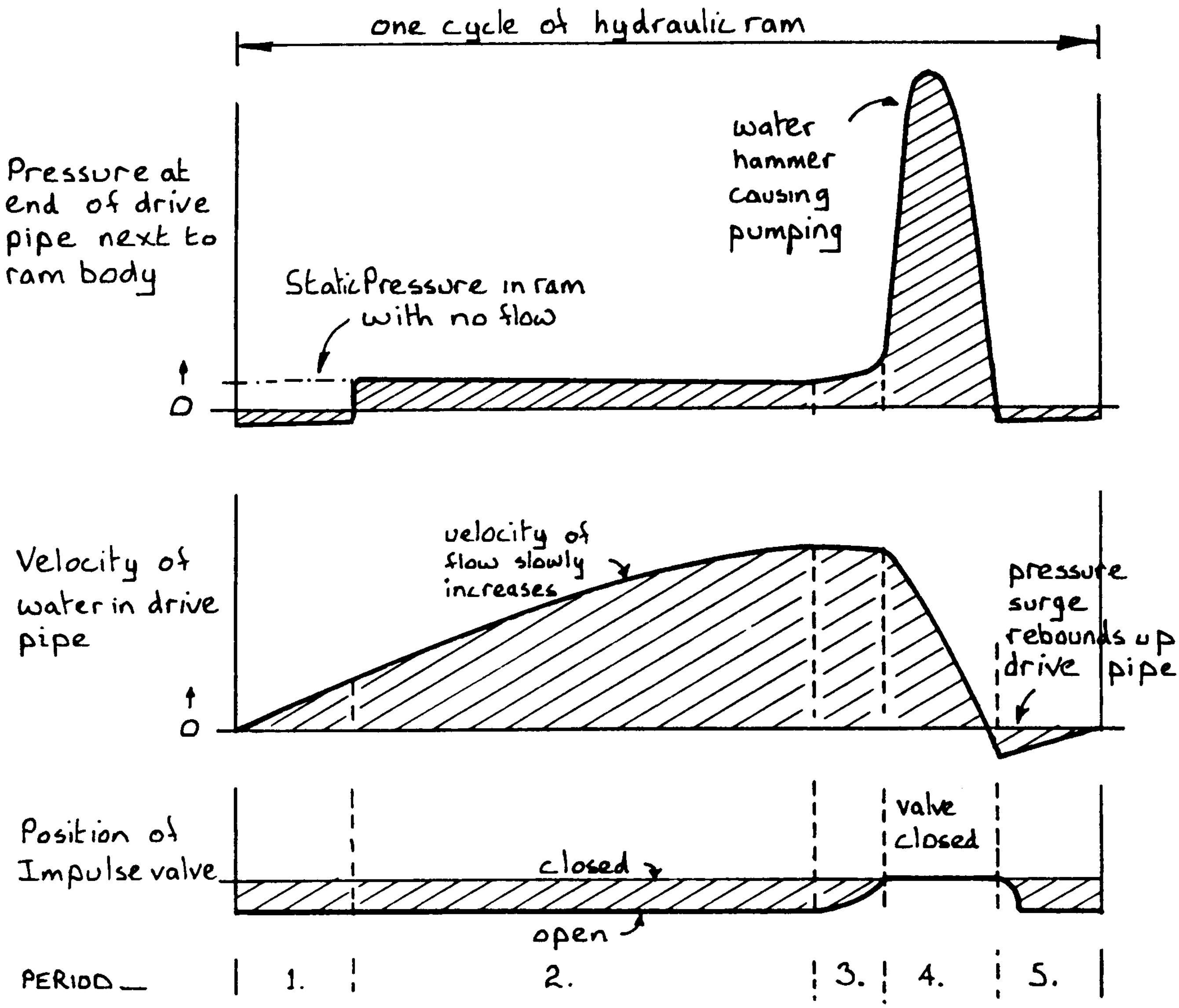
Large rams must therefore be made from iron castings, or welded steel pipe. A technical description of casting and workshop processes are outside the scope of this manual, but if you have these skills and the necessary equipment available, this part of the manual will show you the main design features to be considered before you design a ram for production.

2. Ram performance

The way that automatic hydraulic rams work is outlined briefly in Part 1, and there is little to add to this except to show on a diagram one pressure pulse cycle of a ram. The diagrams in Fig. 6 show in a very simplified and ideal form the pressure and velocity at the end of the drive pipe, and the position of the impulse valve, during one cycle.

Rams were built and used for nearly a century before any intensive research was carried out on their operational characteristics, and they seem to be almost foolproof in operation. Recent research has clarified the way that rams seem to work, - references to this work can be found in the bibliography.

FIG. 6 DIAGRAMS SHOWING ONE PRESSURE PULSE CYCLE OF HYDRAULIC RAM.



Period 1.	End of previous ram cycle, velocity of water through ram begins to increase through open impulse valve; slight negative pressure in ram body.
Period 2.	Flow increases to a maximum through open impulse valve.
Period 3.	Impulse valve begins to close causing pressure to build up inside ram. The velocity of flow through the ram has reached a maximum, the maximum velocity being controlled by ram size.
Period 4.	Impulse valve has closed, causing the pressure pulse or hammer to pump some water through the delivery valve. Velocity of flow through ram rapidly decreases.
Period 5.	Pressure pulse rebounds back up drive pipe, causing a slight suction in ram body. Impulse valve opens under this suction and its own weight.

Water begins to flow again through the impulse valve, and the ram cycle is repeated.

3. Some design considerations

3.1 CONSTRUCTION MATERIALS

When the column of water in the drive pipe is suddenly retarded by the closing impulse valve, the pressure build up compresses the water, causing the elastic materials making up the drive pipe and ram body to stretch. In this way, part of the energy of the pressure pulse is used in straining the pipe walls. An ideal installation would be one made of completely rigid, inelastic, materials, and in this case an instantaneous reduction in the flow velocity of 0.3 metres/second would cause a pressure head of about 4.6 kgm/cm^2 i.e. a head of nearly 48 metres of water. With the materials and valves that are available, it is not possible to achieve this and Fig.7 shows the equivalent pressure head produced when different materials are used to construct the ram.

3.2 DRIVE PIPE

a) Length and diameter

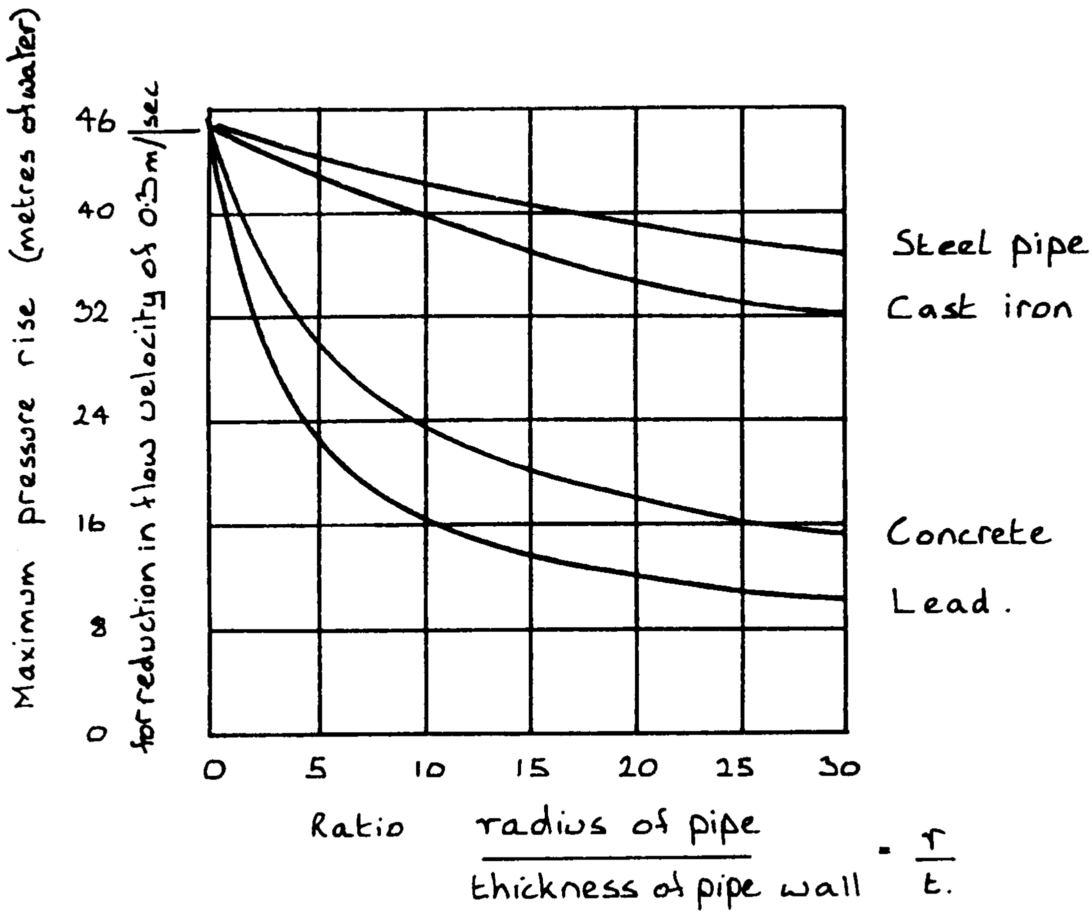
Research has shown that the size of the drive pipe does not affect the ram performance over a very wide range of flow conditions, and the pipe diameter is usually determined by the pipe materials available. It is not possible to calculate the size of pipe needed - the flow of water down the pipe varies cyclically, and the amount of water that the ram will use depends mainly on the size of the impulse valve and the supply and delivery heads.

Some idea of a suitable drive pipe diameter for a ram of known size can be found from the information given in Table 2 on commercial rams. The ratio of pipe length to diameter ($\frac{L}{D}$) should in any case be between the limits $\frac{L}{D}$ = 150 to 1000; outside these limits, the performance of the ram is impaired. These limits seem to be determined by the ability of the water column in the drive pipe to accelerate after it has been stopped.

The cost of the drive pipe is a very major item in a ram installation, and the pipe should therefore be chosen to have a small diameter; however, if the pipe is too small in diameter, the viscosity of the water and the friction on the pipe walls will slow down the accelerating water column and reduce the efficiency of the ram.

The drive pipe diameter is first chosen to correspond with the size of the ram body, or from a comparison with the commercial rams, and the length of the pipe found from this, using a ratio $\frac{L}{D}$ of about 500.

FIG. 7 COMPARISON OF WATER HAMMER PULSE PRESSURE WITH DIFFERENT MATERIALS AND VARYING THICKNESS OF DRIVE PIPE WALLS.



An ideal drive pipe would be made from steel, and the walls of the pipe would be very thick in relation to the pipe diameter. The diagram above shows that with an increase in the ratio $\frac{r}{t}$, the maximum pressure increase can be expected to fall and the ram will not be able to pump very efficiently. It can also be seen that concrete is a poor material for ram construction.

If the instantaneous reduction in flow velocity is 1 metre/second, then the maximum pressure head increase will be $\frac{1.0}{0.3}$ x 46 or 154 metres of water.

With an instantaneous reduction in flow velocity of 5 metres/second, the maximum pressure head should be $\frac{5.0}{0.3}$ x 46, or 765 metres of water. In practice, the ram would have to be very large to allow water to reach a velocity of 5 metres/second down the drive pipe.

Some ram manufacturers suggest that the drive pipe length be 4 or 5 times the supply head.

The length of the drive pipe is quite an important dimension for the ram design - the compression wave of water must reach the open source and be dissipated before the water in the drive pipe can flow again through the impulse valve. The drive pipe length would be critical for a site which had a source a long way from the ram, with a low supply head. In this case, a stand pipe or feeder tank should be installed.

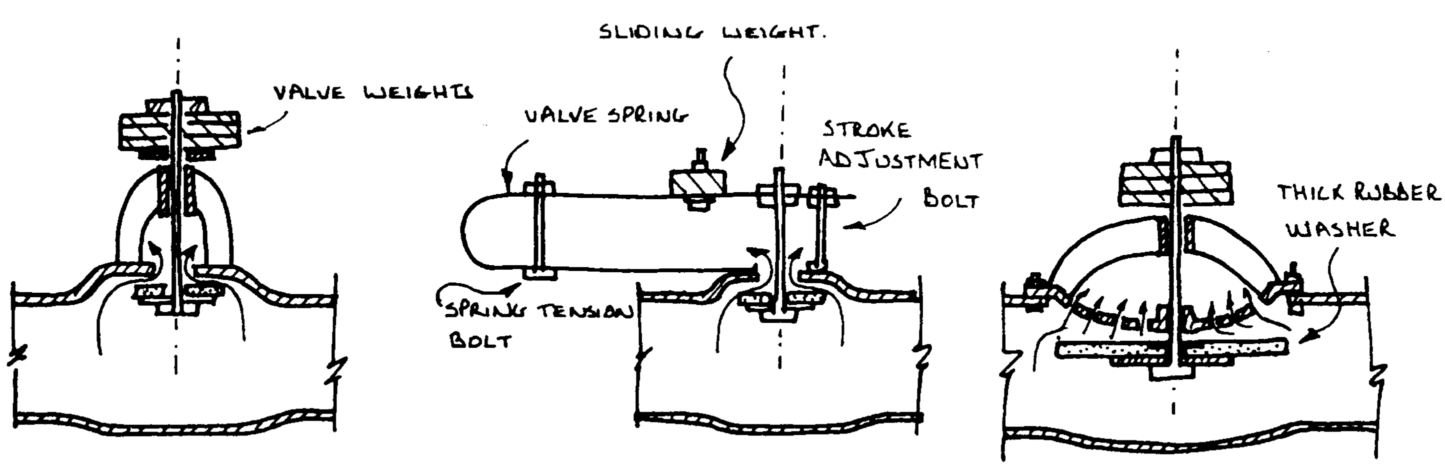
The inlet to the drive pipe must always be submerged to prevent air from entering the pipe; air bubbles in the drive pipe will absorb the energy of the pressure pulse, reducing the ram efficiency. For this reason, the drive pipe must not be laid with any upward bends or humps that could act as air traps.

b) Pipe smoothness.

The column of water in the drive pipe accelerates and is stopped very rapidly many times a minute. The walls of the drive pipe should therefore be as smooth as possible, otherwise the efficiency of the ram will be greatly reduced. This is especially true if a small diameter drive pipe is chosen; a large diameter drive pipe will have much lower velocities and smaller friction losses. Concrete lined pipes give a roughwall finish with fairly high friction losses.

3.3 IMPULSE VALVE

This is a vital part of the ram, and it should be designed so that it's weight and stroke can be adjusted for tuning:



a) SIMPLE CLACK VALVE   b) CLACK VALVE WITH SPRING   c) FLEXIBLE RUBBER WASHER.

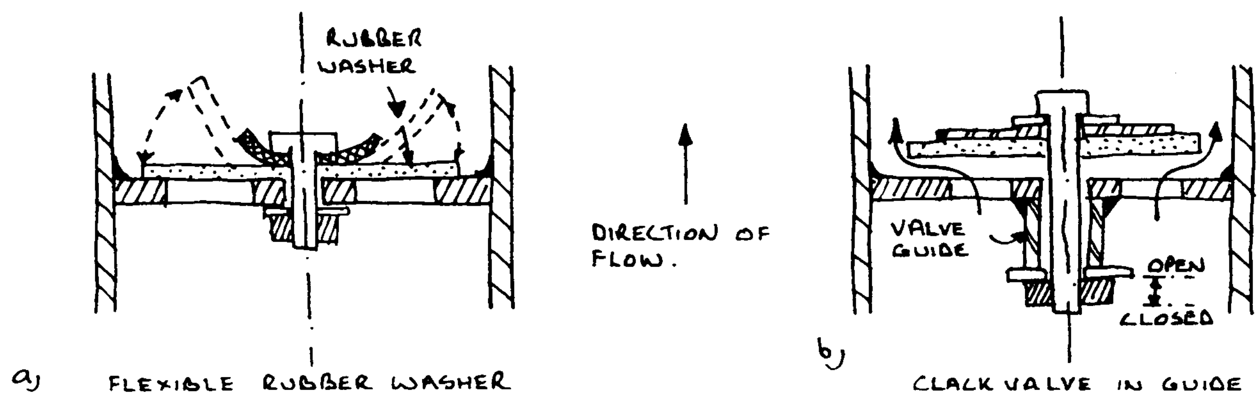
SOME TYPES OF SUCCESSFULL IMPULSE VALVES.

A heavy weight and a long stroke will allow high flow rates through the impulse valve, building up the powerful hammer pulse needed to drive water to high heads; a small weight and short stroke will 'beat' more quickly and deliver larger volumes to lower heads. There has been very little research carried out into the best shape of the impulse valve, but the simple clack valve seems to perform quite efficiently.

Various spring devices have been tried to cause the impulse valve to shut and open more quickly, and several commercial models incorporate these refinements, (see b above). It is not known if this increases the efficiency of the ram to any great extent, but it does avoid the need for sliding bearings which have to be replaced when worn.

3.4 DELIVERY VALVE

The delivery valve should have a large opening to allow the pumped water to enter the air chamber with little obstruction to flow. It can be a simple non-return valve made from stiff rubber, or operate as a clack valve:



DELIVERY NON-RETURN VALVES

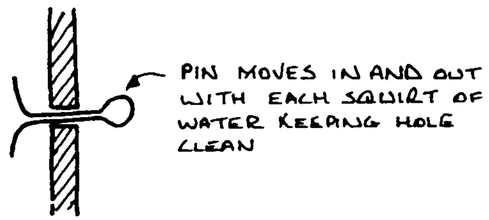
3.5 AIR CHAMBER

This should be as large as possible to compress and cushion the pressure pulse from the ram cycle, allowing a more steady flow through the delivery pipe with less friction loss. If the air chamber becomes filled completely with water, the ram will pound savagely and may result in breakage; when this occurs, the ram must be stopped immediately. Some authorities suggest that the volume of the air chamber should be equal to the volume of water in the delivery pipe. On long delivery pipe lengths, this would give an absurdly large air chamber, and a smaller size should be chosen.

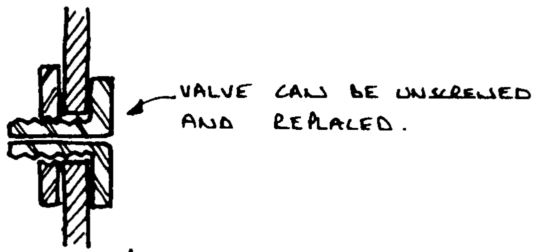
3.6 AIR VALVE

The air stored in the air chamber is either slowly absorbed by the turbulence of the water entering through the delivery valve, or is lost into the delivery pipe. This air has to be replaced by the air valve.

The air valve should be adjusted so that it gives a small spurt of water with each compression pulse. If the valve is open too far, the air chamber will fill with air, and the ram will then pump only air. If the valve is not sufficiently open and does not allow enough air to enter, the ram will pound with a metallic sound and break - this condition should be corrected immediately by increasing the opening of the air valve.



a) SIMPLE VALVE WITH SPLIT PIN



b) RE-PLACEABLE VALVE

3.7 DELIVERY PIPE FROM RAM TO HEADER TANK

Water can be pumped by a ram to any distance, but a long pipe will involve some work by the ram in moving the water against pipe friction. The delivery pipe may be made from any material, including plastic hose-pipe, providing that it can stand the pressure of the water. Several rams can also be connected to the same delivery pipe if the initial ram installation proves to be too small.

The ram should therefore, be located as near as possible to the header tank and the delivery pipe should be made larger with long distances, or with increased volumes of pumped water:-

Pumped water (1000 litres/day)	3	9	14	23	55	90	135
Delivery pipe bore (cms)	2.0	2.5	3.0	4.0	5.0	6.0	8.0

TABLE 2 PUMPING PERFORMANCE OF BLAKES RAMS.

This table gives the quantity, in litres, of water raised every 24 hours, for each litre of supply flow used per minute, under the chosen conditions of delivery head and supply head. These figures have been obtained from field trials on Blakes rams, which operate at efficiencies of about 65%.

Supply Head (H_s) (Metres)	Delivery Head (h_d). (Metres)											
	5	7.5	10	15	20	30	40	50	60	80	100	125
1.0	144	77	65	33	29	19.5	12.5					
2.0		220	156	105	79	53	33	25	19.5	12.5		
3.0			260	180	130	87	65	51	40	27	17.5	12
4.0				255	173	115	86	69	53	36	23	16
6.0					282	185	140	112	93.5	64.5	47.5	34.5
7.0						216	163	130	109	82	60	48
8.0							187	149	125	94	69	55
9.0							212	168	140	105	84	62
10.0							245	187	156	117	93	69
12.0							295	225	187	140	113	83
14.0								265	218	167	132	97
16.0									250	187	150	110
18.0									280	210	169	124
20.0										237	188	140

TABLE 3 CAPACITY OF BLAKES RAMS

This table shows the supply discharge Q_s which can be used by Blakes Hydrams of different sizes.

Size of Hydram (Blakes)		1	2	3	3½	4	5	6
Internal Diameter (bore)	mm	32	38	51	63.5	76	101	127
	ins	1¼	1½	2	2½	3	4	5
Supply Discharge Q_s (litres/min)	From	7	12	27	45	68	136	180
	to*	16	25	55	96	137	270	410
Maximum height to which Hydram will pump water (h_d)	metres	150	150	120	120	120	105	105

* Note: The higher values of Q_s are the volumes of water used by the Hydrams at their maximum efficiency; the rams do not have the capacity to pass larger amounts than those given.

Designing the ram size

The site conditions of supply and delivery head, and supply discharge must first be measured before a ram size can be chosen to pump water at the required rate.

The ram performance data given in Tables 2 and 3 has been obtained by 'Blakes Hydrams Ltd.' (see bibliography) from field trials on their rams. These operate at a maximum overall efficiency of about 65%.

$$\text{Efficiency } E = \frac{q_d \times h_d}{Q_s \times H_s} \times 100\%$$

where q_d = pumping rate (litres/min)
Q_s = supply flow rate (litres/min)
h_d = delivery head (metres)
H_s = supply head (metres)

The overall pumping efficiency of a ram depends on the materials used to make the ram, the design of the ram, and its tuning - the efficiency cannot be calculated from basic principles. However, if a ram is designed to the general recommendations given in this manual, its efficiency of operation will not be very much less than that quoted by Blakes Hydrams Ltd. for their equipment, and Tables 2 and 3 may be used with confidence.

<u>Example of ram design calculation</u>

Site measurements:

Supply Head (H_s) = 5.0 metres
Delivery Head (h_d) = 40.0 metres
Amount to be pumped/day (q_d) = 8500 litres

From Table 2, with H_s = 5.0 m, h_d = 40.0 m, and if the flow rate down the drive pipe is 1 litre/min, then 118 litres of water will be pumped each day to the header tank.

But 8500 litres/day are needed at the header tank, and the ram which can pump this needs to be able to use a supply flow of:-

$$Q_s = \frac{8500}{118} = 72.0 \text{ litres/min}$$

Now, from Table 3, a Blakes No. 3½ ram will be satisfactory, or a ram with an internal bore greater than 63.5 mm.

5. Laboratory tests carried out on the ram built from Part 1 instructions.

The ram pump described in Part 1 of this manual, was constructed and tested in the laboratory. Our observations are given below.

5.1 OPERATING THE RAM.

The ram can be made to operate for different conditions:-

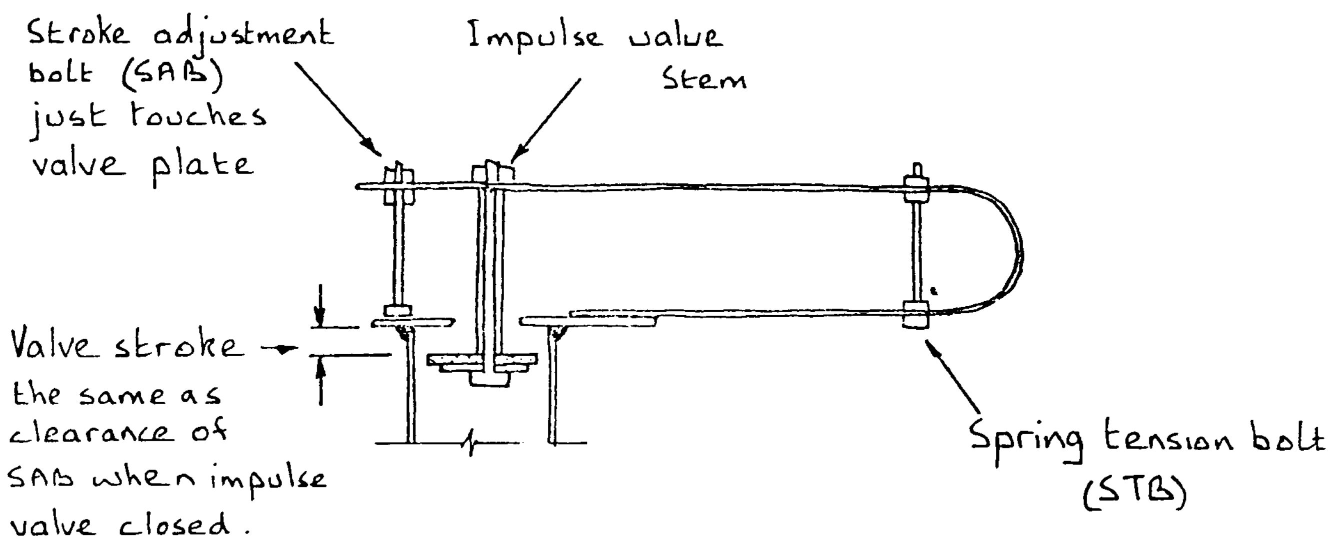
a) to pump as much water (q_d) as possible up to the header tank. This means that the flow at the source must always be greater than the flow into the drive pipe.

b) to operate with a limited flow from the source. The pump must then work with this flow (Q_s) at the highest efficiency possible. The water level at the source should always cover the inlet to the drive pipe, or the ram will suck in air and cease to work.

5.2 OBSERVATIONS ON RAM BEHAVIOUR.

The following general remarks may be made:-

a) the pumping rate (q_d) reached a peak during adjustment of valve stroke and spring tension; tuning the ram with the stroke



adjustment bolt (SAB), and spring tension bolt (STB) is quite critical but is very simple in practice.

b) there are several positions of both the SAB and STB which give the same pumping rate (q_d), but using different amounts of water from the source (Q_s). The setting with the shortest stroke, the lowest spring tension, and using the smallest amount of water, should be chosen in order to reduce valve wear and wastage of water.

c) adding weights to the valve spring will reduce the spring tension needed for slow beating on large stroke lengths; this may be necessary or the spring will become distorted when tuning for high supply heads.

5.3 TESTING THE RAM.

The ram was constructed in the way described in Part 1 and tested in the laboratory for a wide range of valve settings. The supply and delivery heads were kept constant throughout the tests, and our results may well form a different pattern to those of a ram tested under different heads.

The impulse valve was tuned in the way described above, and the pumping rate (q_d), supply flow (Q_s), spring tension (W), valve beat, and stroke (S), measured and recorded. The spring tension (W) was the force required to just hold the valve closed with no water flowing; it was measured using a small spring balance attached to the impulse valve bolt.

Other tests were carried out on the ram in a similar way by adding weights onto the impulse valve bolt and taking readings as the valve stroke was reduced. The STB was not adjusted, and the valve stroke was not measured. These are tests B1, B2 and B3 in Table 4.

5.4 TEST RESULTS

The results of our tests are given in Table 4 and the following observations can be made:-

a) At a valve stroke of 11 mm the force required to shut the valve was 0.91 kgm, and the valve did not shut by itself when water flowed.

b) At each valve stroke setting, increasing the spring tension increased the pressure of water needed from the flow to shut the valve. The supply flow (Q_s) and valve beat varied with spring tension, giving different pumping rates (q_d). The peak pumping rate does not necessarily mean that the ram is operating at its greatest efficiency (E).

c) Decreasing the valve stroke decreased the amount of flow through the ram at the initial STB setting.

d) Adding weights to the impulse valve beat does not seem to improve the performance of the ram, except that it needs less water down the drive pipe. It is possible that using weights instead of tensioning the spring will lengthen the life of the spring.

Table 4. Test results on automatic hydraulic ram.

Supply Head (H_s) = 1.70m Delivery Head (h_d) = 4.04m

$$\text{Efficiency } E = \frac{q_d \times h_d}{Q_s \times H_s} \times 100\%$$

Test No.	Spring Tension W (Kgms)	Valve Stroke (mm)	Valve Beats (cycles/min)	q_d (L/min)	Q_s (L/min)	E%
A1	0.91	11.00	-	-	-	-
A2	0.78	9.5	58	2.60	21.10	29
	0.82	9.5	58	2.70	19.70	32
	0.96	9.5	50	2.40	22.60	25
A3	0.64	8.0	80	2.50	15.64	38
	0.77	8.0	66	2.80	18.02	37
	0.87	8.0	45	1.90	23.70	19
A4	0.54	6.0	96	2.35	10.85	52
	0.64	6.0	78	2.82	14.66	46
	0.82	6.0	58	2.60	19.06	32
	0.95	6.0	48	2.40	23.44	24
A5	0.36	3.5	160	1.32	6.46	49
	0.45	3.5	134	1.76	7.40	57
	0.59	3.5	116	2.00	8.50	55
	0.73	3.5	96	2.42	11.30	51
	0.82	3.5	66	2.68	15.76	40
B1	2.31		152	1.25	5.40	55
			128	1.50	7.25	49
			104	1.94	9.69	46
			88	2.16	12.11	42
			78	2.23	12.64	42
B2	4.60		154	1.44	6.71	51
			132	1.60	6.68	57
			100	2.02	10.46	46
			76	2.24	14.31	37
B3	9.14		250	0.72	2.85	60
			116	2.00	8.34	57

6. Annotated Bibliography for the Automatic Hydraulic Ram

6.1 "The Automatic Hydraulic Ram" - J. Krol, PROC.I.MECH.E., 1951 vol.164, pp.103

This paper gives a thorough analysis of the theoretical cycle of operation of the hydraulic ram in terms of the physical dimensions and properties of the materials making up the ram. It emphasises the importance of the correct tuning of the impulse valve. Performance curves for the experimental ram are given, with H_s = 13 ft (4 metres), D = 2 inches (5 cms), hd varied, and impulse valve characteristics varied. This is a most useful technical paper.

"After describing the operation of a typical hydraulic ram installation, the paper reviews the fundamentals of the water hammer as a prerequisite to the proper understanding of the limitations of this hydraulic machine. The historical development is discussed in some detail with the object of ascertaining what research work remained to be done. The author presents his own theory based on the application of general laws of mechanics to the study of a specially designed experimental hydraulic ram. By means of a theory developed, which agrees satisfactorily with experiment, it is possible to forecast the behaviour of any automatic hydraulic ram, provided that the following four properties at a given installation have been determined separately by experiment: (a) loss of head in the drive pipe; (b) loss of head due to the impulse valve; (c) drag coefficient of the impulse vales; and (d) head lost during the period of retardation."

6.2 "The Hydraulic Ram" - N.G. Calvert, THE ENGINEER, April 19th,1957.

Extensive experiments were carried out to understand the performance characteristics of the hydraulic ram. This is perhaps the most definitive technical paper available:-

"The possible independent variables of a hydraulic ram installation are considered and by certain assumptions their number is reduced to eight. Hence five dimensionless parameters are needed to describe the dependent variables. These are the Reynolds number, the Froude number, the Mach number, the head ratio and the coefficient of fluid friction. Each parameter is investigated in turn and it is found that the Reynolds number is ineffective in machines of practical size and that a range exists over which the Mach number has little influence. The Froude number is the criterion defining the possibility of operation and (subject to a satisfactory value for the Froude number), output and efficiency are defined by the head ratio. The optimum external conditions of operation are investigated and the conditions governing model tests are laid down".

6.3. "Drive Pipe of Hydraulic Ram" - N.G.Calvert, THE ENGINEER December 26th, 1958

This paper is a continuation of the work described in reference 6.2. and gives limits to the dimensions of the drive pipe.

"In an earlier article (Calvert, 1957) the author applied the methods of dimensional analysis to a hydraulic ram installation. The relevant parameters were shown to be the head ratio, the friction coefficient, and the dimensionless numbers corresponding to those of Froude, Reynolds and Mach. Of these the first three were shown to be the most significant. In the present investigation the ram itself (as distinct from the whole installation) has been considered as an entity. The length of drive pipe then becomes an extra variable and the relevant dimensionless ratio is taken as the L/D value for the pipe. As with all the other factors connected with the hydraulic ram, knowledge of the best length of drive pipe is purely empirical. Records of systematic experiments on this variable are rare; the author does not know of any since those of Eytelwein (1803). Krol (1951) developed analytic expressions for ram performance in terms of drive pipe length and hence predicted a set of characteristic curves, but produced no experimental work in support of them."

6.4 "Hydraulic Ram as a Suction Pump" - N.G.Calvert, THE ENGINEER, Vol. 209, April 18th, 1960, pp.608

An adaption of the hydraulic ram to act as a suction pump is described; possible applications might include the drainage of low lying land, the emptying of canal locks, pits, etc. The hydraulic ram can be adaptable to many other uses, such as a compressor, motor, etc.

6.5 "The Hydraulic Ram for Rival Water Supply" - F.Molyneux, FLUID HANDLING, October 1960,.pp.274

A general description of the hydraulic ram, with a design problem worked out. The impulse valve is a weighted rubber ball, which would be very difficult to tune.

6.6 "A Hydraulic Ram for Village Use" - V.I.T.A., U.S.A.

Working instructions and drawings on how to construct a small, simple hydraulic ram from commercially available water pipe fittings. The ram described had a supply head H_s = 6.5 m, delivery head h_d = 14 m, supply discharge Q_s = 35 litres/min, delivery discharge q_d = 7 litres/min. It is thus only used for small water supplies.

The impulse valve is designed to act on a sprung mechanism; the delivery valve is a simple clack valve.

6.7 "How to Design and Build a Hydraulic Ram" - Technical Bulletin, Technical Service Publishing Co., Chicago, 1938.

A manual on the field survey, design, construction, and installation of a simple hydraulic ram, giving step by step instructions; it includes design and performance graphs of the ram. This is a useful paper; the impulse valve of the ram appears to be unduly complicated, and the ram would not appear to be an improvement on the VITA ram.

6.8 "Rife Rams - a Manual of Information" - Rife Hydraulic Engine Manufacturing Co., Box 367, Millburn, New Jersey, U.S.A.

This manual refers to the rams manufactured by the company, but it gives an excellent set of instructions on the field survey, design, construction, and installation of their equipment.

6.9 "Blake Hydrams" - John Blake Ltd., PO Box 43, Royal Works, Accrington, Lancashire, BB5 5LP, UK.

Much of the design information in this manual used information published by J. Blake Ltd.

6.10 J. Wright Clarke - "Hydraulic Rams, their principles and construction". 1899 80pp
B.T. Botsford, 94 High Holborn, London.

This technical book written in 1899 describes the techniques used in that time to construct hydraulic rams. It is interesting as it describes the effect of the ram on the inferior materials of the time and the adoptions needed to cope with the lower strengths. However, there is little information given in this publication that is not given in the other references cited.

6.11 "An Innovation in Water Ram Pumps for Domestic and Irrigation Use" - P.D. Stevens-Guille, APPROPRIATE TECHNOLOGY May 1978 vol. 5 no. 1

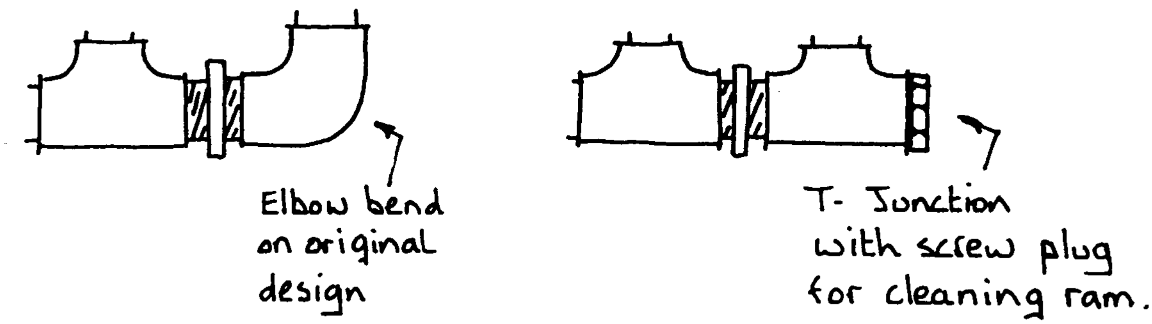
This article describes a hydraulic ram which incorporates two commercially available valves.

7. Appendix

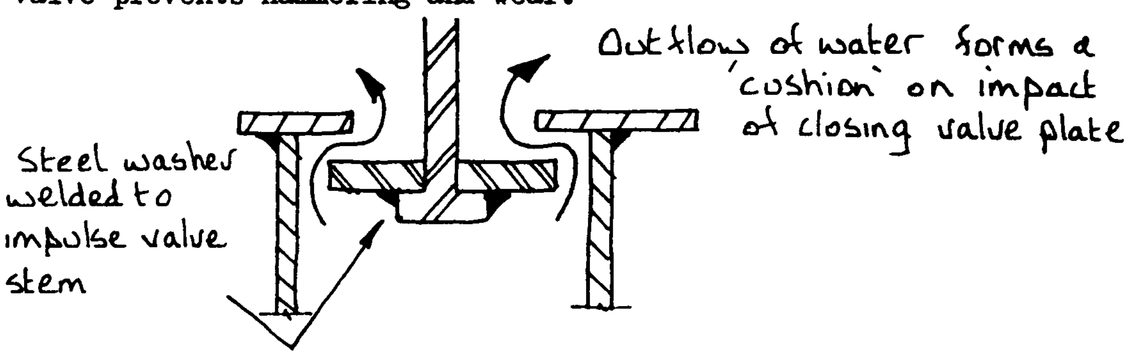
SOME SUGGESTIONS FOR IMPROVEMENTS TO THE RAM.

1. Received from N. Martin & R.Burton, Department of Mechanical Engineering, Papua New Guinea University of Technology, P.O.Box 793, Lae, Papua New Guinea.

Experimental work on simple ram pumps is being carried out at this University. A suggestion has been made that the elbow bend on the ram body should be replaced by a plugged 'T' junction. The plug can then be removed to flush out the ram without taking the impulse valve to pieces.



These writers also suggest that the rubber washer for the impulse valve is not needed, as the cushion of water flowing out of the valve prevents hammering and wear.



2. Several different designs for the automatic hydraulic ram pump have been tested at Eindhoven Technical College, Holland. Details can be obtained from:-

Appropriate Technology Unit,
Technische Hogeschool Eindhoven,
EINDHOVEN, HOLLAND.

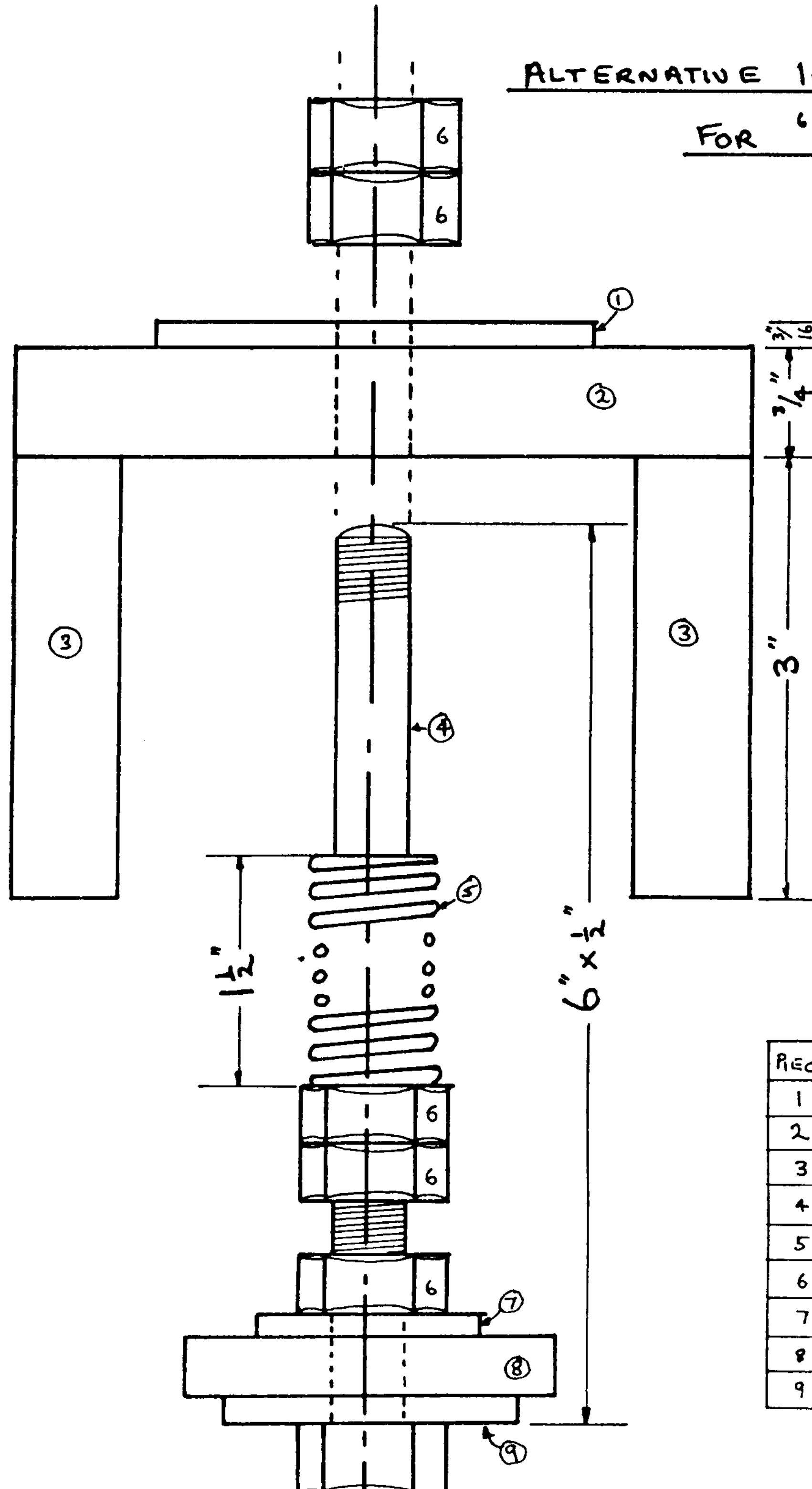
3. Alternative impulse valve design sent by UNICEF Village Technology Unit, Karen Centre, near Nairobi, Kenya:

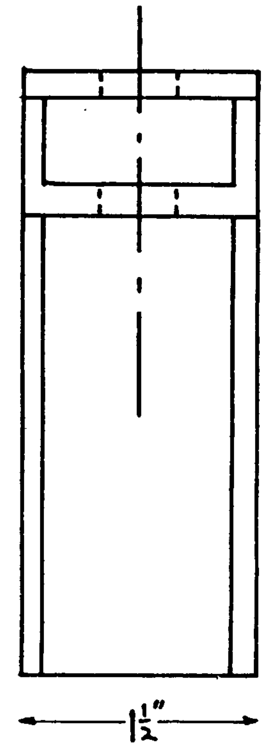
The impulse valve in the drawing overleaf has been constructed as an alternative to the leaf spring operated valve given in this manual - it has proved a reliable and satisfactory alternative.

The valve yoke is welded on to a reducing bush (3" x 2" in our case). The spring was wound from 14 gauge (2mm) fencing wire and its tension adjusted and 'locked' by the two lower nuts. The valve travel is controlled and fixed by the two upper nuts.

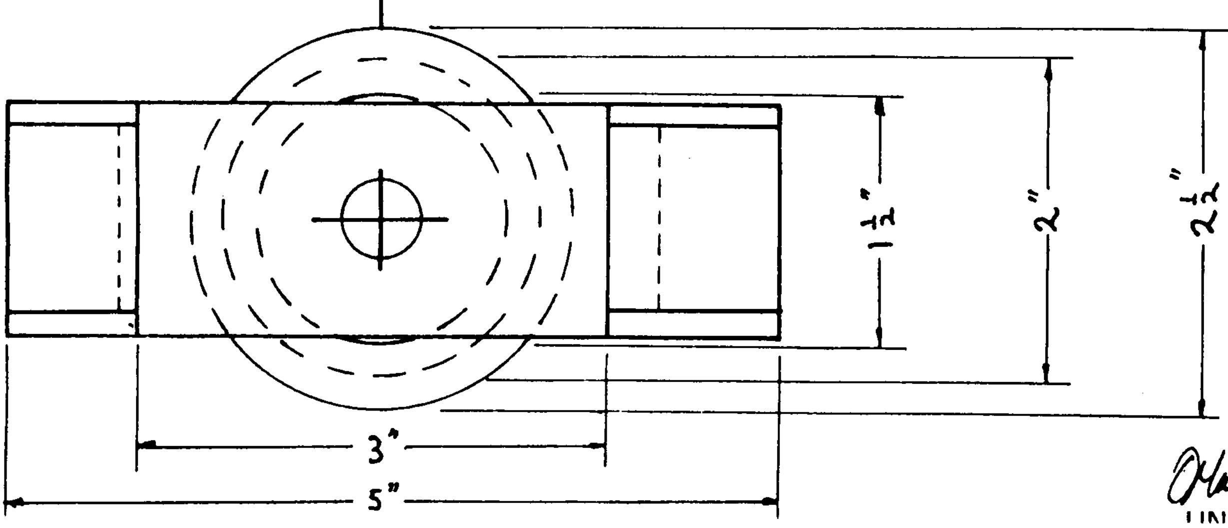
A further improvement would be to include a bushing (½" non-galvanised water pipe) in which the long bolt could slide, although there appears to be little friction between this bolt and the yoke. We (*UNICEF*) have therefore not incorporated it.

ALTERNATIVE IMPULSE VALVE FOR 'ITDG RAM'





PIECE	MATERIAL	SIZE	No
1	3/16" M.S. SHEET	3"x1½"x 3/16"	1
2	1½"x¾" U-CHANNEL	5"	1
3	"	3"	2
4	½" M.S. BOLT	6"x½" FINE	1
5	18G. G.I. WIRE	1½"x½" SPRING	1
6	M.S. NUTS	½" FINE	5
7	1/8" M.S. WASHER	1½" ϕ	1
8	3/8" RUBBER	2½" ϕ	1
9	3/8" M.S. WASHER	2" ϕ	1



16·5·77
UNICEF Nairobi

The Hydraulic Ram

One of the most interesting working models that can be made by the amateur is the hydraulic ram first invented by Montgolfier in 1797 and still used as a means for pumping water in country houses, provided that a continuous supply of water from a stream or brook is available to operate the apparatus. The essential part is a rectangular chamber containing a delivery valve and a spill valve, which will each operate automatically by the water supply once the device has been started. The model shown, Fig. 5/8, has light poppet valves made of brass, each mounted with its axis vertical in the lid of a box made of plastic material, such as a lunch box for carrying sandwiches (see Fig. 5/8*a*). The box being made of transparent plastic, enables the operation of the valves to be seen clearly and of all the models described here this one is probably the most impressive and exciting to those who are unfamiliar with hydraulics.

In the model, the water wasted which passes out through the spill valve on the right is about one quarter of the quantity pumped up through the delivery valve. The air chamber ensures a steady even flow of the delivery in spite of the intermittent flow through the valves. As illustrated, in Fig. 5/8, the upper header tank is 12 in above the receiver tank but the water can be pumped to a very much greater height if it is convenient or necessary to do so. The hydraulic ram will continue to operate by itself without any attention so long as the water supply in the top tank is maintained so that when it is used on remote farms it can be relied upon to continue to operate almost indefinitely with very little maintenance. The only moving parts are the two valves which are lubricated by the water supply.

In constructing this apparatus it is absolutely essential that there should be no leaks in the air chamber and water-box. In the half-section drawing of the ram assembly, Fig. 5/8*a*, the places that have been glued with suitable adhesive (Araldite) have been shown in section as dark segments. The two valves are identical in construction (see Fig. 5/8*b*).

The hydraulic ram depends for its functioning on the wave action set up in the water-box by the closing alternately of the two valves. As each valve closes, a wave is reflected from it through the water in the box until it meets the other valve which thereupon opens, and when the wave energy has been dispersed, the valve closes causing another wave to be reflected in the opposite direction. This alternating flow will continue indefinitely provided that the lift of the two valves has been appropriately adjusted in the first place. Adjustment can be done by trial and error and when the right lift has been found the two nuts must be locked in position on each valve spindle.

To start the ram working one has only to depress the spill valve momentarily. To stop it, the spill valve is held against its seat, where it will remain stationary until depressed again.

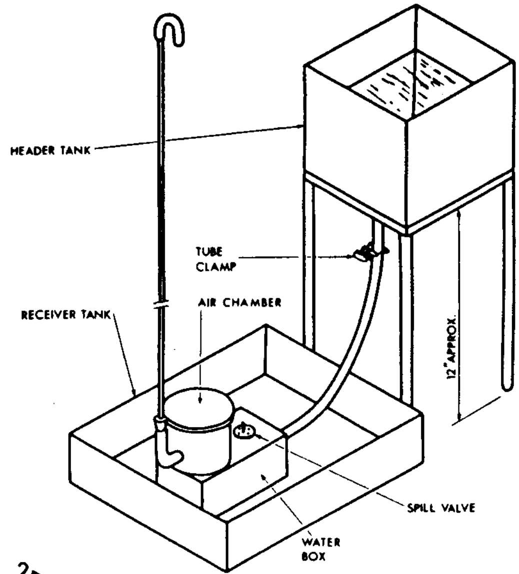


Fig. 5/8 Hydraulic ram—layout

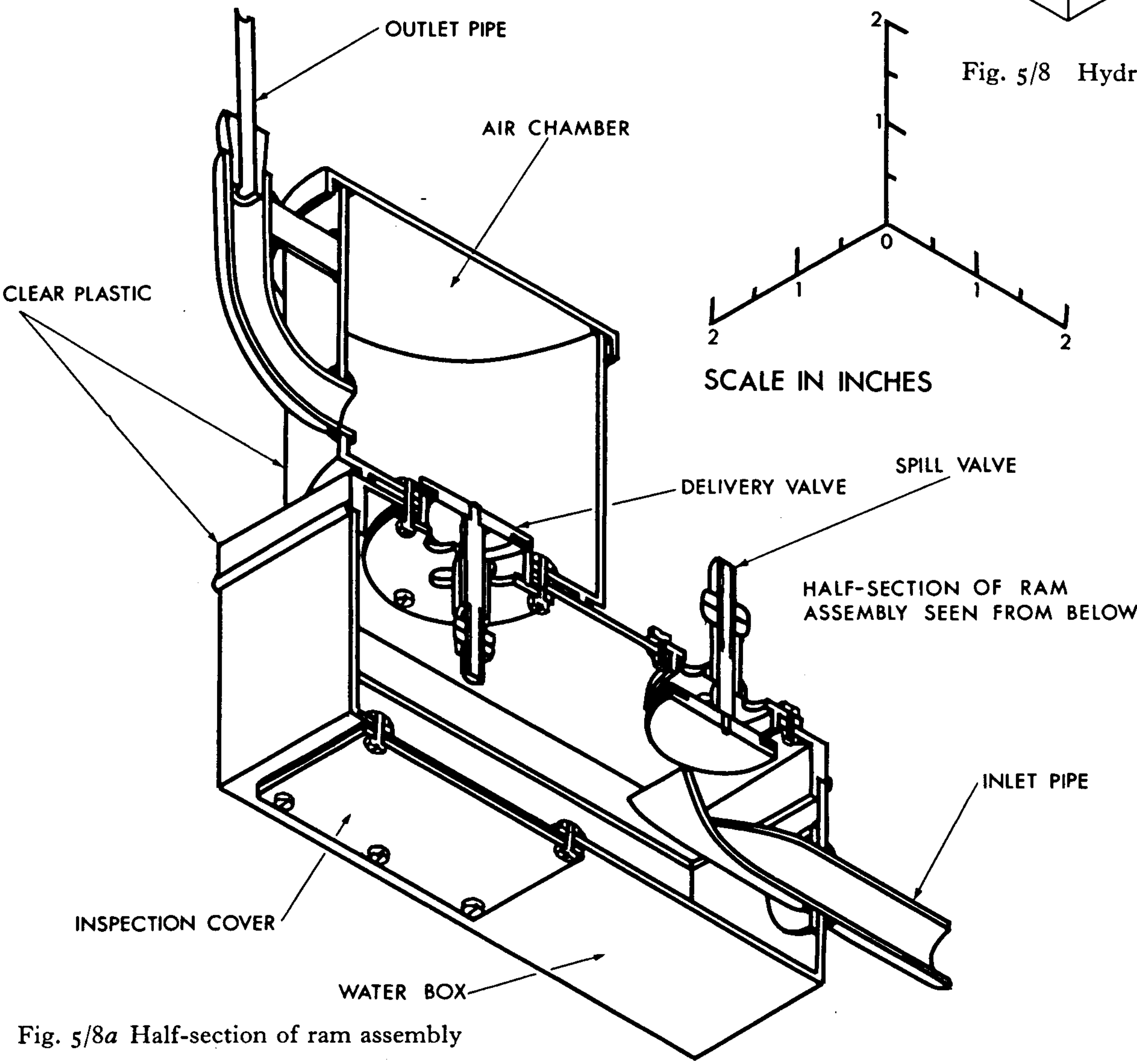


Fig. 5/8*a* Half-section of ram assembly

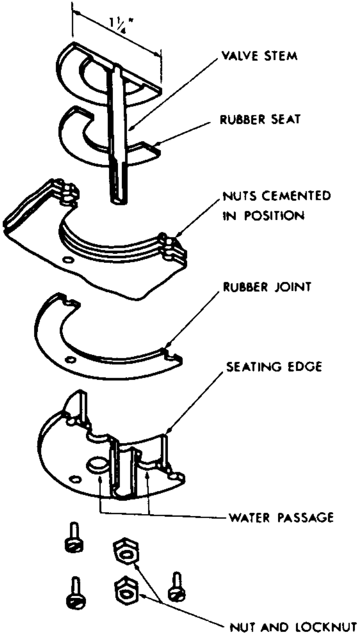


Fig. 5/8*b* Exploded view of valve —hydraulic ram

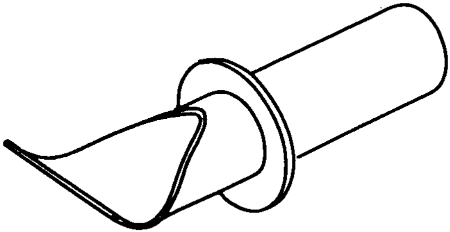


Fig. 5/8c View of inlet pipe
—hydraulic ram

ESTIMATING SMALL STREAM WATER FLOW

A rough but very rapid method of estimating water flow in small streams is given here. In looking for water sources for drinking, irrigation or power generation, one should survey all the streams available.

If sources are needed for use over a long period, it is necessary to collect information throughout the year to determine flow changes--especially high and low flows. The number of streams that must be used and the flow variations are important factors in determining the necessary facilities for utilizing the water.

Tools and Materials

Timing device, preferably watch with second hand

Measuring tape

Float (see below)

Stick for measuring depth

The following equation will help you to measure flow quickly: $Q = K \times A \times V$, where:

Q (Quantity) = flow in liters per minute

A (Area) = cross-section of stream, perpendicular to flow, in square meters

V (Velocity) = stream velocity, meters per minute

K (Constant) = a corrected conversion factor. This is used because surface flow is normally faster than average flow. For normal stages use K = 850; for flood stages use K = 900 to 950.

FIGURE 1

To Find A (Area) of a Cross-Section

The stream will probably have different depths along its length so select a place where the depth of the stream is average.

1. Take a measuring stick and place it upright in the water about 50cm from the bank.

2. Note the depth of water.

3. Move the stick 1 meter from the bank in a line directly across the stream.

4. Note the depth.

5. Move the stick 1.5 meters from the bank, note the depth, and continue moving it at 50cm intervals until you cross the stream.

Note the depth each time you place the stick upright in the stream. Draw a grid, like the one in Figure 2, and mark the varying depths on it so that a cross-section of the stream is shown. A scale of 1cm to 10cm is often used for such grids. By counting the grid squares and fractions of squares, the area of the water can be estimated. For example, the grid shown here has a little less than 4 square meters of water.

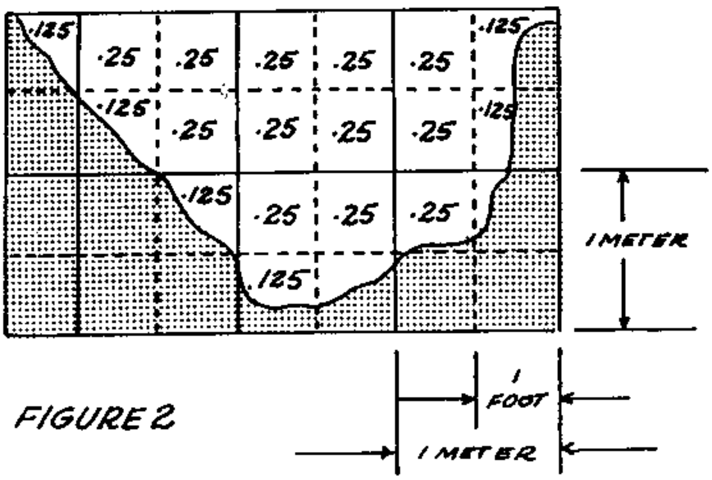


FIGURE 2

To Find V (Velocity)

Put a float in the stream and measure the distance of travel in one minute (or fraction of a minute, if necessary.) The width of the stream should be as constant as possible and free of rapids, where the velocity is being measured.

A light surface float, such as a chip, will often change course because of wind or surface currents. A weighted float which sits upright in the water will not change course so easily. A lightweight tube or tin can, partly filled with water or gravel so that it floats upright with only a small part showing above water, will not change course so easily and makes a better float for measuring.

Measuring Wide Streams

For a wide, irregular stream, it is better to divide the stream into 2 or 3 meter sections and measure the area and velocity of each. Q is then calculated for each section and the Qs added together to give a total flow.

Example (see Figure 2):

Cross section is 4 square meters

Velocity of float = 6 meters traveled in 1/2 minute

Stream flow is normal

$$Q = 850 \times 4 \times \frac{6 \text{ meters}}{.5 \text{ minute}}$$

Q = 40,800 liters per minute
or
680 liters per second

Using English Units

If English units of measurement are used, the equation for measuring stream flow is: Q = K x A x V, where:

Q = flow in U.S. gallons per minute

A = cross-section of stream, perpendicular to flow, in square feet

V = stream velocity in feet per minute

K = a corrected conversion factor: 6.4 for normal stages; 6.7 to 7.1 for flood stages

The grid to be used would be similar to the one in Figure 3; a commonly used scale is 1" to 12".

Example:

Cross-section is 15 square feet

Velocity of float = 20 feet traveled in 1/2 minute

Stream flow is normal

$$Q = 6.4 \times 15 \times \frac{20 \text{ feet}}{.5 \text{ minute}}$$

Q = 3800 gallons per minute

Source:

Design of Fishways and Other Fish Facilities by C. H. Clay, P. E. Department of Fisheries of Canada, Ottawa, 1961.

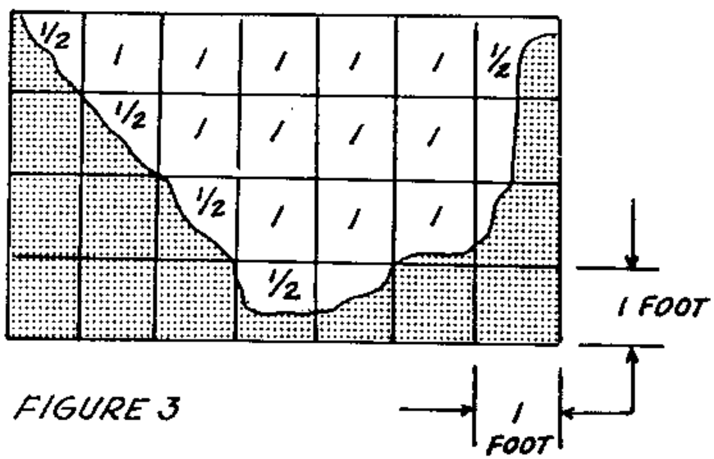
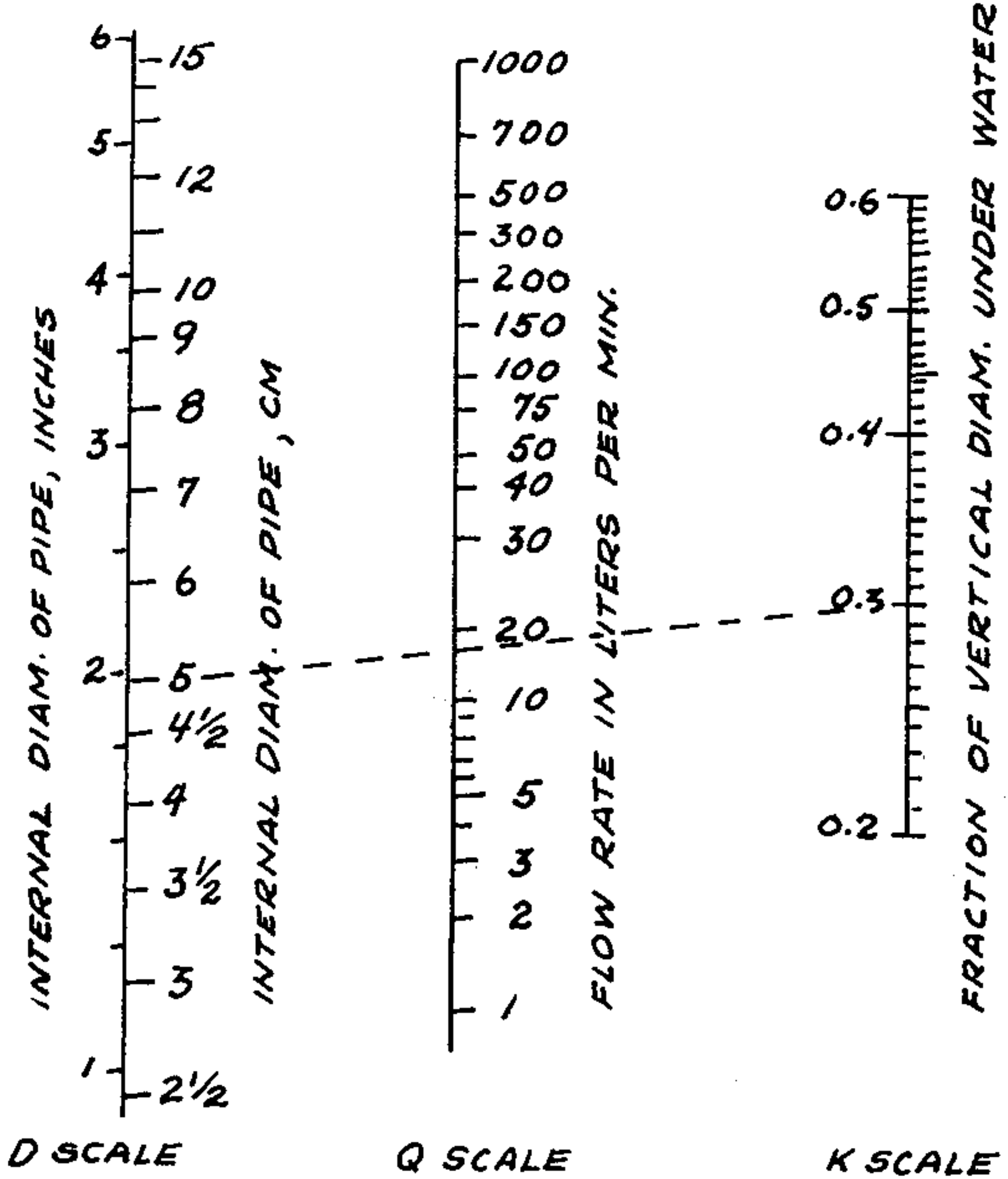


FIGURE 3

FIGURE 2


INTERNAL DIAM. OF PIPE, INCHES
INTERNAL DIAM. OF PIPE, CM
FLOW RATE IN LITERS PER MIN.
FRACTION OF VERTICAL DIAM. UNDER WATER
6
5
4
3
2
1
15
12
10
9
8
7
6
5
4½
4
3½
3
2½
1000
700
500
300
200
150
100
75
50
40
30
20
10
5
3
2
1
0.6
0.5
0.4
0.3
0.2
D SCALE
Q SCALE
K SCALE

MEASURING THE FLOW OF WATER IN PARTIALLY FILLED PIPES

The flow of water in partially-filled horizontal pipes or circular channels can be determined--if you know the inside diameter of the pipe and the depth of the water flowing--by using the alignment chart (nomograph) in Figure 2.

This method can be checked for low flow rates and small pipes by measuring the time required to fill a bucket or drum with a weighed quantity of water. A liter of water weighs 1kg (1 U.S. gallon of water weighs 8.33 pounds).

Tools and Materials

Ruler to measure water depth (if ruler units are inches, multiply by 2.54 to convert to centimeters)

Straight edge, to use with alignment chart

The alignment chart applies to pipes with 2.5cm to 15cm inside diameters, 20 to 60% full of water, and having a reasonably smooth surface (iron, steel, or concrete sewer pipe). The pipe or channel must be reasonably horizontal if the result is to be accurate. The eye, aided by a plumb bob line to give a vertical reference, is a sufficiently good judge. If the pipe is not horizontal another method will have to be used. To use the alignment chart, simply connect the proper point on the "K" scale with the proper point of the "d" scale with the straight edge. The flow rate can then be read from the "q" scale.

q = rate of flow of water, liters per minute 8.33 pounds = 1 gallon.

d = internal diameter of pipe in centimeters.

K = decimal fraction of vertical diameter under water. Calculate K by measuring the depth of water (h) in the pipe and dividing it by the pipe diameter (d), or $K = \frac{h}{d}$ (see Figure 1).

Example:

What is the rate of flow of water in a pipe with an internal diameter of 5cm running 0.3 full? A straight line connecting 5 on the d-scale with 0.3 on the K-scale intersects the q-scale at a flow of 18 liters per minute.

Source:

Greve Bulletin, Purdue University (12, No. 5, 1928, Bulletin 32).

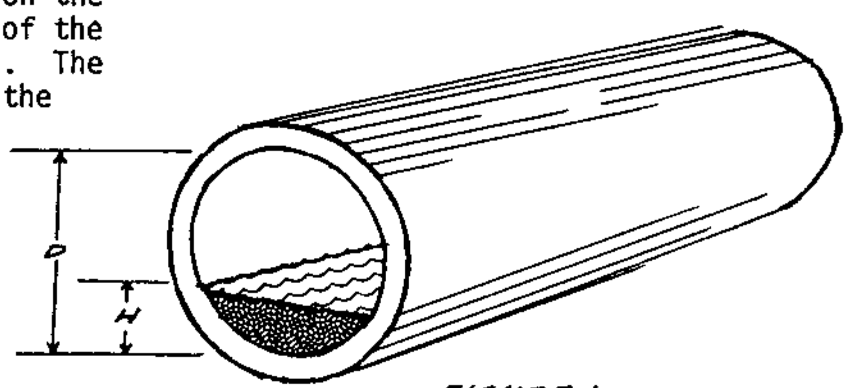
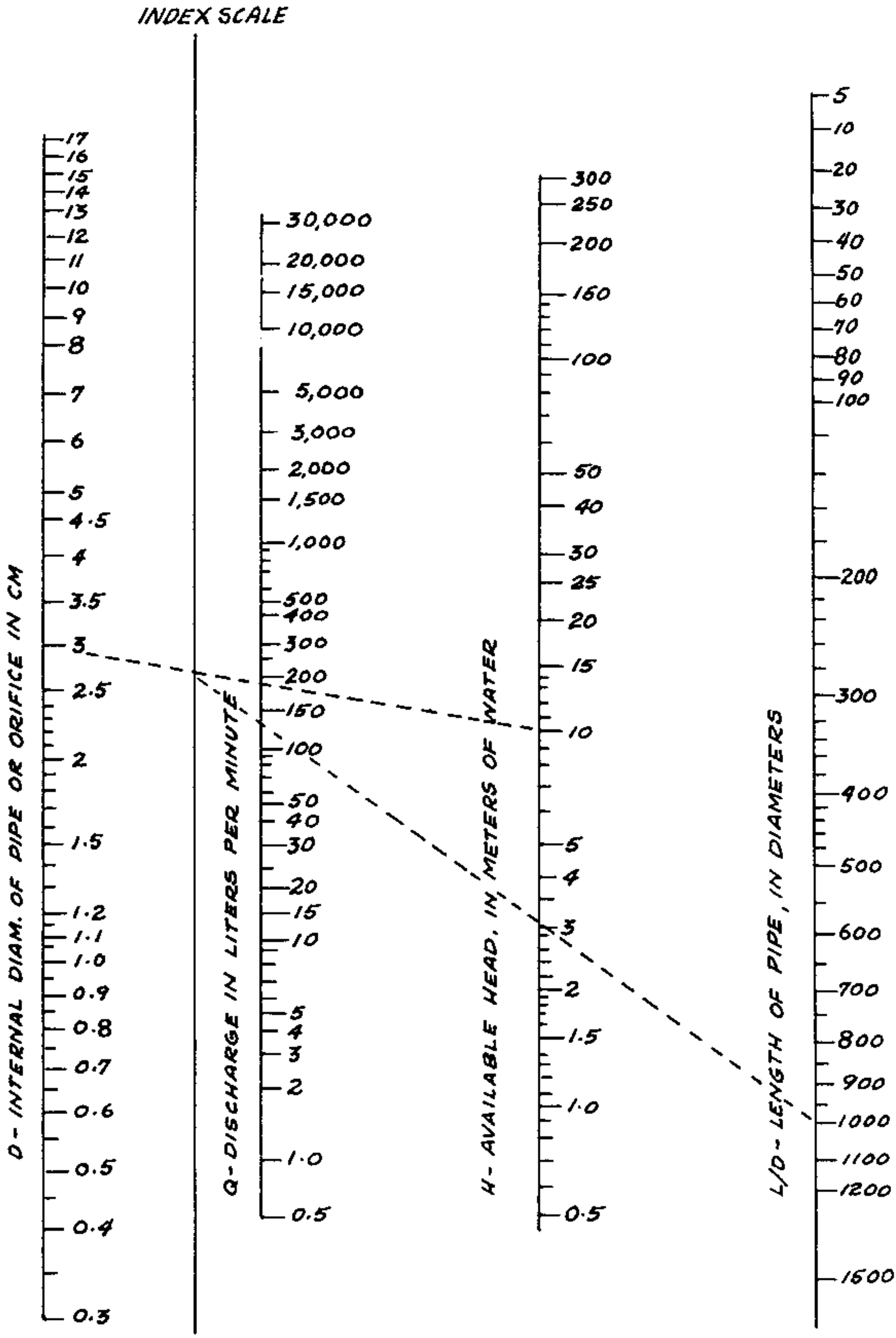


FIGURE 1

FIGURE 1



Alignment chart for determining probable water flow with known reservoir height and size and length of pipe.

DETERMINING PROBABLE WATER FLOW WITH KNOWN RESERVOIR HEIGHT AND SIZE AND LENGTH OF PIPE

The alignment chart in Figure 1 gives a reasonably accurate determination of water flow when pipe size, pipe length and height of the supply reservoir are known.

The example given here is for the analysis of an existing system. To design a new system, assume a pipe diameter and solve for flow-rate, repeating the procedure with new assumed diameters until one of them provides a suitable flow rate.

Materials

Straight edge, for use with alignment chart

Surveying instruments, if available

The alignment chart was prepared for clean, new steel pipe. Pipes with rougher surfaces or steel or cast iron pipe which has been in service for a long time may give flows as low as 50 percent of those predicted by this chart.

The available head (h) is in meters and is taken as the difference in elevation between the supply reservoir and the point of demand. This may be crudely estimated by eye, but for accurate results some sort of surveying instruments are necessary.

For best results, the length of pipe (L) used should include the equivalent lengths of fittings as described in handbook entry "Flow Resistance of Pipe Fittings," p. 80. This length (L) divided by the pipe internal diameter (D) gives the necessary "L/D" ratio. In calculating L/D, note that the units of measuring both "L" and "D" must be the same, e.g.: feet divided by feet; meters divided by meters; centimeters by centimeters.

Example:

Given Available Head (h) of 10 meters, pipe internal diameter (D) of 3cm, and equivalent pipe length (L) of 30 meters = 3000cm.

$$\text{Calculate } L/D = \frac{3000\text{cm}}{3\text{cm}} = 1000$$

The alignment chart solution is in two steps:

1. Connect Internal Diameter 3cm to Available Head (10 meters), and make a mark on the Index Scale. (In this step, disregard "Q" scale)

2. Connect mark on Index Scale with L/D (1000), and read flow rate (Q) of approximately 140 liters per minute.

Source:

Crane Company Technical Paper #407, pages 54-55.

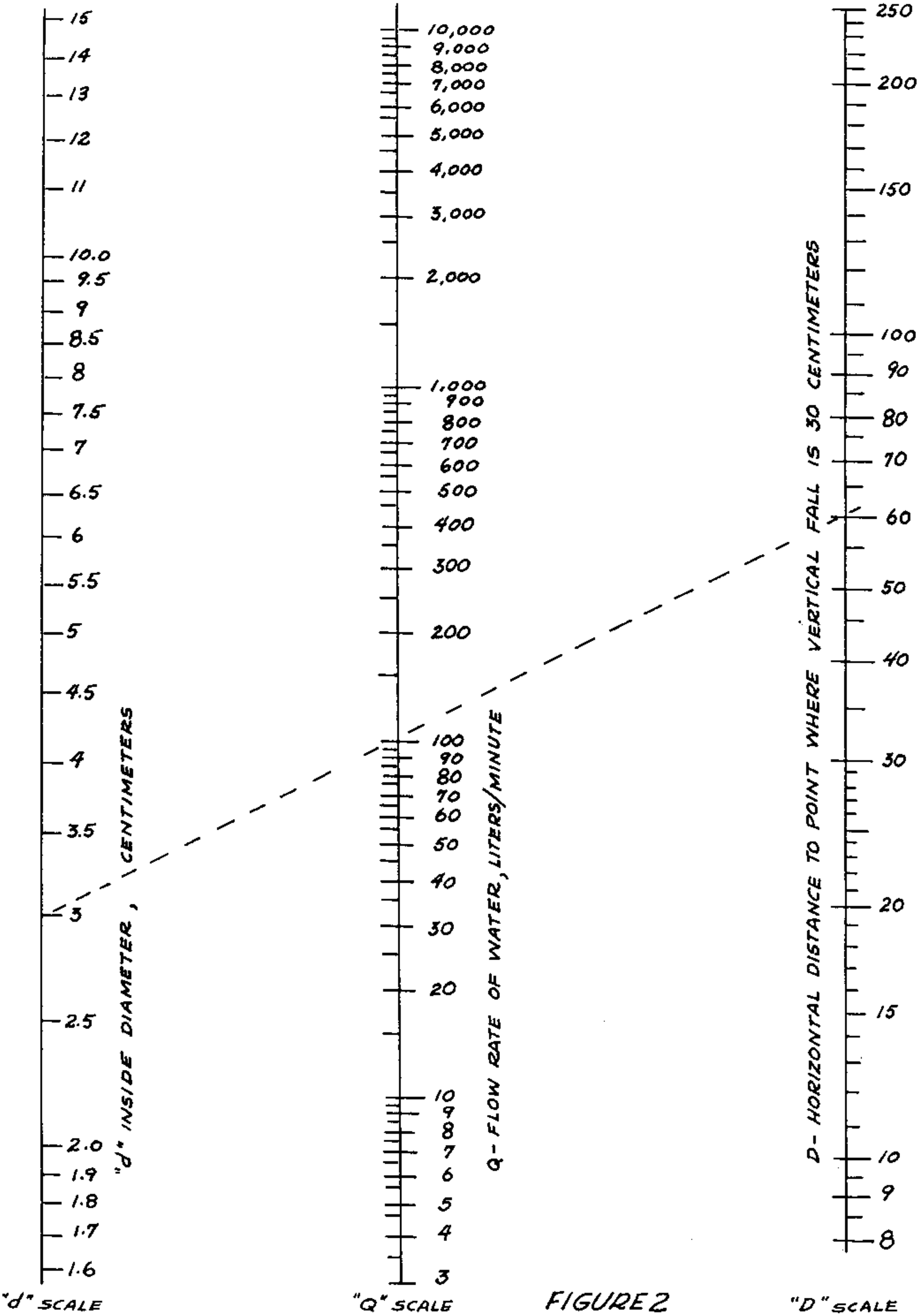

"d" INSIDE DIAMETER, CENTIMETERS
Q- FLOW RATE OF WATER, LITERS/MINUTE
D- HORIZONTAL DISTANCE TO POINT WHERE VERTICAL FALL IS 30 CENTIMETERS
15
14
13
12
11
10.0
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2.0
1.9
1.8
1.7
1.6
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
250
200
150
100
90
80
70
60
50
40
30
20
15
10
9
8
"d" SCALE
"Q" SCALE
"D" SCALE

FIGURE 2

ESTIMATING WATER FLOW FROM HORIZONTAL PIPES

If a horizontal pipe is discharging a full stream of water, you can estimate the rate of flow from the alignment chart in Figure 2. This is a standard engineering technique for estimating flows; its results are usually accurate to within 10 percent of the actual flow rate.

Materials

Straightedge and pencil, to use alignment chart

Tape measure

Level

Plumb bob

The water flowing from the pipe must completely fill the pipe opening (see Figure 1). The results from the chart will be most accurate when there is no constricting or enlarging fitting at the end of the pipe.

Example:

Water is flowing out of a pipe with an inside diameter (d) of 3cm (see Figure 1). The stream drops 30cm at a point 60cm from the end of the pipe.

Connect the 3cm inside diameter point on the "d" scale in Figure 2 with the 60cm point on the "D" scale. This line intersects the "q" scale at about 100 liters per minute, the rate at which water is flowing out of the pipe.

Source:

"Flow of Water from Horizontal Open-end Pipes," by Clifford L. Duckworth, Chemical Processing, June 1959, p. 73.

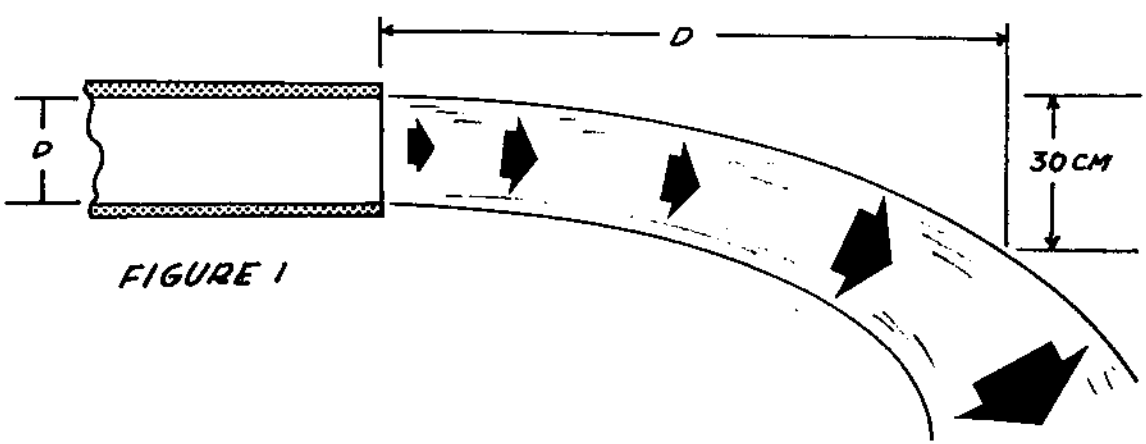


FIGURE 1

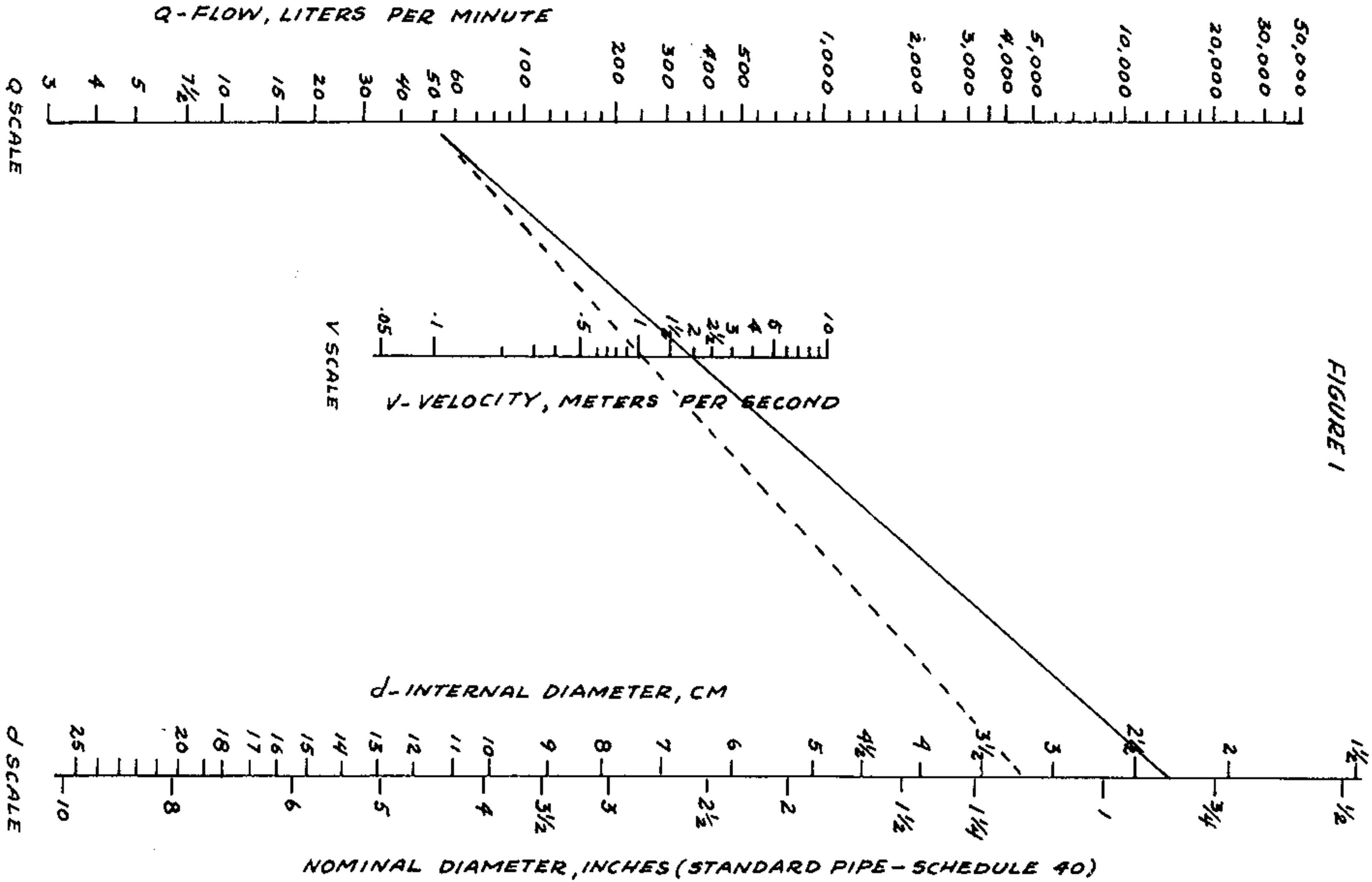

Q-FLOW, LITERS PER MINUTE
Q SCALE
3 4 5 7½ 10 15 20 30 40 50 60 100 200 300 400 500 1,000 2,000 3,000 4,000 5,000 10,000 20,000 30,000 50,000
V SCALE
.05 .1 .5 1 1½ 2 2½ 3 4 6 10
V-VELOCITY, METERS PER SECOND
d-INTERNAL DIAMETER, CM
d SCALE
25 20 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4½ 4 3½ 3 2½ 2 1½
10 8 6 5 4 3½ 3 2½ 2 1½ 1¼ 1 ¾ ½
NOMINAL DIAMETER, INCHES (STANDARD PIPE-SCHEDULE 40)

FIGURE 1

DETERMINING PIPE SIZE OR VELOCITY OF WATER IN PIPES

The choice of pipe size is one of the first steps in designing a simple water system.

The alignment chart in Figure 1 can be used to compute the pipe size needed for a water system when the water velocity is known. The chart can also be used to find out what water velocity is needed with a given pipe size to yield the required rate of flow.

Tools and Materials

Straightedge and pencil

Practical water systems use water velocities from 1.2 to 1.8 meters per second. Very fast velocity requires high pressure pumps which in turn require high pressure pumps which in turn require large motors and use excessive power. Velocities which are too low are expensive because larger pipe diameters must be used.

It may be advisable to calculate the cost of two or more systems based on different pipe size. Remember, it is usually wise to choose a little larger pipe if higher flows are expected in the next 5 or 10 years. In addition, water pipes often build up rust and scale reducing the diameter and thereby increasing the velocity and pump pressure required to maintain flow at the original rate. If extra capacity is designed into the piping system, more water can be delivered by adding to the pump capacity without changing all the piping.

To use the chart, locate the flow (liters per minute) you need on the Q-scale. Draw a line from that point, though 1.8m/sec velocity on the V-scale to the d-scale. Choose the nearest standard size pipe.

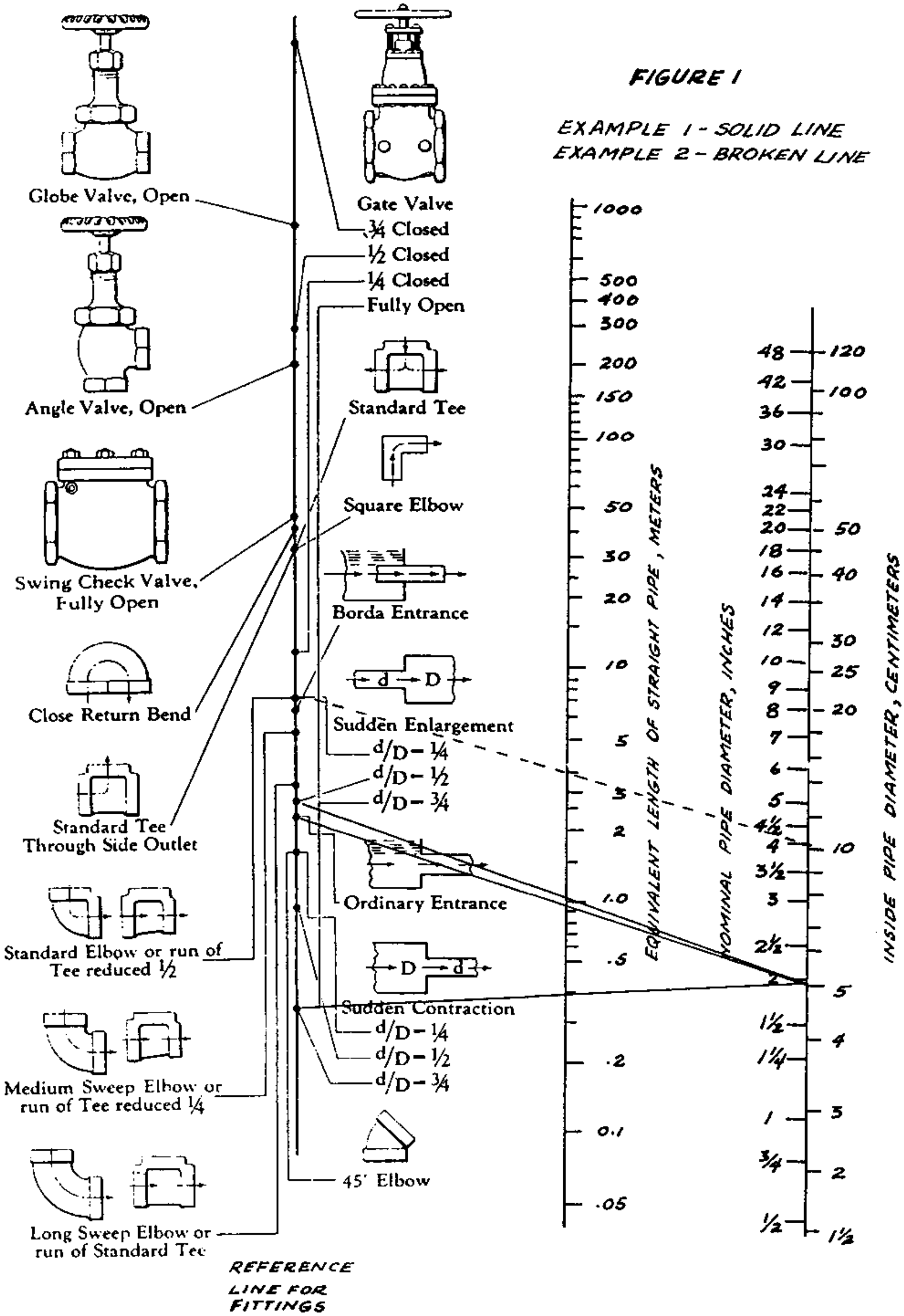
Example:

Suppose you need a flow of 50 liters per minute at the time of peak demand. Draw a line from 50 liters per minute on the Q-scale through 1.8m/sec on the V-scale. Notice that this intersects the d-scale at about 2.25. The correct pipe size to choose would be the next largest standard pipe size: e.g. 1" nominal diameter, U.S. Schedule 40. If pumping costs (electricity or fuel) are high, it would be well to limit velocity to 1.2m/sec and install a slightly larger pipe size.

Source:

Crane Company Technical Paper #409, pages 46-47.

Resistance of Valves and Fittings to Flow of Fluids



ESTIMATING FLOW RESISTANCE OF PIPE FITTINGS

One of the forces which a pump must overcome to deliver water is the friction/resistance of pipe fittings and valves to the flow of water. Any bends, valves, constrictions or enlargements (such as passing through a tank) add to friction.

The alignment chart in Figure 1 gives a simple but reliable way to estimate this resistance: it gives the equivalent length of straight pipe which would have the same resistance. The sum of these equivalent lengths is then added to the actual length of pipe: this gives the total equivalent pipe length, which is used in the following entry, "Determining Pump Capacity and Horsepower Requirement," to determine total friction loss.

Rather than calculate the pressure drop for each valve or fitting separately, this chart will give the equivalent length of straight pipe.

Valves: Note the difference in equivalent length depending on how far the valve is open.

1. Gate Valve - full opening valve; can see through it when open; used for complete shut off of flow.
2. Globe Valve - cannot see through it when open; used for regulating flow.
3. Angle Valve - like the globe, used for regulating flow.
4. Swing Check Valve - a flapper opens to allow flow in one direction but closes when water tries to flow in the opposite direction.

Fittings

Study the variety of tees and elbows: note carefully the direction of flow through the tee. To determine the equivalent length of a fitting, (a) pick proper dot on "fitting" line, (b) connect with inside diameter of pipe, using a straight edge; read equivalent length of straight pipe in meters, (c) add the fitting equivalent length to the actual length of pipe being used.

Source:

Crane Company Technical Paper #409, pages 20-21.

Example 1:

Pipe with 5cm inside diameter	Equivalent Length in Meters
a. Gate Valve (fully open)	.4
b. Flow into line - ordinary entrance	1.0
c. Sudden enlargement into 10cm pipe ($d/D = 1/2$)	1.0
d. Pipe length	10.0
Total Equivalent Pipe Length	12.4

Example 2:

Pipe with 10cm inside diameter	Equivalent Length in Meters
a. Elbow (standard)	4.0
b. Pipe length	10.0
Total Equivalent Pipe Length	14.0

DETERMINING PUMP OUTLET SIZE AND HORSEPOWER REQUIREMENT

With the alignment chart in Figure 2, you can determine the necessary pump size (diameter of discharge outlet) and the amount of horsepower needed to power the pump. The power can be supplied by men or by motors.

A man can generate about 0.1 horsepower (HP) for a reasonably long period and 0.4 HP for short bursts. Motors are designed for varying amounts of horsepower.

Tools

Straight edge and pencil for alignment chart

To get the approximate pump size needed for lifting liquid to a known height through simple piping, follow these steps:

1. Determine the quantity of flow desired in liters per minute.

2. Measure the height of the lift required (from the point where the water enters the pump suction piping to where it discharges).

3. Using the entry "Determining Pipe Size or Velocity of Water in Pipes," page 78, choose a pipe size which will give a water velocity of about 1.8 meters per second (6' per second). This velocity is chosen because it will generally give the most economical combination of pump and piping; Step 5 explains how to convert for higher or lower water velocities.

4. Estimate the pipe friction-loss "head" (a 3-meter "head" represents the pressure at the bottom of a 2-meter-high column of water) for the total equivalent pipe length, including suction and discharge piping and equivalent pipe lengths for valves and fittings, using the following equation:

   Friction-loss head =

   $$\frac{F \times \text{total equivalent pipe length}}{100}$$

   where F equals approximate friction head (in meters) per 100 meters of pipe. To get the value of F, see the table in Figure 1. For an explanation of total equivalent pipe length, see the preceding entry.

5. To find F (approximate friction head in meters per 100m of pipe) when water velocity is higher or lower than 1.8 meters per second, use the following equation:

   $$F = \frac{F_{\text{at 1.8m/sec}} \times V^2}{1.8\text{m/sec}^2},$$

   where V = higher or lower velocity

   Example:

   If the water velocity is 3.6m per second and $F_{\text{at 1.8m/sec}}$ is 16, then:

   $$F = \frac{16 \times 3.6^2}{1.8^2} = \frac{16 \times 13}{3.24} = 64$$

6. Obtain "Total Head" as follows: Total Head = Height of Lift + Friction-loss Head

Pipe inside diameter:	cm	2.5	5.1	7.6	10.2	15.2	20.4	30.6	61.2
	inches*	1"	2"	3"	4"	6"	8"	12"	24"
F (approximate friction loss in meters per 100 meters of pipe)		16	7	5	3	2	1.5	1	0.5

Figure 1. Average friction loss in meters for fresh water flowing through steel pipe when velocity is 1.8 meters (6 feet) per second.

*For the degree of accuracy of this method, either actual inside diameter in inches or nominal pipe size, U.S. Schedule 40, can be used.

7. Using a straight edge, connect the proper point on the T-scale with the proper point on the Q-scale; read motor horsepower and pump size on the other two scales.

   Example:

   Desired flow: 400 liters per minute

   Height of lift: 16 meters, No fittings

   Pipe size: 5cm

   Friction-loss head: about 1 meter

   Total head: 17 meters

   Solution:

   Pump size: 5cm

   Motor horsepower: 3HP

Note that water horsepower is less than motor horsepower (see HP-scale, Figure 2). This is because of friction losses in the pump and motor. The alignment chart should be used for rough estimate only. For an exact determination, give all information on flow and piping to a pump manufacturer or an independent expert. He has the exact data on pumps for various applications. Pump specifications can be tricky especially if suction piping is long and the suction lift is great.

Conversion to Metric Horsepower

Given the limits of accuracy of this method, metric horsepower can be considered roughly equal to the horsepower indicated by the alignment chart. Actual metric horsepower can be obtained by multiplying horsepower by 1.014.

Source:

Nomographic Charts, by C. A. Kulman, McGraw-Hill Book Co., New York, 1951, pages 108-109.

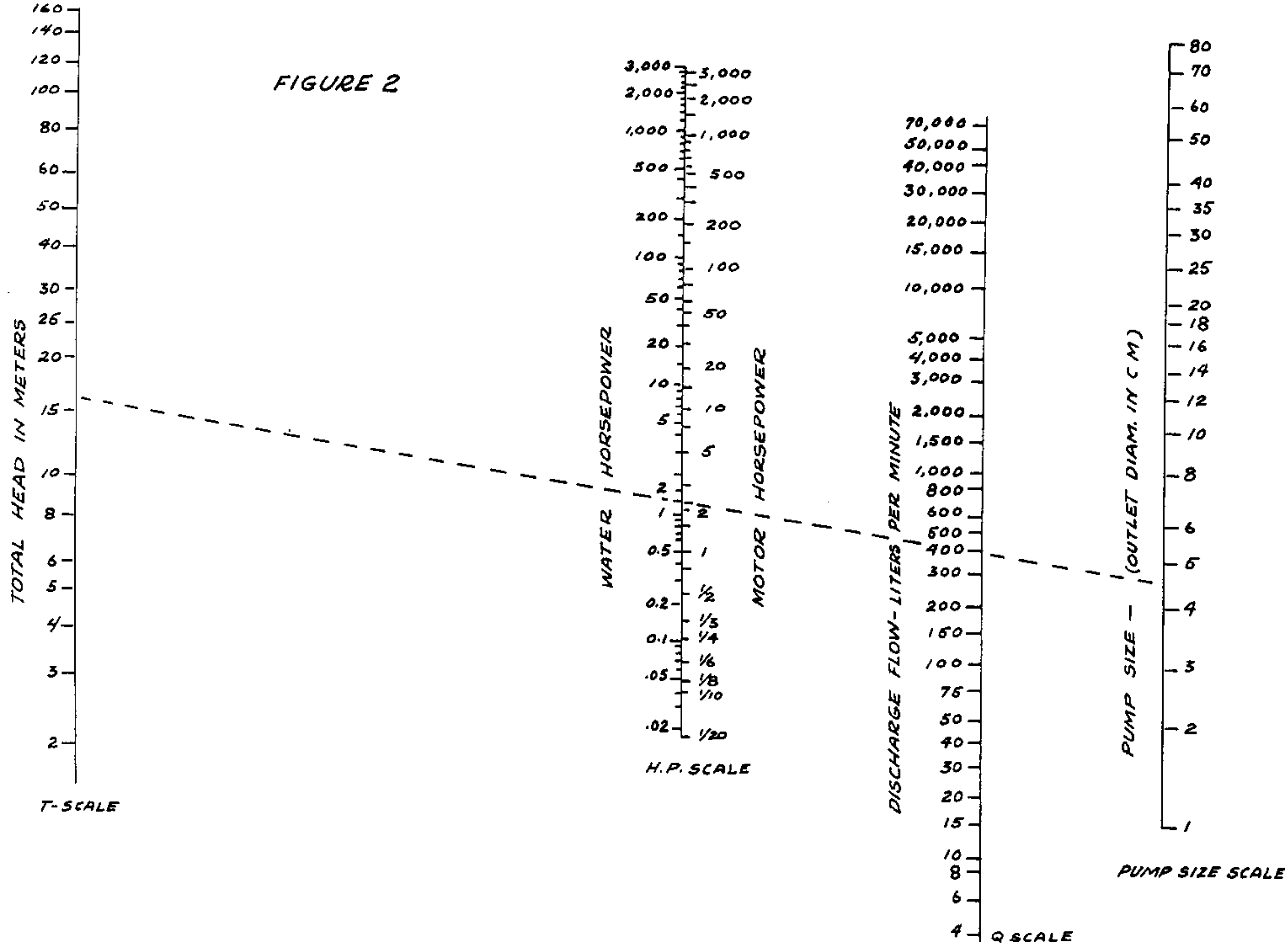


FIGURE 2
TOTAL HEAD IN METERS
T-SCALE
160
140
120
100
80
60
50
40
30
26
20
15
10
8
6
5
4
3
2
WATER HORSEPOWER
MOTOR HORSEPOWER
H.P. SCALE
3,000
2,000
1,000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
.05
.02
1/2
1/5
1/4
1/6
1/8
1/10
1/20
DISCHARGE FLOW- LITERS PER MINUTE
Q SCALE
70,000
50,000
40,000
30,000
20,000
15,000
10,000
5,000
4,000
3,000
2,000
1,500
1,000
800
600
500
400
300
200
150
100
75
50
40
30
20
15
10
8
6
4
PUMP SIZE - (OUTLET DIAM. IN C M)
PUMP SIZE SCALE
80
70
60
50
40
35
30
25
20
18
16
14
12
10
8
6
5
4
3
2
1

DETERMINING LIFT PUMP CAPABILITY

The height that a lift pump can raise water depends on altitude and, to a lesser extent, on water temperature. The graph in Figure 1 will help you to find out what a lift pump can do at various altitudes and water temperatures.

Tools

Measuring tape

Thermometer

If you know your altitude and the temperature of your water, Figure 1 will tell you the maximum allowable distance between the pump cylinder and the lowest water level expected. If the graph shows that lift pumps are marginal or will not work, then a force pump should be used. This involves putting the cylinder down in the well, close enough to the lowest expected water level to be certain of proper functioning.

The graph shows normal lifts. Maximum possible lifts under favorable conditions would be about 1.2 meters higher, but this would require slower pumping and would probably give much difficulty in "losing the prime."

Check predictions from the graph by measuring lifts in nearby wells or by experimentation.

Source:

Mechanical Engineer's Handbook, by Theodore Baumeister, 6th edition, McGraw-Hill Book Co., New York, copyright 1958. Used by permission. (Adapted.)

Example:

Suppose your elevation is 2000 meters and the water temperature is 25C. The graph shows that the normal lift would be 4 meters.

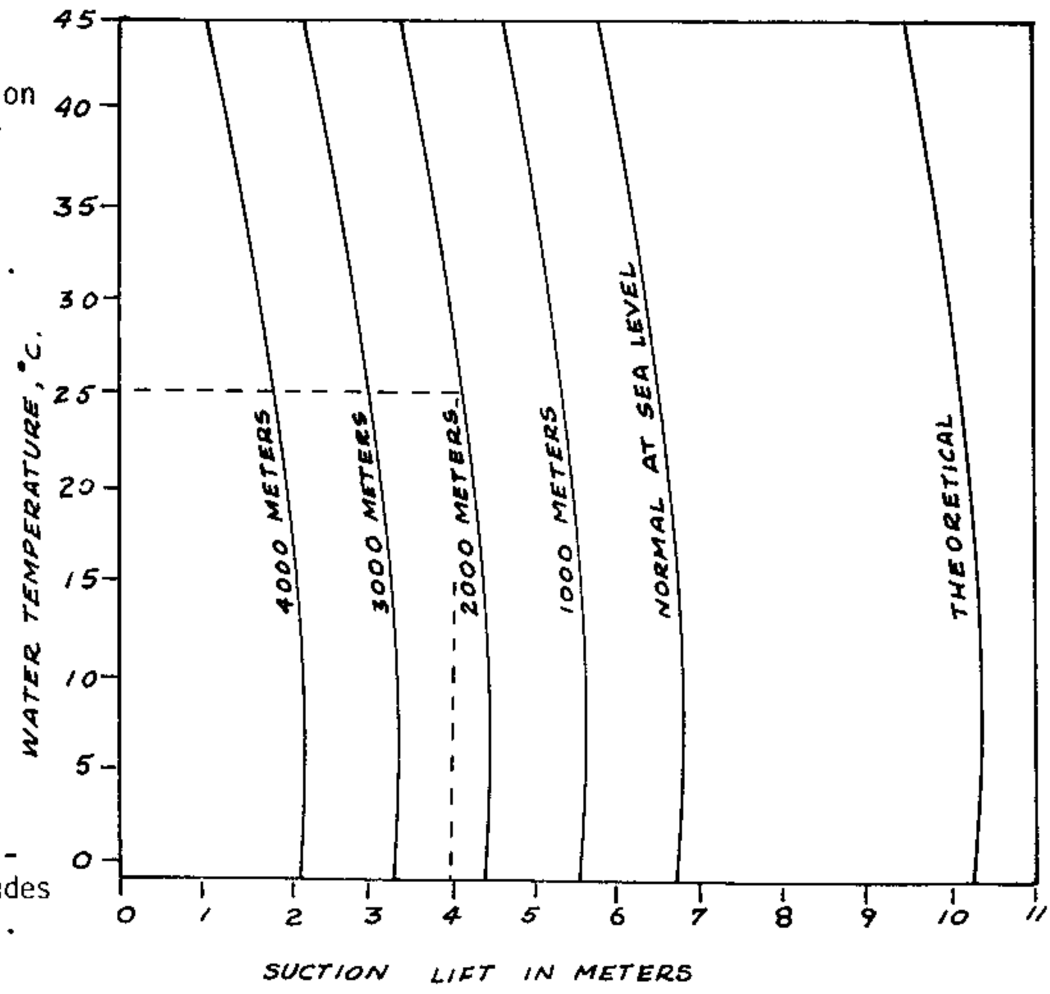


FIGURE 1

Figure 1. Graph showing lift pump capabilities at various altitudes and water temperatures. Broken lines indicate example given in text.

WATER, PRESSURE AND FLOW. Water is composed of two gases, hydrogen and oxygen, in the ratio of two volumes of the former to one of the latter. Water boils under atmospheric pressure at 212 degrees F. and freezes at 32 degrees F. Its greatest density is at 39.1 degrees F., when it weighs 62.425 pounds per cubic foot. The pressure in pounds per square inch of water that is not moving, against the sides of any pipe, vessel, container, or dam is due solely to the "head" or height of the surface of the water above the point at which the pressure is considered. The pressure is equal to 0.433 pound per square inch for every foot of the head, at a temperature of 62 degrees F. For higher temperatures, the pressure slightly decreases in the proportion indicated by the table "Weight of Water per Cubic Foot at Different Temperatures." The pressure per square inch is equal in all directions, downwards, upwards, and sideways. Water can be compressed only in a very slight degree, the compressibility being so slight that, even at the depth of a mile, a cubic foot of water weighs only about one-half pound more than at the surface.

Flow of Water in Pipes. — The quantity of water that will be discharged through a pipe depends primarily upon the head and also upon the diameter of the pipe, the character of the interior surface, and the number and shape of the bends. The head may be either the actual distance between the levels of the surface of water in a reservoir and the point of discharge, or it may be caused by mechanically applied pressure, as by pumping, in which case the head is calculated as the vertical distance corresponding to the pressure. One pound per square inch is equal to 2.309 feet head, or 1 foot head is equal to a pressure of 0.433 pound per square inch.

All formulas for finding the amount of water that will flow through a pipe in a given time are approximate. The formula below will give results within 5 or 10 per cent of actual results, if applied to pipe lines carefully laid and in a fair condition.

$$V = C\sqrt{\frac{hD}{L + 54\,D}},$$

in which

V = approximate mean velocity in feet per second;
C = coefficient from table;
D = diameter of pipe in feet;
h = total head in feet;
L = total length of pipe line in feet.

Values of Coefficient C

Diameter of Pipe, Feet	Diameter of Pipe, Inches	C	Diameter of Pipe, Feet	Diameter of Pipe, Inches	C
0.1	1.2	23	2.0	24	57
0.2	2.4	30	2.5	30	60
0.3	3.6	34	3.0	36	62
0.4	4.8	37	3.5	42	64
0.5	6.0	39	4.0	48	66
0.6	7.2	42	5.0	60	68
0.7	8.4	44	6.0	72	70
0.8	9.6	46	7.0	84	72
0.9	10.8	47	8.0	96	74
1.0	12.0	48	10.0	120	77
1.5	18.0	53	....	....	....

Example. — A pipe line, 1 mile long, 12 inches in diameter, discharges water under a head of 100 feet. Find the velocity and quantity of discharge.

From the table, the coefficient C is found to be 48 for a pipe 1 foot in diameter; hence:

$$V = 48\sqrt{\frac{100 \times 1}{5280 + 54 \times 1}} = 6.57 \text{ feet per second.}$$

To find the discharge in cubic feet per second, multiply the velocity found by the area of cross-section of the pipe in square feet:

$$6.57 \times 0.7854 = 5.16 \text{ cubic feet per second.}$$

The loss of head due to a bend in the pipe is most frequently given in the equivalent length of straight pipe, which would cause the same loss in head as the bend.

Weight of Water per Cubic Foot at Different Temperatures

Temp. Deg. F.	Weight per Cubic Foot, Pounds	Temp. Deg. F.	Weight per Cubic Foot, Pounds	Temp. Deg. F.	Weight per Cubic Foot, Pounds	Temp. Deg. F.	Weight per Cubic Foot, Pounds
32	62.42	180	60.55	320	56.66	470	50.2
40	62.42	190	60.32	330	56.30	480	49.7
50	62.41	200	60.12	340	55.94	490	49.2
60	62.37	210	59.88	350	55.57	500	48.7
70	62.31	212	59.83	360	55.18	510	48.1
80	62.23	220	59.63	370	54.78	520	47.6
90	62.13	230	59.37	380	54.36	530	47.0
100	62.02	240	59.11	390	53.94	540	46.3
110	61.89	250	58.83	400	53.50	550	45.6
120	61.74	260	58.55	410	53.00	560	44.9
130	61.56	270	58.26	420	52.6	570	44.1
140	61.37	280	57.96	430	52.2	580	43.3
150	61.18	290	57.65	440	51.7	590	42.6
160	60.98	300	57.33	450	51.2	600	41.8
170	60.77	310	57.00	460	50.7	.....	.....

Volume of Water at Different Temperatures

Degrees F.	Volume	Degrees F.	Volume	Degrees F.	Volume
39.1	1.00000	104	1.00767	167	1.02548
50	1.00025	113	1.00967	176	1.02872
59	1.00083	122	1.01186	185	1.03213
68	1.00171	131	1.01423	194	1.03570
77	1.00286	140	1.01678	203	1.03943
86	1.00425	149	1.01951	212	1.04332
95	1.00586	158	1.02241	....	....

Experiments show that a right-angle bend should have a radius of about three times the diameter of the pipe. Assuming this curvature, then, if D is the diameter of the pipe in inches and L is the length of straight pipe in feet which causes the same loss of head as the bend in the pipe, the following formula gives the equivalent length of straight pipe that should be added to compensate for a right-angle bend:

$$L = 4\,D \div 3.$$

Thus the loss of head due to a right-angle bend in a 6-inch pipe would be equal to that in 8 feet of straight pipe. Experiments undertaken to determine the losses due to valves in pipe lines indicate that a fully open gate valve in a pipe causes a loss of head corresponding to that in a length of pipe equal to six diameters.

Table 4.18 Characteristics of water lifting devices.

KEY TO SYMBOLS

Water Source	*Power Source*	*Use*
St = Stream, river, canal	H = Human	Do = Domestic
La = Lake, pond, tank	A = Animal	L = Livestock
Dw = Dug well	W = Wind	Ir = Irrigation
Bh = Bore-hole	IC = Diesel, Petrol	Dr = Land Drainage
	E = Electrical	
	Es = Solar-electric	

Other

Var. = Variable, FD = Free discharge, DL = Delivery lift

TYPE OF EQUIPMENT	WATER SOURCE				LIFT Approx. range	OUTPUT Average	POWER SOURCE						USE			
	St	La	Dw	Bh	m	m³/h	H	A	W	IC	E	Es	Do	L	Ir	Dr
Buckets and Scoops																
Swing basket	*	*			0·1–0·6	5	*								*	*
Scoop	*	*			0·1–1·0	8	*								*	*
Counterpoise lift (shadouf)	*	*	*		1·5–2·5	5	*						*	*	*	*
Rope and bucket	*	*	*		1·5–10	1	*						*	*		
Rope and bucket (mohte)	*	*	*		4–9	12		*					*	*	*	
Water ladder	*	*			0·75–3·5	5	*						*	*	*	
Chain and washer pump	*	*	*		1·5–6	18	*						*	*	*	
Persian wheel, saqia	*	*			1·5–9	14		*							*	*
Noria	*	*			0·3–1·8	90		*							*	*
Noria	*	*			0·3–1·8	var.				*	*				*	*
Water wheel	*				3–7	var.			*				*	*	*	
Positive Displacement Pumps																
Reciprocating, barrel above ground—Shallow well, FD	*	*	*		up to 6	var.	*		*	*			*	*	*	
〃 —Shallow well, DL	*	*	*		var.	var.	*		*	*			*	*	*	
Reciprocating, barrel below ground—Deep well, FD			*	*	var.	var.	*		*	*	*		*	*	*	
〃 —Deep well, DL			*	*	var.	var.			*	*	*		*	*	*	
Semi-rotary	*	*	*		var.	var.	*						*	*		
Archimedean screw	*	*			0·25–0·75	22	*								*	*
Archimedean screw	*	*			3–10	var.				*	*				*	*
Helical rotor ('Mono')				*	var.	var.	*			*	*		*	*	*	
Diaphragm	*	*	*		var.	var.	*			*	*		*	*	*	*
Rotodynamic Pumps																
Centrifugal, single stage	*	*	*		up to 100	var.				*	*	*	*	*	*	*
Centrifugal, multi-stage	*	*	*		100–1000	var.				*	*		*	*	*	*
Vertical spindle				*	var.	var.				*	*		*	*	*	*
Propeller or axial flow	*	*			up to 30	var.				*	*		*	*	*	*
Submersible				*	up to 1000	var.				*	*		*	*	*	*
Miscellaneous																
Hydraulic ram	*				up to 200	var.			*				*	*		
Air lift				*	var.	var.				*	*		*	*		

Sources: James Goodman, *'A Study of the use, efficiency and performance of simple water lifting devices used for irrigation'*. National College of Agricultural Engineering, Silsoe, UK., 1977.
Godofredo Salazar and Charles J. Moss, *An overview of the water pumping equipment available to small farmers*. International Rice Research Institute, Philippines, 1978.
A.C. Twort, R.C. Hoather, F.M. Law, *Water Supply*, (Chapter 12), Edward Arnold, 1974.
Appropriate Technology, Vol. 9, No. 1.

APPENDIX: Conversion Factors

To convert from:	To:	Multiply by:
Length		
centimeters (cm)	inches	0.394
feet (ft)	centimeters	30.5
inches (in)	centimeters	2.54
kilometers (km)	miles	0.621
meters (m)	feet	3.28
meters (m)	yards	1.094
miles (mi)	kilometers	1.609
millimeters (mm)	inches	0.0394
yards (yd)	meters	0.914
Area		
acres	hectares	0.405
acres	sq. meters	4047
hectares (ha)	acres	2.47
hectares (ha)	sq. meters	10,000
sq. centimeters (cm^2)	sq. inches	0.155
sq. feet (ft^2)	sq. meters	0.0929
sq. inches (in^2)	sq. centimeters	6.45
sq. kilometers (km^2)	sq. miles	0.386
sq. kilometers (km^2)	hectares	100
sq. meters (m^2)	sq. feet	10.76
sq. yards (yd^2)	sq. meters	0.836
Volume		
barrels (petroleum, bbl)	liters	159
cubic centimeters (cm^3)	cubic inches	0.0610
cubic feet (ft^3)	cubic meters	0.0283
cubic inches (in^3)	cubic centimeters	16.39
cubic meters (m^3)	cubic feet	35.3
cubic meters (m^3)	cubic yards	1.308
cubic yards (yd^3)	cubic meters	0.765
gallons (gal) US	liters	3.79
gallons (gal) Imp.	liters	4.545
gallons (gal) Imp.	gallons, US	1.20
Weight		
grams (g)	ounces, avdp.	0.0353
kilograms (kg)	pounds	2.205
ounces avdp. (oz)	grams	28.3
pounds (lb)	kilograms	0.454
tons (long)	pounds	2240
tons (long)	kilograms	1016
tons (metric)	pounds	2205
tons (metric)	kilograms	1000
tons (short)	pounds	2000
tons (short)	kilograms	907

continued

To convert from:	To:	Multiply by:
Pressure		
atmosphere	grams/sq.cm	1033
atmosphere	pounds/sq.in	14.7
pounds/sq.in (psi)	grams/sq.cm	70.3
Energy		
British thermal units (Btu)	kilojoules	1.054
calories (cal)	joules	4.19
ergs	joules	1×10^{-7}
kilojoules (kJ)	Btu	0.948
joules (J)	calories	0.239
kilowatt-hours (kWh)	megajoules	3.6
megajoules (MJ)	kilojoules	1000
gigajoules (GJ)	megajoules	1000
terajoules (TJ)	gigajoules	1000
Energy Density		
Btu/gal	joules/cm^3	0.27
Btu/ft^3	kJ/m^3	36.5
Power		
horsepower (hp)	Btu/min	42.4
horsepower (hp)	horsepower (metric)	1.014
horsepower (hp)	kilowatts	0.746
kilowatts (kW)	horsepower	1.341
watts (W)	Btu/hour	3.41
watts (W)	joules/sec	1
Miscellaneous		
liter petrol	megajoules	35
kilogram oil	megajoules	43.2
barrel oil equivalent	gigajoules	6.1
ton coal equivalent	gigajoules	29.3
ton coal equivalent	barrels oil equivalent	4.8
pounds/acre	kilograms/hectare	1.1

SI units and conversion factors

Basic SI units, prefixes, and most common derived SI units used

Basic SI units

Quantity	*Basic unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampère	A
Temperature	kelvin	K

SI prefixes

Prefix	*Symbol*	*Factor*	*Prefix*	*Symbol*	*Factor*
exa	E	10^{18}	deci	d	10^{-1}
peta	P	10^{15}	centi	c	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	µ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto	h	10^{2}	femto	f	10^{-15}
deca	da	10^{1}	atto	a	10^{-18}

Most common derived SI units

Quantity	*Unit*	*Symbol*
Area	square metre	m^2
Volume (contents)	cubic metre	m^3
Speed	metre per second	m/s
Acceleration	metre per second, squared	m/s^2
Frequency	hertz	Hz (= s^{-1})
Pressure	pascal	Pa (= N/m^2)
Volume flow	cubic metre per second	m^3/s
Mass flow	kilogram per second	kg/s
Density (specific mass)	kilogram per cubic metre	kg/m^3
Force	newton	N (= $kg.m/s^2$)
Energy/heat/work	joule	J (= N.m)*
Power/energy flow	watt	W (J/s)
Energy flux	watt per square metre	W/m^2
Calorific value (heat of combustion)	joule per kilogram	J/kg
Specific heat capacity	joule per kilogram kelvin	J/kg K
Voltage	volt	V (= W/A)

* NB The joule can also be written in the form watt second (1J = 1W.s)

Conversion of non-SI units to SI units

Although academic scientists and engineers may be strict in their use of SI units for their calculations, a number of non-SI units are still in everyday use. For example, engines are still sold by cc (cubic centimetres) and hp (horse power), and water-pumping windmill manufacturers often quote in terms of cubic feet of the same type of equipment there is not always consistency. In order to be able to compare different manufacturers' products, therefore, it is important to be able convert the different data to a common unit. The following tables give some useful conversion factors for many of the common non-SI units.

Conversion factors

Length

Unit (symbol)	millimetre (mm)	metre (m)	kilometre (km)	inch (in.)	foot (ft)	mile (m.)
	1	0.001	10^{-6}	0.0394	0.0033	5.4×10^{-7}
	1000	1	0.001	39.4	3.28	5.4×10^{-4}
	10^{6}	1000	1	39360	3280	0.5392
	25.4	0.025	2.5×10^{-5}	1	0.083	1.4×10^{-5}
	305	0.305	3.0×10^{-4}	12	1	1.9×10^{-4}
	1.6×10^{6}	1609	1.609	63360	5280	1

Area

Unit (symbol)	square metre (m^2)	hectare (ha)	square kilometre (km^2)	square foot (ft^2)	acre –	square mile (sq. m.)
	1	10^{-4}	10^{-6}	10.76	2.5×10^{-4}	3.9×10^{-7}
	10000	1	0.01	1.1×10^{5}	2.471	3.9×10^{-3}
	10^{6}	100	1	1.1×10^{7}	247.1	0.386
	0.0929	9.3×10^{-6}	9.3×10^{-8}	1	2.3×10^{-5}	3.6×10^{-8}
	4047	0.4047	4×10^{-3}	43560	1	1.6×10^{-3}
	2.6×10^{6}	259	2.590	2.8×10^{7}	640	1

Volume

Unit (symbol)	litre (l)*	cubic metre (m^3)	cubic inch (in^3)	US gallon (gal)	Imperial gallon (gal)	cubic foot (ft^3)
	1	10^{-3}	61.02	0.264	0.220	0.0353
	1000	1	6102	264	220	35.31
	0.0164	1.6×10^{-5}	1	4.3×10^{-3}	3.6×10^{-3}	5.8×10^{-4}
	3.785	3.8×10^{-3}	231.1	1	0.833	0.134
	4.546	4.5×10^{-3}	277.4	1.201	1	0.160
	28.32	0.0283	1728	7.47	6.23	1

* L in some countries

Mass

Unit (symbol)	gram (g)	kilogram (kg)	tonne (t)	pound (lb)	ton –
	1	0.001	10^{-6}	2.2×10^{-3}	9.8×10^{-7}
	1000	1	0.001	2.205	9.8×10^{-4}
	10^{6}	1000	1	2205	0.984
	453.6	0.4536	4.5×10^{-4}	1	4.5×10^{-4}
	10^{6}	1016	1.016	2240	1

Velocity

Unit (symbol)	metres per second (m/s)	kilometres per hour (km/h)	feet per second (ft/s)	miles per hour (mph)	knots (kt)
	1	3.60	3.28	2.237	1.942
	0.278	1	0.912	0.621	0.539
	0.305	1.097	1	0.682	0.592
	0.447	1.609	1.467	1	0.868
	0.566	1.853	1.689	1.152	1

Frequency

Unit (symbol)	hertz (Hz)	revolutions per minute (rpm)	radians per second (rad/s)
	1	60	6.283
	0.0167	1	0.1047
	0.159	9.549	1

Conversion factors

Flow rate

Unit *(symbol)*	*litres per minute* *(l/min)*	*cubic metres per second* *(m³/s)*	*Imperial gallons per minute* *(gal(Imp)/min)*	*cubic feet per second* *(ft³/s)*
	1	1.7×10^{-5}	0.220	5.9×10^{-4}
	60000	1	13206	35.315
	4.546	7.6×10^{-5}	1	2.7×10^{-3}
	1699	0.0283	373.7	1

Force

Unit *(symbol)*	*newton* *(N)*	*kilonewton* *(kN)*	*kilogram force* *(kgf)*	*tonne force* *(t)*	*pound force* *(lbf)*	*ton force* –
	1	0.001	0.102	1×10^{-4}	0.225	1×10^{-4}
	1000	1	102	0.102	225	0.100
	9.807	0.010	1	0.001	2.205	9.8×10^{-4}
	9807	9.807	1000	1	2205	0.984
	4.448	0.004	0.5436	4.5×10^{-4}	1	4.5×10^{-4}
	9964	9.964	1016	1.1016	2240	1

Torque

Unit *(symbol)*	*newton-metre* *(Nm)*	*kilonewton-metre* *(kNm)*	*foot-pound* *(ft.lb)*
	1	0.001	0.738
	1000	1	738
	1.365	1.4×10^{-3}	1

Work/heat/energy (smaller quantities)

Unit *(symbol)*	*calorie* *(cal)*	*joule* *(J)*	*watt-hour* *(Wh)*	*British Thermal Unit* *(BTU)*	*footpound force* *(ft.lbf)*	*horsepower-hour* *(hp.h)*
	1	4.182	1.2×10^{-3}	3.9×10^{-3}	3.088	1.6×10^{-6}
	0.239	1	2.8×10^{-4}	9.4×10^{-4}	0.7376	3.7×10^{-7}
	860.4	3600	1	3.414	2655	1.3×10^{-3}
	252	1055	2.93	1	778	3.9×10^{-4}
	0.324	1.356	3.8×10^{-4}	1.3×10^{-3}	1	5.0×10^{-7}
	6.4×10^{5}	2.6×10^{6}	745.7	2546	2.0×10^{6}	1

Work/heat/energy (larger quantities)

Unit *(symbol)*	*kilocalorie* *(kcal)*	*megajoule* *(MJ)*	*kilowatt hour* *(kWh)*	*British Thermal Unit* *(BTU)*	*horsepower-hour* *(hp.h)*
	1	4.2×10^{-3}	1.2×10^{-3}	3.968	1.6×10^{-3}
	239	1	0.2887	947.8	0.3725
	860.4	3.600	1	3414	1.341
	0.252	1.1×10^{-3}	2.9×10^{-4}	1	3.9×10^{-4}
	641.6	2.685	0.7457	2546	1

Conversion factors

Power

Unit (symbol)	watt (W or J/s)	kilowatt (kW)	metric horse-power (CV)	foot-pound per second (ft.lbf/s)	horse-power (hp)	British Thermal Units per minute (BTU/min)
	1	0.001	1.4×10^{-3}	0.7376	1.3×10^{-3}	0.0569
	1000	1	1.360	737.6	1.341	56.9
	735	0.735	1	558	1.014	41.8
	1.356	1.4×10^{-3}	1.8×10^{-3}	1	1.8×10^{-3}	0.077
	746	0.746	0.9860	550	1	42.44
	17.57	0.0176	0.0239	12.96	0.0236	1

Power flux

Unit (symbol)	watts per square metre (W/m^2)	kilowatts per square metre (kW/m^2)	horsepower per square foot (hp/ft^2)
	1	0.001	1.2×10^{-4}
	1000	1	0.1246
	8023	8.023	1

Calorific value (heat of combustion)

Unit (symbol)	calories per gram (cal/g)	megajoules per kilogram (MJ/kg)	British thermal units per pound (BTU/lb)
	1	4.2×10^{-3}	1.8
	239	1	430
	0.556	2.3×10^{-3}	1

Density (specific mass) and (net) calorific value (heat of combustion) of fuels

	Density (kg/m^3)	Calorific value (MJ/kg)
LPG	560	45.3
Gasoline (petrol)	720	44.0
Kerosene	806	43.1
Diesel oil	850	42.7
Fuel oil	961	40.1
Wood, oven-dried	varies	16–20
Natural gas	—	$103 m^3$ at 1013 mbar, 0°C = 39.36×10^9 J

NB These values are approximate since the fuels vary in composition and this affects both the density and calorific value.

Replacement values

When trying to compare different fuel options, energy planners often use replacement values, which indicate in a specific situation how much fuel it would take to replace another one. For example, the tonne coal equivalent (tce) would be used to say how much coal it would take to replace a given quanity of oil or natural gas. The table below gives some of the most common equivalence values.

Fuel	Unit	Tonnes of coal equivalent (tce)	Tonnes of oil equivalent (toe)	Barrels of oil equivalent (boe)	GJ*
Coal	tonne	1.00	0.70	5.05	29.3**
Firewood (air-dried)	tonne	0.46	0.32	2.34	13.6
Kerosene	tonne	1.47	1.03	7.43	43.1
Natural gas	$1000 m^3$	1.19	0.83	6.00	34.8
Gasoline (petrol)	barrel***	0.18	0.12	0.90	5.2
Gasoil/diesel	barrel***	0.20	0.14	1.00	5.7

* GJ/tonne is numerically equivalent to MJ/kg

** The energy content of 1 tce and 1 toe varies. The values used here are the European Community norms: 1 tce = 29.31×10^9 J and 1 toe = 41.868×10^9 J

*** 1 barrel of oil = 42 US gallons = $0.158987 m^3$

Conversion factors

Power equivalents

	Mtoe/yr	*Mbd*	*Mtce/yr*	GW_{th}	*PJ/yr*
Mtoe/yr	1	0.02	1.55	1.43	45
Mbd	50	1	77	71	2235
Mtce/yr	0.65	0.013	1	0.92	29
GW_{th}	0.70	0.014	1.09	1	32
PJ/yr	0.02	4.5×10^{-4}	0.034	0.031	1

Mtoe/yr = Million tonnes of oil per year
Mbd = Million barrels of oil per day
Mtce/yr = Million tonnes of coal equivalent per year
GW_{th} = Gigawatts thermal (see page 203 for further information)
PJ/yr = Petrajoules per year

Conversions: length

Use of the table: the number of inches to be converted, which is made up by the number of inches at the head of a column and the fraction at the side of a line, is converted to the number in the position where line and column meet.
For example, 1 1/64 in = 1 in + 1/64 in = 25.797 mm

Inches and fractions of an inch to Millimetres 1 in = 25.4 mm

in → ↓	0	1	2	3	4	5	6	7	8	9	10	11	← in ↓
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	254.000	279.400	0
1/64	0.397	25.797	51.197	76.597	101.997	127.397	152.797	178.197	203.597	228.997	254.397	279.797	1/64
1/32	0.794	26.194	51.594	76.994	102.394	127.794	153.194	178.594	203.994	229.394	254.794	280.194	1/32
3/64	1.191	26.591	51.991	77.391	102.791	128.191	153.591	178.991	204.391	229.791	255.191	280.591	3/64
1/16	1.588	26.988	52.388	77.788	103.188	128.588	153.988	179.388	204.788	230.188	255.588	280.988	1/16
5/64	1.984	27.384	52.784	78.184	103.584	128.984	154.384	179.784	205.184	230.584	255.984	281.384	5/64
3/32	2.381	27.781	53.181	78.581	103.981	129.381	154.781	180.181	205.581	230.981	256.381	281.781	3/32
7/64	2.778	28.178	53.578	78.978	104.378	129.778	155.178	180.578	205.978	231.378	256.778	282.178	7/64
1/8	3.175	28.575	53.975	79.375	104.775	130.175	155.575	180.975	206.375	231.775	257.175	282.575	1/8
9/64	3.572	28.972	54.372	79.772	105.172	130.572	155.972	181.372	206.772	232.172	257.572	282.972	9/64
5/32	3.969	29.369	54.769	80.169	105.569	130.969	156.369	181.769	207.169	232.569	257.969	283.369	5/32
11/64	4.366	29.766	55.166	80.566	105.966	131.366	156.766	182.166	207.566	232.966	258.366	283.766	11/64
3/16	4.762	30.162	55.562	80.962	106.362	131.762	157.162	182.562	207.962	233.362	258.762	284.162	3/16
13/64	5.159	30.559	55.959	81.359	106.759	132.159	157.559	182.959	208.359	233.759	259.159	284.559	13/64
7/32	5.556	30.956	56.356	81.756	107.156	132.556	157.956	183.356	208.756	234.156	259.556	284.956	7/32
15/64	5.953	31.353	56.753	82.153	107.553	132.953	158.353	183.753	209.153	234.553	259.953	285.353	15/64
1/4	6.350	31.750	57.150	82.550	107.950	133.350	158.750	184.150	209.550	234.950	260.350	285.750	1/4
17/64	6.747	32.147	57.547	82.947	108.347	133.747	159.147	184.547	209.947	235.347	260.747	286.147	17/64
9/32	7.144	32.544	57.944	83.344	108.744	134.144	159.544	184.944	210.344	235.744	261.144	286.544	9/32
19/64	7.541	32.941	58.341	83.741	109.141	134.541	159.941	185.341	210.741	236.141	261.541	286.941	19/64
5/16	7.938	33.338	58.738	84.138	109.538	134.938	160.338	185.738	211.138	236.538	261.938	287.338	5/16
21/64	8.334	33.734	59.134	84.534	109.934	135.334	160.734	186.134	211.534	236.934	262.334	287.734	21/64
11/32	8.731	34.131	59.531	84.931	110.331	135.731	161.131	186.531	211.931	237.331	262.731	288.131	11/32
23/64	9.128	34.528	59.928	85.328	110.728	136.128	161.528	186.928	212.328	237.728	263.128	288.528	23/64
3/8	9.525	34.925	60.325	85.725	111.125	136.525	161.925	187.325	212.725	238.125	263.525	288.925	3/8
25/64	9.922	35.322	60.722	86.122	111.522	136.922	162.322	187.722	213.122	238.522	263.922	289.322	25/64
13/32	10.319	35.719	61.119	86.519	111.919	137.319	162.719	188.119	213.519	238.919	264.319	289.719	13/32
27/64	10.716	36.116	61.516	86.916	112.316	137.716	163.116	188.516	213.916	239.316	264.716	290.116	27/64
7/16	11.112	36.512	61.912	87.312	112.712	138.112	163.512	188.912	214.312	239.712	265.112	290.512	7/16
29/64	11.509	36.909	62.309	87.709	113.109	138.509	163.909	189.309	214.709	240.109	265.509	290.909	29/64
15/32	11.906	37.306	62.706	88.106	113.506	138.906	164.306	189.706	215.106	240.506	265.906	291.306	15/32
31/64	12.303	37.703	63.103	88.503	113.903	139.303	164.703	190.103	215.503	240.903	266.303	291.703	31/64
1/2	12.700	38.100	63.500	88.900	114.300	139.700	165.100	190.500	215.900	241.300	266.700	292.100	1/2
33/64	13.097	38.497	63.897	89.297	114.697	140.097	165.497	190.897	216.297	241.697	267.097	292.497	33/64
17/32	13.494	38.894	64.294	89.694	115.094	140.494	165.894	191.294	216.694	242.094	267.494	292.894	17/32
35/64	13.891	39.291	64.691	90.091	115.491	140.891	166.291	191.691	217.091	242.491	267.891	293.291	35/64
9/16	14.288	39.688	65.088	90.488	115.888	141.288	166.688	192.088	217.488	242.888	268.288	293.688	9/16
37/64	14.684	40.084	65.484	90.884	116.284	141.684	167.084	192.484	217.884	243.284	268.684	294.084	37/64
19/32	15.081	40.481	65.881	91.281	116.681	142.081	167.481	192.881	218.281	243.681	269.081	294.481	19/32
39/64	15.478	40.878	66.278	91.678	117.078	142.478	167.878	193.278	218.678	244.078	269.478	294.878	39/64
5/8	15.875	41.275	66.675	92.075	117.475	142.875	168.275	193.675	219.075	244.475	269.875	295.275	5/8
41/64	16.272	41.672	67.072	92.472	117.872	143.272	168.672	194.072	219.472	244.872	270.272	295.672	41/64
21/32	16.669	42.069	67.469	92.869	118.269	143.669	169.069	194.469	219.869	245.269	270.669	296.069	21/32
43/64	17.066	42.466	67.866	93.266	118.666	144.066	169.466	194.866	220.266	245.666	271.066	296.466	43/64
11/16	17.462	42.862	68.262	93.662	119.062	144.462	169.862	195.262	220.662	246.062	271.462	296.862	11/16
45/64	17.859	43.259	68.659	94.059	119.459	144.859	170.259	195.659	221.059	246.459	271.859	297.259	45/64
23/32	18.256	43.656	69.056	94.456	119.856	145.256	170.656	196.056	221.456	246.856	272.256	297.656	23/32
47/64	18.653	44.053	69.453	94.853	120.253	145.653	171.053	196.453	221.853	247.253	272.653	298.053	47/64
3/4	19.050	44.450	69.850	95.250	120.650	146.050	171.450	196.850	222.250	247.650	273.050	298.450	3/4
49/64	19.447	44.847	70.247	95.647	121.047	146.447	171.847	197.247	222.647	248.047	273.447	298.847	49/64
25/32	19.844	45.244	70.644	96.044	121.444	146.844	172.244	197.644	223.044	248.444	273.844	299.244	25/32
51/64	20.241	45.641	71.041	96.441	121.841	147.241	172.641	198.041	223.441	248.841	274.241	299.641	51/64
13/16	20.638	46.038	71.438	96.838	122.238	147.638	173.038	198.438	223.838	249.238	274.638	300.038	13/16
53/64	21.034	46.434	71.834	97.234	122.634	148.034	173.434	198.834	224.234	249.634	275.034	300.434	53/64
27/32	21.431	46.831	72.231	97.631	123.031	148.431	173.831	199.231	224.631	250.031	275.431	300.831	27/32
55/64	21.828	47.228	72.628	98.028	123.428	148.828	174.228	199.628	225.028	250.428	275.828	301.228	55/64
7/8	22.225	47.625	73.025	98.425	123.825	149.225	174.625	200.025	225.425	250.825	276.225	301.625	7/8
57/64	22.622	48.022	73.422	98.822	124.222	149.622	175.022	200.422	225.822	251.222	276.622	302.022	57/64
29/32	23.019	48.419	73.819	99.219	124.619	150.019	175.419	200.819	226.219	251.619	277.019	302.419	29/32
59/64	23.416	48.816	74.216	99.616	125.016	150.416	175.816	201.216	226.616	252.016	277.416	302.816	59/64
15/16	23.812	49.212	74.612	100.012	125.412	150.812	176.212	201.612	227.012	252.412	277.812	303.212	15/16
61/64	24.209	49.609	75.009	100.409	125.809	151.209	176.609	202.009	227.409	252.809	278.209	303.609	61/64
31/32	24.606	50.006	75.406	100.806	126.206	151.606	177.006	202.406	227.806	253.206	278.606	304.006	31/32
63/64	25.003	50.403	75.803	101.203	126.603	152.003	177.403	202.803	228.203	253.603	279.003	304.403	63/64

Use of the tables: the number to be converted, which is made up by adding
the unit at the side of a line to the unit at the head of a column,
is converted to the number in the position where line and column meet.
For example, 11 in = 10 in + 1 in = 279.400 mm

Inches to Millimetres 1 in = 25.4 mm

Note. This table can also be used for converting milli-inches (mils or 'thou') to micrometres ('microns')

in →	0	1	2	3	4	5	6	7	8	9	← in
↓	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	↓
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	0
10	254.000	279.400	304.800	330.200	355.600	381.000	406.400	431.800	457.200	482.600	10
20	508.000	533.400	558.800	584.200	609.600	635.000	660.400	685.800	711.200	736.600	20
30	762.000	787.400	812.800	838.200	863.600	889.000	914.400	939.800	965.200	990.600	30
40	1016.000	1041.400	1066.800	1092.200	1117.600	1143.000	1168.400	1193.800	1219.200	1244.600	40
50	1270.000	1295.400	1320.800	1346.200	1371.600	1397.000	1422.400	1447.800	1473.200	1498.600	50
60	1524.000	1549.400	1574.800	1600.200	1625.600	1651.000	1676.400	1701.800	1727.200	1752.600	60
70	1778.000	1803.400	1828.800	1854.200	1879.600	1905.000	1930.400	1955.800	1981.200	2006.600	70
80	2032.000	2057.400	2082.800	2108.200	2133.600	2159.000	2184.400	2209.800	2235.200	2260.600	80
90	2286.000	2311.400	2336.800	2362.200	2387.600	2413.000	2438.400	2463.800	2489.200	2514.600	90
100	2540.000										100

in →	0	10	20	30	40	50	60	70	80	90	← in
↓	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	↓
0	0.000	254.000	508.000	762.000	1016.000	1270.000	1524.000	1778.000	2032.000	2286.000	0
100	2540.000	2794.000	3048.000	3302.000	3556.000	3810.000	4064.000	4318.000	4572.000	4826.000	100
200	5080.000	5334.000	5588.000	5842.000	6096.000	6350.000	6604.000	6858.000	7112.000	7366.000	200
300	7620.000	7874.000	8128.000	8382.000	8636.000	8890.000	9144.000	9398.000	9652.000	9906.000	300
400	10160.000	10414.000	10668.000	10922.000	11176.000	11430.000	11684.000	11938.000	12192.000	12446.000	400
500	12700.000	12954.000	13208.000	13462.000	13716.000	13970.000	14224.000	14478.000	14732.000	14986.000	500
600	15240.000	15494.000	15748.000	16002.000	16256.000	16510.000	16764.000	17018.000	17272.000	17526.000	600
700	17780.000	18034.000	18288.000	18542.000	18796.000	19050.000	19304.000	19558.000	19812.000	20066.000	700
800	20320.000	20574.000	20828.000	21082.000	21336.000	21590.000	21844.000	22098.000	22352.000	22606.000	800
900	22860.000	23114.000	23368.000	23622.000	23876.000	24130.000	24384.000	24638.000	24892.000	25146.000	900
1000	25400.000										1000

Millimetres to Inches 1 mm = 0.039 370 in

Note. This table can also be used for converting micrometres ('microns') to milli-inches (mils or 'thou')

mm →	0	1	2	3	4	5	6	7	8	9	← mm
↓	in	in	in	in	in	in	in	in	in	in	↓
0	0.000	0.039	0.079	0.118	0.157	0.197	0.236	0.276	0.315	0.354	0
10	0.394	0.433	0.472	0.512	0.551	0.591	0.630	0.669	0.709	0.748	10
20	0.787	0.827	0.866	0.906	0.945	0.984	1.024	1.063	1.102	1.142	20
30	1.181	1.220	1.260	1.299	1.339	1.378	1.417	1.457	1.496	1.535	30
40	1.575	1.614	1.654	1.693	1.732	1.772	1.811	1.850	1.890	1.929	40
50	1.969	2.008	2.047	2.087	2.126	2.165	2.205	2.244	2.283	2.323	50
60	2.362	2.402	2.441	2.480	2.520	2.559	2.598	2.638	2.677	2.717	60
70	2.756	2.795	2.835	2.874	2.913	2.953	2.992	3.031	3.071	3.110	70
80	3.150	3.189	3.228	3.268	3.307	3.346	3.386	3.425	3.465	3.504	80
90	3.543	3.583	3.622	3.661	3.701	3.740	3.780	3.819	3.858	3.898	90
100	3.937										100

mm →	0	10	20	30	40	50	60	70	80	90	← mm
↓	in	in	in	in	in	in	in	in	in	in	↓
0	0.000	0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543	0
100	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.693	7.087	7.480	100
200	7.874	8.268	8.661	9.055	9.449	9.843	10.236	10.630	11.024	11.417	200
300	11.811	12.205	12.598	12.992	13.386	13.780	14.173	14.567	14.961	15.354	300
400	15.748	16.142	16.535	16.929	17.323	17.717	18.110	18.504	18.898	19.291	400
500	19.685	20.079	20.472	20.866	21.260	21.654	22.047	22.441	22.835	23 228	500
600	23.622	24.016	24.409	24.803	25.197	25.591	25.984	26.378	26.772	27.165	600
700	27.559	27.953	28.346	28.740	29.134	29.528	29.921	30.315	30.709	31.102	700
800	31.496	31.890	32.283	32.677	33.071	33.465	33.858	34.252	34.646	35.039	800
900	35.433	35.827	36.220	36.614	37.008	37.402	37.795	38.189	38.583	38.976	900
1000	39.370										1000

Conversions: length

Use of the tables: the number to be converted, which is made up by adding the unit at the side of a line to the unit at the head of a column, is converted to the number in the position where line and column meet. For example, 11 in = 10 in + 1 in = 27.940 cm

Inches to Centimetres   1 in = 2.54 cm

in → ↓	0	1	2	3	4	5	6	7	8	9	← in ↓
	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	
0	0.000	2.540	5.080	7.620	10.160	12.700	15.240	17.780	20.320	22.860	0
10	25.400	27.940	30.480	33.020	35.560	38.100	40.640	43.180	45.720	48.260	10
20	50.800	53.340	55.880	58.420	60.960	63.500	66.040	68.580	71.120	73.660	20
30	76.200	78.740	81.280	83.820	86.360	88.900	91.440	93.980	96.520	99.060	30
40	101.600	104.140	106.680	109.220	111.760	114.300	116.840	119.380	121.920	124.460	40
50	127.000	129.540	132.080	134.620	137.160	139.700	142.240	144.780	147.320	149.860	50
60	152.400	154.940	157.480	160.020	162.560	165.100	167.640	170.180	172.720	175.260	60
70	177.800	180.340	182.880	185.420	187.960	190.500	193.040	195.580	198.120	200.660	70
80	203.200	205.740	208.280	210.820	213.360	215.900	218.440	220.980	223.520	226.060	80
90	228.600	231.140	233.680	236.220	238.760	241.300	243.840	246.380	248.920	251.460	90
100	254.000										100

in → ↓	0	10	20	30	40	50	60	70	80	90	← in ↓
	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	0
100	254.000	279.400	304.800	330.200	355.600	381.000	406.400	431.800	457.200	482.600	100
200	508.000	533.400	558.800	584.200	609.600	635.000	660.400	685.800	711.200	736.600	200
300	762.000	787.400	812.800	838.200	863.600	889.000	914.400	939.800	965.200	990.600	300
400	1016.000	1041.400	1066.800	1092.200	1117.600	1143.000	1168.400	1193.800	1219.200	1244.600	400
500	1270.000	1295.400	1320.800	1346.200	1371.600	1397.000	1422.400	1447.800	1473.200	1498.600	500
600	1524.000	1549.400	1574.800	1600.200	1625.600	1651.000	1676.400	1701.800	1727.200	1752.600	600
700	1778.000	1803.400	1828.800	1854.200	1879.600	1905.000	1930.400	195 .800	1981.200	2006.600	700
800	2032.000	2057.400	2082.800	2108.200	2133.600	2159.000	2184.400	2209.800	2235.200	2260.600	800
900	2286.000	2311.400	2336.800	2362.200	2387.600	2413.000	2438.400	2463.800	2489.200	2514.600	900
1000	2540.000										1000

Centimetres to Inches   1 cm = 0.393 701 in

cm → ↓	0	1	2	3	4	5	6	7	8	9	← cm ↓
	in	in	in	in	in	in	in	in	in	in	
0	0.000	0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543	0
10	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.693	7.087	7.480	10
20	7.874	8.268	8.661	9.055	9.449	9.843	10.236	10.630	11.024	11.417	20
30	11.811	12.205	12.598	12.992	13.386	13.780	14.173	14.567	14.961	15.354	30
40	15.748	16.142	16.535	16.929	17.323	17.717	18.110	18.504	18.898	19.291	40
50	19.685	20.079	20.472	20.866	21.260	21.654	22.047	22.441	22.835	23.228	50
60	23.622	24.016	24.409	24.803	25.197	25.591	25.984	26.378	26.772	27.165	60
70	27.559	27.953	28.346	28.740	29.134	29.528	29.921	30.315	30.709	31.102	70
80	31.496	31.890	32.283	32.677	33.071	33.465	33.858	34.252	34.646	35.039	80
90	35.433	35.827	36.220	36.614	37.008	37.402	37.795	38.189	38.583	38.976	90
100	39.370										100

cm → ↓	0	10	20	30	40	50	60	70	80	90	← cm ↓
	in	in	in	in	in	in	in	in	in	in	
0	0.000	3.937	7.874	11.811	15.748	19.685	23.622	27.559	31.496	35.433	0
100	39.370	43.307	47.244	51.181	55.118	59.055	62.992	66.929	70.866	74.803	100
200	78.740	82.677	86.614	90.551	94.488	98.425	102.362	106.299	110.236	114.173	200
300	118.110	122.047	125.984	129.921	133.858	137.795	141.732	145.669	149.606	153.543	300
400	157.480	161.417	165.354	169.291	173.228	177.165	181.102	185.039	188.976	192.913	400
500	196.850	200.787	204.724	208.661	212.598	216.535	220.472	224.409	228.346	232.283	500
600	236.220	240.157	244.094	248.031	251.969	255.906	259.843	263.780	267.717	271.654	600
700	275.591	279.528	283.465	287.402	291.339	295.276	299.213	303.150	307.087	311.024	700
800	314.961	318.898	322.835	326.772	330.709	334.646	338.583	342.520	346.457	350.394	800
900	354.331	358.268	362.205	366.142	370.079	374.016	377.953	381.890	385.827	389.764	900
1000	393.701										1000

Fractions to Decimals

Fraction	Decimal equivalent	Fraction	Decimal equivalent
1/2	0.5	1/32	0.031 25
1/3	0.333 333	1/33	0.030 303
1/4	0.25	1/34	0.029 412
1/5	0.2	1/35	0.028 571
1/6	0.166 667	1/36	0.027 778
1/7	0.142 857	1/37	0.027 027
1/8	0.125	1/38	0.026 316
1/9	0.111 111	1/39	0.025 641
1/10	0.1	1/40	0.025
1/11	0.090 909	1/41	0.024 390
1/12	0.083 333	1/42	0.023 810
1/13	0.076 923	1/43	0.023 256
1/14	0.071 429	1/44	0.022 727
1/15	0.066 667	1/45	0.022 222
1/16	0.062 5	1/46	0.021 739
1/17	0.058 824	1/47	0.021 277
1/18	0.055 556	1/48	0.020 833
1/19	0.052 632	1/49	0.020 408
1/20	0.05	1/50	0.02
1/21	0.047 619	1/51	0.019 608
1/22	0.045 455	1/52	0.019 231
1/23	0.043 478	1/53	0.018 868
1/24	0.041 667	1/54	0.018 519
1/25	0.04	1/55	0.018 182
1/26	0.038 462	1/56	0.017 857
1/27	0.037 037	1/57	0.017 544
1/28	0.035 714	1/58	0.017 241
1/29	0.034 483	1/59	0.016 949
1/30	0.033 333	1/60	0.016 667
1/31	0.032 258		

Note. For the decimal equivalent of other fractions with 1 as numerator, and a number from 0.01 to 100.9 as denominator, see reciprocals, pages 144–147.

Fractions 3rds	6ths	12ths	24ths	Decimal equivalent
			1	0.041 667
		1	2	0.083 333
			3	0.125
	1	2	4	0.166 667
			5	0.208 333
		3	6	0.25
			7	0.291 667
1	2	4	8	0.333 333
			9	0.375
		5	10	0.416 667
			11	0.458 333
	3	6	12	0.5
			13	0.541 667
		7	14	0.583 333
			15	0.625
2	4	8	16	0.666 667
			17	0.708 333
		9	18	0.75
			19	0.791 667
	5	10	20	0.833 333
			21	0.875
		11	22	0.916 667
			23	0.958 333
3	6	12	24	1

Fractions 1/2's	1/4's	8ths	16ths	32nds	64ths	Decimal equivalent (all figures are exact)
					1	0.015 625
				1	2	0.031 25
					3	0.046 875
			1	2	4	0.062 5
					5	0.078 125
				3	6	0.093 75
					7	0.109 375
		1	2	4	8	0.125
					9	0.140 625
				5	10	0.156 25
					11	0.171 875
			3	6	12	0.187 5
					13	0.203 125
				7	14	0.218 75
					15	0.234 375
	1	2	4	8	16	0.25
					17	0.265 625
				9	18	0.281 25
					19	0.296 875
			5	10	20	0.312 5
					21	0.328 125
				11	22	0.343 75
					23	0.359 375
		3	6	12	24	0.375
					25	0.390 625
				13	26	0.406 25
					27	0.421 875
			7	14	28	0.437 5
					29	0.453 125
				15	30	0.468 75
					31	0.484 375
1	2	4	8	16	32	0.5
					33	0.515 625
				17	34	0.531 25
					35	0.546 875
			9	18	36	0.562 5
					37	0.578 125
				19	38	0.593 75
					39	0.609 375
		5	10	20	40	0.625
					41	0.640 625
				21	42	0.656 25
					43	0.671 875
			11	22	44	0.687 5
					45	0.703 125
				23	46	0.718 75
					47	0.734 375
	3	6	12	24	48	0.75
					49	0.765 625
				25	50	0.781 25
					51	0.796 875
			13	26	52	0.812 5
					53	0.828 125
				27	54	0.843 75
					55	0.859 375
		7	14	28	56	0.875
					57	0.890 625
				29	58	0.906 25
					59	0.921 875
			15	30	60	0.937 5
					61	0.953 125
				31	62	0.968 75
					63	0.984 375
2	4	8	16	32	64	1

Triangulation is an application of the principles of trigonometry to the calculation of inaccessible lines and angles. A common occasion for its use is illustrated in Fig. 1, where the line of survey crosses a stream too wide and deep for actual measurement. Set two points *A* and *B* on line, one on each side of the stream. Estimate roughly the distance *A B*. Suppose the estimate is 425 ft. Set another point *C*, making the distance *A C* equal to the estimated distance *A B* = 425 ft. Set the transit at *A* and measure the angle *B A C* = say, 79° 00′. Next set up at the point *C* and measure the angle *A C B* = say, 56° 20′. The angle *A B C* is then determined by subtracting the sum of the angles *A* and *C* from 180°; thus, 79° 00′ + 56° 20′ = 135° 20′; 180° 00′ − 135° 20′ = 44° 40′ = the angle *A B C*. We now have a side and three angles of a triangle given, to find the other two sides *A B* and *C B*. In trigonometry, it is demonstrated that, *in any triangle the sines of the angles are proportional to the lengths of the sides opposite to them.* In other words, sin *A* : sin *B* = *B C* : *A C*; or, sin *A* : sin *C* = *B C* : *A B*, and sin *B* : sin *C* = *A C* : *A B*.

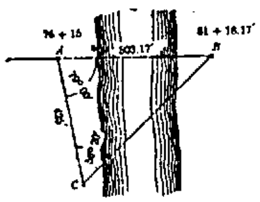


FIG. 1.

Hence, we have sin 44° 40′ : sin 56° 20′ = 425 : side *A B*;

sin 56° 20′ = .83228;

.83228 × 425 = 353.719;

sin 44° 40′ = .70298;

353.719 ÷ .70298 = 503.17 ft. = side *A B*.

Adding this distance to 76 + 15, the station of the point *A*, we have 81 + 18.17, the station at *B*.

Another case is the following: Two tangents, *A B* and *C D* (see Fig. 2), which are to be united by a curve, meet at some inaccessible point *E*. Tangents are the straight portions of a line of railroad. The angle *C E F*, which the tangents make with each other, and the distances *B E* and *C E* are required. Two points *A* and *B* of the tangent *A B*, and two points *C* and *D* of the tangent *C D*, being carefully located, set the transit at *B*, and backsighting to *A*, measure the angle *E B C* = 21° 45′; set up at *C*, and, backsighting to *D*, measure the angle *E C B* = 21° 25′. Measure the side *B C* = 304.2 ft.

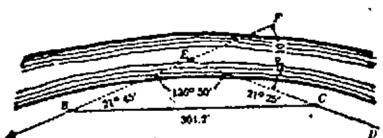


FIG. 2.

Angle *C E F* being an exterior angle of triangle *E B C* equals sum of *E B C* and *E C B* = 21° 45′ + 21° 25′ = 43° 10′; angle *B E C* = 180° − *C E F* = 136° 50′. From trigonometry, we have:

sin 136° 50′ : sin 21° 45′ = 304.2 ft. : *C E*;

sin 21° 45′ = .37056;

.37056 × 304.2 = 112.724352;

sin 136° 50′ = .68412;

side *C E* = 112.724352 ÷ .68412 = 164.77 ft.

Again, we find *B E* by the following proportion:

sin 136° 50′ : sin 21° 25′ = 304.2 : side *B E*;

sin 21° 25′ = .36515;

.36515 × 304.2 = 111.07863;

sin 136° 50′ = .68412;

side *B E* = 111.07863 ÷ .68412 = 162.36 ft.

A building *H*, Fig. 3, lies directly in the path of the line *A B*, which must be produced beyond *H*. Set a plug at *B*, and then turn an angle *D B C* = 60°. Set a plug at *C* in the line *B C*, at a suitable distance from *B*, say, 150 ft. Set up at *C*, and turn an angle *B C D* = 60°, and set a plug at *D*, 150 ft. from *C*. The point *D* will be in the prolongation of *A B*. Then, set up at *D*, and backsighting to *C*, turn the angle *C D D′* = 120°. *D D′* will be the line required, and the distance *B D* will be 150 ft., since *B C D* is an equilateral triangle.

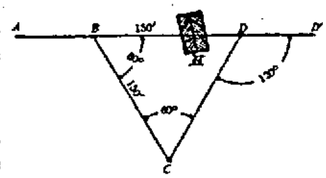


FIG. 3.

A B and *C D*, Fig. 4, are tangents intersecting at some inaccessible point *H*. The line *A B* crosses a dock *O P*, too wide for direct measurement, and the wharf *L M*. *F* is a point on the line *A B* at the wharf crossing. It is required to find the distance *B H* and the angle *F H G*. At *B*, an angle of 103° 30′ is turned to the left and the point *E* set 217′ from *B* = to the estimated distance *B F*. Setting up at *E*, the angle *B E F* is found to be 39° 00′.

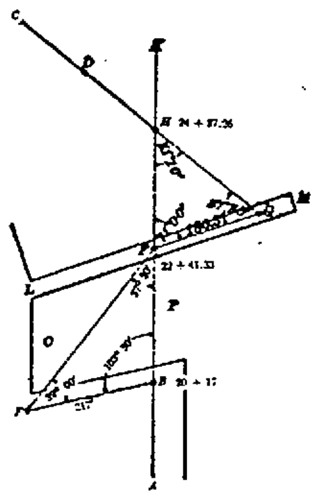


FIG. 4.

Whence, we find the angle *B F E* = 180° − (103° 30′ + 39°) = 37° 30′.

From trigonometry, we have

sin 37° 30′ : sin 39° 00′ = 217 ft. : side *B F*;

sin 39° 00′ = .62932;

.62932 × 217 = 136.56244;

sin 37° 30′ = .60876;

side *B F* = 136.56244 ÷ .60876 = 224.33 ft.

Whence, we find station *F* to be 20 + 17 + 224.33 = 22 + 41.33. Set up at *F* and turn an angle *H F G* = 71° 00′ and set up at a point *G* where the line *C D* prolonged intersects *F G*. Measure the angle *F G H* = 57° 50′, and the side *F G* = 180.3. The angle *F H G* = 180° − (71° + 57° 50′) = 51° 10′. From trigonometry we have

sin 51° 10′ : sin 57° 50′ = 180.3 : side *F H*.

Sin 57° 50′ = .84650; .84650 × 180.3 = 152.62395; sin 51° 10′ = .77897; side *F H* = 152.62395 ÷ .77897 = 195.93 ft.; whence we find station *H* to be 24 + 37.26.

x	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Δ	ADD 1′	2′	3′	4′	5′
	0°·0	0°·1	0°·2	0°·3	0°·4	0°·5	0°·6	0°·7	0°·8	0°·9						
0°	0·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	18	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332		3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506		3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680		3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854		3	6	9	12	14
5	0·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028		3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201		3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374		3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547		3	6	9	11	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719		3	6	9	11	14
10	0·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891		3	6	9	11	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062		3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	17	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402		3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571		3	6	8	11	14
15	0·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740		3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907		3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074		3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239		3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404		3	5	8	11	14
20	0·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567		3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730		3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891		3	5	8	11	13
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	16	3	5	8	11	13
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210		3	5	8	11	13
25	0·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368		3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524		3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679		3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833		3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985		3	5	8	10	13
30	0·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	15	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284		2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432		2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577		2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721		2	5	7	10	12
35	0·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864		2	5	7	9	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	14	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143		2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280		2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414		2	4	7	9	11
40	0·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547		2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	13	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807		2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934		2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059		2	4	6	8	10
45	0·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181		2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	12	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420		2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536		2	4	6	8	10
49	0·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649		2	4	6	8	9

O
H

x	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Δ	ADD				
	0°·0	0°·1	0°·2	0°·3	0°·4	0°·5	0°·6	0°·7	0°·8	0°·9		1′	2′	3′	4′	5′
50°	0·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760		2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	11	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976		2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080		2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	10	2	3	5	7	8
55	0·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281		2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377		2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471		2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	9	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652		1	3	4	6	7
60	0·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738		1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821		1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	8	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980		1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056		1	3	4	5	6
65	0·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128		1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	7	1	2	4	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265		1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330		1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	6	1	2	3	4	5
70	0·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449		1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505		1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558		1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	5	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655		1	2	2	3	4
75	0·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699		1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	4	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778		1	1	2	2	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813		1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845		1	1	2	2	3
80	0·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	3	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900		0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923		0	1	1	1	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	2	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960		0	1	1	1	1
85	0·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974		0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	1	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993		See Table below.				
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998						
89	0·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000						
90	1·0000															

Sines of Angles near 90°

° ′	sine	°	° ′	sine	°
86 48		86·80	87 46		87·7
	0·9985			0·9993	
86 54		86·91	87 56		87·9
	0·9986			0·9994	
87 01		87·02	88 05		88·0
	0·9987			0·9995	
87 08		87·13	88 16		88·2
	0·9988			0·9996	
87 15		87·25	88 29		88·4
	0·9989			0·9997	
87 22		87·37	88 43		88·7
	0·9990			0·9998	
87 30		87·50	89 00		89·0
	0·9991			0·9999	
87 38		87·63	89 25		89·4
	0·9992			1·0000	
87 46		87·78	90 00		90·0

The values in the centre columns represent the sines for all angles lying between the successive ranges shown in the outer columns. Thus sin 87° 20′ is 0·9989. For inverse use, the best angle for a given sine is the one lying midway between the adjacent ranges; if the difference is odd, choose the angle nearer 90°. Thus if sin x = 0·9988, x = 87° 12′.

For tabulated angles read the sine value in the half-line above; e.g., sin 87° 38′ = 0·9991.

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	SUBTRACT 1′	2′	3′	4′	5′
0°	1·000	1·000	1·000	1·000	1·000	1·000	0·9999	0·9999	0·9999	0·9999	·	See table at foot of page.				
1	0·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995						
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987						
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	1	0	0	1	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963		0	0	1	1	1
5	0·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947		0	1	1	1	1
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	2	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905		0	1	1	1	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880		0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	3	0	1	1	2	2
10	0·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820		1	1	2	2	3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785		1	1	2	2	3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748		1	1	2	2	3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	4	1	1	2	3	3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664		1	1	2	3	4
15	0·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617		1	2	2	3	4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	5	1	2	2	3	4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516		1	2	3	3	4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461		1	2	3	4	5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403		1	2	3	4	5
20	0·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	6	1	2	3	4	5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278		1	2	3	4	5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212		1	2	3	4	6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	7	1	2	4	5	6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070		1	2	4	5	6
25	0·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996		1	3	4	5	6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918		1	3	4	5	6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	8	1	3	4	5	7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755		1	3	4	6	7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669		1	3	4	6	7
30	0·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581		1	3	4	6	7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	9	2	3	5	6	8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396		2	3	5	6	8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300		2	3	5	6	8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202		2	3	5	7	8
35	0·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	10	2	3	5	7	8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997		2	3	5	7	9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891		2	4	5	7	9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	11	2	4	5	7	9
39	0·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672		2	4	6	7	9

Cosines of Small Angles

° ′	cosine	°	° ′	cosine	°
0 00		0·0	2 13		2·21
	1·0000			0·9992	
0 34		0·5	2 21		2·36
	0·9999			0·9991	
0 59		0·9	2 29		2·49
	0·9998			0·9990	
1 16		1·2	2 37		2·62
	0·9997			0·9989	
1 30		1·5	2 44		2·74
	0·9996			0·9988	
1 43		1·7	2 51		2·86
	0·9995			0·9987	
1 54		1·9	2 58		2·97
	0·9994			0·9986	
2 03		2·0	3 05		3·08
	0·9993			0·9985	
2 13		2·2	3 11		3·19

This table is similar to that given for sines on page 15; thus

cos 2° 40′ = 0·9989
0·9986 = cos 3° 2′

A
H.

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	SUBTRACT 1′	2′	3′	4′	5′
40°	0·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559		2	4	6	8	9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443		2	4	6	8	10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325		2	4	6	8	10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	12	2	4	6	8	10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083		2	4	6	8	10
45	0·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959		2	4	6	8	10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833		2	4	6	8	11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704		2	4	6	9	11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	13	2	4	7	9	11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441		2	4	7	9	11
50	0·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307		2	4	7	9	11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170		2	5	7	9	11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032		2	5	7	9	12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	14	2	5	7	9	12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750		2	5	7	9	12
55	0·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606		2	5	7	10	12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461		2	5	7	10	12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314		2	5	7	10	12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165		2	5	7	10	12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	15	3	5	8	10	13
60	0·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863		3	5	8	10	13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710		3	5	8	10	13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555		3	5	8	10	13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399		3	5	8	10	13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242		3	5	8	11	13
65	0·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083		3	5	8	11	13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	16	3	5	8	11	13
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762		3	5	8	11	13
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600		3	5	8	11	14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437		3	5	8	11	14
70	0·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272		3	5	8	11	14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107		3	6	8	11	14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940		3	6	8	11	14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773		3	6	8	11	14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605		3	6	8	11	14
75	0·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436		3	6	8	11	14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267		3	6	8	11	14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	17	3	6	9	11	14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925		3	6	9	11	14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754		3	6	9	11	14
80	0·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582		3	6	9	11	14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409		3	6	9	11	14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236		3	6	9	12	14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063		3	6	9	12	14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889		3	6	9	12	14
85	0·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715		3	6	9	12	14
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541		3	6	9	12	15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366		3	6	9	12	15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192		3	6	9	12	15
89	0·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	18	3	6	9	12	15
90	0·0000															

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	ADD 1′	2′	3′	4′	5′
0°	0·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	18	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332		3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507		3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682		3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857		3	6	9	12	15
5	0·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033		3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210		3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388		3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566		3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745		3	6	9	12	15
10	0·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926		3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107		3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290		3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475		3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661		3	6	9	12	15
15	0·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849		3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	19	3	6	10	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230		3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424		3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620		3	7	10	13	16
20	0·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	20	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020		3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224		3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431		3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	21	4	7	11	14	18
25	0·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856		4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	22	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295		4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520		4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	23	4	8	12	15	19
30	0·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985		4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	24	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469		4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	25	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976		4	9	13	17	21
35	0·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	26	4	9	13	17	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	27	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	28	5	9	14	19	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069		5	10	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	29	5	10	15	19	24
40	0·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	30	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	31	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	32	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	33	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	34	6	11	17	23	28
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	36	6	12	18	24	30
46	·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	37	6	12	18	25	31
47	·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	38	6	13	19	25	32
48	·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	40	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708					41	7	14	20	27	34
						1708	1750	1792	1833	1875	42	7	14	21	28	35

O / A.

x	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Δ	ADD 1′	2′	3′	4′	5′
	0°·0	0°·1	0°·2	0°·3	0°·4	0°·5	0°·6	0°·7	0°·8	0°·9						
50°	1·192	196	200	205	209	213	217	222	226	230		1	1	2	3	4
51	·235	239	244	248	253	257	262	266	271	275		1	2	2	3	4
52	·280	285	289	294	299	303	308	313	317	322		1	2	2	3	4
53	·327	332	337	342	347	351	356	361	366	371		1	2	2	3	4
54	·376	381	387	392	397	402	407	412	418	423	5	1	2	3	3	4
55	1·428	433	439	444	450	455	460	466	471	477		1	2	3	4	5
56	·483	488	494	499	505	511	517	522	528	534		1	2	3	4	5
57	·540	546	552	558	564	570	576	582	588	594	6	1	2	3	4	5
58	·600	607	613	619	625	632	638	645	651	658		1	2	3	4	5
59	·664	671	678	684	691	698	704	711	718	725		1	2	3	5	6
60	1·732	739	746	753	760	767	775	782	789	797	7	1	2	4	5	6
61	·804	811	819	827	834	842	849	857	865	873		1	3	4	5	6
62	·881	889	897	905	913	921	929	937	946	954	8	1	3	4	5	7
63	1·963	971	980	988	1·997	2·006	2·014	2·023	2·032	2·041		1	3	4	6	7
64	2·050	059	069	078	087	097	106	116	125	135	9	2	3	5	6	8
65	2·145	154	164	174	184	194	204	215	225	236	10	2	3	5	7	8
66	·246	257	267	278	289	300	311	322	333	344	11	2	4	6	7	9
67	·356	367	379	391	402	414	426	438	450	463	12	2	4	6	8	10
68	·475	488	500	513	526	539	552	565	578	592	13	2	4	6	9	11
69	·605	619	633	646	660	675	689	703	718	733	14	2	5	7	9	12
70	2·747	762	778	793	808	824	840	856	872	888	16	3	5	8	11	13
71	2·904	921	937	954	971	2·989	3·006	3·024	3·042	3·060	17	3	6	9	11	14
72	3·078	096	115	133	152	3·172					19	3	6	9	13	16
						172	191	211	230	251	20	3	7	10	13	17
73	·271	291	312	333	354	376					21	4	7	10	14	18
						376	398	420	442	465	22	4	7	11	15	18
74	·487	511	534	558	582	606					24	4	8	12	16	20
						606	630	655	681	706	25	4	8	13	17	21
75	3·732	758	785	812	839	867					27	4	9	14	18	22
						867	895	923	952	981	29	5	10	14	19	24
76	4·011	041	071	102	134	4·165					31	5	10	16	21	26
						165	198	230	264	297	33	6	11	17	22	28
77	4·331	366	402	437	474	511					36	6	12	18	24	30
						511	548	586	625	665	39	6	13	19	26	32
78	4·705	745	787	829	872	4·915					42	7	14	21	28	35
						4·915	4·959	5·005	5·050	5·097	46	8	15	23	31	38
79	5·145	193	242	292	343	5·396					50	8	17	25	33	42
						396	449	503	558	614	55	9	18	28	37	46
80	5·671	5·730	5·789	5·850	5·912	5·976						10	20	30	41	51
						5·976	6·041	6·107	6·174	6·243		11	23	34	45	56
81	6·314	6·386	6·460	6·535	6·612	6·691						13	25	38	50	63
						6·691	6·772	6·855	6·940	7·026		14	28	42	57	71
82	7·115	7·207	7·300	7·396	7·495	7·596	7·700	7·806	7·916	8·028						
83	8·144	8·264	8·386	8·513	8·643	8·777	8·915	9·058	9·205	9·357						
84	9·514	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20						
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95						
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46						
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27						
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08						
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0						
90	∞															

Differences vary too rapidly for interpolation by P.P.s. See table on page 22.

P.P.s for differences exceeding 14, if not shown on this page, should be taken from the inside end cover of the book. For angles between 72° and 82° P.P.s based on actual differences should be used.

B: ENERGY. #

Solar:

A: Solenergi. / Sunshine Revolution [book, - video also available]. - Harald N. Røstvik, Stavanger Norway/USA 1991 82-91052-01-8 / 82-91052-03-04 / Video - 82-91052-02-6
B: Pratical Photovoltaics. R.J. Komp, Aatec Pub. Ann Arbor Mich. USA 1981/82 0-937948-02-0
C: Strom aus der Sonne. Bernhard Krieg, Elektor Verlag Aachen Germany 1992 3-928051-05-9
D: Sol.tech.3-7723-7792-0/Sol.anlag.3-7723-4452-6/Sol.energ.3-7723-7932-X Hanus, Franzis' De.
E: Thermische Solarnergie. Müller, Franzis' Verlag 85622 Germany [De.] 1997 3-7723-4622-7
F: Compendium in Solar-cookers & Food-dryers. J. Furze 1996
1: SolEnergiCenter Denmark Tel: +45 43 50 43 50 E-mail - www.solenergi.dk
2: EDRC-Univ. of Cape Town S. Africa E-mails - edrc@engfac.uct.ac.za cha@engfac.uct.ac.za

Wind:

A: Forsøgsmøllen Rapport 1-4. Poul La Cour, Denmark 1900/1903
B: Wind Power for Home & Business. Paul Gipe, Chelsea Green Pub. USA 1993 0-930031-64-4
C: Wind Power Plants. E.Hau, Springer Verlag Berlin Germany 1997/98 3-540-57064-0
D: Windgeneratoren Technik. B.Hanus, Franzis' Verlag 85622 Feld. Germany 1997 3-7723-4712-6
E: Wind-turbine Blade Design and Praxis. J. Furze, 1993/94
F: Compendium in Low-cost Wind-mills. J. Furze, 1993/95

Bio-Mass Energy and Fiber Technology:

1: a: Danish Energy Agency. b: Prof. H. Carlsen Danish Technical University.
c: S. Houmøller E-mail - houmoller@dk-teknik.dk d: Bio-Raf, Bornholm Denmark.
2: Prof. H. Stassen, BTG University of Twente Netherlands.
3: Huub J. Gijzen, IHE Delft University Netherlands. [University Cali Columbia]
4: Prof. T. Reed, Bio-Mass Energy Foundation Golden Co. USA. E-m. ReedTB@Compuserve.com
5: Prof. J.R. Moreira, NEGAWATT/BUN São Paulo SP Brazil Fax: +55 [011] 535 30 77
6: Dr. A. Borroto, CEMA University of Cienfuegos Cuba.
7: Dr. P.R. Rogue, CETA University Santa Clara Cuba. E-mail - ceta@ucentral.quantum.inf.cu
8: Prof. R.H. Williams, Center for Energy & Environmental Studies, Princeton University USA.
A: Biolog. Paths to Self-Reliance. R.E.Anderson, Van Nostrand USA/Sweden 1979 0-442-20329-2
B: Energie aus Bio-Mass. Flaig, Mohr. Springer Verlag Berlin Germany 1994 3-540-57227-9
C: Bioenergy for Development. Woods, Hall. FAO-Rome 1994 92-5-103449-4

Bio-Gas Energy. - [Digesters]:

For Large Systems: - Danish Energy Agency. Copenhagen DK Fax: + 45 3311 4743
For Medium-size Systems: - "Danish Bio-Energi" Issue nr. 28/1996 p.10. - nr. 30/96 p.12. & nr. 32/97 p.10. E-mail - biopress@post4.tele.dk
- Dipl.Ing. E.Schneider/Bundschuh Schillerstr.34,80336 München Ge.
- Prof. H. Stassen, BTG University of Twente Netherlands.
For Small Low-cost Units: - Prof. Zhong, Guangzhou Inst. of Geography China.
[Plastic-bag digesters, & Integrated Farming]. - University of Agriculture & Forestry, Thu Duc HCM City Viet Nam, <http//ourworld.compuserve.com/homepages/utaf> <100013.3330@compuserve.com>
- Dr. Bo Göhl FSP: E-mail - fspzim@harare.iafrica.com
- Dr. E. Murgueitio: E-mail - cipav@cali.cetcol.net.co
- Prof. Preston: E-mail - thomas.preston%sarec%ifs.plants@ox.ac.uk
- F. Dolberg: E-mail - frands@po.ia.dk
- Prof. G. Chan: E-mail - 100075.3511@compuserve.com

Plant-oil Engines for Transport and Power-generation. -[cold-pressed non-refined plant oil]:

1: Elsbett Technologie. Industristr.14, 91161 Hilpoltstein/Mfr. Germany Fax: +49 09174 2111
2: Verein. Werkstätten f. Pflanzenöltech. Hauptstr.33,92342 Freyst.-Sulzk.Fax:+49 09179 90562

Wave Power:

1: Danish Energy Agency. Att. Jan Bünger Tel: + 45 3392 6700 E-mail - jbu@ens.dk
2: Erik Skaarup, Wave Plane Int. Cph. Denmark Tel: + 45 3917 9833 / Univ.of Cork Ireland.
A: Power from the Waves, D. Ross Oxford University Press UK 1981//1995/1997

Water-treatment, HydroPower, Water-pumping - etc.:

1: Prof. Thomas L. Crisman, University of Florida Gainesville Florida USA
2: Prof. P. D. Jenssen, Agricultural University of Norway E-mail - petter.jenssen@itf.nlh.no
3: Beth Josephson, Center for Rest. of Waters Falmouth Ma. USA E-mail - bjosephs@mbl.edu
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5: Alexander Gudimov, Murmansk Marine Biological Inst. Russia E-mail - vladimd@fifo.hsf.no
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7: Aleksandra Drizo, Univ. of Edinburgh Scotland E-mail - a.drizo@sac.ed.ac.uk
8: Prof. Ulo Mander, Institute of Geography Univ. of Tartu Estonia E-mail - ylo@math.ut.ee
A: Field Engineering. F. Longland - [P. Stern, ed.], UK 1936//93 0-903031-68-X
B: Mini HydroPower, T. Jiandong et al. UNESCO/John Wiley & Sons UK 1996 0-471-96264-3
C: Compendium in Hydraulic Ram-pumps. J. Furze, 1995

NB: It should be noted that a comprehensive multimedia program on renewable energy on 3 CD's, is issued by the Danish Technological Institute. E-mail - infove@dti.dk
- The Danish branch organization for heat and ventilation: CD - "Multi-Sol", showing mounting/assembly work processes for solar-collectors. http://www.vvsu.dk
- During 1998, a CD on access to wind-energy info. - should be issued under a common EU project, with as the coordinating Danish partner; - Handelshøjskole in Arhus DK.
- A CD with a database on Renewable Energy is available from UNESCO-Publishing Paris.
- An energy/development CD-library is available from Belgium. E-mail - humanity@innet.be http://www.oneworld.org/globalprojects/humcdrom Also check: - //www.crest.org

Plus: - Rainbow Power Company Catalogue, Ninbin NSW 2480 Australia. Fax: + 61 66 89 11 09.
- Catalogue from Real Goods Co. Ukiah CA 95482-3471 USA. Fax: + 1 707 468 94 86 E-mail - realgood@well.sf.ca.us
- Home Power Journal, Post-box 520 Ashland OR 97520 USA. Fax: + 1 916 475 3179.