Landis Hydraulic Ram Pump Performance Calculator

This hydraulic ram pump is dedicated to our good friend and affiliate, Harry Landis, who died in an ultralight airplane accident on 1 November 2015 while in Guatemala at his Finca Ixobel hydraulic ram pump testing site. As requested by his family and in honor of Harry, we are now manufacturing and selling this water pump to keep it available to those self-reliant people who need this pump and who have made it famous for being highly reliable, not requiring any maintenance and lasting several decades if not several lifetimes. This is the improved 2-inch diameter drive line version of the hydraulic ram pump that we helped Harry Landis design and which he sold on eBay for many years. Thank you Harry for all your contributions in improving the state-of-the-art of hydraulic ram pumps. You are and will be sorely missed!

A hydraulic ram pump (often called a "hydram") is a cyclic water pump powered by hydropower. It functions as a hydraulic transformer that uses water at a low head pressure and high flow rate to deliver water at a higher head pressure and lower flow rate. A hydram uses water hammer physics to pump a portion of the input water that powers the hydram to be lifted to a point higher than where the water is originally obtained. A hydram does not require any additional source of power and only uses energy obtained from the water source. As such, a hydram may be used in remote areas where there is both a source of hydropower and a need to deliver water to a destination higher in elevation than the water source. When designing a conventional electro-mechanical pump installation it is entirely acceptable to treat the hydraulic line and pump characteristics separately and then combine these characteristics. However, this would not be an acceptable approach for designing a hydram installation because the operation and performance of a hydram is very strongly influenced by the water hammer physics occurring within the drive line.

There is some terminology associated with a hydram that first needs to be explained and fully understood. The pipe feeding water to the hydram is called the "drive line". The pipe delivering water to the storage tank is called the "delivery line". "Fall" is the total elevation that the water feeding the hydram falls before reaching the hydram. "Lift" is the total elevation that the hydram lifts the water to the storage tank. The water that is used to generate the hydram pumping power, but that does not get delivered to the storage tank, is called "waste" and flows out of the clack/waste valve of the hydram. The hydram operating frequency can be readily heard, timed with a stopwatch, and set to the appropriate frequency (ideally between 40 and 100 cycles/minute) to govern how much water is used to generate the hydram pumping power and the associated delivery line flow rate.

Hydrams are mechanically simple and only have two moving parts, a clack/waste valve and a delivery line check valve. The clack/waste valve essentially senses the velocity of the water flowing through the drive line and at the required peak drive flow rate (which is normally set by tuning the hydram to the frequency setting required to achieve the optimum and maximum delivery flow rate performance), quickly closes causing the water to suddenly stop which creates the water hammer effect that produces the hydram pumping power. The purpose of the delivery line check valve is to only allow water to flow one-way through the delivery line when this water hammer effect occurs, and to not allow any delivered water to back-flow into the hydram and out the clack/waste valve when the water hammer effect is not present. While the function of this delivery line check valve may sound simple enough, this check valve must be very efficient (i.e., not create significant friction head loss) in order to maximize delivery flow rate performance, operate at high delivery line pressures, operate at high instantaneous flow rates that may be several hundred times larger than the average delivery line flow rate, and accomplish about 100,000 cycles per day for many decades without failing.

A hydram has three distinct operational phases: acceleration, delivery and recoil. During the acceleration phase, which begins at the exact moment when the clack/waste valve first opens, the water accelerates down the drive line, through the hydram, and discharges out the open clack/waste valve. As the flow rate increases, it reaches a velocity where the drag force is sufficient to start closing the clack/waste valve very quickly.

During the delivery phase, which begins at the exact moment when the clack/waste valve first closes, the water that is flowing down the drive line with considerable momentum suddenly slows down. It is this large change in kinetic water energy that is used to create the hydram pumping power. For a fraction of a second, the water in the hydram, which is normally considered to be incompressible, is actually compressed causing a very large and very rapid rise in the water pressure within the hydram which is known as water hammer. When this water hammer pressure wave exceeds the delivery line pressure, the delivery line check valve opens and water is forced through the check valve and through the delivery line into the storage tank. The delivery line check valve stays open until the water flow in the drive line is nearly stopped and the pressure in the hydram drops below the delivery line pressure, causing the check valve to close. During the recoil phase, which begins at the exact moment when the delivery line check valve first closes, the water that is flowing down the drive line finally comes to a complete stop and recoils against BOTH the closed check valve and the closed clack/waste valve (e.g., like a rubber ball thrown against a hard wall) sending both a water hammer pressure wave and water hammer flow wave back up the drive line and out the drive line inlet. The water hammer pressure wave travels at the effective speed of sound in drive line and the water hammer flow wave travels much slower. The water hammer flow wave recoil effect causes the pressure in the hydram to then drop below atmospheric pressure causing the clack/waste valve to open, causing air to be drawn through the high friction snifter valve (if one is installed) and causing air to be drawn through the low friction clack/waste valve. These three operational phases then repeat continuously, which steadily forces water through the delivery line into the storage tank. Hydrams also often incorporate a hydraulic accumulator (i.e., either an air bladder tank or a non-bladder air tank that uses a hydram snifter valve to keep the non-bladder tank full of air) to smooth the pulsating water that flows through delivery line check valve into a smoother delivery line flow rate.

We have seen hydrams made with plastic or aluminum components, but they never work very well and don't last very long because the plastic flexes which reduces efficiency and the aluminum/plastic eventually fails from the large number of water hammer pressure stress cycles, often in excess of 150,000 cycles per day. Plastic is also subject to sunlight UV degradation. You will notice that manufacturers who sell production aluminum/plastic hydrams often sell repair kits for them too. And these mass produced aluminum/plastic hydrams that always seem to come and go on the marketplace often cost way more than the 40+ year time tested Landis hydram. Furthermore, drinking water that comes in contact with aluminum or plastics containing BPA has been shown to be detrimental to one's health. The Landis hydram is constructed mostly of carbon steel (stronger and more rust resistant than cast iron) and the remaining other components are constructed from NSF certified materials. Unlike many hydrams, every component of the Landis hydram is DIY friendly and can be easily DIY modified/repaired as desired/needed.

Traditionally, hydrams have used a waste (clack) valve much like the valves in a car engine to close the drive pipe and generate the pressure pulse which pumps the water to the storage reservoir. The main cause of failure or reduced efficiency in these pumps has been the wearing of the waste valve guide due to metal against metal movement, sometimes aggravated by silt or grit in the water, as well as uneven wear on the valve seat, leading to incomplete sealing and loss of pressure.

The Landis hydram design is a considerable improvement over traditional hydrams, as it basically eliminates this cause of failure and poor operation. In the Landis design, the waste valve and guide is replaced by a polished glass ball which closes against a thick rubber seat. The ball rests in a sort of cage, and when the flow of water past it is sufficient, it is carried upward against the rubber seat, thus stopping the flow, and causing a water hammer pressure pulse in the drive pipe. This pressure pulse opens the check valve beneath the ballast tank which causes water to flow into the ballast tank until the pressure pulse is dissipated. The check valve then closes, the waste valve ball drops, and the cycle repeats. Since the waste valve ball is round, it will wear evenly (if it ever wears at all), so it will always seal well against the rubber seat. The frequency setting of the Landis hydram is adjusted by loosening a nut on the bottom of the clack/waste valve cylinder, turning the shaft to raise or lower the cage holding the glass ball, and then tightening the nut after the required operating frequency is achieved. Raising the cage increases the operational frequency and lowering the cage decreases the operational frequency.

While appearing mechanically simple, hydrams do exhibit complex behavior that can result in erratic and unreliable operation. This calculator determines the kinetic water energy that can be generated by accelerating water through the drive line given the initial potential water energy after accounting for the friction characteristics of the drive line and the hydram. This calculator then determines the percentage of this kinetic energy that may be used for hydram pumping power after accounting for the friction characteristics of the check valve, the friction characteristics of the delivery line, and the quantized energy effect caused by the even or odd number of water hammer flow waves that occur in the drive line based on the innovative research and excellent work done by O'Brien 1933, Rennie 1980 and Thomas 1994. As such, this calculator models the complex behavior that may result in erratic and unreliable operation so this behavior can be accurately forecast during the hydram installation design phase and thus avoided during actual hydram operation. This calculator was developed by Borst Engineering & Construction LLC and may well be the most sophisticated and accurate hydram performance calculator available today.

This calculator assumes and is only valid for a hydram installation that uses a steel drive line and a polyethylene or PVC delivery line. You should always first communicate and coordinate with the local Department of Fish and Wildlife, and local Water Resources Department BEFORE constructing any water work project.

To use this calculator, enter ALL of the following input parameters as indicated:

1) **Maximum Available Water Source Flow Rate (Gallons/Minute)** - This is the maximum flow rate of the water source that is available to feed the hydram. You may measure this maximum flow rate with a bucket and a stopwatch. You should initially enter a very large value (e.g., 1000) into the calculator and click Solve, to determine the **Drive Flow Rate** output parameter. The **Drive Flow Rate** is the minimum amount of water source flow rate required by the hydram to operate at the optimum **Actual Frequency Setting** output value for the installation input parameters you entered into the calculator. If the water source can easily supply this minimum flow rate, the water source is NOT limiting and you should just continue to use this very large value for the maximum available water source flow rate.

   If the water source can NOT supply this amount, you will need to use the **Desired Frequency Setting** logic input parameter to operate the hydram at a higher frequency than the previously determined optimum **Actual Frequency Setting** so as to reduce the **Drive Flow Rate** to a flow rate that can be easily supplied by the water source. Doing this will likely increase the **Installation Efficiency** output parameter and decrease the **Delivery Flow Rate** output parameter. You may also need to change the installation input parameters in order to reduce the **Drive Flow Rate** to a flow rate that can be easily supplied by the water source. This maximum available water source flow rate input parameter is primarily intended to make sure that you are fully aware that each hydram installation has a minimum **Drive Flow Rate** requirement that can NOT be violated. If the water source flow rate ever becomes less than this required **Drive Flow Rate** (perhaps because of a drive line blockage or a decrease in the Fall), the hydram may stop operating, which will usually result in the clack/waste valve getting stuck in the open position.

2) **Fall 1 - Water Elevation above Drive Line Inlet (Feet)** - This is the height of the water surface above the drive line inlet. This allows addressing the situation of feeding your hydram from below

the base of a dam. If you can measure the static pressure at the drive line inlet, Fall 1 is this pressure in PSI divided by 0.433.

3) **Fall 2 - Drive Line Inlet Elevation above Pump (Feet)** - This is the elevation difference between the drive line inlet and the hydram inlet. This allows addressing the situation of feeding your hydram from just below the surface of a stream using gravity flow pipe. Your site and installation may have a combination of Fall 1 and Fall 2 and you may need to enter values for both.

4) **Lift - Desired Pumping Elevation above Pump (Feet)** - This is the elevation of the storage tank above the hydram. The Lift must be at least greater than two times the total **Fall** input parameters in order for the hydram to operate. It is recommended that the Lift be greater than five times the total **Fall** input parameters to ensure good operational reliability.

5) **Drive Line Nominal Diameter (Inches)** - This is the standard nominal diameter of the drive line pipe. If you enter a standard pipe size (e.g., 0.5, 0.75, 1.0, 1.25, 1.5, 2, 2.5 or 3.0 inches), the calculator will use the actual inside diameter of standard steel pipe. For example, the actual inside diameter of 1.5 inch standard steel pipe is 1.61 inches. If you have nonstandard pipe, enter the actual inside diameter.

6) **Drive Line Length (Feet)** - This is the length of the drive line, which should be completely straight, between the drive line inlet and the hydram (i.e., drive line outlet). Standard steel pipe generally comes in lengths of 21 ft. ***Please note that there is both a minimum and maximum acceptable drive line length.*** Please consider the **Minimum Drive Line Length** and **Maximum Drive Line Length** output parameter limits. The **Actual Frequency Setting** output parameter that will be required to operate a hydram with a drive line that violates these drive line limits may be higher or lower than the hydram is actually capable of achieving. The drive line length has a significant effect on delivery flow rate performance and the optimum drive length is typically midway between the **Minimum Drive Line Length** and **Maximum Drive Line Length**. So, in some cases, it may be appropriate to put a standpipe somewhere between the water source and the drive line inlet to shorten the drive line length to allow staying within these limits. If this is done, the pipe upstream of the standpipe can be made of polyethylene or PVC for economic advantage. The standpipe should be at least 4 times the diameter of the drive line. The top of the standpipe should be a couple feet higher in elevation than the water surface elevation of the water source feeding it.

7) **Delivery Line Nominal Diameter (Inches)** - This is the standard nominal diameter of the delivery line. If you enter a standard pipe size (e.g., 0.5, 0.75, 1.0, 1.25, 1.5, 2, 2.5 or 3.0 inches), the calculator will use the actual inside diameter of polyethylene or PVC pipe. For example, the actual inside diameter of 0.75 inch standard polyethylene tube is 0.82 inches. If you have nonstandard pipe, enter the actual inside diameter.

8) **Delivery Line Length (Feet)** - This is the length of the delivery line between the hydram and the storage tank.

9) **Desired Frequency Setting (Cycles/Minute)** - This is an input logic parameter that allows you to either request the calculator attempt to determine the optimum frequency setting that will provide the maximum **Delivery Flow Rate** output parameter with at least 75% operational reliability, or to request the calculator to attempt to determine the **Delivery Flow Rate** at some other desired frequency setting without any operational reliability restriction. You should normally just leave this

input logic parameter blank and have the calculator attempt to determine the optimum frequency setting. ***Please be aware that the calculator may NOT be able to determine an optimum frequency setting for all possible installation input parameters that are entered.*** If the calculator is able to determine an optimum frequency setting, this optimum frequency setting will be displayed by the **Actual Frequency Setting** output parameter and ALL the output parameters will be based on this optimum frequency setting.

Using some other desired frequency setting in lieu of the optimum frequency setting may be beneficial when the **Maximum Available Water Source Flow Rate** input parameter is limiting. You may enter a desired frequency setting to have the calculator attempt to determine the **Delivery Flow Rate** at this different frequency setting. ***Please be aware that the calculator may NOT be able to determine a solution for every Desired Frequency Setting that is entered.*** If the calculator is NOT able to determine a solution for the entered desired frequency setting, the **Actual Frequency Setting** output parameter will display the optimum frequency setting and ALL the output parameters are based on this optimum frequency setting and NOT on the entered desired frequency setting. If the calculator is able to determine a solution within plus or minus 0.49 CPM of the entered desired frequency setting, this desired frequency setting is displayed by the **Actual Frequency Setting** output parameter and ALL the output parameters are based on this desired frequency setting. You should carefully consider the ramifications of the **Operational Reliability** output parameter BEFORE planning on operating the hydram at this desired frequency setting.

Click Solve after initially entering ALL of the required input parameters or after changing ANY of the required input parameters to obtain the following output parameters:

1) **Delivery Flow Rate (Gallons/Day & Gallons/Minute)** - This is the average flow rate through the delivery line into the storage tank. This delivery flow rate is used to determine the friction head loss of the delivery line its effect on the associated **Installation Efficiency** output parameter. Please note that the delivery flow rate will change for different frequency settings. You may measure this average flow rate with a bucket and a stopwatch.

   If the delivery flow rate is 0, the calculator could not determine an optimum frequency solution for the installation input parameters. You should check the **Drive Line Length** input parameter to verify that it is within the acceptable range of the **Minimum Drive Line Length** and **Maximum Drive Line Length** output parameters. You should check the **Lift** input parameter to verify that it is significantly less than the **Maximum Pumping Elevation** output parameter. Check if any of the other installation input parameters are perhaps not reasonable. Consider using the **Desired Frequency Setting** logic input parameter to enter different frequency settings to see if the calculator can determine any solutions. If a solution can be determined, but the **Operational Reliability** output parameter is less than 75%, this may well be the problem. The calculator will only provide an optimum frequency setting and the associated delivery flow rate if it can find a solution that results in the operational reliability being equal or greater than 75%. The installation input parameters you have entered may NOT provide adequate operational reliability.

2) **Waste Flow Rate (Gallons/Minute)** - This is the average flow rate of water out the clack/waste valve. Please note that the waste flow rate will change for different frequency settings. You may measure this average flow rate with a bucket and a stopwatch.

3) **Drive Flow Rate (Gallons/Minute)** - This is the average flow rate through the drive line between the time when the clack/waste valve just opens and the time when the clack/waste valve just closes, while also accounting for the time duration that the clack/waste valve remains closed. Please note that the drive flow rate will change for different frequency settings and is limited to the **Maximum Available Water Source Flow Rate** input parameter. Since this average flow rate is internal to the installation, you can NOT measure this flow rate with a bucket and a stopwatch. However, this average flow rate is equal to the sum of the **Delivery Flow Rate** and **Waste Flow Rate** output parameters, which you may measure with a bucket and a stopwatch.

4) **Actual Frequency Setting (Cycles/Minute) –** This is the actual frequency setting that the calculator is able to determine a solution and ALL the output parameters are ALWAYS based on this displayed actual frequency setting solution. When the **Desired Frequency Setting** logic input parameter is left blank and the calculator is able to determine a solution, this is the optimum frequency setting such that the hydram delivers the maximum **Delivery Flow Rate** output parameter with at least 75% operational reliability. For this case, this optimum frequency setting will displayed and ALL the output parameters are based on this optimum frequency setting solution. When a desired frequency setting is entered for the **Desired Frequency Setting** and the calculator is able to determine a solution within plus or minus 0.49 CPM of this desired frequency setting, this desired frequency setting is displayed and ALL the output parameters are based on this desired frequency setting. The hydram operational frequency can be readily heard, timed with a stopwatch and set to this displayed actual frequency setting, which ideally should be between 40 and 100 CPM.

5) **Installation Efficiency (Percent)** - This is a measure of how well the overall hydram installation converts the available input power of the water source into output pumping power. As such, the installation efficiency represents the **Pumping Power** output parameter divided by the **Drive Power** output parameter. The installation efficiency may theoretically range from 0 to 100%. Please note that maximum installation efficiency does NOT result in maximum delivery flow rate performance. A hydram typically provides maximum delivery flow rate performance when the installation efficiency is between 50% and 70%. However, operating at a higher installation efficiency may be beneficial when the **Maximum Available Water Source Flow Rate** is limited.

6) **Minimum Drive Line Length (Feet)** - This is an estimate of the shortest length of drive line that can be successfully used as established by Calvert (1960). The calculator does NOT limit the **Delivery Flow Rate** output parameter based on this minimum drive line length estimate. However, the optimum **Actual Frequency Setting** output parameter that is required to operate a hydram with a drive line less than this minimum drive line length estimate may be <u>higher</u> than the hydram is actually capable of achieving (e.g., more than 120 CPM).

7) **Maximum Drive Line Length (Feet)** - This is an estimate of the longest length of drive line that can be successfully used as established by Calvert (1960). The calculator does NOT limit the **Delivery Flow Rate** output parameter based on this maximum drive line length estimate. However, the optimum **Actual Frequency Setting** output parameter that is required to operate a hydram with a drive line more than this maximum drive line length estimate may be <u>lower</u> than the hydram is actually capable of achieving (e.g., less than 20 CPM).

8) **Nominal Delivery Line Pressure (Pounds/Square Inch)** - This is the pressure that would be measured in the delivery line at the hydram outlet while the hydram is operating. This pressure is the sum of the static water pressure between the hydram and the storage tank plus the increased

pressure caused by friction in the delivery line from operating at the **Delivery Flow Rate** output parameter.

9) **Nominal Drive Line Pressure (Pounds/Square Inch)** - This is the pressure that would be measured in the drive line at the hydram inlet while the hydram is operating when the clack/waste valve is open. This pressure is the static water pressure between the hydram and the drive line inlet minus the reduced pressure caused by friction in the drive line from operating at the **Drive Flow Rate** output parameter.

10) **Maximum Water Hammer Drive Line Pressure (Pounds/Square Inch)** - This is the pressure that would be measured in the drive line that results from the water hammer pressure wave developed at the instant the clack/waste valve closes.

11) **Maximum Pumping Elevation (Feet)** - This is an estimate of the maximum pumping elevation that the hydram is capable of delivering water to a storage tank based on the **Maximum Water Hammer Drive Line Pressure** output parameter. The calculator does NOT actually limit the **Delivery Flow Rate** output parameter based on this maximum pumping elevation estimate. However, the **Delivery Flow Rate** will tend to approach 0 as the **Lift** input parameter approaches this maximum pumping elevation.

12) **Drive Power (Watts)** - This is the available input power to the hydram that is generated from the acceleration of water through the drive line. The drive power is a function of the **Nominal Drive Line Pressure** and **Drive Flow Rate** output parameters.

13) **Pumping Power (Watts)** - This is the actual output power of the hydram used to deliver the water to the storage tank. The pumping power is a function of the **Nominal Delivery Line Pressure** and **Delivery Flow Rate** output parameters. The pumping power also represents the **Drive Power** output parameter times the **Installation Efficiency** output parameter.

14) **Operational Reliability (Percent)** - This is the hydram clack/waste valve operational reliability forecast at the **Actual Frequency Setting** output parameter. The lower the operational reliability, the higher is the likelihood that clack/waste valve operation will be unreliable. When clack/waste valve operation is unreliable, the hydram may not initially start or the hydram may stop operating after some period of time if any of the installation conditions change (e.g., the Fall or the frequency setting change), which will usually result in the clack/waste valve getting stuck in the closed position. Operational reliability will vary between 0% and 100% when the **Desired Frequency Setting** input parameter is used to enter a frequency setting. At least 75% operational reliability is recommended, which is the minimum value the calculator will determine an optimum **Actual Frequency Setting** output parameter when the **Desired Frequency Setting** input parameter is left blank and NOT used to enter a frequency setting.