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

MODULE 6: HYDRAULIC RAM PUMP SYSTEMS

Acknowledgments

The Department Technology Unit of Warwick University

For this module, the main source of information comes from the DTU of Warwick University and their book “Hydraulic Hydraulic Ram Pumps – A guide to Hydraulic Ram Pump water supply systems”. Their recommendations were adapted to the local context of the province of NTT, Indonesia.

Allowing the use of their experience for training purposes is very much appreciated.

Alternative Indigenous Development Foundation Incorporated

A field visit to AID Foundation in Bacolod, Philippines increased our understanding of Hydraulic Ram Pump Systems design, implementation and important issues to answer.

With their 10 year experience on Hydraulic Ram Pump Systems, they were able to guide us through questions unsolved. Many thanks are due to their team for their welcome, support and collaboration.

ACF – Water, Sanitation and Hygiene Department Soe, Indonesia

This module has been written and illustrated by the ACF mission in Indonesia.

Thanks are due to a curious, innovative and hardworking team in the ACF WASH department of the base of Soe, in the province of East Nusa Tenggara, Indonesia. The research and development of a local design was possible thanks to their work in the field with the communities. This module is written based on their experience.

Initiated and supported by the technical advisor Ludovic Arnout and undertaken by the program manager David Wala, this project was implemented with enthusiasm among all the team.

In the field, Doda Nugroho, Matriks Samloy, Yaret Nenobesi, Adrianus Dambuk, Inyo J. Tallo, Alfred Nenohai, Izul Fitri worked with professionalism to implement the pilot sites.

In the workshop, special thanks are due to Aloysius Jawa Ama for his great spirit, his innovative ideas on producing a local design and for the seriousness and the energy he invested in manufacturing the Hydraulic Ram Pumps.

Thanks also to George Manu for the field surveys and the translation of this module in Indonesian.

Dominique Browne

Table of contents

Contents

Table of figures

Introduction

A technology that avoids constrains of water supplies in rural areas

In many parts of the world, villages are situated above the spring: it does not allow water to flow to compounds by gravity. For example, in East Nusa Tenggara (NTT) province, Indonesia, 70 percent of the population lives upstream the closest source of water. A pump is needed to lift the water from this source to their compound.

Dr. Terry Thomas from the Warwick University, UK explained in 1994 that “whilst in general the power for water-lifting can come from engines, electrical mains, animals, humans or renewable (climatic) sources, in the particular context of rural areas in poor countries the choice is more constrained.

In many such countries:

- There are virtually no rural electrical mains;
- Engines pose problems of both fuelling and maintenance;
- Draught animals may be unavailable or difficult to apply to water lifting; and
- Renewable are erratic, complex and import intensive.”

The Hydraulic Ram Pump (Hydram) stays away from these constrains:

- The source of energy of this technology is the water itself and gravity. It has a low cost maintenance cost;
- It works as long as water is available;
- The pump has very few moving parts that are simple to produce locally and to maintain by the community itself.

A technology to be reintroduced

Dr Terry Thomas followed his explanation on Hydraulic Ram Pumps: “they were invented 200 years ago and are still manufactured in over ten countries. They were once commonplace in Europe, The Americas, Africa and some parts of Asia. They have however been largely displaced by motorized pumping in richer countries, whilst in developing countries their use is concentrated in China, Nepal and Colombia.

Generally, in rural areas of developing countries, this skill has been lost since about 1950, and the intermediaries that used to connect manufacturers to users have disappeared. Old systems lie broken for lack of fairly simple maintenance: new systems are few.”

Even if the Hydram technology is not trivial: designing systems that are reliable, economic and durable (e.g. against flood, theft, silt) takes some experience, it is possible to reintroduce this technology for rural communities and local manufacturers. Skills to manufacture, design, implement and maintain are basic and it is believed that this module will allow technicians to undertake the installation of Hydraulic Ram Pump Systems (RPS).

The development of the RPS is also an opportunity for irrigation which consumes a lot of water. There is a difference between water for agriculture and drinking water: the quality standard is low. It implies that most of the stream could be a potential site for installing a Hydram. The Gravity Fed System (GFS) can avoid the use of pipe which increases the cost efficiency. Moreover, most of the fields are close to the streams (i.e. the difference of altitude is not important) which allows a high volume delivered.

Disregarding social and organizational factors, the technical niche of the Hydram can be described as moist hilly rural areas where there is no mains electricity but a need for lifting water from streams or springs.

Objectives of this module

This module is designed to answer the questions of all stakeholders involved in water: potential manufacturers, local and international non-governmental organizations, governments, and local universities.

Part of the training on GFS, this module wishes to increase the scope of implementation of GFS: sources can not only come from upstream a targeted community but also from downstream.

This module is divided in five parts:

- The principle of the Hydram;
- A description of the different element composing a Hydram;
- A detailed description of the Hydram components and their;
- Guidelines to implement a RPS in a targeted area;
- The process of the local manufacture of the Hydram.

Adapted to NTT, Indonesia, appendices present contacts and break-downs of costs according to the local suppliers. They also include data on local Hydram System implemented by ACF. Theses appendices wish to be examples for future successful GFS including RPS in NTT, Indonesia and that this combination replicates in similar context for other countries.

Figure 1: Hilly landscape of NTT, Indonesia

I. Principle

I.1. Theory

I.1.1. Energy

Cars, airplanes, light bulb, water pumps, computers, the human body have all something in common: *they need energy to work*. This energy can come from many sources such as electricity, fuel, manpower, food.

Different technologies are used to transform one source of energy to another. For example, car engines transform the chemical energy of the fuel into mechanical energy allowing wheels to rotate. Another example related to water supply projects is electric pumps: they use electricity to transform electrical energy into potential energy of the lifted water.

The potential energy is the energy of every object due to its altitude. The object needs another source of energy to be lifted and will lose its potential energy if it falls.

Hydrams are designed to lift water (i.e. give potential energy to the water) from a low cost source of energy. Avoiding using fuel and electricity, the *water hammer effect* has shown to be efficient and is the principle of Hydrams.

I.1.2. Water hammer effect

The water hammer effect is a phenomenon that increases the pressure of water in a pipe over a short period of time.

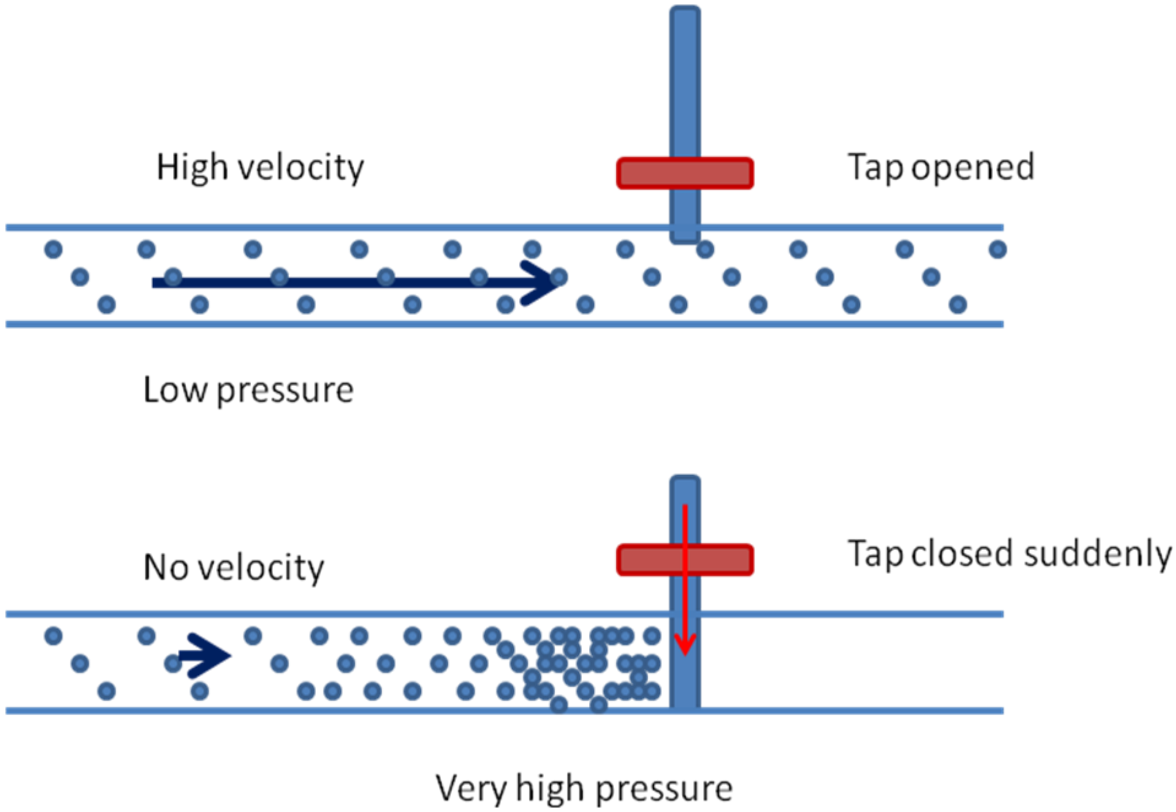


Figure 2: Water hammer effect

If the velocity of the water in a pipe is high enough, a fast closure of the pipe will cause a water hammer effect as shown in Figure 2. The water flowing will be compressed to the valve which has been closed suddenly. As a comparison, if a hundred people run very fast in a corridor and suddenly, they face a closed door, the space between them will be reduced, everybody will touch each other. In the same way, with velocity, water has kinetic energy. By closing quickly the pipe, this kinetic energy will be transformed into pressure.

This effect is characterized by a loud noise that is similar to a hammer banging a metal component.

I.2. Application for the Hydraulic Ram Pump

The Hydram uses the water hammer effect to "use the energy of a large amount of water falling from a small height to lift a small amount of this water to a much greater height" (Dr T. Thomas, 2005) as shown in Figure 3.

From a source of water (i.e. spring or stream), the water is driven to the Hydram based downstream. The pump suddenly stops the flow causing a water hammer effect. It allows the water under pressure in the Hydram body to enter into a delivery pipe.

The special feature of the Hydram is that *the water hammer effect is caused by the water itself*. The flowing water applies pressure on a valve that closes the pipe automatically. This is why the Hydram does not use any electricity or fuel.

However, as the water hammer effect is caused by the water, the water needs to go out: this is called the *waste water*. This is not really wasted because the Hydram cannot work without it. So, the Hydram will use only 20 to 40 percent of the water coming inside it (i.e. the *feed water*): this is the *delivery water*.

A non-return valve at the beginning of the delivery pipe stops the water to go back into the pump body. After continuous water hammer effects, water is added in the delivery pipe with a great pressure. It allows the water to flow upward up to a storage tank.

The pressure is transform into potential energy.

The efficiency of RPS is between 50 to 80 percent depending on the quality of material, the design and the age of the components.

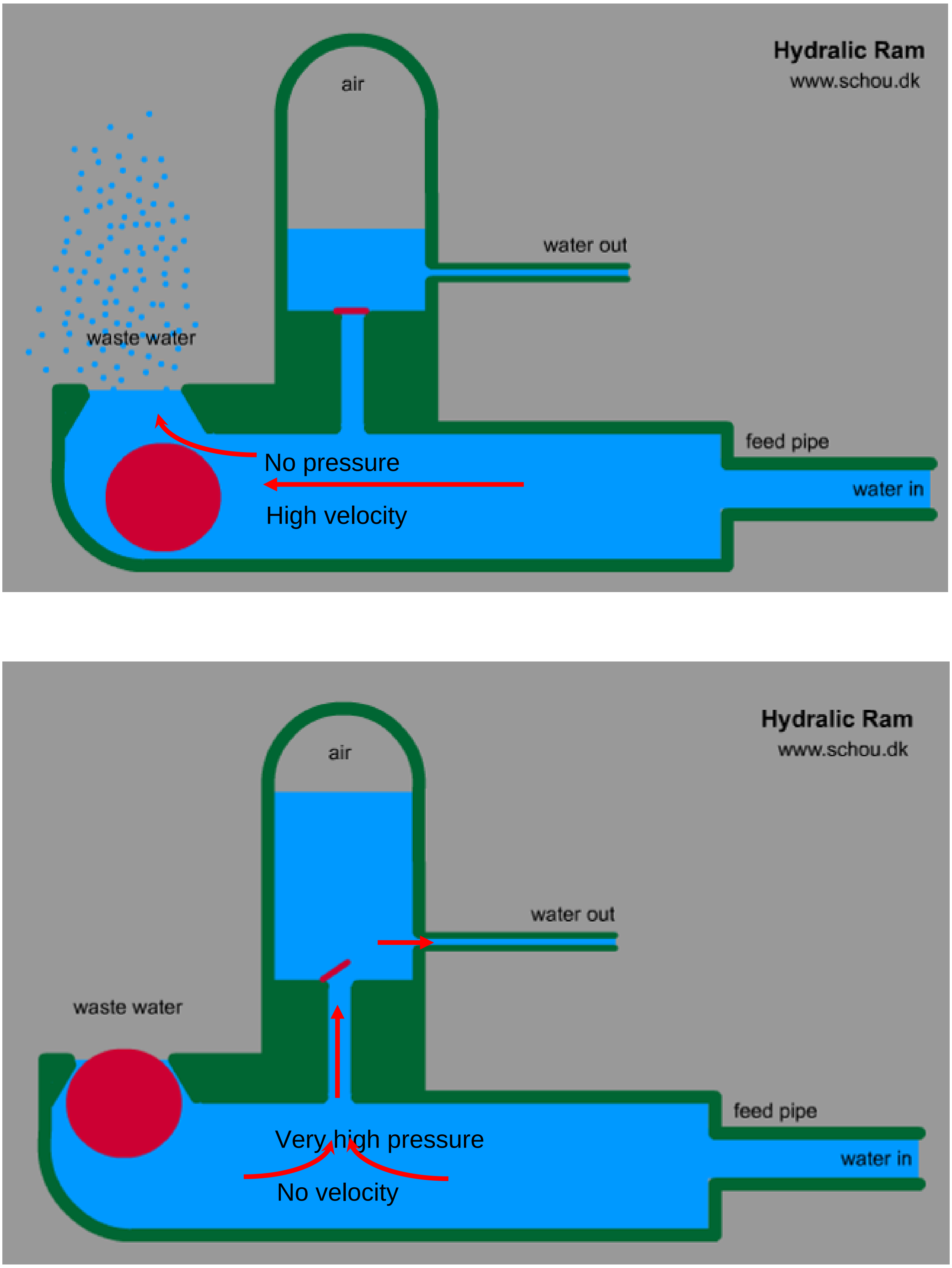


Figure 3: Application of the water hammer effect on the Hydraulic Ram Pump

II. Components and their functions of the system

II.1. The Hydraulic Ram Pump System

II.1.1. Objectives

A RPS has different objectives:

- Lift water from a source of water to a targeted community;
- Resist to external aggressions such as time, rain, mud, organic matter, shocks, theft, and landslide; and
- Resist to internal fatigue due to the shocks of the water hammer effect.

II.1.2. Description

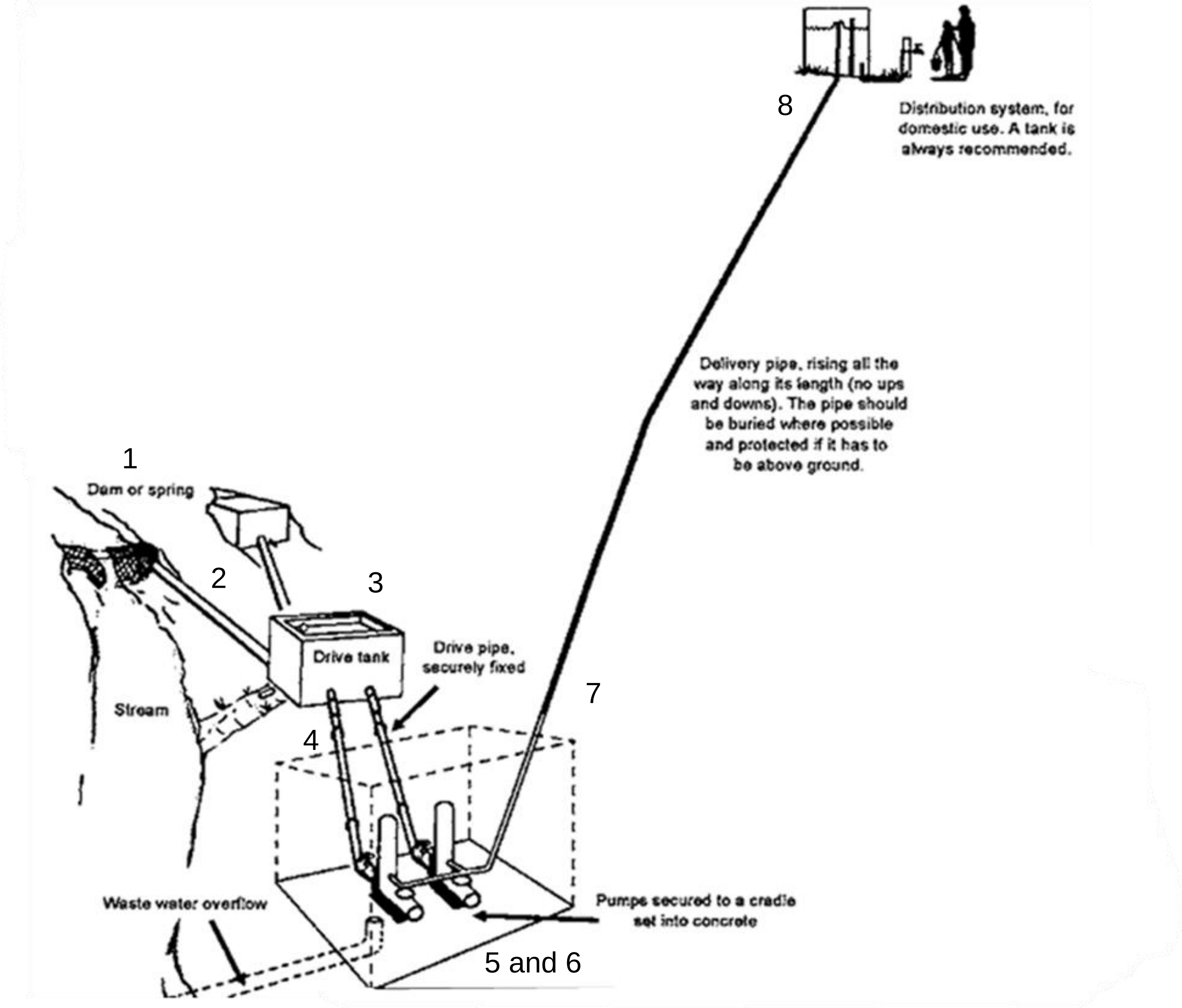


Figure 4: Hydraulic Ram Pump System

Figure 4 presents a design of a RPS from the DTU which has two pumps. The choice of the number of pumps depends on the site.

Composition of a Hydraulic Ram Pump System

A RPS is used within a GFS. The water entering in the storage tank of a GFS comes from the RPS.

A RPS has 7 main components as shown in Figure 4:

1. A spring or stream catchment;
2. A feed pipe;
3. A header tank;
4. One or multiple drive pipes;
5. A pump basement;
6. One or multiple Hydrams;
7. One or multiple delivery pipes; and
8. A storage tank.

The water comes from a stream or a spring. If the source of water is a stream, the water quality is most likely unable to reach ACF standards (please refer to Module 1 Introduction for further information about water quality treatment) for drinking purposes.

In addition, sedimentation can be used to avoid silt and sand in the pump.

Following the route of the water in the Hydraulic Ram Pump System

1 and 2 The water is caught by the spring catchment (or the stream catchment) and driven to the header tank by the feed pipe. The spring or stream catchment is the first barer to prevent organic matters to enter in the system and to reduce the efficiency of the system. Since the design is the same as a stream or spring catchment for a GFS already detailed in Module 4 Construction; refer to this module for further information.

3 The header tank allows a continuous flow to the drive pipe and the pump(s); it is as well the last barer to prevent sediments to enter in the pump.

4 and 5 The drive pipe is made from galvanized iron (G.I.). It has to support the water hammer effect which is running continuously. The drive pipe is designed to conduct water as fast as possible to the pump: it must be straight.

6 The Hydram is the most critical infrastructure of the system. A full chapter is dedicated to its description and local manufacture.

7 The Hydram is attached to the pump basement. It has to absorb the shocks of the water hammer effect. The pump basement has to be carefully design because it is subject to the fatigue of the water hammer effect and is very difficult to maintain without stopping the pump from running.

8 The delivery pipe conducts the water from the pump to the storage tank. The delivery pipe is designed like a delivery pipe of a GFS: the pressure of the delivery water, the flow of the delivery water, and its route are the main input to choose the type of pipes needed.

9 The storage tank is used to hold water before it is delivered to communities by a GFS. This infrastructure is detailed in Module 2 Principles and sizing; refer to this module for further information.

II.2. Header tank

II.2.1. Objectives

The header tank has five objectives:

- To prevent solid elements and air to enter in the Hydram;
- To allow a continuous flow in the Hydram;
- To allow the water to enter with a high velocity in the Hydram; and
- To resist to external aggressions;
- To allow the self-maintenance of the RPS.

II.2.2. Description

In order to fulfill the uses of the header tank, the design of the header tank depends on the characteristics of the water that flows in:

- Quality: impurities, sand, leaves, mud; and
- Quantity: flow available by the source of the water.

Size

A Hydram cannot work automatically if air enters inside the Hydram body. It means that the entrance of the drive pipe must be always under water. As a consequence, the size of a header tank is decided according to the flow available by the source of water. Then, if the quality of the water is poor (e.g. from a stream), it is important for the sediments to have time in the header tank to settle down in the bottom of the tank. Two compartments can be constructed.

The volume of the header tank for a RPS can be calculated like the header tank for a GFS; refer to Module 2 Principles and sizing for further details.

It is easier to construct a square tank (i.e. for the construction of the molds for concrete). The side in which the drive pipes are casted must allow at least 10 centimeters of space between two pipes.

The height of the tank must allow the water to be at least 30 centimeters above the drive pipes.

Connections

The inlet of the header tank is the feed pipe.

The outlets of the header tank are:

- The drive pipes;
- The wash out pipe on each compartment; and
- The overflow pipe.

The maintenance of the header tank is allowed by a manhole located on the top; if two compartments exist, the trap must allow cleaning both.

The drive pipes cannot only be casted in the wall of the tank; the wall thickness is not enough to hold the shocks of the water hammer effects. It is recommended to add concrete around the entrance of the drive pipe.

For maintenance purposes, it is recommended to install ball valve to allow an easy opening of the drive pipes. Ball valve are recommended over gate valve: gate valve close automatically under the effect of the water hammer effect when the pump is running

II.2.3. Example

The header tank for the RPS differs from the one from the GFS only by adding the drive pipe as straight as possible toward the pump basement. It is recommended to reinforce the wall where the drive pipes are: this solution allows the header tank to sustain against the water hammer effects.

Figure 5.a: Header tank for 6 pumps from AID Foundation

Figure 5.b: Header tank for 2 pumps from AID Foundation

In Figure 5.b, High Density Polyethylene pipes are used, it is recommended to bury them in the ground to avoid the damaging effects from sunrays: pipes get brittle and is more likely to break.

II.3. Drive pipe

II.3.1. Objectives

A drive pipe has two objectives:

- To allow the water entering in the pump body from the header tank with high velocity; and
- To resist to the shocks of the water hammer effect.

II.3.2. Description

A drive pipe is linked to only one pump. It cannot be made out of plastic because it cannot sustain the pressure. It is highly recommended to use first quality galvanized iron (G.I.) pipes. Poor quality of G.I. pipes will lead to difficult maintenance soon after the installation such as repairing leakage.

The efficiency of the pump increases if the components of the system do not absorbs the shocks of the water hammer effect. For the drive pipe, it means that it must be very rigid and tightly hold with clamps on supports casted into concrete.

Finally, the shock wave that goes along the drive pipe at each water hammer effect leads to a fatigue of the weakest part of the pipe: the threads at each end. This is a main cause of leakage. It is highly recommended to weld flanges all along the pipe and to insert a rubber seal between them. AID Foundation's experience has proven that it increases the longevity of the drive pipe.

The design of the flange for a 2” drive pipe is given in the appendix xx.

Example

Flanges

Figure 6: Drive pipe and flanges

II.4. Pump basement

II.4.1. Functions

The functions of the pump basement are:

- To hold the Hydram against the shocks of the water hammer effect; and
- To collect the waste water and to direct it to a targeted location to avoid having a muddy area around the pump and cavitations.

II.4.2. Description

The pump basement must be made out from the most solid concrete. Four screws are casted in the basement: the Hydram is to be located thanks to these screws.

The only critical part of constructing a pump basement is the alignment with the pump basement so that the drive pipe is perfectly straight. How to do this task properly is explained in the part Application on site.

II.4.3. Example

Figure 7: Construction of pump basement, NTT

Pumps are flooded, Philippines

Cage protect the pumps, NTT

Pumps are inside a pump house, Philippines

Figure 8: Types of pump basement

The minimum requirements for the design of the pump basement are shown in the following pictures.

- The waste water needs to be kept inside and then, directed to an area by a pipe to the original bed of the stream. If not, the area around the pump basement will be surrounded by mud;
- Because the whole pump basement is in a hilly area, it means that additional attention needs to be paid on the anchorage to the ground;

- It is useful to prevent people to access to the Hydram apart from the water committee for security constraints (i.e. children playing, thieves attracted by bolts and nuts)

II.5. Delivery pipe

II.5.1. Description

References to Module 2

The delivery pipe for a RPS is designed as a delivery pipe for a GFS; refer to Module 2 for further details:

- It needs to be buried to avoid external aggression;
- The delivery height minimizes the internal diameter of the pipe (i.e. the small diameter creates more head losses);
- The delivery height also designs the pressure that the pipe can hold and as a consequence, the material of the pipe; and
- The route of the pipe must avoid going alternatively up and down and should stay straight as much as possible.

Main delivery pipe and multiple delivery pipes

In most of the sites where the Hydram can be implemented, more than one pump will be installed for two reasons:

- The water available allows to use two or more Hydrams;
- Even if the volume of water is not enough, it is advised to install two pumps and run only one: the water will still be supplied during the maintenance.

There are now two choices:

- To connect each outlet of the Hydrams together after 50 meters to a main delivery pipe. This option has shown good results.
- To connect each outlet of the Hydrams to a delivery pipe (i.e. if there are 3 pumps, there will be 3 delivery pipes). AID Foundation believes after their experience that this method allows a greater overall delivery flow in the storage tank. The main disadvantage of this solution is its cost. This solution is certainly more efficient; however, no study has been implemented on site to evaluate the improvement of efficiency.

Minimizing head losses

The use of elbows, tees, and reducers must be minimized in order to reduce head losses.

Especially at the exit of the pump, elbows and tees are creating head losses that reduce a lot the flow of water in the storage tank. Indeed, at the exit of the pumps, the flow is not yet constant: the water travels by waves that flow at high velocity. The head loss at high velocity is greater than at low velocity. This is why is advised to avoid elbows and tees at the beginning of the delivery pipes.


Delivery pipes buried in the ground and rocks show the position


90˚ degree elbows at the outlet increase head losses


Delivery pipes are straight: flow is linear

Figure 9: Delivery pipes

The first picture shows how AID Foundation burry the delivery pipe and then mark the route with rocks to remember the location.

The second picture is a try made by ACF: this is a mistake not to make. The water flows out with velocity directly into an elbow. As a consequence, head losses are created and the delivery flow decreases.

The third picture is a good practice learned from AID Foundation: the outlet of the air chamber is aimed toward the final direction of the delivery pipe.

High Density Polyethylene is recommended because of its ease of installation (i.e. the roll can be sold up to 50 meters). Galvanized iron or PVC pipes are easy to find in NTT, Indonesia but are more time consuming (i.e. the length is 6 meter long and the connection takes time; it also reduce the risk of leakages).

III. The pump

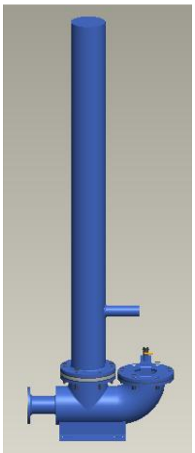
III.1. General description

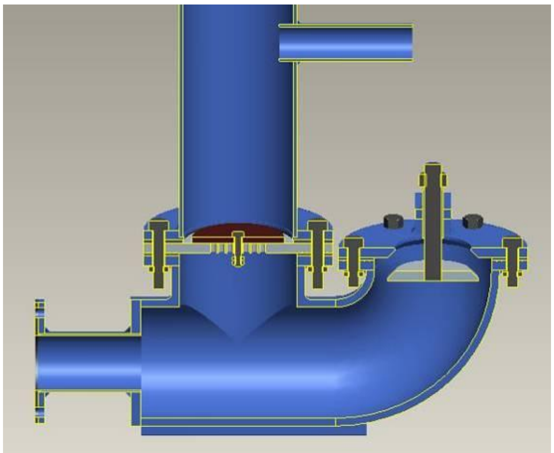
The Hydram has many designs all over the world.

Figure 10: Example of Hydraulic Ram Pumps around the world

ACF has adapted a design from different existing solutions (i.e. mainly from the DTU) in order to adapt to:

- The local manufacture in NTT, Indonesia; and to
- The need of the user in NTT, Indonesia in particular with the height needed from the source of water to the village.





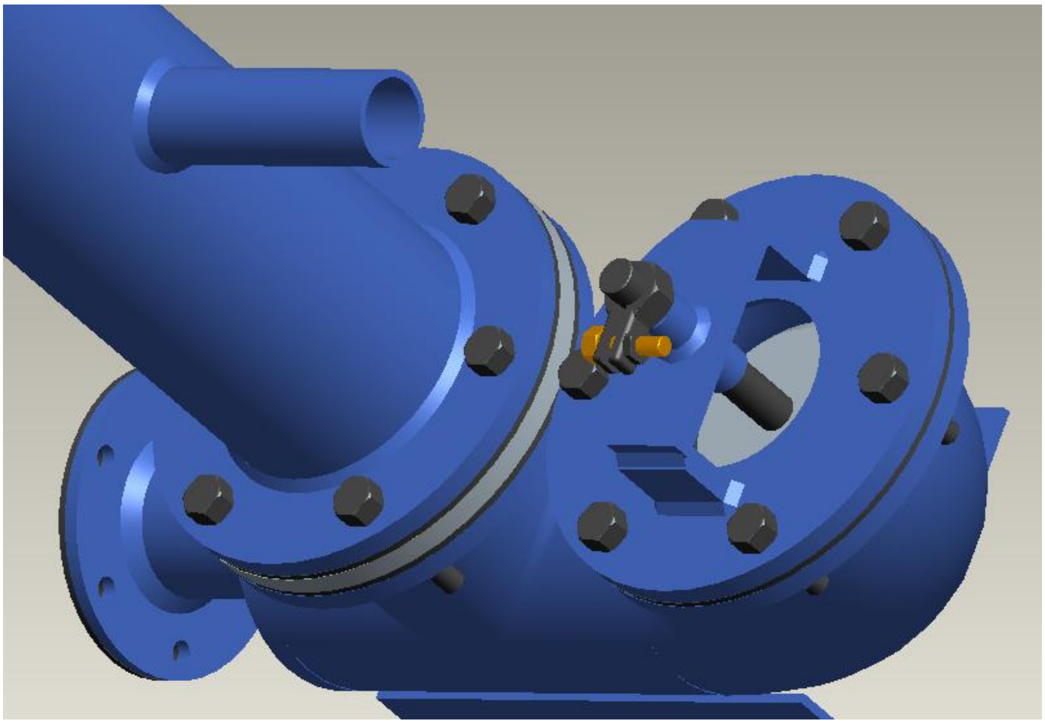


Figure 11: Hydraulic Ram Pump from ACF design

III.2. Description of components

III.2.1. The pump body

The pump body of a Hydram needs to be robust: it is the center of the water hammer effect.

Figure 12.a: Pump body

The ACF design uses a 4” GI tee and a 4” GI elbow welded together. It gives three openings:

- One input, the connection to the drive pipe; and
- Two outputs, the connections to the impulse valve and to the delivery valve.

Similar to the drive pipe, flanges are used because threads are not reliable enough. A rubber seal is added between flanges to protect the pump from leaking.

Figure 12.b: Pump body with supports, flanges and reducer

Two supports are also welded to allow the fixation of the Hydram on the pump basement.

The water enters from the drive pipe into the pump body and flows directly to the impulse valve.

III.2.2. Impulse valve

Figure 13: Impulse valve and its components

The impulse valve is located above the elbow of the pump body.

The impulse valve of the ACF design of the Hydram is mainly based on the design from the DTU. It is composed of three components:

- The plate;
- The plug; and
- The locking bolt.

The impulse valve is the part that allows the water to create continuous water hammer effects. The plug needs to be wide enough so that the water pushes it upward.

The closure needs to be fast and clear. This is why it is important to guide the plug vertically. Also, it is recommended that the contact surfaces between the plate and the plug are conical: this contact is better than flat surfaces for waterproof purposes.

The locking nut is used to stop the plug falling downward. It allows the modification of the length of the stroke of the plug. This option is better than putting simple nuts on the plug. One or two nuts are not enough: they get loose by the continuous hits when the plug goes down. This device makes sure that the length of the stroke stays the same until further modification during maintenance.

III.2.3. Delivery valve

The delivery valve is located above the tee of the pump body.

The delivery valve is a non-return valve: it allows the water to go from the pump body to the air vessel and forbid the water to flow in the opposite direction. When the pressure inside the pump body is higher than the pressure in the air vessel, the valve opens and let the water flows.

The delivery valve is made out of three components:

- The delivery plate;
- The delivery plug; and
- The bolt.

Bottom

Top

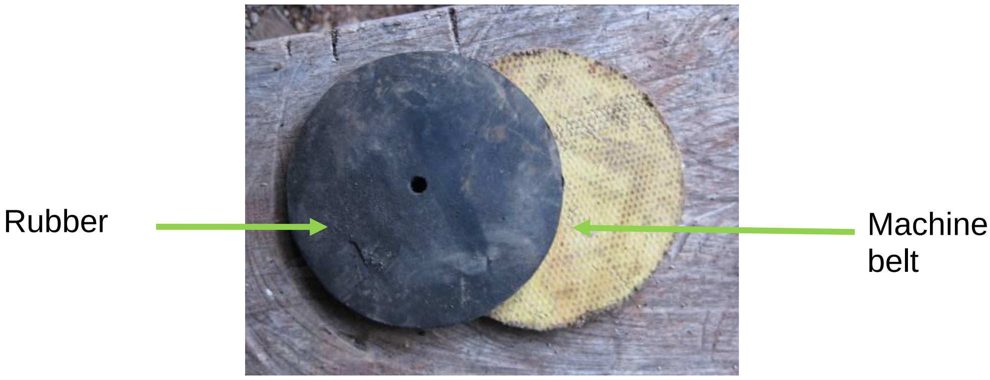


Figure 14: Delivery valve

Most of the design of Hydrams uses rubber to close the delivery valve; ACF takes the advice of AID Foundation: the design of the delivery valve uses machine belts as material.

III.2.4. Air vessel

Figure 15: Air vessel

The air vessel is located above the delivery valve.

The air vessel is a vital component of the Hydram and is visually its main characteristic. Without it, the water coming through the delivery valve would have a great velocity and too much head losses would be created. With the air vessel, the air is slowed down because the air inside the air vessel acts like a spring. The air vessel improves a lot the efficiency of the pump.

III.2.5. Snifter valve

The snifter valve is a device to allow the air to enter in the air vessel.

It is important to have this supply of air because the air in the air vessel is mixed with the water while the Hydram is running. As a consequence, the volume of air reduces. The snifter valve allows maintaining a necessary level of air inside the air vessel.

The DTU design uses a valve with a rubber seal. If the hole is very small (i.e. 1 to 2 mm of diameter), the system is working and the pressure will not reduce too much even if there is water going out. ACF chose to use just a small hole.

Figure 16: Snifter valve

IV. Application on site

This part is essentially based on the very useful book Hydraulic Hydrams from the DTU.

IV.1. Project management of a Hydraulic Ram Pump project

Time management

From the idea of installing a RPS to the exciting time of watching water flowing in the storage tank, it takes time. As the project can only be successful if the community is involved, trained and monitored, it takes even more time.

The time with the community is more than important: it is necessary for the success of the project. The transport and the time consuming maintenance are two factors which cannot allow a company, an NGO or the government to ensure a frequent and adapted maintenance of the RPS. The users are adapted to this task: it is why they need to be part of the project from the beginning.

A RPS project should include the following steps:

- The socialization with the targeted community and planning of the participation;
- The field survey of the area;
- The design;
- The supply of material on site;
- The construction;
- The tests and first maintenance;
- The training of the water committee;
- The handover of the RPS;
- The evaluation.

All these phases need to be implemented with constant cooperation and communication with the community. Many of these phases have been described in the previous modules (i.e. socialization with the community and training with the community in Module 5, surveying in Module 3, part of design in Module 2, part of construction in Module 3).

This module focuses on the survey of the area for the RPS, the design and construction of the header tank, the drive pipe, the pump basement, the Hydram and the delivery pipe, and the tests.

The time taken for each phase depends on:

- The distance that separates the targeted community from the office of the organization;
- The season (i.e. during the wet season, construction takes twice as much time as the dry season);
- The human resources available (both from the community and from the organization);

- The complexity of the topography and the system (i.e. number of pumps, number of route and of storage tank)
- Agricultural and cultural calendar.

The duration of a project varies from one site to another: they last between 2 to 3 months long.

Human resources management

For a RPS project as for a GFS project, the team should include:

- 1 water technician trained in RPS for the design, the planning, and the management of the teams;
- 1 logistician for the supplies to the sites, the follow-up of materials; vehicles, and accommodation of workers on site;
- 1 foreman overseeing plumbing and brickwork teams;
- 1 mason foreman;
- 2 assistant masons preparing mould and concrete work;
- 1 plumber foreman installing and connecting pipes;
- 2 assistant plumbers laying and connecting pipes
- Daily labor for trench digging, transporting material (i.e. it is better if the workers are from the community).

Cost management

The range of the cost of a RPS varies from USD 2,000 to 6,000. The figures below are an example from AID Foundation that gives a good estimation of the amount spent on each component:

▪ Spring catchment tank	USD 80
▪ Drive tank	USD 59
▪ Hydram foundation	USD 62
▪ Hydram and accessories	USD 322
▪ Diversion pipe	USD 834
▪ Drive pipe	USD 201
▪ Delivery pipe	USD 468
▪ Distribution line & 3 tap stands	USD 148
▪ Management and Training	USD 1,044
▪ Community cost (in kind)	USD 307

Appendix xx is dedicated to the cost analysis of an example of a RPS.

IV.2. Survey a potential site

The DTU design assignment procedure to survey a potential site is adapted to the reality of the field and very helpful to the designer. It is presented in appendix xx. Important points are described in the following paragraphs.

IV.2.1. Calculation of the delivery flow

The calculation of the flow that may be supplied to the community (i.e. delivery flow) use the following inputs:

- The drive flow in liter per second (Q);
- The drive height in meter (H);
- The delivery height (h); and
- The efficiency of the pump in percentage (μ).

The formula is:

$$q = \frac{H \times Q \times \mu}{h}$$

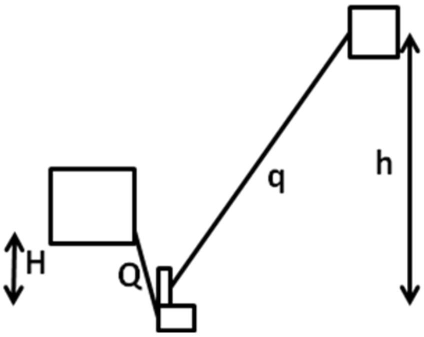


Figure 17: Efficiency formula

IV.2.2. Constraints

From the water required by the community

The design of the site is driven by the objective of supplying enough water to the targeted community based on identified needs (refer to Module 3 for further details on water requirements). If a site cannot provide enough water, other solutions need to be found.

From the pump

A particular Hydram works under a particular range of drive flow and of drive height. If the drive height or the drive flow is too low, the water has not enough energy to create a water hammer effect. If the drive height or the drive flow is too high, the energy of the water causes too much stress on the pump and reduces its lifetime.

The ACF design is mainly based on the design made by the DTU in 1998. It allows a drive height from 2 to 15 meters, and a drive flow from 0.6 to 2 liters per second.

From the position of the storage tank

A too high delivery height causes not only the reduction of the delivery flow and the important reduction of the efficiency of the pump but also, it will cause stress on the pump itself due to the pressure in the delivery pipe.

The DTU recommends that the delivery height does not exceed 100 meters for their Hydraulic Ram Pump S2. The ACF design is based on the DTU Hydraulic Ram Pump S2.

From the topography

The height between the header tank and the pump basement is critical. The efficiency of the Hydram relies on them. Moreover, their position is also important: a slope not steep enough does not allow the water to flow fast in the drive pipe.

The length of the drive pipe (L) and the drive height (H) should have a ratio not exceeding 7 (i.e. the slope is not steep enough; too much head losses will be created):

$$\alpha = \frac{L}{H} \leq 7$$

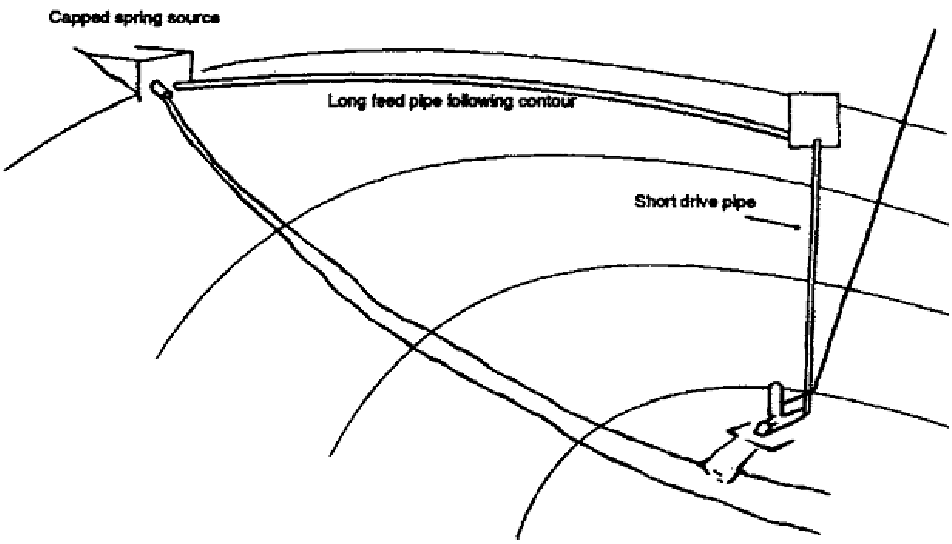


Figure 18: Topography and drive pipe position

From the environment

It is important to consider the environment of the site to position the RPS infrastructures.

- Cutting trees should be avoided; in any case, permission from the owner of the land or from the community should be obtained;
- In the region of NTT, Indonesia hard rain is common causing erosion and landslide. The civil work design should avoid any risk of such accident causing the rupture of the system and a costly rehabilitation.
- The route of the delivery pipe should anticipate problems caused by crossing rivers, roads, lands with cattle;

- Children are naturally playing with water: designs should avoid allowing children to play on pipes, on tanks (i.e. for security reasons).
- The material used to construct a RPS is attractive: bolts, nuts, screw, maintenance material, pipe should be kept from the temptation as much as possible.

In order to avoid as much as possible these problems, experience is the best tool. The community knows best their land, their people and their habits. Dialogues, ideas and initiatives from the community need to be encouraged by the project manager.

Figure 19: Community meeting

From the cost

Cost efficiency is an important consideration. The choice of the route of the delivery pipe, of the number of pumps to be installed, of the type of support for the drive pipe and of the delivery pipe will change the cost. The designer will have to balance between reliability, efficiency and cost.

A cost analysis is given in appendix xx.

From the water needs downstream

The Hydram is not taking all the water of a source. However, it is important to survey the need of the villagers around the source of water and downstream. People are probably used to bath or fetch the water at the source. It is important to identify their need and not to deprive them of their natural access to water.

IV.3. Installation

1 For the implementation of the project, it is important to start by the stream or spring catchment. The catchment tank will give the flow available compared to the estimated flow found during the survey. Modifications of the design of the rest of the system may be useful.

Position the beginning of the feed pipe toward the header tank.

2 Then, according to the topography, construct the header tank and position:

- the end of the feed pipe toward the stream or spring catchment; and
- The drive pipes toward the pump basement.

The drive pipes need to be as straight as possible. A method is to use a string attached on the position of the beginning of the drive pipe to the future position of the Hydram as shown in the following picture.

Figure 20: Aligning header tank and pump basement

3 Dig and burry the feed pipe.

Figure 21: Burring delivery pipe

4 Construct the pump basement

Two critical issues are raised:

- The pump basement need to be perfectly straight to ensure an easy translation of the plug up and down the guide of the impulse valve; and

- The 4 screws casted in the pump basement need to be perfectly aligned with the drive pipe to ensure an optimum positioning of the Hydram.

Figure 22: Construction of the pump basement

5 Install the drive pipes and their supports. Installed in the beginning with support made of wood, the mason constructs supports to ensure that the drive pipes are straight and do not move during the water hammer effect. Avoiding movements of the drive pipe allows an increase of the pressure in the pump body and an increase of the pump efficiency. Clamps are attached tightly to the support (i.e. screws are casted in the concrete) to maintain the drive pipes.

Figure 23: Drive pipes and supports

6 The digging and burial of the delivery pipe is a long and human resource demanding task. It can be started in parallel to the tasks described previously. It is important to start by the bottom (i.e. position of the pump basement) avoid digging and installing the pipe.

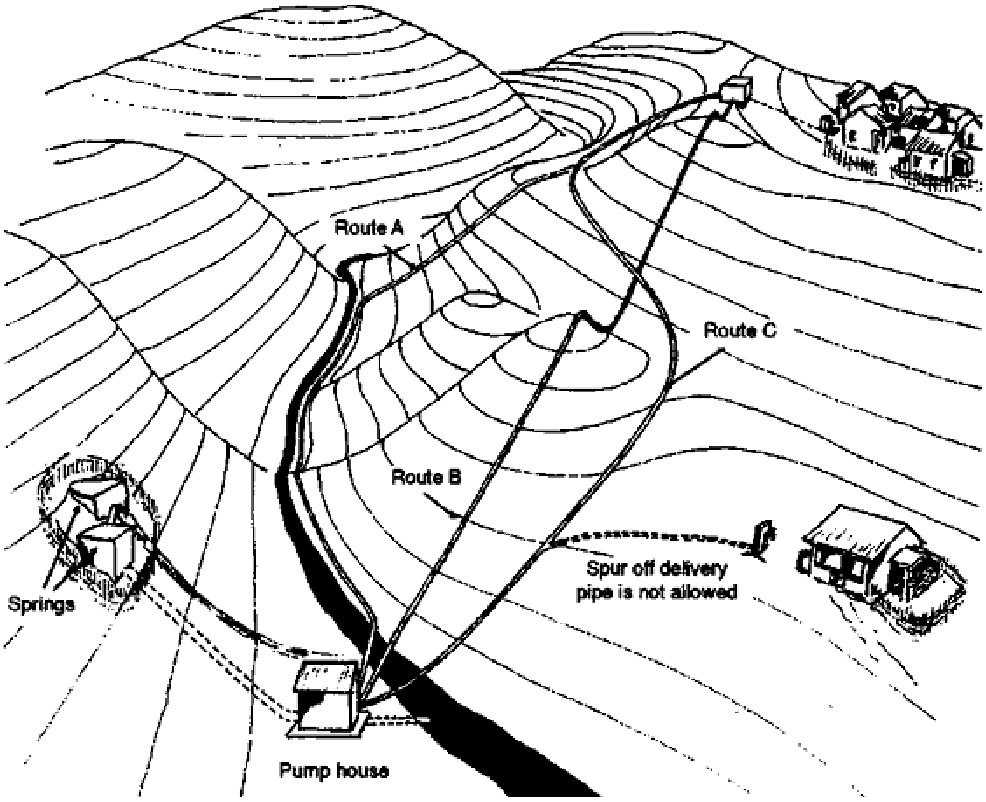


Figure 24: Choice of route for the delivery pipe

In the Figure 24, three routes are drawn and only the route C is correct.

× The route A is too long and the beginning is too flat (i.e. the cost is too high and there are high risk that the pipe goes downhill and uphill alternatively).

× The route B is the shortest but goes over a hill and down and goes up again: There will be a problem of air blocked at the top of the hill.

✓ The route C is a good balance between the length and a constant slope uphill.

7 Connecting the multiple delivery pipe to the main pipes

In case two or more Hydrams are on the same pump basement, a choice of using one main delivery pipe or multiple delivery pipes has to be made by the project manager. It is a balance between cost and efficiency.

If the connection of the outlets of the Hydrams (i.e. the beginning of the delivery pipe) is too close to the Hydram, there is a high chance that the water of one outlet flows backward in another outlet. This is because the water hammer effects of the pumps do not happens exactly at the same time.

It is recommended to connect the outlets at least 50 meters after the Hydrams. At this distance the flow of the water is more constant and the connection happens with less head losses.

IV.4. Starting the Hydraulic Ram Pump System

Before starting the Hydraulic Ram Pump

Make sure that:

- Bolts are tight (air vessel, pump body);
- The feed pipe flow is constant, header tank is clean and full and overflow is operating;
- The pump basement is clear; and
- The impulse valve is removed.

To remove all undesired material inside the drive pipe:

- Open the ball valve at the drive pipe gently from closed to full; and
- Close the drive pipe.

Finally:

- Clean the snifter valve; and
- Put back the impulse valve.

Starting the Hydraulic Ram Pump

- Open the ball valve at the drive pipe until all the air is out and flow is constant; and
- Prime the Hydram;
- Look for problems (i.e. leakages, moving parts, bolts and nuts, pipe connections).

Priming the Hydraulic Ram Pump

Why priming?

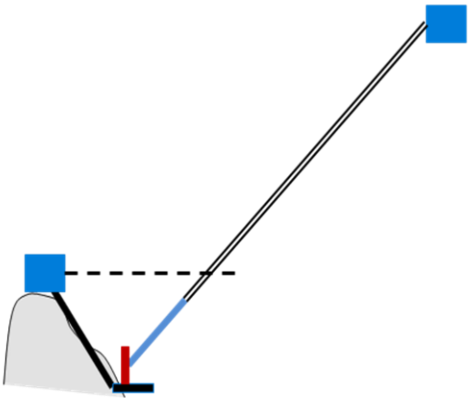
Before running the Hydram, there is no water in the delivery pipe: above the delivery valve in the air vessel, there is only air.

Figure 25.a: when starting the Hydram, the water flows not only through the impulse valve but also through the delivery valve. This is because the delivery valve stays open: there is not any pressure above the valve to close it. As a consequence, not enough water flows through the impulse valve to create a strong hammer effect.

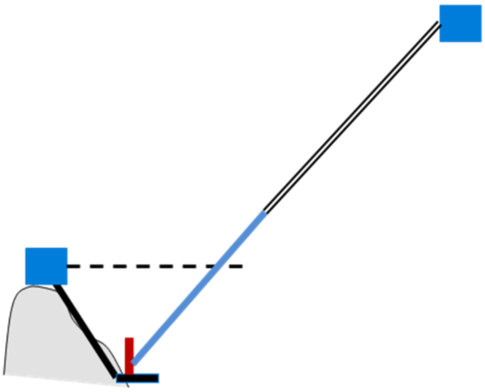
Without a strong hammer effect, the depression that allows the impulse valve to open is not possible. It is why priming is needed to help the impulse valve going down.

Figure 25.b: After that the water in the delivery pipe reaches the same height as the header tank, the situation changes and the pump can work automatically. The pressure above the delivery valve is greater than below when the water is accelerating and flows only through the impulse valve.

It creates a strong hammer effect that increases the pressure to open the delivery valve, let the water flow in the delivery pipe, and allows a depression. This depression makes the impulse valve open and the cycles of the Hydram can run automatically.



a. Priming is needed



b. The Hydraulic Ram Pump works automatically

Figure 25: Why priming

How to prime the Hydraulic Ram Pump?

Figure 26: Priming the Hydraulic Ram Pump

Only by pushing down the plug of the impulse valve with a foot, the technician is able to open the impulse valve to start a new cycle. After that the water reaches a high enough point in the delivery pipe, the plug will go down automatically and the technician can stop and focus on checking for problems and leakages.

Adjusting the stroke

Trials and tests need to be carried out to look for the best balance between delivery flow and waste flow.

The locking nut is designed to increase or decrease the length stroke of the plug in the impulse valve.

The longer the stroke the stronger the water hammer effect is. When the plug is down, more waste water is able to flow out increasing the velocity of the drive water. As a consequence, this high velocity is causing a strong water hammer effect.

However, this relation is not linear: the velocity reaches even if the stroke is at its maximum. It is causing a waste of water much greater than the increase of the delivery flow: the efficiency reduces.

On the opposite, a too small stroke cannot create a water hammer effect strong enough to have the required delivery flow, or even not strong enough to make the Hydram work automatically.

The DTU gives well explained recommendations on tuning the Hydram for different purposes.

"Peak output

When there is plenty of drive water available (e.g. wet season) 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 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 recommended maximum stroke.

Peak efficiency

When there is a limited amount of drive water available (e.g. dry season), it is important that the pumps installed are tuned down to use most of the drive water to be lifted and delivered. This corresponds to a small length stroke."

IV.5. Common problems and maintenance

The main problems of the RPS are the leakages and the blockages of the pipes:

- Leakages will come mainly from the pipe connections; and
- Blockages from a poor protection of the catchment or the header tank.

The maintenance procedure designed by the DTU is given in appendix xx.

V. Local manufacture of the pump

V.1. Starting a local manufacture

V.1.1. Skilled technician

The manufacture of the Hydram designed by ACF needs skills available in NTT and in most part of the world. The technician has to know how to:

- Weld for waterproof connections and with different material;
- Drill;
- Cut iron plate;
- Use a lathe machine;
- Read technical drawing.

A mechanic that has worked for repairing car or motorbikes is adapted to this job.

V.1.2. Supply of material

The technician needs:

- 4" GI pipes, elbows and tees of first quality;
- 2" GI pipes;
- 3/4" pipes for gas;
- A crow bars;
- 6 mm and a 10 mm stainless steel plates (mild iron plate is stronger and can corrode, use anti-corrosion paint under a layer of color paint to improve a little the longevity);
- 3/4" stainless steel bolts and nuts;
- 3 mm rubber surfaces (inside tube of truck can be used if still of good quality: no visible damage); and
- 90˚ profiles 5 x 5 cm.

V.1.3. Equipment and tools

The workshop needs to be equipped with:

- A lathe machine;
- A welding plant and welding rod;
- A drilling machine and drilling bits;
- A cutting machine and cutting disc;
- A cutting torch and oxygen bottle;
- A grinder;
- Diameter measurer, ruler, carpenter measurer, marker, paint, a level, spanners, keys, etc;

- Safety goggles, safety gloves, ear plug, mask to protect from metallic dust; and
- A generator in case of black-out of electricity.

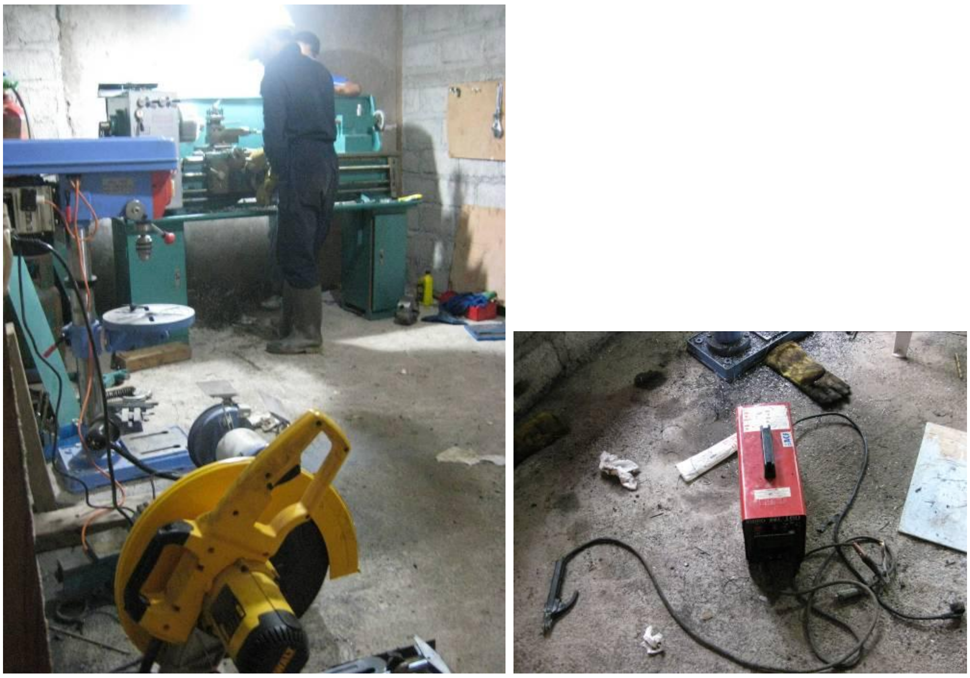


Figure 27: Tools and equipment

V.2. Steps to follow for local manufacture

Technical drawings are given in appendix xx.

V.2.1. Flanges, reducer, top of the air chamber and plates

The technician cuts the 10 mm stainless steel plate to produce the flanges with the cutting torch. After grinding, the flange (i.e. or reducer…) is taken to the lathe machine to for surfacing and making the PCD.

Figure 28: Cutting the iron plate

The PCD are concentric circles on the surfaces that will be in contact to the rubber seal. It helps the rubber seal to anchor and resist to the high pressure given by the water hammer effect. If not, the rubber moves and leakages appear.

Finally, drill the holes for the bolt and flanges are ready for being welded to the pump body.

This step is the same for the flanges for the drive pipe and for reducing on end of the tee for connecting the drive pipe. A pipe used for the drive pipe (i.e. 2”) is welded on to create the inlet of the pump.

Figure 29: Flanges, plates, reducer, and top of air chamber manufacture

V.2.2. Pump body

The first step is to weld the GI tee and the GI elbow together with a strong waterproof weld. Then, the reducer, and finally the support are welded.

Figure 30: Welding the pump body

Two 90˚ profiles are cut and holes are drilled in them to create the support of the pump. The position of the holes needs to match the position of the screws on the pump basement. Then, it is ready to be welded to the pump body.

Figure 31: Supports on pump body

V.2.3. Snifter valve

The snifter valve is a 2 mm hole in the pump body 2 cm below the delivery valve. The technician needs to weld a point on the pump body to add material and then, drill inside. If the hole is too big while the pump is running (i.e. too much leakage of water), a nail can be placed inside the hole to reduce it.

Figure 32: Snifter valve manufacture

V.2.4. Delivery valve

The delivery valve manufacture starts like the flanges except it has no large hole at its center like the flanges or the plate for the impulse valve. It has small holes drilled with the hand drilling machine and with 6 mm drilling bits.

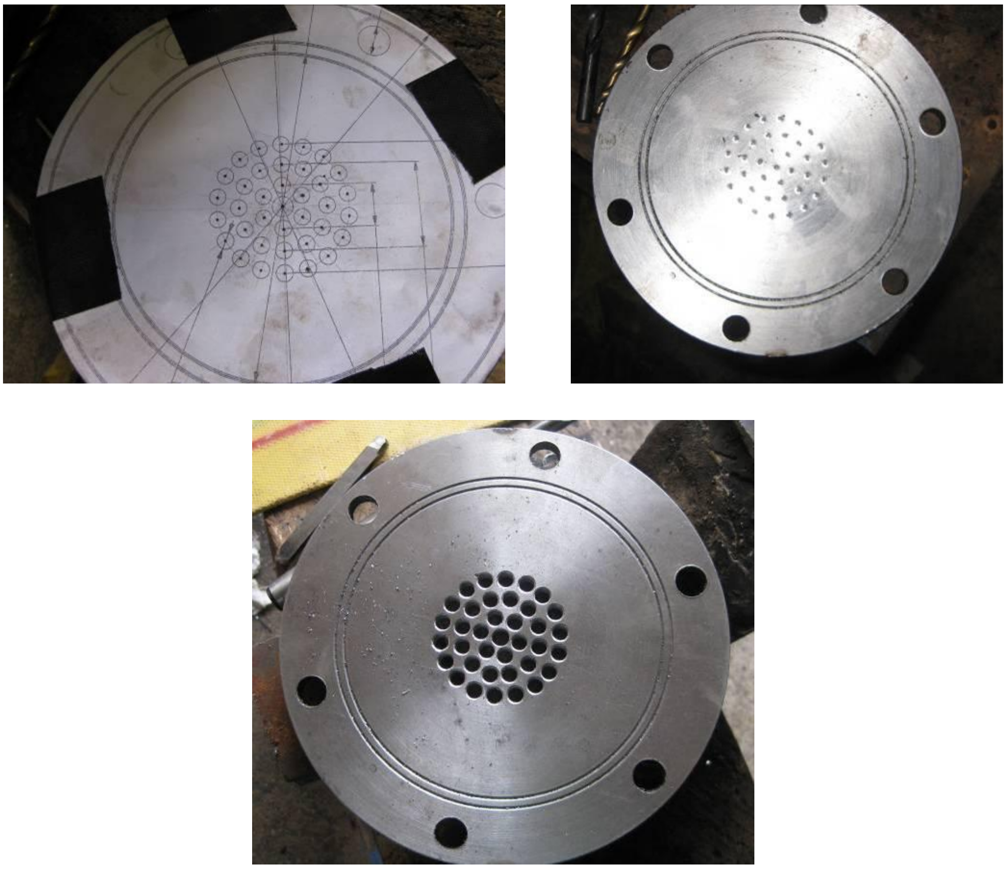


Figure 33: Delivery valve manufacture

V.2.5. Impulse valve

The impulse valve is the most complicated component to manufacture in the Hydram.

The plate

Starting with a plate like the flanges, do not make the hole in the center in the beginning: this step will be at last. Then, produce the support for the guide with rectangles from the iron plate.

Figure 34: Manufacture of the support for the impulse valve guide

The iron plate is cut to produce rectangles that will support the guide. After, all steps are done on the lathe machine.

First, the top is manufactured: the top side faces the cutting tools:

- Surface the top;
- Position and weld the support for the guide;
- Drill a hole to put the guide inside the top rectangle;
- Weld the guide;
- Finish.

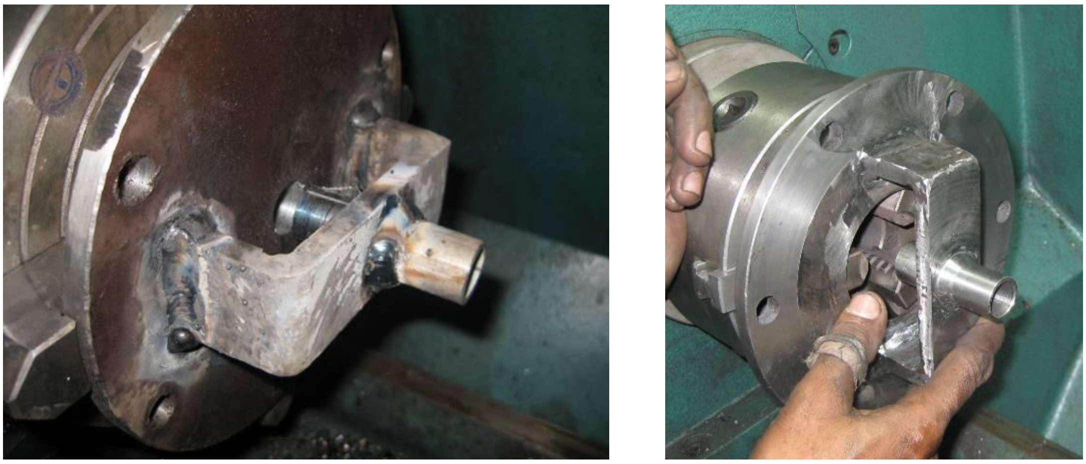


Figure 35: Manufacture of the top of the impulse valve plate

On a second time, the bottom side of the stop bar faces the cutting tools:

- Cut the center hole in the plate;
- Cut the 45˚ angle edge;

- Drill inside the guide (i.e. the technician is sure that the edge and the inside of the guide are aligned: this is important for the movement of the plug).
- Make the PCD;
- Finish.

Figure 36: Manufacture of the bottom of the impulse valve plate

The plug

The manufacture of the plug is done in three times. First, the technician has to prepare the plate and the stem respectively from the 10 mm iron plate and from the crow bar.

For the stem:

- Cut a 170 mm long piece; and
- With the lathe machine, cut off one end to 12^- mm diameter on 20 mm.

For the plate:

- Cut a disc of 100 mm diameter;
- Drill a 12^+ mm hole at its center;
- Position the stem inside and weld the stem to the plug on the lathe machine;
- Surface the crow bar until a diameter of 18 mm;
- Turn the assembly on the other side on the lathe machine (i.e. the bottom of the plug facing the cutting tools, the lathe machine attaching the stem);
- Weld the stem to the plug on the lathe machine;
- Cut of the weld with the lathe machine so that the lathe machine can hold the plug from the bottom;
- Turn the assembly so that the stem is facing the cutting tools of the lathe machine;
- Now, in one position, the technician can surface the edge of the disc with a 45° degree angle, surface the stem for a good translation in the guide and make the threads for the locking nut.

Figure 37: Manufacture of the stem of the impulse valve

V.2.6. Air chamber

In order to manufacture the air chamber:

- Cut a 1.2 m long piece of the 4” pipe.
- Position and weld the flange on the 4” pipe on one side;
- Position and weld the top of the air chamber on the other side; and
- With the welding machine, make a 1 ¼” hole inside the 4” pipe 200 mm above the flange.
- With a 1 ¼” pipe, cut a 200 mm long piece and make threads to connect with a union to make the outlet; and
- Weld the outlet in the air chamber.

Figure 38: Manufacture of the air vessel

V.2.7. Finishing

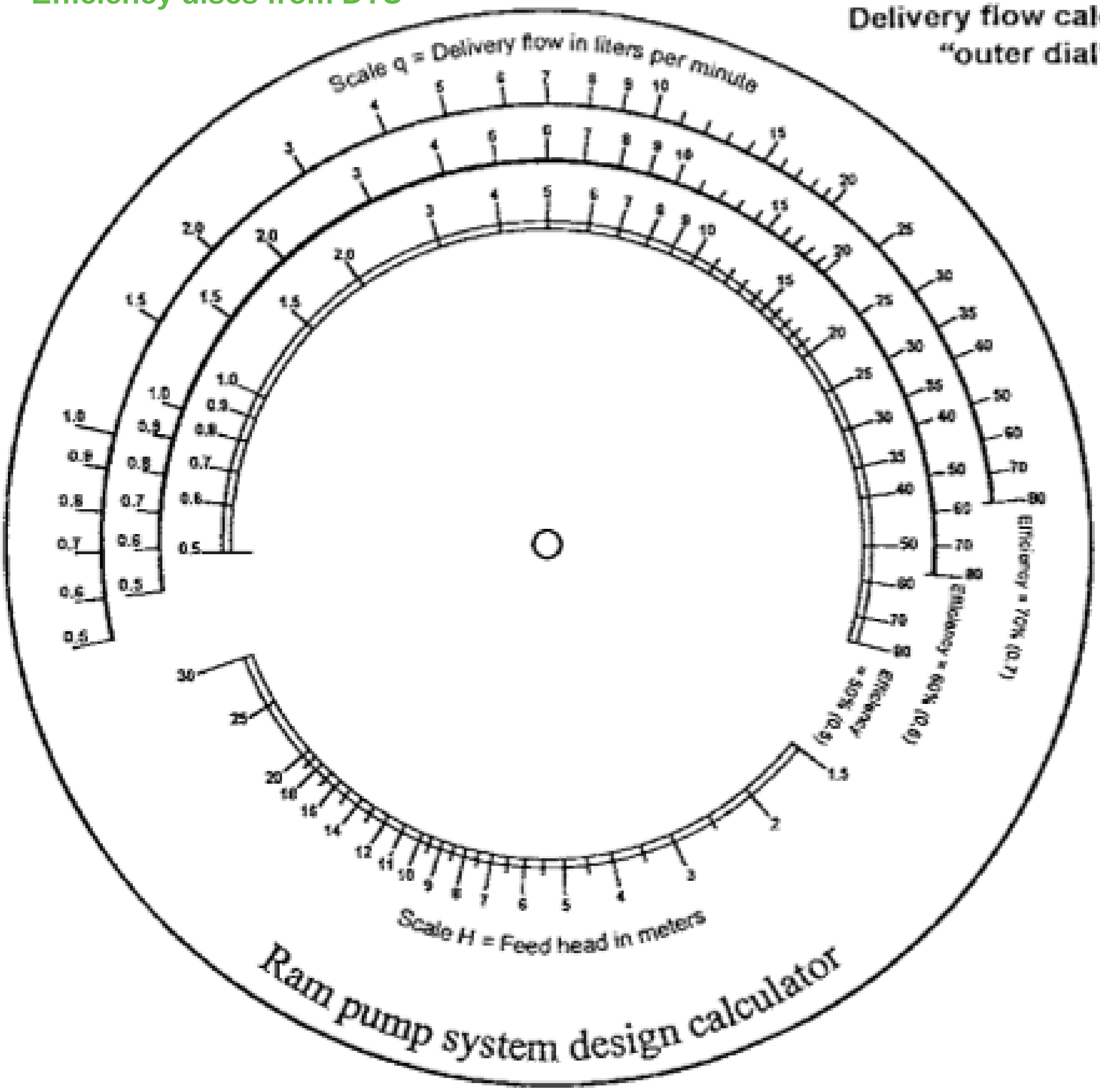
To finish, it is important to protect the all parts except from the stem and the bolts from corrosion:

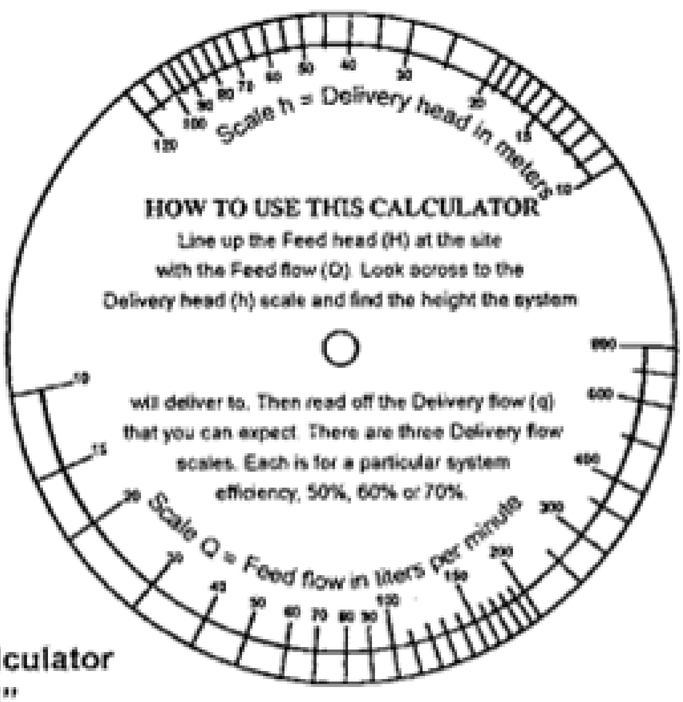
- Paint a layer of anticorrosion paint, then a layer of color paint.

Appendices

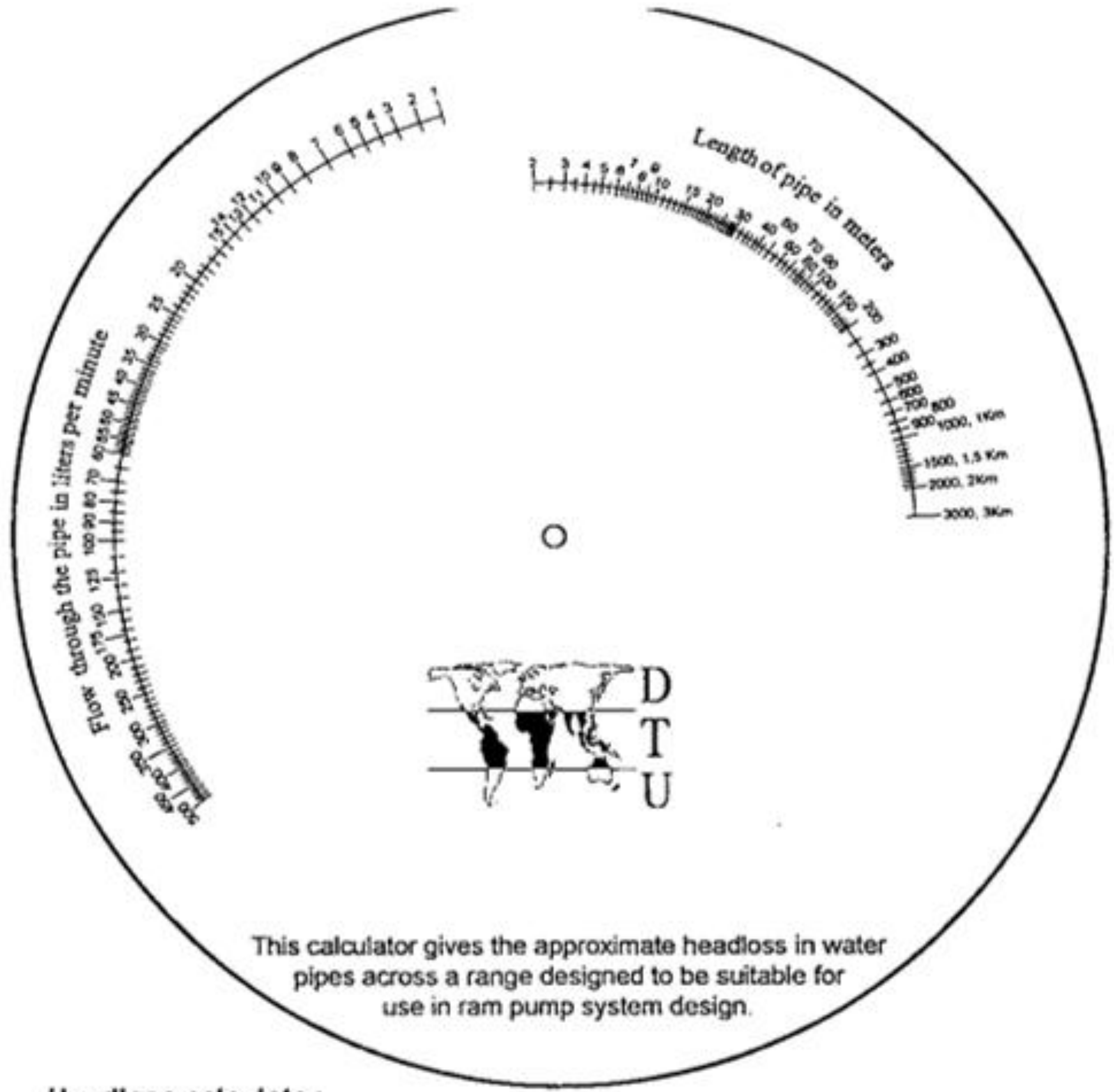
Efficiency discs from DTU

Delivery flow calculator
“outer dial”





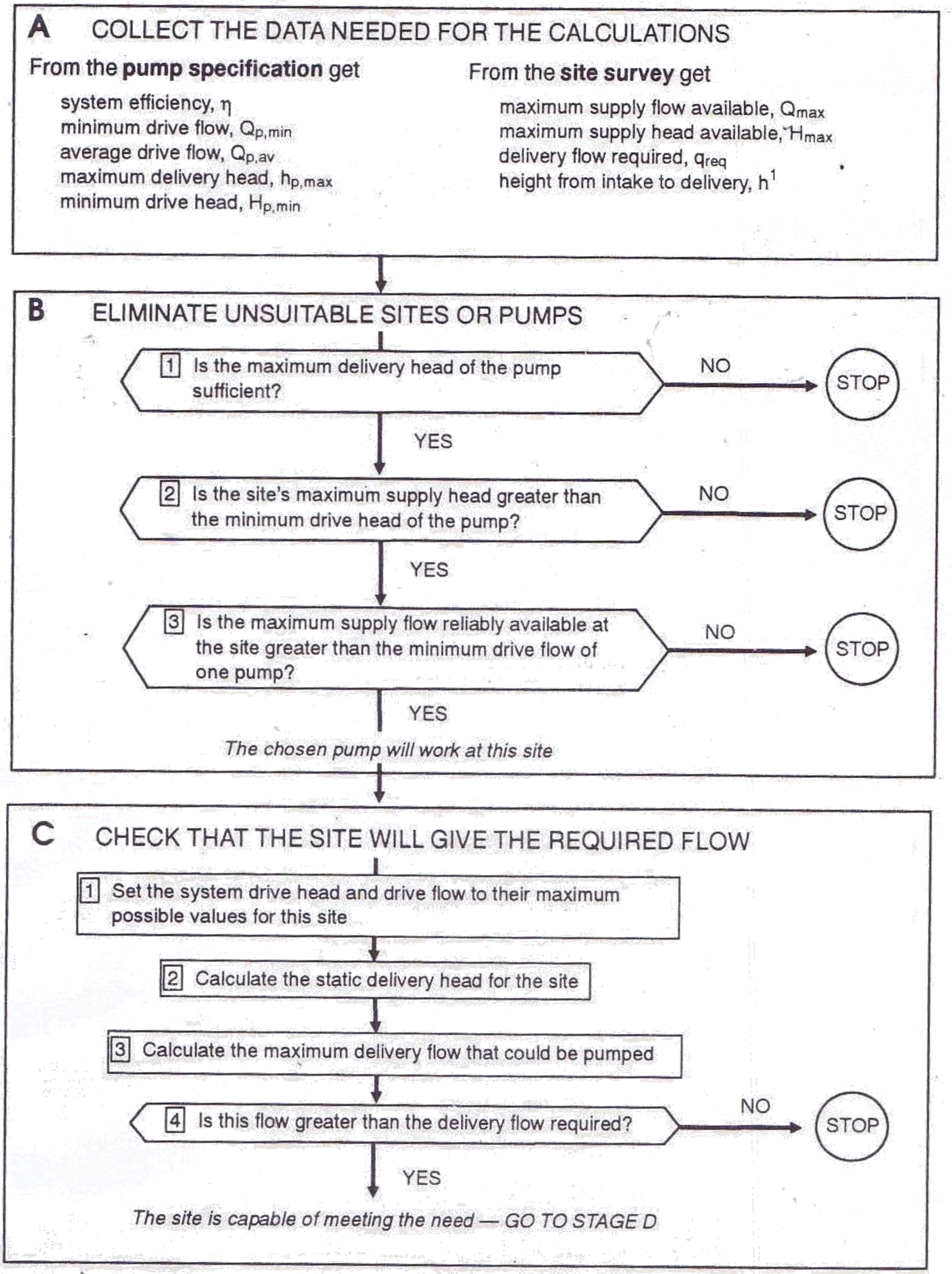
Delivery flow calculator
“inner dial”



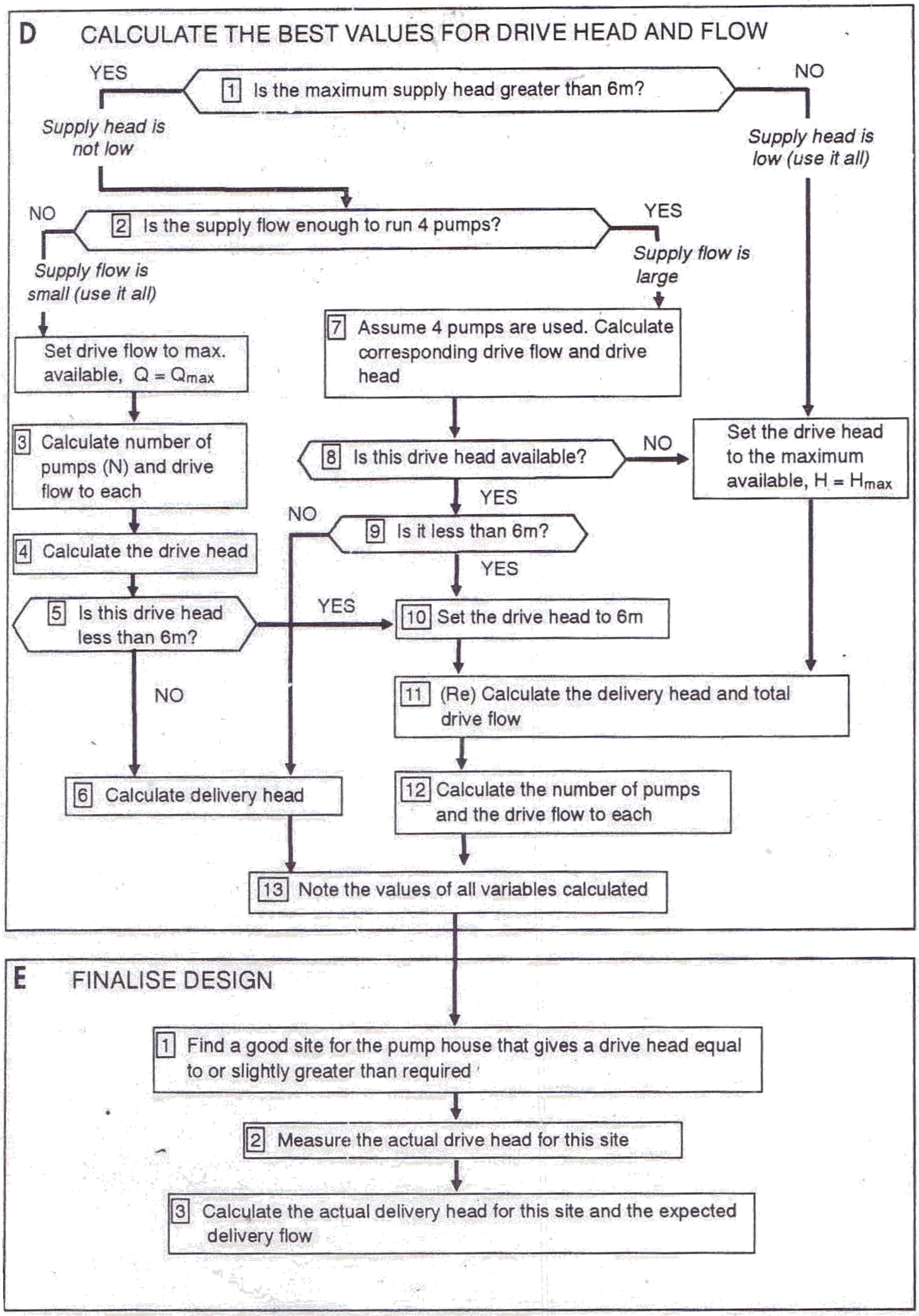
Headloss calculator "outer dial"

System design procedure from DTU

Flow chart of system design process (see notes on each stage)



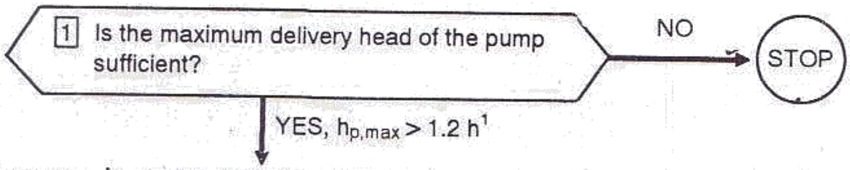
Design assessment procedure



Notes on stage B: Eliminate unsuitable sites

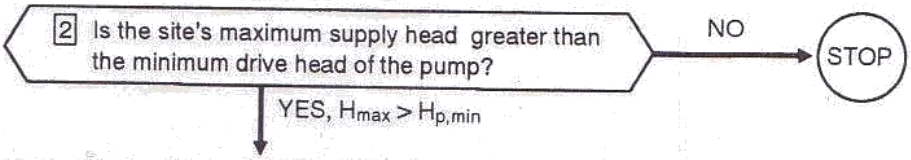
The measured variables of a site must first be checked against the particular limitations of the pump being used. Three steps are necessary.

Step 1



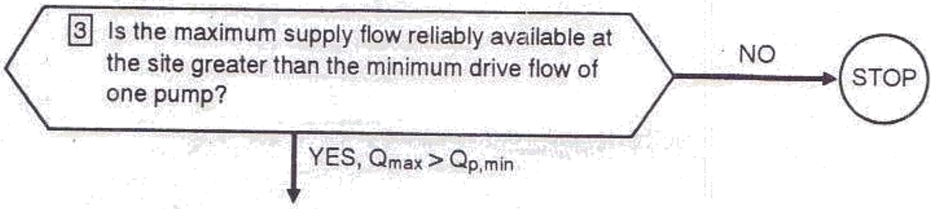
To test whether the pump is strong enough we need to compare the maximum head to which it can reliably deliver with the delivery head it will experience on this site. The dynamic delivery head (experienced when the system is running) is the delivery head h, plus the friction head loss in the delivery 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: $\eta = \dfrac{qh}{QH}$ can be rearranged to give: $q = \dfrac{QH\eta}{h}$

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

NO ← 9 Is it (the drive head) less than 6m

↓ 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.

Common problems and maintenance from DTU

Personal notes

Personal notes

System commissioning and operation

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.

The ACF Hydraulic Ram Pump 2'' characteristics

Drive pipe size: Ø 2''

Minimum drive flow $Q_{p,min}$: 0.6 liters per second
Maximum drive flow $Q_{p,max}$: 2 liters per second
Average drive flow $Q_{p,av}$: 1.3 liters per second

Minimum drive height $H_{p,min}$: 6 meters
Maximum drive height $H_{p,max}$: 10 meters

Maximum delivery height h: 150 meters

Efficiency (also depend on the system) μ: 60 percent

Estimated flow range q: 1 to 25 liters a minute

Frequency of stroke 25 to 50 stroke a minute

Exercices

5 exercises are presented below in order to understand better the process presented by the DTU. Corrections are following.

The pump characteristics are the one of the ACF Hydraulic Ram Pump 2” given above except for the efficiency. In these exercises, the efficiency µ is estimated to be 55%.

The staff on field faces 5 different potential sites. The goal is to avoid the sites where the demand of the community cannot be reached. Then, if the site can provide enough water, drive height, drive flow, number of pumps, delivery height, and delivery flow must be calculated.

The characteristics of the site have been evaluated during a site survey and are collected in the table below.

#	Maximum drive flow available Q_{max} (l/s)	Maximum drive head available H_{max} (m)	Delivery flow required q_{req} (l/s)	Height from intake to delivery h_1 (m)
1	5	1,5	0,18	55
2	8	10	0,24	120
3	5	15	0,62	70
4	7	12	0,4	100
5	8	15	0,15	135
6	5	15	0,18	100
7	10	6,5	0,2	140
8	5	15	0,18	66
9	8	8	0,18	90
10	8	5	0,2	70

Corrections

Site 1:

Step B.3: not valid. There is not enough drive head available to run this pump. The water could not get enough speed and kinetic energy to produce a strong water hammer effect. The technician has to find another site with greater drive head.

$$H_{max} < H_{p,min}$$

$$1.5 < 6$$

Site 2:

Part B is valid: the site can allow at least one pump to run.

Part C is valid: the demand of the community is reached. If all drive head and drive height is used, the maximum delivery flow is:

$$h = h_1 + H = 120 + 10 = 130$$

$$q_{max} = H \times Q \times \mu / h = 10 \times 8 \times 0.55 / 130 = 0.33 \text{ l/s}$$

$$q_{max} > q_{req}$$

$$0.33 > 0.24$$

Now, the technician has to find value to avoid wasting money (i.e. in pipes).

Part D:

Step 1: the maximum drive height is greater than 6 meter.

$$H_{max} = 10 > 6 \qquad \text{Go to step 2}$$

Step 2: the maximum drive flow is greater than the flow to run 4 pumps.

$$Q_{max} = 8 > 1.3 \times 4 = 5.2 = 4 \times Q_{p,av} \qquad \text{Go to step 7}$$

Step 7: the drive flow Q is set at 5.2 l/s for 4 pumps. The drive head calculated using a 5.2 l/s requires 11 meters of drive head.

$$H = h_1 \times q_{req} / (\mu \times Q - q_{req}) = 120 \times 0.24 / (0.55 \times 5.2 – 0.24) = 11$$

Step 8: the drive head required is not available. $H = 11 > 10 = H_{max}$

The drive head is now set at its maximum $H = H_{max} = 10$ meters   Go to step 11

Step 11: the delivery head is now equal to h = h1 + H = 120 + 10 = 130 m

The drive flow equals 5.7 l/s per second (i.e. 1.4 l/s per pump for 4 pumps).

Site 3

Part C is not valid: the required flow is cannot be reached even if one pump can run. The required flow is too great.

$$q_{max} = H_{max} \times Q_{max} \times \mu / (h_1 + H_{max}) = 5 \times 15 \times 0.55 / (70 + 15) = 0.49 < 0.62 = q_{req}$$

The technician has to find another site.

Site 4

Part B and Part C are valid: the technician can install a RPS on this site.

Part D

Step 1: the maximum drive height is greater than 6 meter.

$$H_{max} = 10 > 6 \qquad \text{Go to step 2}$$

Step 2: the maximum drive flow is lower than the flow to run 4 pumps.

$$Q_{max} = 5 < 1.3 \times 4 = 5.2 = 4 \times Q_{p,av} \qquad \text{Go to step 3}$$

Step 3: the drive flow is set at its maximum. Q = 5 l/s. 4 pumps are still chosen to propose more flexibility in term of maintenance and for potential future needs.

N = 4 and the flow per pump equals 1.25 l/s.

The drive flow Q is 5 l/s for 4 pumps. The drive head is:

$$H = h_1 \times q_{req} / (\mu \times Q - q_{req}) = 100 \times 0.18 / (0.55 \times 5 – 0.18) = 7$$

Step 4: The delivery head is equal to h = 7 + 100 = 107 meters.

Site 5

Part B and Part C are valid: the technician can install a RPS on this site.

Part D

Step 1: the maximum drive height is lower than 6 meter.

$$H_{max} = 5 < 6 \quad \text{Go to step 11}$$

Step 11: The drive height is set at its maximum $H = H_{max} = 5$; so the delivery height is $h = h_{max} = h1 + H = 70 + 5 = 75$.

$$Q = qreq \times h / (\mu \times H) = 0.2 \times 75 / (0.55 \times 5) = 5.45 \text{ l/s}$$

Cost analysis in NTT for a ACF Hydraulic Ram Pump 2”

Cost of the manufacture

Material for 1 unit of Ram Pump						
Item	Components	Qt	Cost per unit		Cost	
101	Galvanised Iron T 4"	1	IDR	140,000	IDR	140,000
102	Galvanised Iron Elbow 4"	1	IDR	120,000	IDR	120,000
103	Flange	2	IDR	40,000	IDR	80,000
104	End Plate	1	IDR	15,000	IDR	15,000
105	Bolt 1 1/2"	6	IDR	15,000	IDR	90,000
106	Bolt 2 1/2"	6	IDR	20,000	IDR	120,000
107	Spring ring	12	IDR	1,000	IDR	12,000
108	Rubber seals	3	IDR	10,000	IDR	30,000
109	Galvanised Iron pipe 2"	1	IDR	10,000	IDR	10,000
	Total Pump body				IDR	617,000
201	Guide	1	IDR	20,000	IDR	20,000
202	Impulse valve plate	1	IDR	40,000	IDR	40,000
203	Impulse valve plug	1	IDR	15,000	IDR	15,000
204	Locking nut	1	IDR	15,000	IDR	15,000
205	Impulse valve stem	1	IDR	15,000	IDR	15,000
206	Impulse stop valve	1	IDR	30,000	IDR	30,000
	Total Impulse valve				IDR	135,000
301	Delivery valve plate	1	IDR	40,000	IDR	40,000
302	Delivery valve rubber	1	IDR	20,000	IDR	20,000
303	Screw	1	IDR	4,000	IDR	4,000
304	Nut	2	IDR	1,500	IDR	3,000
305	Spring ring	1	IDR	1,000	IDR	1,000
	Total Delivery valve				IDR	68,000
401	Bottom flange air vessel plate	1	IDR	40,000	IDR	40,000
402	Top end air vessel plate	1	IDR	15,000	IDR	15,000
403	Galvanised Iron pipe	1	IDR	200,000	IDR	200,000
404	Outlet	1	IDR	10,000	IDR	10,000
	Total Air vessel valve				IDR	265,000
500	Support	2	IDR	5,000	IDR	10,000
501	Bolt	4	IDR	8,000	IDR	32,000
502	Spring ring	4	IDR	1,000	IDR	4,000
	Total Support				IDR	46,000
600	Bolt 2 1/2"	6	IDR	20,000	IDR	120,000
601	Bolt 1 1/2"	6	IDR	15,000	IDR	90,000
602	Rubber seals	3	IDR	10,000	IDR	30,000
603	Delivery valve rubber	1	IDR	20,000	IDR	20,000
	Total spare parts kit				IDR	260,000
	Total cost of material for a Ram Pump				**IDR**	**1,391,000**

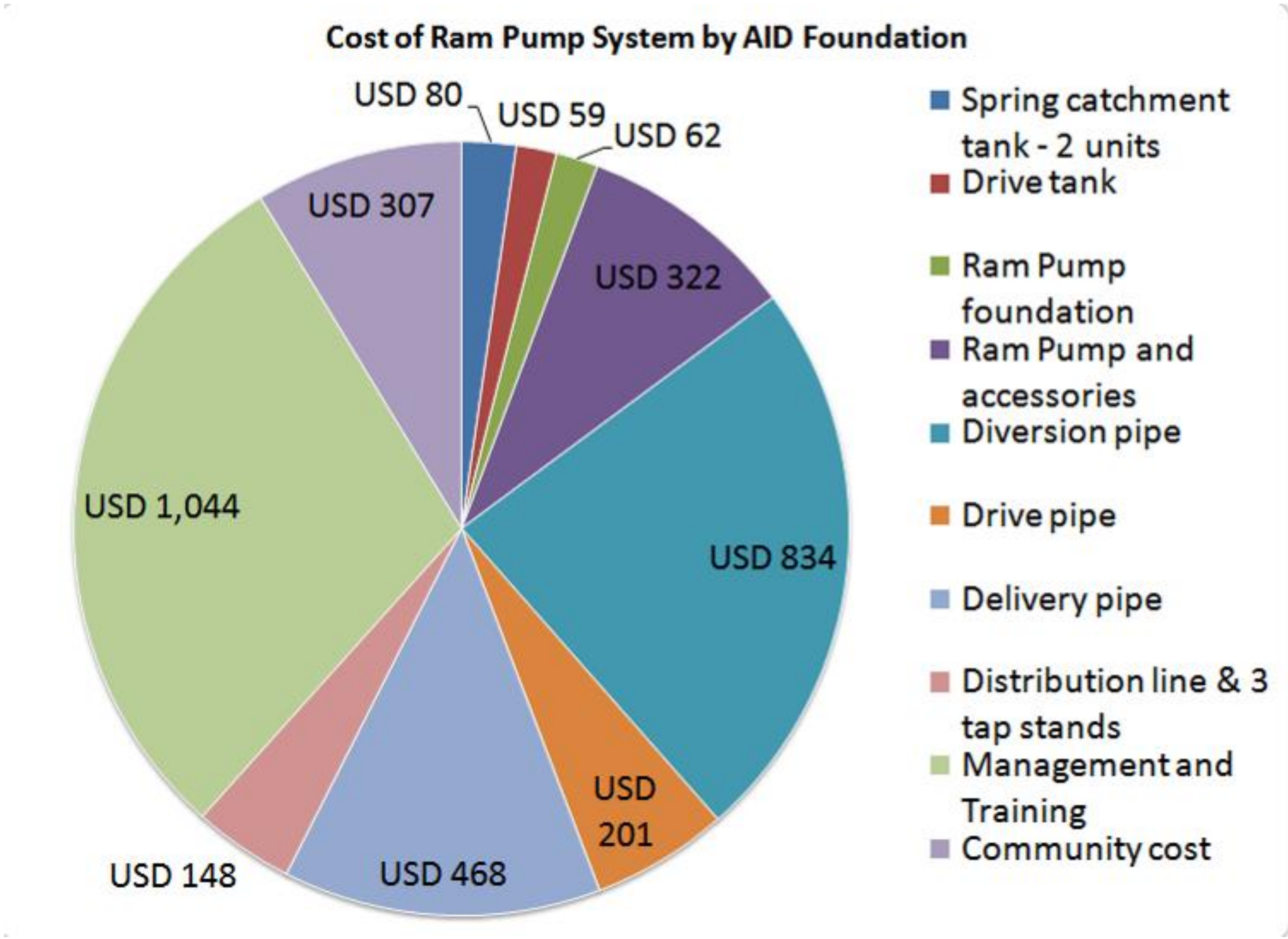
	Sector		Cost for a set of 10 pumps
I	Additional 30% for increase of material cost Supply of material	IDR	18,083,000
II	Transport from supplier to manufacturer	IDR	1,500,000
III	Labour of manufacture	IDR	500,000
IV	5% of the supply of the material Power for manufacture	IDR	904,150
V	20% of the supply of the material Depreciation of Machines	IDR	3,616,600
VI	30% of the supply of the material Benefit on the manufacture	IDR	5,424,900
	Total	IDR	30,028,650
	Unit selling price ex-factory	**IDR**	**3,010,000**
			US$ 301

Cost evaluation made by ACF in March 2009
Supplies are from Soe and Kupang
Manufacturer in Soe

Pump
Ram Pump 2" ACF

Cost break-down of complete Ram Pump System from AID Foundation						
# Item description	Quantity	Unit	Rate (PHP)	Amount (PHP)	Amount (USD)
100 Spring catchment tank - 2 units				**PHP 3,594**	**USD 80**
101 Cement	7	bag	PHP 210	PHP 1,470	USD 33
102 Binding wire	1	roll	PHP 1,450	PHP 1,450	USD 32
103 Reinforced-bars	1	piece	PHP 222	PHP 222	USD 5
104 GI Tie Wire # 18	0.5	kg	PHP 78	PHP 39	USD 1
105 Hardcore	0.25	cubic m.	PHP 650	PHP 163	USD 4
106 Sand	0.5	cubic m.	PHP 500	PHP 250	USD 6
200 Drive tank				**PHP 2,671**	**USD 59**
201 Cement	5	bag	PHP 210	PHP 1,050	USD 23
202 Binding wire	0.5	roll	PHP 1,450	PHP 725	USD 16
203 Reinforced-bars	2	piece	PHP 222	PHP 444	USD 10
204 GI Tie Wire # 18	0.5	kg	PHP 78	PHP 39	USD 1
205 Hardcore	0.25	cubic m.	PHP 650	PHP 163	USD 4
206 Sand	0.5	cubic m.	PHP 500	PHP 250	USD 6
300 Ram Pump foundation				**PHP 2,795**	**USD 62**
301 Cement	6	bag	PHP 210	PHP 1,260	USD 28
302 Binding wire	0.5	roll	PHP 1,450	PHP 725	USD 16
303 Reinforced-bars	2	piece	PHP 222	PHP 444	USD 10
304 GI Tie Wire # 18	1	kg	PHP 78	PHP 78	USD 2
305 Hardcore	0.25	cubic m.	PHP 650	PHP 163	USD 4
306 Sand	0.25	cubic m.	PHP 500	PHP 125	USD 3
400 Ram Pump and accessories				**PHP 14,500**	**USD 322**
401 1 1/2"Ø Hygraulic Ram Pump	1	piece	PHP 11,000	PHP 11,000	USD 244
402 Tool kit	1	piece	PHP 3,500	PHP 3,500	USD 78
500 Pipe and accessories				**PHP 67,617**	**USD 1,503**
510 Feed pipe				**PHP 37,515**	**USD 834**
511 ISO HDPE Hoe 1 1/2"Øx60m SDR - 11	5	roll	PHP 6,765	PHP 33,823	USD 752
512 ISO Plastic Replacement 1 1/2"Ø	10	piece	PHP 212	PHP 2,117	USD 47
513 ISO Plastic Coupling 1 1/2"Ø	3	piece	PHP 342	PHP 1,025	USD 23
514 GI coupling 1 1/2"Ø	10	piece	PHP 45	PHP 450	USD 10
515 GI Tee 1 1/2"Ø	2	piece	PHP 50	PHP 100	USD 2

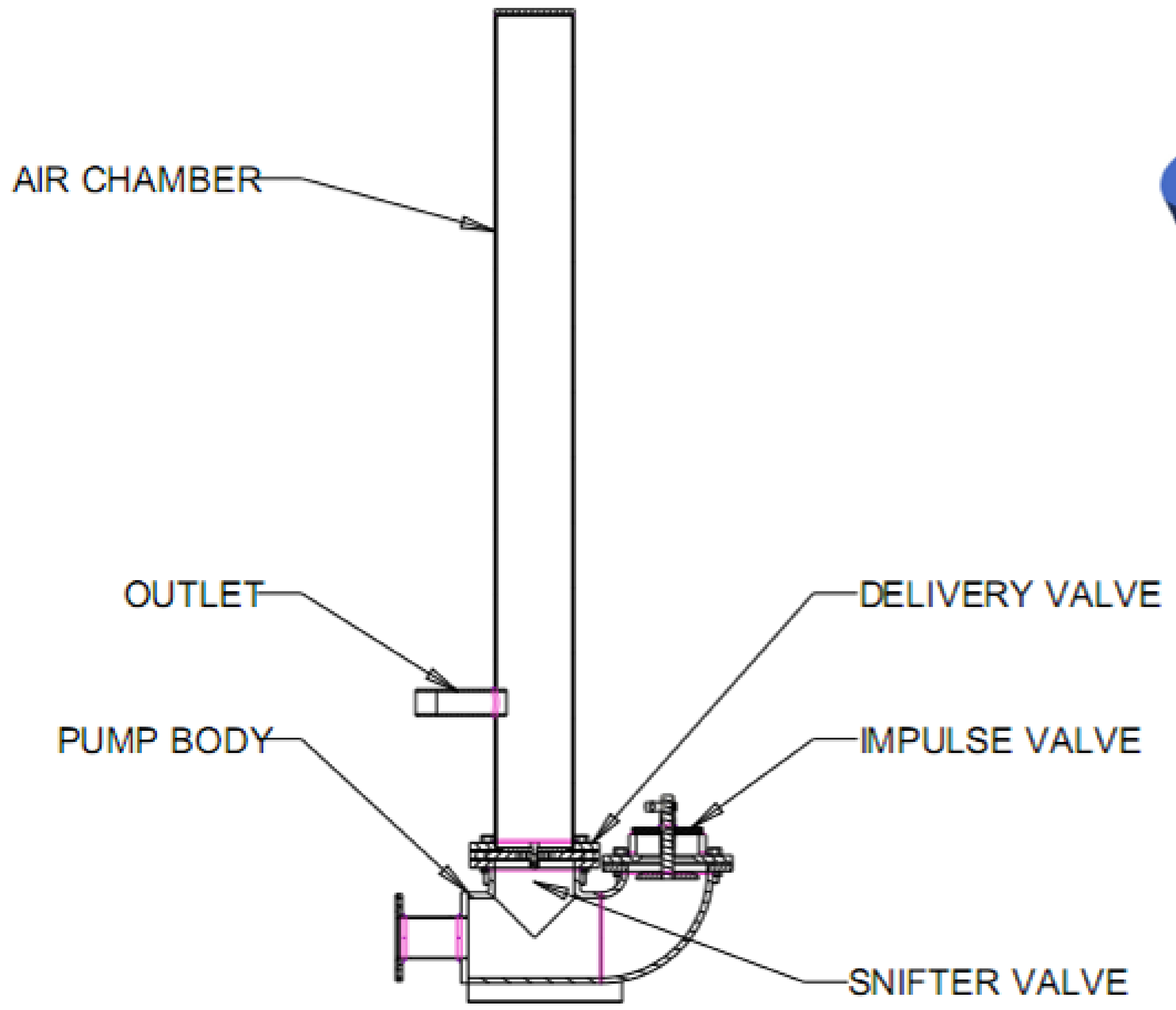
Cost break-down of complete Ram Pump System from AID Foundation						
#	Item description	Quantity	Unit	Rate (PHP)	Amount (PHP)	Amount (USD)
520	**Drive pipe**				**PHP 9,049**	**USD 201**
521	GI Pipe 1 1/2"Øx60m S40	5	length	PHP 1,308	PHP 6,539	USD 145
522	Welding rod (6013)	3	kg	PHP 85	PHP 255	USD 6
523	Portland Cement	8	bag	PHP 210	PHP 1,680	USD 37
524	Sand	0.5	cubic m.	PHP 500	PHP 250	USD 6
525	Hardcore	0.5	cubic m.	PHP 650	PHP 325	USD 7
530	**Delivery pipe**				**PHP 21,053**	**USD 468**
531	ISO HDPE Hose 1"Øx100m SDR - 11	3.5	roll	PHP 3,705	PHP 12,968	USD 288
532	ISO HDPE Hose 3/4"Øx100m SDR - 11	2	roll	PHP 3,424	PHP 6,849	USD 152
533	ISO Brass Replacemet 1"Ø	1	piece	PHP 240	PHP 240	USD 5
534	ISO Brass Replacemet 3/4"Ø	1	piece	PHP 162	PHP 162	USD 4
535	ISO Plastic Reducer 1"Øx3/4"Ø	1	piece	PHP 105	PHP 105	USD 2
536	ISO Plastic Coupling 1"Ø	2	piece	PHP 95	PHP 190	USD 4
537	ISO Plastic Coupling 3/4"Ø	1	piece	PHP 95	PHP 95	USD 2
538	GI Pipe 3/4"Øx6m S40	0.5	length	PHP 600	PHP 300	USD 7
539	GI Elbow 3/4"Øx45˚	3	piece	PHP 15	PHP 45	USD 1
540	Teflon Tape 1/2"	4	roll	PHP 25	PHP 100	USD 2
600	**Distribution line & 3 tap stands**				**PHP 6,659**	**USD 148**
601	ISO HDPE Hose 1/2"øx300m	1	roll	PHP 4,338	PHP 4,338	USD 96
602	ISO Plastic Replacement 1/2"	6	piece	PHP 54	PHP 324	USD 7
603	ISO Plastic Coupling 1/2"	1	piece	PHP 90	PHP 90	USD 2
604	Brass faucet 1/2"	3	piece	PHP 150	PHP 450	USD 10
605	Gate Valve 1/2"	3	piece	PHP 272	PHP 817	USD 18
606	GI Elbow 1/2"x90˚	6	piece	PHP 15	PHP 90	USD 2
607	GI Coupling 1/2"	6	piece	PHP 12	PHP 72	USD 2
608	GI Nipple 1/2"x4"	6	piece	PHP 22	PHP 130	USD 3
609	GI Nipple 1/2"x24"	3	piece	PHP 66	PHP 198	USD 4
610	Teflon tape	6	roll	PHP 25	PHP 150	USD 3
611	Cement	6	bag	PHP 210	PHP 1,260	USD 28
612	Sand	0.5	cubic m.	PHP 500	PHP 250	USD 6
613	Harcore	0.5	cubic m.	PHP 650	PHP 325	USD 7
614	Binding wire	1	roll	PHP 1,450	PHP 1,450	USD 32
700	**Management and Training**				**PHP 47,000**	**USD 1,044**
	Supervision and technology transfer				PHP 42,000	USD 933
	Social Preparation				PHP 5,000	USD 111
800	**Community cost**				**PHP 13,800**	**USD 307**
100	Spring catchment tank - 2 units				PHP 3,594	USD 80
200	Drive tank				PHP 2,671	USD 59
300	Ram Pump foundation				PHP 2,795	USD 62
400	Ram Pump and accessories				PHP 14,500	USD 322
510	Feed pipe				PHP 37,515	USD 834
520	Drive pipe				PHP 9,049	USD 201
530	Delivery pipe				PHP 21,053	USD 468
600	Distribution line & 3 tap stands				PHP 6,659	USD 148
700	Management and Training				PHP 47,000	USD 1,044
800	Community cost				PHP 13,800	USD 307
	Total				**PHP 158,634**	**USD 3,525**


Cost of Ram Pump System by AID Foundation
USD 80
USD 59
USD 62
USD 307
USD 322
USD 1,044
USD 834
USD 201
USD 148
USD 468
Spring catchment tank - 2 units
Drive tank
Ram Pump foundation
Ram Pump and accessories
Diversion pipe
Drive pipe
Delivery pipe
Distribution line & 3 tap stands
Management and Training
Community cost

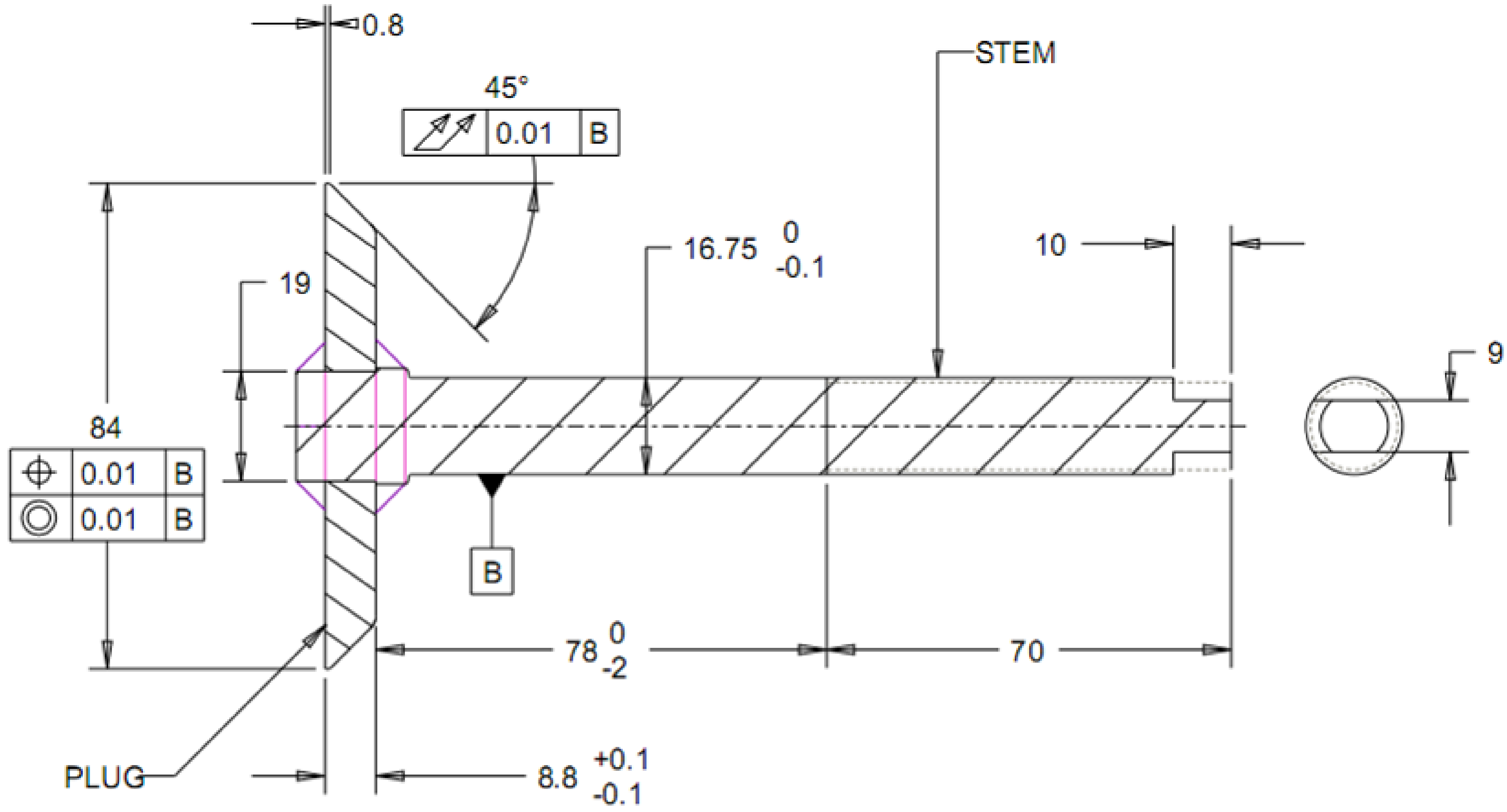
Technical drawings of ACF Hydraulic Ram Pump 2” design

The technician for the manufacture is able to find the technical drawings of:

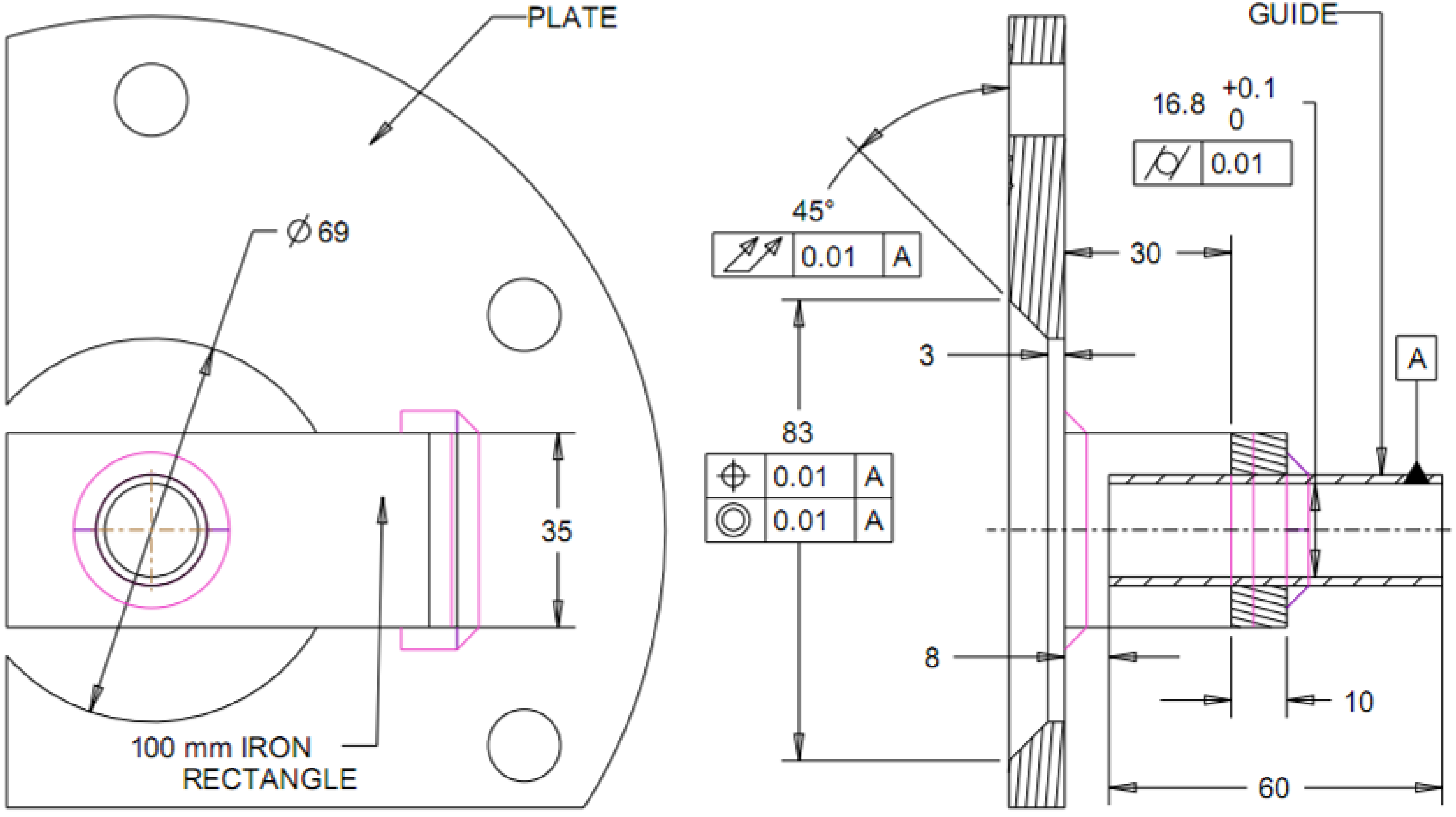
- The ACF Hydraulic Ram Pump 2”;
- The impulse valve plug;
- The impulse valve plate;
- The delivery valve;
- The pump body with supports, flanges and the reducer; and
- The air vessel.



Scale: 0.100	HYDRAULIC RAM PUMP 2"	
D. Browne	Action Contre la Faim	March 2009

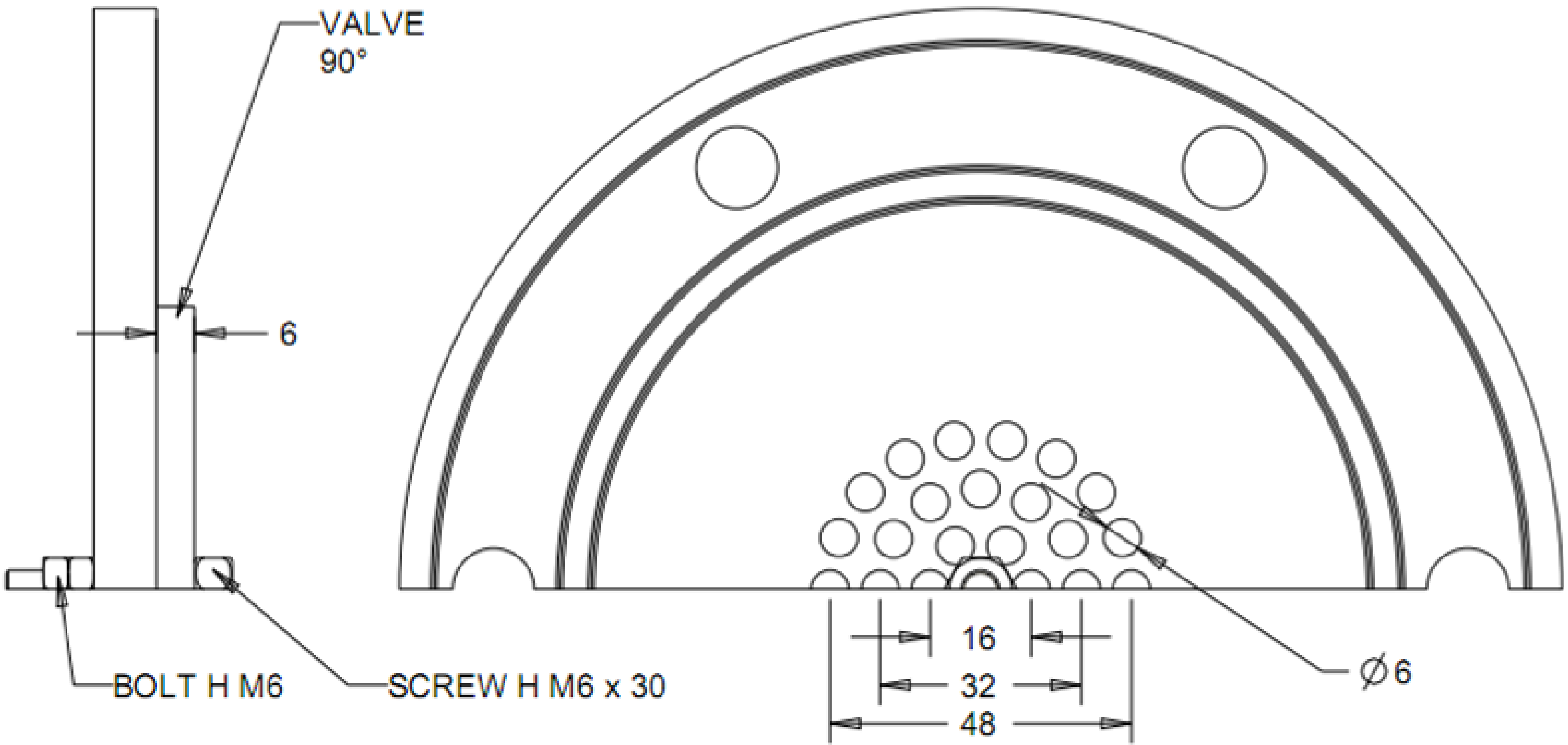


Scale: 1.000	IMPULSE VALVE PLUG 2"	
D. Browne	Action Contre la Faim	March 2009

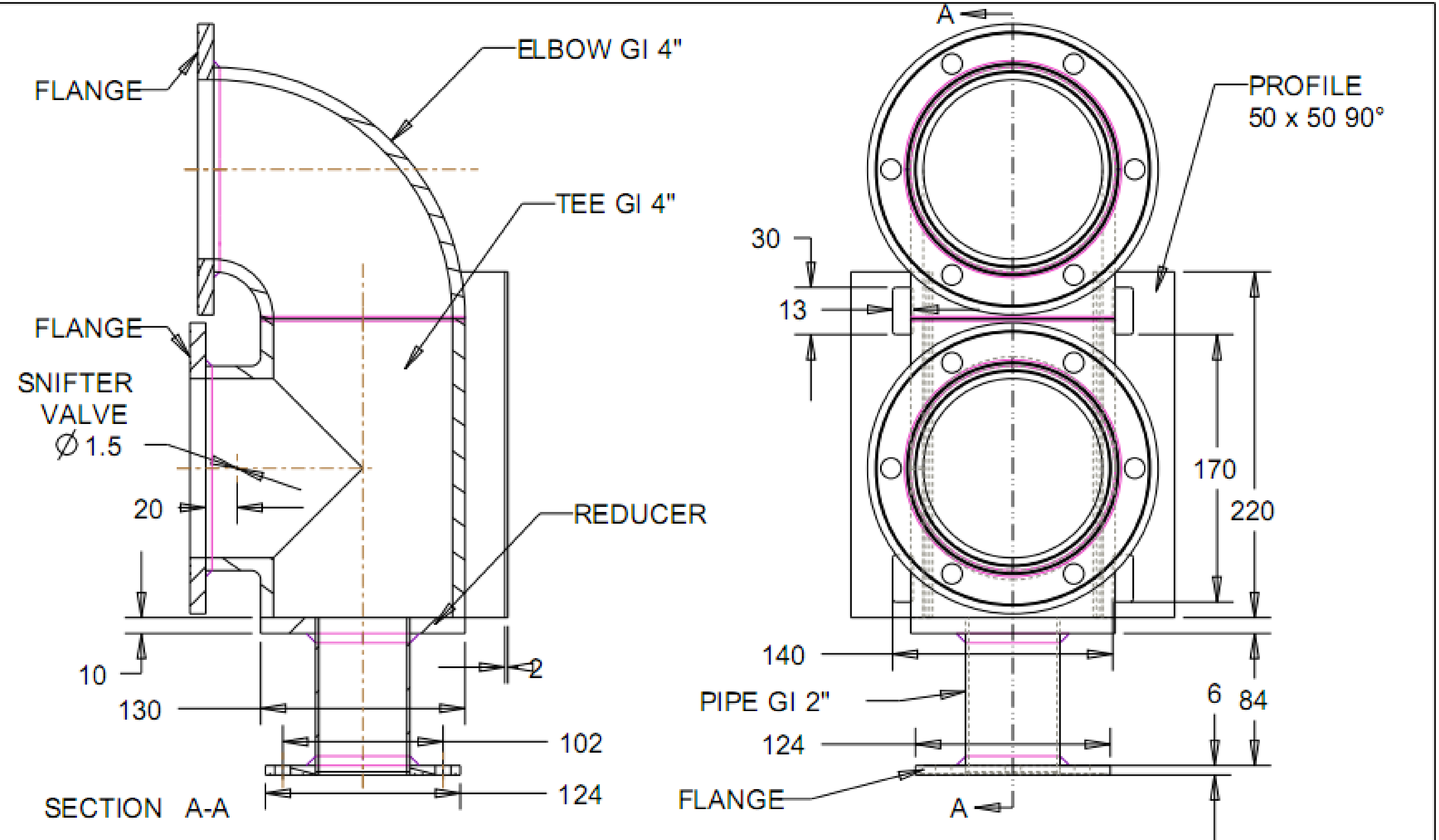


Scale: 1.000	IMPULSE VALVE STOP BAR 2"

D. Browne	Action Contre la Faim	March 2009

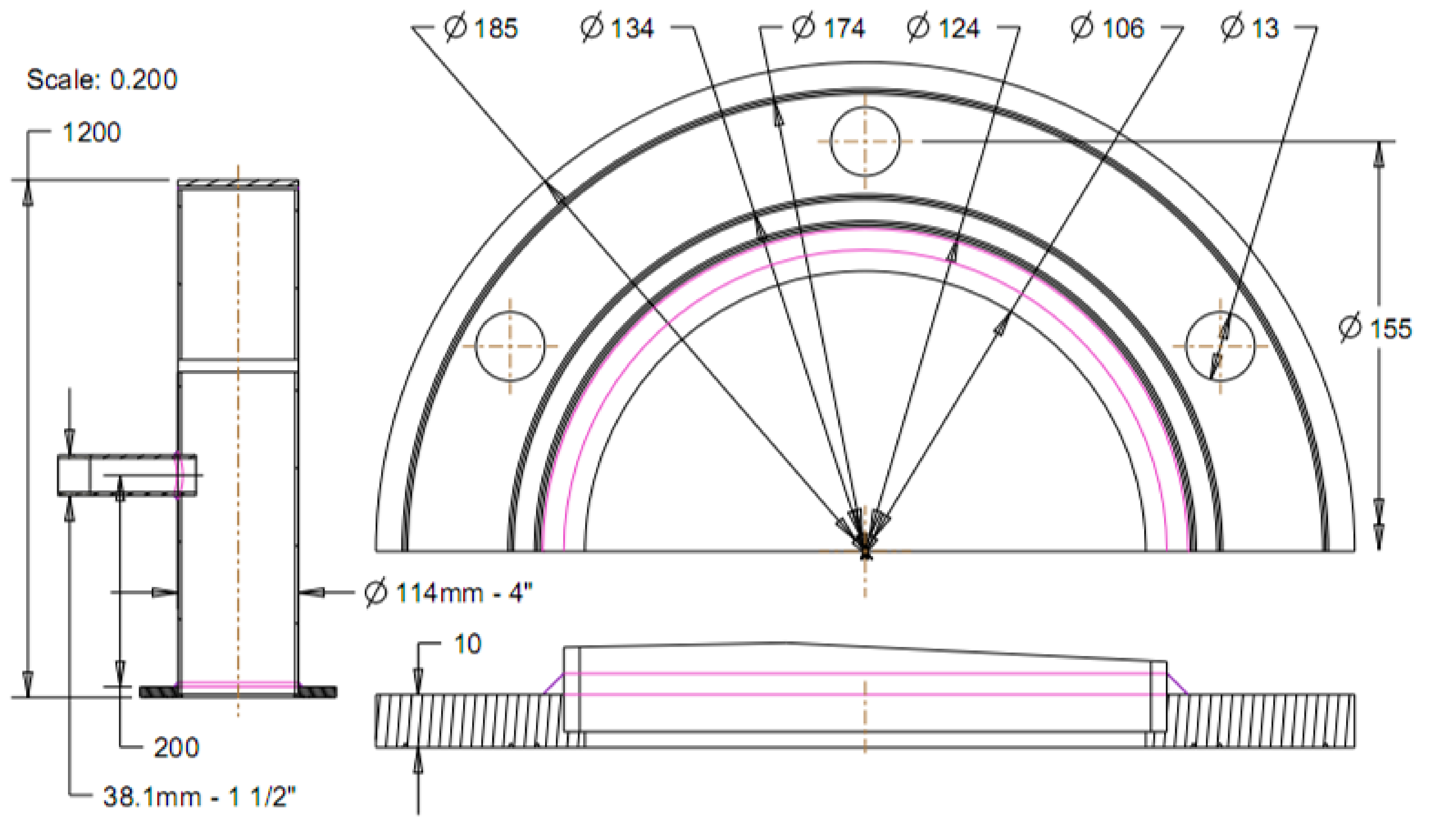


Scale: 1.000	DELIVERY VALVE 2"	
D. Browne	Action Contre la Faim	March 2009



Scale: 0.300	PUMP BODY 2"

D. Browne	Action Contre la Faim	March 2009



Scale: 1.000	AIR CHAMBER 2"	
D. Browne	Action Contre la Faim	March 2009

Contact list

Action Contre la Faim, Paris Headquarter
Technical advisor
10, rue de Niepce
75013 Paris

ACF, Base of Soe
Program coordinator
JL Gajah Mada 56
SOE
TTS, NTT, Indonesia
Phone: (+62) 0388 214 08
Fax: (+62) 0388 22 432
Email: progco-soe@id.missions-acf.org

ACF, David Wala
Water, Sanitation and Hygiene Program Manager
Email: wash-soe@id-missions-acf.org

ACF, Dominique Browne
Intern on Hydraulic Ram Pump Systems
Email: dobrowne@gmail.com

Alternative Indigenous Development Foundation, Auke Idzenga
Head of Technical Department
AIDFI Bldg., Murcia Road, Mansilingan,
6100 Bacolod City
Philippines
Tel: (+ 63) 034 – 4463629
Fax: (+ 63) 034 – 4462330
E-mail: aidfi@hotmail.com

References and further reading

Hydraulic Ram Pumps – A guide to ram pump water supply systems

T.D. Jeffery, T.H. Thomas, A.V. Smith, P.B. Glover, P.D.Fountain
The Department Technology Unit – Warwick University
MDG Publishing, Warwickshire 2005

Water, Sanitation and Hygiene for populations at risk

Action Contre la Faim
Hermann, Paris - 2005

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

Module 1 *General information on water and water supplies*

Module 2 *Principles and sizing of a gravity-fed system*

Module 3 *Feasibility study for the construction of a gravity-fed system*

Module 4 *Construction of a gravity-fed system*

Module 5 *Maintenance of infrastructures*

Module 6 *Hydraulic Ram Pump Systems*

The present booklets have been designed and produced by Action contre la Faim in the frame of a water, sanitation and hygiene program implemented in NTT province, Indonesia. Thanks to the financial support of the private company AQUA - PT Tirta Investama.