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REPORT FOR A RAM PUMP AND IRRIGATION SYSTEM INSTALLED AT A POTATOES SA DEVELOPMENT SITE IN KZN

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Introduction

During 2009 a partnership between Potatoes SA and the KZN Department of Agriculture and Environmental Affairs (subsequently and currently: KZN Department of Agriculture and Rural Development) was established whereby small-scale black growers in KZN could be mentored into becoming capable and financially successful potato farmers. The partnership entailed sponsorship of all potato seed tubers, fertilizer and related inputs to suitable candidate growers for 0.2 ha of potato production with the prospect of sponsorship on a declining proportional scale for subsequent years from Potatoes SA. Extension officers of the KZN Department of Agriculture allocated to the districts of candidate growers were assigned to do mentoring of the growers under supervision by an appointed Potatoes SA official and a potato researcher of the KZN Department of Agriculture. These positions were assigned from the start of the partnership to Louis Pretorius and Morgan Naidoo respectively, while I (Michael Relihan) who was conducting potato research trials for the KZN Department of Agriculture & Rural Development at the time was included in the technical advisory committee and became the secretary for the minutes of such meetings that included attendance of assigned extension officers. Candidate black growers and their land units were selected by this technical committee that met 3 to 4 times per year on the basis of their farming experience, suitability of the proposed site for production and related aspects including accessibility of the site.

One of the important site criteria for approval of a candidate site was access to a reliable source of irrigation water and possession of an irrigation system that was effective to apply adequate amounts of irrigation water for potato production. Some summer production sites at locations that reliably received high levels of summer rainfall were exempt from this requirement, but it was a necessary criterion for most of the selected sites across KZN. At an early stage of this partnership it was recognized that capacity to apply adequate irrigation for potato production was a major constraint that greatly limited the number of qualifying sites. Usually, a source of irrigation water was not very distant, but the capacity to pump from it was the limitation. Most areas where such development sites were located were remote and did not have Eskom electrical supply laid on. They were often accessed via travelling many kilometers on poor dirt roads which was a deterrent to transport petrol for petrol-powered irrigation pumps, as was the cost of petrol to pump adequate irrigation. After recognition of the importance of this constraint, I proposed at technical meetings that renewable 'free' energy irrigation pumping systems should be considered as an alternative to electrical-powered or petrol-powered irrigation systems. This proposal encompassed energy from solar power, wind and water energy from a source stream as options, but a ram pump system powered by water energy was proposed as widely applicable. Unfortunately, consultation with engineers of the department at the time failed to elicit support from them for these ideas, so I as a qualified Plant Pathologist with some self-taught experience in making equipment took up the challenge to demonstrate application of the concept by installation of a ram pump powered irrigation system at a candidate production site. Prior to this I had a basic knowledge of ram pumps but had never before made or installed one, so this became a learning experience involving some setbacks. I was permitted to take on this project between my other research responsibilities and it was allocated a research project code: HS2009_3. Potatoes SA agreed to pay for irrigation fittings and piping, while my transport to the site was via vehicles of the KZN Department of Agriculture and at their expense. The lessons learned from this installation were deemed very valuable to share with others and hence this report for the web site.

The site selected for a ram pump installation

Among the sites under consideration in 2009 was a site at Vulamehlo district inland of Umzinto at the South Coast. The site was remote from developed areas and accessible via some distance of travel on dirt roads over hilly terrain. This site was adjacent to the small KaMampungushe river which was a tributary to the Umkomaas / Mkomazi River. I inspected the site and considered it suitable for installation of a ram pump. I was concerned about the lack of a steep drop in the river near the site, but I thought that this issue could be overcome with a long siphon pipe taking the water to a stand pipe close to the ram pump with adequate head for operation of the ram pump. A map location and Google maps satellite photo of the site is presented in Fig. 6.1 and 6.2 respectively.

Design and construction of the ram pump

I found many ram pump designs of considerable diversity on the internet. One of the designs initially most valued was of the Papua New Guinea ram pump (Inversin 1977), though aspects of some other designs were appealing. I decided to make an impulse valve much like that of the Papua New Guinea ram pump, but with a different non-return valve position and different pressure chamber.

The impulse valve (Fig. 1.1), also called the waste valve and clack valve, was made from a 3 inch stainless steel nipple cut in half and other stainless steel components. To the threaded end of the nipple was welded a large laser-cut stainless washer to create the sealing surface for the valve. On the other end was a segment of small stainless pipe welded on end via flanges across the middle cut area of the nipple to serve as a mounted bush for the valve. I had an 8 mm hole drilled through this along the center axis of the nipple on a lathe at an engineering firm. The valve was made from a long 8 mm threaded bolt with 2 large matching washers. A cotter-pin type of fitting was made from pipe segments which locked in a rubber washer and its covering stainless washer at the base of the bolt. The valve assembly was fitted with a lower spring and upper spring either side of its bush that enabled adjustment of its operation. Initially, I thought the valve would operate better with large weights attached to its top and fitted these (Fig. 1.5), but later found that it worked better without them, as long as suitable springs were selected and the correct locking nut position was set. Two drawbacks to this impulse valve design were identified (See Fig. 1.6). Firstly, the bolt of the valve would have been made easier and stronger without the cotter-pin assembly on the rubber seal if a short bolt was welded back to back with the long bolt to which the seal with its washers could be fitted. Secondly, the wear and tear on both the bolt and the circular bush supporting it was more than anticipated and an insert sleeve into the bush area would have reduced wear and could be replaced with little trouble.

I desired the ram pump to be a secure anchor for the end of the drive pipe and in order to achieve a secure connection to the pump I decided to internalize the non-return valve within the pressure chamber (Fig. 1.3) rather than expose the more vulnerable brass delivery non-return valve to great leverage forces, and for the added reason of having a larger pressure chamber (less subject to pressure fluctuation), to be mounted horizontally so that water entering this did not need to change direction and which should aid efficiency of the pump. Some other good designs of ram pumps also internalized the delivery non-return valve (Than 2008, Thomas 2008, Anonymous 1, Spruce 2010), though all of these had a vertically-orientated pressure chamber.

In retrospect, while these were good motivations, the complexity of a special mounting for internalizing the non-return valve (Fig. 1.2) was a drawback, and perhaps a better plan would be to securely concrete in the end of the drive pipe than depend on the ram pump as a secure anchor point. On the other hand, to securely anchor the drive pipe requires having the drive pipe position and orientation fixed at the start, and I did need to alter its position after lengthening it to achieve an optimum pumping performance. I made the pressure chamber from wide galvanized iron piping with a welded on front threaded opening (Fig. 1.3), and with stainless nipples welded on and then painted with rust-protective paint. Another lesson learned was that the greater part of the pressure chamber could be made cheaper, easier, less prone to theft for scrap metal, and immune from rust by making it mostly out of concrete (adopted in the construction of a new prototype pump recently). While the pressure chamber was tricky to make, it served its purpose well and was a satisfactory design. The pressure chamber was mounted onto a stand made of welded angle iron that was hot-dipped galvanized and to which the chamber was attached by large U-bolts (Fig. 1.4 and 1.5)

Photos of ram pump construction

Fig 1.1 Impulse valve of stainless steel. The body was a 3 inch BSP barrel nipple cut in half with a disk welded to the bottom end. A cut pipe segment with flange was welded to the top as a guide for the axis of the valve made of a stainless bolt with seal on its end.

Fig. 1.2 A stainless fitting made to screw into the pressure chamber with the outer nipple (at left) connecting to a T in which the impulse valve fitted, and the inner nipple (at right) connecting to a flap-type non-return valve.

Fig. 1.3 Ram pump steel pressure vessel (main view) showing threaded opening on top, output nipple (left side) and a pressure-release nipple (lower right side). The Inset lower left shows the fitting with attached non-return valve that screwed into its opening.

Fig. 1.4 Ram pump assembled except for the impulse valve to screw into the large threaded T (center). Barely visible at the top of the outer nipple of the fitting screwed into the pressure vessel is a snifter valve comprising a hole with a slotted machine screw in it.

Fig 1.5 Assembled ram pump. Initially the impulse valve was fitted with disk-weights for control which were removed later as it operated better without them.

Fig. 1.6 Bolt axis of impulse valve (upper) showing severe abrasion after several months of operation and lower seal showing wear and a tear.

Initial installation of the ram pump at Vulamehlo

After making the ram pump at Cedara and Pietermaritzburg, a basic test was set up from a swimming pool which demonstrated pumping, albeit weakly due to a very short drive pipe. In order to install a siphon pipe, 100m of 50 mm ID black polyethylene piping was purchased. This being somewhat tricky to fit to the allocated bakkie from Cedara, I proceeded to make a special scaffold that attached to the towbar and roofrack of my own Toyota Avante and successfully transported the roll of piping to the site with this (Fig. 2.1) though the front horizontal strut of the roof-rack bent. The piping was rolled down to the site of installation near the river where potatoes had already been planted as part of the Potatoes SA transformation development program (Fig. 2.2).

I decided that a brick pumphouse was needed to shield the ram pump from damage due to rocks rolling down the river or floating logs when the river was high and so commissioned two locals to build this for me (Fig. 2.3). The ram pump had a low profile but this pumphouse was made more than 1 m high mainly because of an intention to be able to install a petrol pump on top of the ram pump. Serious mistakes were made with this pumphouse which allowed it to be swept away by a flood much later: namely (i) the foundation should have been excavated properly to hard rock and securely concreted to this, (ii) it should have had a lower profile, and (iii) it should have been installed further inwards into the bank and further from the river course. The ram pump was bolted to the floor of the pumphouse on its galvanized stand (Fig. 2.4). A galvanized drive pipe was connected to this via the union attached to a 45 ° elbow. The drive pipe went up the bank to a concrete stand pipe made for this with stainless fittings concreted into it (Fig. 2.6). The ram pump mounting position was selected so that tightening or loosening the 45 ° elbow oriented the drive pipe close to the orientation of the river bank.

Initially a simple sand bag weir was made for temporarily securing the siphon pipe at the opposite end up the river (Fig. 2.5). The end of the siphon pipe was fitted with a simple slide-on polyethylene pipe fitted into a plastic bottle and around the whole assembly an orange bag was fitted as a filter (Fig. 2.5). Two simple concrete molds were made of wood for casting of concrete mountings to anchor the siphon pipe in the river (Fig. 3.1 and 3.1). These concrete mountings were attached to solid rock in the river course by stainless threaded rods epoxied into the rock.

The initial installation of the ram pump was very unsatisfactory since the it often stopped pumping and its output pressure was very low. It took some time before I discovered that weights on the impulse valve (Fig. 1.5 & 5.2) could be replaced by springs which caused the valve to work better. A greater improvement to the pump itself resulted much later after lengthening the drive pipe and moving the stand pipe upstream. Performance of the pump was also inadequate due to insufficient flow of water through the siphon pipe through which the flow frequently declined until cleared. The cause was discovered to be a combination of air lock mostly, but also sediment in the siphon pipe, due to vertical undulation of the siphon pipe that created low and high points. The siphon pipe was then re-routed in the river winding down in such a way as to minimize vertical fluctuation, in some places with excavation under the pipe and in other places propping it up with large rocks. After re-routing the siphon pipe it operated better, but much later it became necessary to install a second adjacent siphon pipe in the upper section and join to a 75mm pipe in the lower section to get adequate flow to the stand pipe, which was only done after construction of the weir. Due to these setbacks the ram pump was not utilized for that season’s potato crop. Irrigation was applied to the crop by means of a petrol pump at the river, but the installation of the ram pump was still deemed to have prospects for success and use with other crops and therefore not abandoned then.

Construction of a weir

A few high water events occurred that summer which were able to dislodge the sand bags causing the siphon pipe to pull away, so I decided that installation of a concrete weir in place of the sand bags was required, but its construction was postponed to winter when the river was at its lowest and after getting a permit to install one. Construction of the weir became the most challenging aspect of the ram pump installation, and in retrospect could have been avoided by constructing a sump collection point instead especially because it was eventually compromised by a major flood.

Construction of the weir began by carting a large concrete lintel from Cedara to the site on a trailer (Fig 3.3). This lintel was retrieved from demolished buildings at Cedara. Getting this lintel to the site of the weir was a challenge since the nearest roads were a few hundred meters away. With help from locals it was moved across the stream and over undulating terrain on concrete rollers with support from a scaffold of pipes, and pulled along with a hand winch (Fig. 3.4 & 3.5). On each side of the stream holes were excavated to rock below for concrete struts for the weir and these were lowered into position using a heavy-duty tripod that I specially made (Fig. 3.6).

Photos of initial ram pump installation

Fig. 2.1 My own Toyota Avante fitted with a tow bar strut that connected to a cross member on the roof rack for transport of 100m of HDPE 50 mm piping needed for the ram pump site. Mkomazi river in background.

Fig. 2.2 The site at Vulamehlo to which the HDPE piping was delivered. Background is an area planted to potatoes as a Potatoes SA transformation project. This piping was used for the siphon pipe in the river (below).

Fig. 2.3 Mini pump house to shield the ram pump, just after completion of the brick laying by 2 locals. The foundation should have been excavated to solid rock and its height should have been much lower because eventually a massive flood ripped the whole thing out.

Fig. 2.4 Michael Relihan attending to the ram pump after installation. In the foreground going right is a 1.5 inch NB drive pipe that connected to a stand pipe on the bank of the river. A small black plastic pipe (lower left) is the ram pump output pipe going up the hill.

Fig. 2.5 An initial temporary weir made with sand bags. A crude filter made from a plastic bottle (inset top right) was enclosed in an orange bag and fitted to the opening of the siphon pipe.

Fig. 2.6 The stand pipe made from concrete pipe that connected the siphon pipe (bottom right) to the drive pipe for the ram pump (background). Stabilized by cable attachment to a concrete stake.

Photos of how the siphon pipe was anchored and commencement of weir construction

<table>
<tr><td></td><td></td></tr>
<tr><td>Fig. 3.1 Cement castings of clamp bases made for anchoring the siphon pipe to rocks in the river.</td><td>Fig. 3.2 An illustration of a siphon pipe clamp that was mounted on a rock in the river. The outer stainless steel flange was held down by nuts on two threaded rods that were embedded into the rock.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fig. 3.3 Commencement of construction of a weir by transport of a large concrete lintel salvaged from a demolished building at Cedara to the ram pump site on a trailer.</td><td>Fig. 3.4 Showing movement of the weir's lintel on rollers (previously garage door counter weights) by locals supported by a pipe scaffold and dragged by hand-operated winch attached to trees on the route.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fig. 3.5 Illustration of the weir's lintel adjacent to where it would be installed on the river. Local youth attending.</td><td>Fig. 3.6 Showing installation of a concrete lateral strut of the weir lintel into a hole by a friend helping. The strut was lowered in position by the large tripod shown that was made for the project by Michael Relihan.</td></tr>
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I also specially made another pipe gantry that was used to orientate and lower the concrete lintel into position (Fig. 4.1). These tools were well suited to their use and positioning of the lintel was not difficult. The lintel was initially bolted to its lateral struts by specially made anchors made of stainless steel (Fig. 4.2).

The permit for the weir required installation of a sluice gate so that flow of the river could be maintained in drought conditions. A suitable sluice gate was made from a concrete pipe to which a stainless steel flange was attached in which a flat plate could slide to open and close this (Fig. 4.3). I was astonished how effectively it could block water flow when closed after installation into the weir.

Construction of the weir entailed excavation by hand down to solid bed rock at that location and then segments of the weir floor were cast in such a way as to permit unobstructed flow of the river until the sluice gate was concreted in through which the flow was then diverted (Fig. 4.4 & 4.5). This was a very laborious task which involved several trips down there on Sundays and I employed help from friends and locals with the concreting operation at my expense (Fig. 4.6). A side channel was concreted to divert some flow around the lintel and 50 mm wide stainless pipe was concreted into the wall as the main feed to the siphon pipe (Fig. 4.6 and 5.1). The weir was completed in the latter part of 2010 during the early part of summer. Issues with adequate pump performance took some time to resolve that summer but the ram pump was made operational (see Fig. 5.2). While improvements to the pump were made I also realized that a customized low pressure irrigation system would also have to be installed since the low fall in the river to the ram pump severely limited its capacity to pump to a high pressure.

Due to other research commitments installation of such an irrigation system had to be put on hold until the winter of 2011.

Installation of irrigation lines and system

Having thus committed to this project in a major way, it was clear that the installation could not be permanently acceptable without installation of a compatible low pressure irrigation system. An unused 5000L JoJo tank in the area was allocated by the locals to this project and moved adjacent to an access road running down a boundary fence towards the ram pump's location at an altitude of 15-20m higher than the ram pump (Fig. 5.3). A plan was devised for installation of permanent buried pipes connecting the ram pump to the JoJo tank in a line up the hill with a T branching off at the upper end of two fields that bordered the river.

Suitable plastic piping of various diameters was scrounged from unused excess at Cedara and some fittings and small amounts of extra piping were also purchased and transported to the site. A dumping ground of damaged concrete pipe was found at Cedara from which segments of concrete pipe were cut with an angle grinder and transported to the site. These segments were epoxied to a size-matched paving stone for the base and holes for piping were drilled through with diamond coring bits on site (Fig. 5.4). The concrete segments were placed at major junctions of piping in the land in such a way as to protect the couplings from traffic of vehicles and animals (Fig. 5.5 & 5.6). The major irrigation lines were installed in 2011, but much of this was still on the surface. At this stage some of the piping was damaged by a fire that broke out which gave impetus to getting the replacement piping placed in trenches. Locals were paid to dig trenches for the piping which entailed several hundred meters of trench (Fig. 5.3, 5.5 & 5.6). The last trench to be completed was one going up to the JoJo tank and this was completed late in 2012.

The map location of the site is shown in Fig. 6.1 and the plan of the irrigation system is shown in Fig. 6.2. This system permitted the ram pump to pump all the time while allowing irrigation to be controlled for lands 1 and 2 via the taps at the T junction and elbow junction (Fig. 5.3, 5.5 & 5.6). A microjet irrigation system was conceived and designed to run from irrigation lines horizontally across the land or lands at 5 m intervals (Fig. 6.3 & 6.4). This system entailed a hexagonal grid of mono-spinner microjets attached to creosoted poles to be staked into the land with microjets spaced 5.8m apart in the lines. Many of these sprinklers were bought and assembled for use but they were not utilized initially since the system was first connected to an ordinary impact sprinkler in land 2 where a smaller area had been cultivated for maize and vegetable production. The ram pump was found to be able to produce adequate pressure for operation of an impact sprinkler (Fig. 6.5). The installation of the irrigation lines and functionality of the system was virtually complete late in 2012 and cell phone video was obtained showing operation of the ram pump and use of the sprinkler on 2012-11-25 shortly before disaster struck the project.

Photos of construction of the weir

Fig. 4.1 Showing the weir's lintel after lowering into position on its two lateral concrete struts. The steel scaffold shown here was used to position the lintel and it was made by Michael Relihan.

Fig. 4.2 Showing how the weir lintel was attached to a lateral strut by custom made stainless steel anchors bolted to the weir lintel and the strut on the upstream side.

Fig. 4.3 A custom-made weir sluice pipe made from a stainless steel flange screwed to the end of a concrete pipe that had slots either side for a plate to slide. This sluice pipe functioned amazingly well.

Fig. 4.4 Showing concreting of the weir. The entire base was excavated down to bed rock and concreted in sections allowing flow of the river at each side of it prior to concreting in the weir sluice pipe.

Fig. 4.5 Showing progress with weir concreting from the downstream side with the sluice pipe already concreted in.

Fig. 4.6 Late stages of weir concreting. A stainless steel pipe was fitted through the weir at the location where the helper is working for connection to the siphon tube.

Photos of the completed weir, operating pump and installation of irrigation lines

Fig. 5.1 The weir after completion of concreting. To improve flow down to the stand pipe two siphon pipes were installed as shown.

Fig. 5.2 A cell phone video frame of the operating ramp pump at an early installation stage. Its operation was improved by removing the disk weight from the impulse valve which had springs installed on its shaft instead.

Fig. 5.3 Showing the piping connection to a JoJo tank uphill from the ram pump and roughly about 300m from it. This tank provided water head pressure close to 1.5 bars at the land where irrigation was supplied.

Fig. 5.4 Showing how a diamond coring bit fitted to a heavy duty drill was used to make holes into concrete pipe segments for protecting pipe couplings.

Fig. 5.5 The pipe couplings between the ram pump (shown far lower right), the JoJo tank (shown upper left) and the irrigation line to the land (shown lower left). A second infeed pipe from the river was also installed (with tap) to which a petrol pump could be connected.

Fig. 5.6 The pipe couplings at the upper centre of the land. The large pipe at the right connects to the pipe couplings shown in Fig. 5.5 The pipe to which the pipe wrench is attached went down to irrigation connection points along the fence between adjacent lands.

Photos of the irrigation setup and flood damage

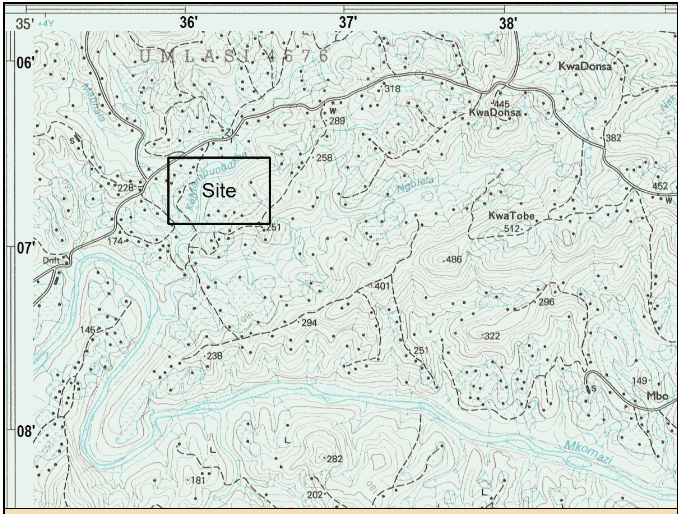

Fig. 6.1 Location of the site on a 1:50 000 map of the ram pump irrigation project on the KaMampungushe tributary to the Mkomazi river at Vulamehlo.

Fig. 6.2 A Google maps satellite photo of the Vulamehlo ram pump installation site with location of irrigation system and land units superimposed.

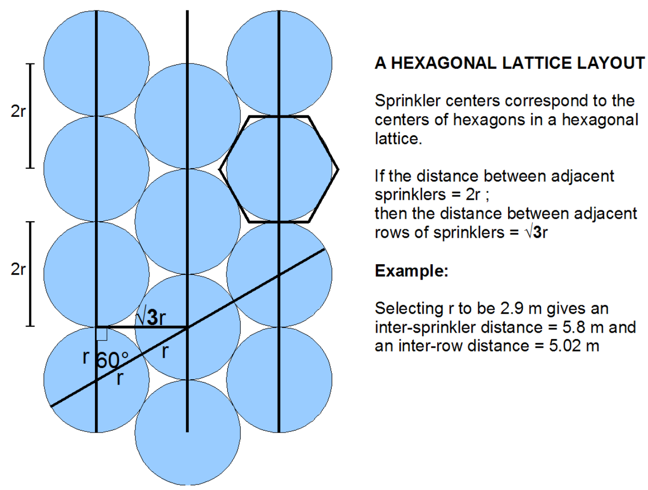

Fig. 6.3 Proposed layout of a low pressure sprinkler system to be installed at the site. Microjet sprinklers (see Fig. 6.4) were capable of an irrigation spray radius greater than 2.9m at about 1.5 bars pressure.

Fig. 6.4 Microjet sprinklers were made up and attached to creosote poles for installation according to the proposed low pressure sprinkler system (Fig. 6.3) but these were not installed before the project ended.

Fig. 6.5 A photo (from cell phone video) of an operating impact sprinkler connected to the ram pump powered irrigation system in land 2 (see Fig. 6.2). The sprinkler had adequate pressure from the JoJo tank to operate.

Fig. 6.6 A photo of the weir soon after a massive flood had occurred (about 2012-12-10). This flood carved a new river course next to the weir as shown, ripped out large trees next to the river, and ripped out the pump house and ram pump. The project ended soon after.

Disastrous flood damage and termination of the project

It was most disheartening when I learned that a massive flood had hit the area around 2012-12-10. Initially a technician from Cedara working with me went to see the damage and took some photos and video, but later I was able to see the damage myself. I hardly recognized the area since many of the trees lining the river were gone and the river course changed. A new river channel had been carved adjacent to the weir (Fig. 6.6) and the pump house below was entirely ripped away. I found part of the pump house wall more than 100m downstream, but the ram pump was gone. The stand pipe was washed down stream but it was retrieved. A major road bridge near the site was also severely damaged and was unusable for some time. The concrete weir itself was not moved and only very minor damage to a corner was seen, but the anticipated costs of building concrete side extensions to the weir to render it functional again was huge. I had also committed to taking charge of the plant health diagnostic service lab at Cedara by that stage which was a much more time-demanding position at Cedara. These circumstances, and the views of senior staff prevailed and forced me to abandon the ram pump project there, though the locals at the site still had benefit of the installed irrigation lines.

Although this ram pump installation project did not remain operational, it worked for long enough to demonstrate that a ram pump could be used to power a small scale irrigation system at a location with a low fall in the river. I, as a qualified plant pathologist, had achieved this with self-taught knowledge of construction, but some mistakes due to inexperience were made. If there had been involvement of qualified engineers of the KZN Department of Agriculture, some early challenges could have been overcome sooner and possibly the loss of the ram pump and damages to the system could have been prevented, but such help was not available. A few years later now, I have noted that the lessons learned from this project would be valuable to share with others and this motivated this publication.

Performance parameters of the installed ram pump

Several of the key performance parameters of the installed ram pump were not measured as I was focused on finalizing the irrigation piping in the land when the flood bypassed the weir and took the pump. However, I was able to establish from video that the ram pump operated at about 35 cycles per minute on 2011-12-13. The head from the water in the stand pipe to the impulse valve was about 1.8 m and flowed through a 1.5 inch nominal bore (48 mm OD) drive pipe of length approximately 22 m. The flow rate through the drive pipe was not measured, but very roughly estimated at about 80L/min. The pump was able to fill up a 5000 L JoJo tank up the hill at approximately 18 m height above the ram pump, but unfortunately the time it took to do this was not measured and thus the delivery output was not available for the efficiency to be calculated. The pressure generated by the head to the JoJo tank was adequate for good operation of an impact sprinkler in the land below where mixed vegetables and maize were planted in 2012 (see Fig. 6.5).

Derivation of Rankine ram pump efficiency formula

I have encountered several articles with in depth mathematical models dealing with the operation of ram pumps (Kahangire 1986, Schiller 1986; Than 2008; Suarda et al. 1984; Fatahi-Alkouhi et al. 2019). Those who are interested can find value in these, but I am of the opinion that delving into this can easily cause one to miss seeing the wood for the trees. The one simple formula that appears most useful for ram pump feasibility calculations is the Rankine efficiency formula (Kahangire 1986; US Aid 1982; Jennings 1996).

This formula was used by several sources encountered but I re-derived it (see below) after not accessing a source that did so (though I chose different symbols for the formula). For this derivation we ignore the oscillatory flow of water in the drive pipe and approximate by using the potential energy lost as if it were uniform flow, but this approximation is a reasonable one.

Let

W_1 = the potential energy lost by a given volume of water passing the bottom end of the drive pipe of the ram

W_2 = the potential energy gained by a given volume of water passing into the bottom end of the delivery pipe

P_1 = the power released by loss in potential energy of a given volume of water passing the bottom end of the drive pipe of the ram in a given time

P_2 = the power transferred by gain in potential energy of a given volume of water passing into the bottom end of the delivery pipe in a given time

t = the given time during which power is lost from the drive pipe and gained by the delivery pipe

This transfer of power is obviously incomplete as some is lost at the pump by its operation. So we can define the efficiency as:

$E = P_2/P_1$ [which lies between 0 and 1 and typically between 0.4 and 0.8]

= $(W_2/t)/(W_1/t)$
Rearranging: $(W_2/t) = E(W_1/t)$

The efficiency factor E defined above is known as the Rankine efficiency factor (Kahangire 1986).

Now the potential energy lost by depressurizing a given volume of pressurized water is computed as:
$W_1 = p_1V_1$ (https://energyeducation.ca/encyclopedia/Energy_from_water)
where:
p_1 = the static pressure of the water at the bottom end of the drive pipe
V_1 = the volume of pressurized water passing the end of the drive pipe in time t
similarly:
the potential energy gained by pressurizing a given volume of water is computed as $W_2 = p_2V_2$
where:
p_2 = the static pressure of the water at the bottom end of the delivery pipe
V_2 = the volume of pressurized water passing into the bottom end of the delivery pipe in time t

Substituting for W_1 and W_2 above we get:
$(p_2.V_2/t) = E(p_1V_1/t)$

Now the static pressures at the bottom of the drive pipe and delivery pipe respectively are determined by the water heads:
$p_1 = h_1\rho g$ and $p_2 = h_2\rho g$
where:
h1 = the height difference in m between the entrance to the drive pipe and the bottom of it
h2 = the height difference in m between the exit point of the delivery pipe and the bottom of it
ρ = the density of water
g = acceleration due to gravity 9.8 m/s^2

Substituting again:
$(h_2\rho gV_2/t) = E(h_1\rho gV_1/t)$
and eliminating ρg each side by division we get:
$h_2(V_2/t) = E.h_1(V_1/t)$
$\Leftrightarrow$ $(V_2/t) = E.(h_1/h_2)(V_1/t)$

Now the volume of flow per unit of time is simply flow rate so we can define flow rates Q_1 and Q_2:
$Q_1 = V_1/t$
$Q_2 = V_2/t$
(with the understanding that flow rate is over the same time period)

We then get the useful and simple form of the Rankine efficiency formula:

$$Q_2 = (E.Q_1.h_1)/h_2$$

Energy losses that reduce E are due to kinetic energy of splashing water released from the impulse valve, flow impedance in the drive pipe, impulse valve, delivery valve and delivery pipe, and sound/vibration energy when the impulse valve closes. This equation has been derived assuming SI units, but in fact it applies to any units of flow rate and heights.
Other efficiency formulas with greater precision to particular pump setups have been defined (see Kahangire 1986), but the Rankine efficiency formula is widely utilized to give an understanding of the potential output of a ram pump based on the head ratios and the flow rate through the drive pipe. For this purpose, it is common to postulate an efficiency factor = 0.6 for a fairly good pump, but this is of course dependent on the design and installation features of the pump.
Using this efficiency formula, we can compute a performance table with example parameters:

Ram pump performance illustrated using Rankine efficiency formula

$$Q_2 = (E.Q_1.h_1)/h_2$$

50	**Q_1 = Source flow rate (in drive pipe) in liters/minute**
0.6	**E = Efficiency of ram pump**

h_1 = Working Fall (m)	**h_2 = Lift Height to which Water is Raised Above the Ram (m)**										
	5	**7.5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**80**	**100**
1	6.0	4.0	3.0	2.0	1.5	1.0	0.8				
1.5	9.0	6.0	4.5	3.0	2.3	1.5	1.1	0.9			
2		8.0	6.0	4.0	3.0	2.0	1.5	1.2	1.0	0.8	
2.5		10.0	7.5	5.0	3.8	2.5	1.9	1.5	1.3	0.9	0.8
3			9.0	6.0	4.5	3.0	2.3	1.8	1.5	1.1	0.9
3.5				7.0	5.3	3.5	2.6	2.1	1.8	1.3	1.1
4				8.0	6.0	4.0	3.0	2.4	2.0	1.5	1.2
5				10.0	7.5	5.0	3.8	3.0	2.5	1.9	1.5
6					9.0	6.0	4.5	3.6	3.0	2.3	1.8
7						7.0	5.3	4.2	3.5	2.6	2.1
8						8.0	6.0	4.8	4.0	3.0	2.4
9							6.8	5.4	4.5	3.4	2.7
10							7.5	6.0	5.0	3.8	3.0
12							9.0	7.2	6.0	4.5	3.6
14								8.4	7.0	5.3	4.2
16									8.0	6.0	4.8
18									9.0	6.8	5.4
20										7.5	6.0

Example calculation of irrigation pumping requirements for potatoes (L/min)

Let us suppose the plan is to irrigate 0.2 ha of potatoes with a peak irrigation demand of 30 mm per week, while factoring an average of 15 mm/week rainfall during the middle of the summer rainfall season for a precipitation total of 45 mm/week which is approximately the target requirement at potato tuber initiation.

Since 1 mm of irrigation = 1 L/m^2 we require 2000x30 = 60000 L/week

The ram pump operates for 24 hours per day so the pumping demand here in liters per minute is simply 60000/(7 x 24 x 60) = 5.95 L/min

Example calculation of potential irrigation that can be delivered by the ram pump (L/min)

If we assume that the ram pump is 5 m below the land adjacent to the river where irrigation is to be applied, and if we require 1.3 bars water pressure there, then a pump delivery head of 5 m + 13 m = 18 m is required.

So assuming (and selecting figures closely reflecting the installed ram pump)

h_1 = 1.8m

h_2 = 18m

Q_1 = 80 L/min

E = 0.6

Substituting into the Rankine efficiency formula we get:

Q_2 = (0.6 x 80 x 1.8)/18 = 4.8 L/min

In this scenario the ram pump has a pumping deficit of 1.15 L/min (=5.8 mm/week on 0.2 ha) at an efficiency factor of 0.6. However, if a pump efficiency of 0.7 could be achieved then the pump would deliver 5.6 L/min and have a pumping deficit of 0.35 L/min (= 1.76 mm/week on 0.2 ha).

In this example scenario where there is a shortfall in the amount that can be pumped, we would need to choose to plant and irrigate an area less than the 0.2 ha at the same rate of irrigation, or lower the target irrigation rate to be applied, or supplement with a temporarily-installed petrol pump to make up the pumping shortfall.
At a pumping rate of 5.6 L/min the pump can deliver 8064 L/day, but if a 5000 L holding tank is installed, overflow water waste can be avoided by irrigating twice per day with 75% applied in the early morning over 3 hours starting between 5 and 6 a.m. and 25% mid to late afternoon over 1 hour.

Key advice for installation of a ram pump irrigation system

Ram pump site selection advice.

1. Avoid sites with a low gradient of fall in the river.
   A low gradient of fall along the river makes a ram pump installation unsuitable. The system reported on here is probably near the gradient limits of a ram pump-powered irrigation system. Long siphon pipes easily block with air or sediment if the fall is low and these can be more easily snagged with the river is in flood. I would recommend a drop of more than 2m within 100m along the river in order to consider installation of a ram pump to power an irrigation system. Suitable sites are plentiful in the high altitude midlands near the Drakensberg in KZN, but rather scarce close to the coast. A better type of pump for this scenario is the propeller-powered rife-ram pump (in spite of the name it has no resemblance to a ram pump).
2. Only install a weir if the river runs over rock in a narrow channel with rocky banks both sides
   It is very expensive to build a weir with strong banks resilient to flood damage where the river passes through alluvial terrain such as at this site. Huge amounts of concrete would be required for a resilient weir at such a site. I later realized that this type of site might be suitable if a special sump is built to hold the siphon pipe in the river, rather than building a weir, but this means less head pressure since the water is not dammed up. Building a weir requires a permit, and this is another reason to avoid building a weir and to install a sump instead.
3. Position the ram pump far into the river bank where it can be mounted onto solid rock
   The nature of a ram pump dictates that it has to be mounted close to the water level of the river, except if the river has a large drop and head can be sacrificed. To protect the ram pump from flood damage it should be positioned into the river bank away from the river course and then firmly mounted onto solid rock or onto concrete cast onto such rock.
4. Make sure the siphon pipe can be routed and secured to the river with a steady fall
   A big lesson learned from this project was just how effectively air can block water flow in a pipe. The more vertical undulations there are in a pipe and the greater the undulation, the more easily air can collect at the apex of the undulation and restrict water flow. This is especially the case where the gradient in the river is low. If there is a steep fall in the river a siphon pipe can usually be dispensed with, but they are even needed if the fall is very large and the pump distant in order to shorten the drive pipe to prevent high pressure damage to the pump. In most ram pump installation scenarios with small slopes a siphon pipe will be needed. The siphon pipe running to the stand pipe must be routed to have a steady fall down the river. To clear flow obstructions that do develop with time, disconnect the lower end of the siphon pipe from the stand pipe and lie it down in the river for a few hours since this will cause a fast flow to flush out both air and sediment. Re-attach again after the obstruction has been cleared. A long siphon pipe must be securely mounted to the river bed in such a way that it is not easily snagged by objects moving downstream. Very large diameter siphon pipes are unsuitable to route and mount so if flow to the stand pipe is inadequate then install one or more extra siphon pipes (but installation of extra siphon pipes also creates problems).
5. Carefully select a suitable drive pipe and mount using concrete to solid rock.
   Once the diameter, length, position and orientation of a drive pipe has been worked out for a site, then make sure it can be firmly mounted to rock at that location or it will be vulnerable to being ripped away and damage the pump also. Making the drive pipe longer enables the pump to generate greater pressures, but pumping rate is severely sacrificed if it is made too long. Drive pipes must be almost straight and wide enough for their length and flow rate also since wall friction is a limiting factor in long pipes.

Ram pump design advice

1. Build a pump of a suitable size to achieve desired pressure and flow rates

   A large ram pump can generally be tuned to work with a fairly small flow so larger is generally better, but this has limits also and large pumps are much more expensive to install. If the accessible flow in the river is usually small, then installation of a large pump will be a waste since it requires a large siphon pipe and drive pipe to operate optimally. Use the Rankine efficiency formula by the method demonstrated in this article to determine what size and configuration of pump is needed, and if this is feasible.

2. A concrete pressure chamber and concrete stand pipe is likely to be effective and cheap

   Concrete pipes as used for sewerage systems by municipalities are very hard and durable. They do not rust, are not a temptation to scrap metal thieves, and can often be sourced cheaply by cutting pieces out of broken pipes using an angle grinder with a diamond disk. A builder's epoxy can be used to seal ends and glue in pipe fittings with high strength. A stand pipe such as was made for this project out of concrete was very suitable.

3. Make or source a high quality impulse valve

   The impulse valve is the main means of controlling the pump and a good design is essential. It should not be too small or it will restrict flow rate through the drive pipe. The open position of the valve must provide good clearance to flow also. The speed of flow that triggers it to slam shut should be easily adjusted. The impulse valve used for this project was easy to adjust and functioned well, but it needed a removable bush installed to reduce damage due to wear. Good alternative designs to consider are the ball type used for the Meriba ram pump (Anonymous 1), and the long plate type of the DTU P90 hydraulic ram pump (Thomas 2008).

4. A flap-type or moveable flange non-return valve fitted into the pressure chamber is advised

   A ram pump must have a non-return valve between the impulse valve and the pressure chamber. An ordinary brass spring-loaded or flap type non-valve can be used, but these are vulnerable to damage from leverage forces if connected outside of the pressure chamber. The design of the pump used, and several other good designs, have located this valve within the pressure chamber, and sometimes as a simple flap (Than 2008; Anonymous 1; Thomas 2008; Spruce 2012).

Ram pump-powered irrigation system advice

1. Lay out the main irrigation piping lines similar to the plan adopted here (Fig. 5.6)

   A ram pump is designed to pump 24 hours per day (if the river has water). In order to get the value out of the pump it must be able to pump to a holding tank or reservoir without interfering with irrigation. The T-branch piping plan as shown in Fig. 5.6 achieves this effectively. Between the pump and the T a small diameter pipe is suitable since the flow here is slow, but a large diameter pipe is needed from the T to the tank and for the lateral pipe coming from the T. This arrangement reduces pressure losses with large flow rates while irrigating.

2. Install sprinklers that work effectively at low pressures

   If ram pumps have to pump to high pressures, then volume pumped is severely sacrificed. A ram pump powered by a low fall cannot produce high pressures anyway. Sprinklers that require high pressures to operate are thus incompatible with ram pump powered systems. Fortunately, there are options for this. The microjet sprinklers illustrated here can operate with less than a bar pressure. Another good sprinkler is the mini-wobbler type that can operate well with a little more than a bar. The best system for the smaller feeder piping is something like the hexagonal lattice illustrated (Fig. 6.1). For potatoes it is highly recommended that the feeder lines be attached to cables strung overhead at about 4 m height since all the tillage of land preparation, ridging, furrow closing and harvesting of potatoes does not interfere with the irrigation system. The other advantage of low pressure systems is that since each sprinkler applies water at a slow rate, many sprinklers can run at the same time, and for a site of about 0.1 to 0.2 ha, perhaps the whole land can be irrigated at once. With such a system there is no need to move drag lines or sprinklers around since opening or closing a single tap controls the whole irrigation system.

3. Apply long daily irrigation with all or most around dawn in the morning.

   The slow rate of irrigation from each sprinkler necessitates a long application time to get adequate precipitation. Irrigation at dawn is the best time to supply water just before the plants need it for transpiration, while reducing evaporation loss before the temperatures climb high. Night irrigation means wet leaves at night and this means DISEASE because pathogenic fungi and bacteria have ideal conditions to infect without ultraviolet damage! Never irrigate at night or late afternoon except under extremely dry conditions. If the holding tank or reservoir capacity is small, another smaller irrigation in the afternoon can be applied so that overflow losses can be avoided.

Ram pump installation societal advice

1. Expert local consultation and specialist spares for free energy irrigation may be hard to find

   When I embarked on this ram pump project I found that local irrigation companies did not market free-energy pumping systems and were generally ignorant of such systems. They focused on conventional high pressure installations based on electrical and fuel-powered centrifugal pumps powering impact sprinklers and center pivots. I did not know anyone experienced with ram pump installations or any commercial installers of ram pumps at that time, and consequently fell back on my own ingenuity to resolve issues using internet searches for solutions. The publications cited in this article are worth consulting for more advice. The accessibility of information on constructing such pumps has improved a lot in recent years including internet resources such as YouTube videos that are very informative, but local expertise may still be hard to get in some areas.

2. A ram pump and free energy demonstration site at an agricultural facility is needed.

   While the locals where this ram pump were installed were interested in the project and were utilized as labor for aspects of this project, I found that they could not sustain the project without my in-depth involvement. This was partly due to the novelty of the system and ignorance about it, but a major aspect of the problem was lack of clear ownership and responsibility for the site since the land was not owned by them but used with permission from a local authority. This co-operative style land use situation prevails in many areas of KZN and it hinders the entrepreneurial spirit. The transformation program of the partnership between Potatoes SA and the KZN Department of Agriculture does foster ownership and mentoring towards commercially successful agriculture, and has been a very successful program in KZN. When this ram pump project terminated in 2013, I asked for support to install a free-energy irrigation system at Cedara where working systems could be demonstrated to interested small scale growers, but because no engineers could be involved, and since I was now over-committed to the diagnostic service, this was not approved. I still believe that a free-energy demo site is worth implementing since it can educate interested entrepreneurial small scale growers to install their own systems that they take responsibility for. This is much better way than trying to install and sustain a remote irrigation project for a community where there is no local ownership of the system.

Construction of a new prototype ram pump with concrete pressure vessel in 2020.

Early in 2013, just before the ram pump project was officially terminated mostly as a consequence of the flood damage in December 2012, I had conceived improvements to the design of the first ram pump. I designed profiles to cut out from stainless steel sheet and arranged for Laser Profiling to do the laser cutting for me. These were components for making an elbow flange mounting, adapted impulse valve, and new design non-return valve. I commenced making up a new impulse valve and non-return valve with this material and almost finished these, but this work was terminated and shelved (literally) with the end of the project in 2013.

Towards the end of the Covid 19 level 4 lockdown period at Cedara, whilst making other equipment vital for our diagnostic service, I found the 2013-made ram pump components in storage and then decided to resume completing their construction as well as the construction of a concrete pressure vessel for a new prototype ram pump. I had decided to prepare a final ram pump project report available from our departmental website and wanted a better ending to the report than the demise of the project due to flood damage. This new ram pump construction work took several weeks in spare time, often after hours or on weekends (being lower priority than essential work) and was eventually completed in early July 2020. Photos of components of this new prototype ram pump and their construction are presented in Figures 7.1 to 7.6. The following key design changes were made:

Impulse valve (Fig. 7.5, 7.6): Of almost the same design as used in the first ram pump, but a steel pipe was welded centrally inside of which a removable vesconite (or brass) sleeve could be inserted as the guide (bush) for the shaft of the valve so that these could be replaced when worn without re-manufacturing the valve. The pipe guide and inserts was machined for me on the lathe by LK Engineering. I made the impulse valve shaft from 2 bolts welded back to back dispensing with the original complicated sleeve locking system for the rubber seal that fitted on a single bolt.

Non-return valve (Fig. 7.6): A stainless 2 inch nominal bore hex nipple was cut into 2 equal halves (enough for 2 valves). A laser-cut flange with multiple holes was welded to the cut end of one of these halves. The outside end of this was faced off in the lathe by LK Engineering. The moveable flap washer was fitted onto a vesconite guide that was bolted through the center of the valve.

Flange-mounted elbow connection to pressure vessel: A flange with multiple laser-cut holes (Fig. 7.1) was welded to a 2 inch nominal bore stainless elbow for the mounting of the non-return valve onto a concrete pressure vessel. I tapped a 10mm thread into the elbow for a removable snifter valve.

Snifter valve (Fig. 7.6): The snifter valve of the first ram pump was simple to make and worked well. I decided to use the same intrinsic design except for fitting this into a removable 10 mm brass bolt so that the whole snifter valve could be removed for maintenance or replacement. It was made by fitting a 4mm stainless bolt with 2 ground grooves into a 4 mm hole drilled into the brass bolt.

Pressure vessel (Fig. 7.1 to 7.4): My experience with working with concrete pipes used for making the stand pipe and irrigation coupling containers had impressed on me the great strength of such concrete pipes which are resistant to cracking even when exposed to severe hammering with large hammers, but they can be cut with diamond-coated angle-grinding disks. The pressure vessel is the largest part of the pump and is subject to rusting if made from ordinary steel and is also a temptation to thieves for its scrap metal value. Since pressure vessel manufacture from steel is expensive, especially with galvanizing costs included, and is eventually subject to corrosion, I decided to make the pressure vessel from concrete piping and paving stones. The concrete components were cut with an angle grinder and diamond coring bits and then 8 mm thread bar was epoxied into the base for mounting the flange-mounted elbow connection. A ¾ inch drain nipple was also epoxied into the concrete base, while a ¼ inch socket (for pressure gauge fitting) was epoxied into the concrete top. The concrete top and bottom pieces were then epoxied onto the concrete pipe. Laser-cut triangular bolt mountings were epoxied to the corners of the base so that it could be mounted thereby to concrete strips with 10mm stainless threadbar. A waterproofing coat was applied in 2 steps by soaking the pressure vessel internally in sodium silicate solution, followed by draining and soaking in calcium nitrate solution. The concrete mounting strips are intended to be concreted in at the ram pumps mounting position.

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Photos of constructing a new prototype ram pump (2020)

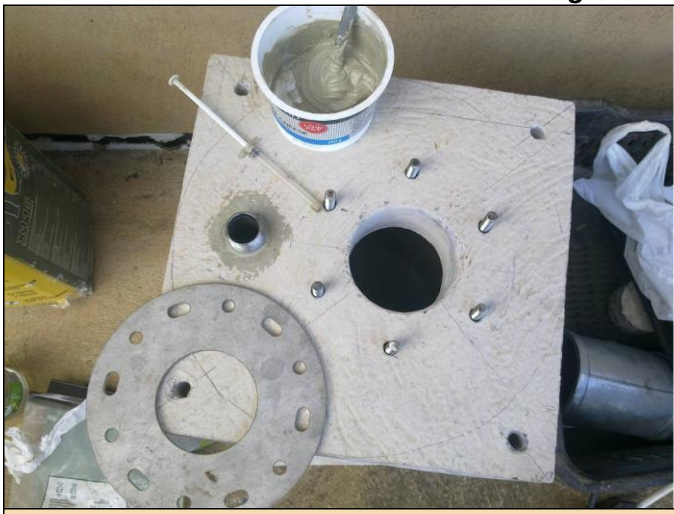

Fig. 7.1 The start of the epoxy operation for the concrete base of the pressure vessel after drilling holes for the mounting plate threadbar and other holes.

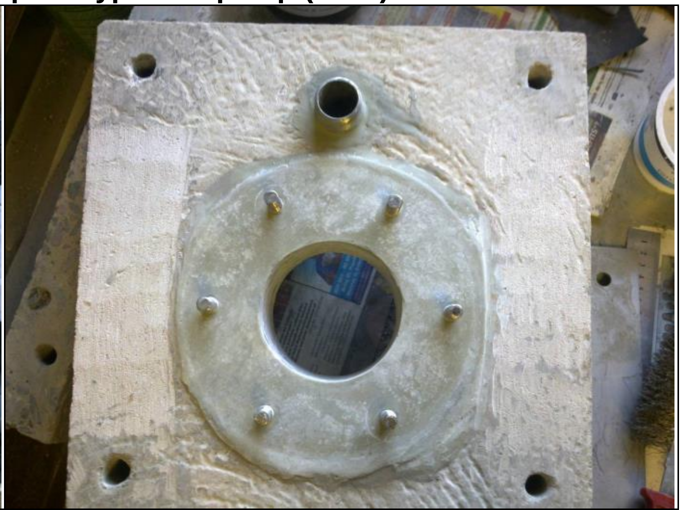

Fig. 7.2 Final sculptured epoxy surface for the flange gasket to seat against. This needs to be flat and smooth for a good seal.

Fig. 7.3 Completed pressure vessel prior to epoxying the top end on.

Fig. 7.4 Underside of completed pressure vessel with ram pump operating valves disconnected from it.

Fig. 7.5 Mounting of the central guide pipe of the impulse valve prior to welding it to the body of the impulse valve. Alignment done using a drill press.	Fig. 7.6 The operating valves of the ram pump disconnected from the pressure vessel. The top left inset shows the flanged elbow with snifter valve and non-return valve (in open position).

It is my hope that this new prototype ram pump could later be installed as a demonstration ram pump at Cedara (for which a possible location has been identified). Such a demonstration site would be most valuable for the education of the application of ram pumps to agricultural college students, visiting farmers and researchers. Since I cannot afford to get involved with commercial installation of such pumps I have arranged that a Pietermaritzburg local (Eddie Heslop 084-4128831) can manufacture and install ram pumps of similar-design to this prototype. Ram pumps of a good design, but of full metal construction, have also been installed for years now in our province by the company: Evergreen Gravity Pumps (https://evergreengravitypumps.co.za/our-installations/).

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Yours Sincerely, **(July 2020)**

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