

Physics Extended Essay

Research Question:

How does the height and flow of the waterfall affect the amount of electricity generated by a tiny, pumped storage system?

Introduction:

These days, electricity is a basic necessity for our everyday existence and can be found anywhere in this planet. Our mobile devices, computers, TVs, and additionally our kitchenware are all powered by it. Although a large portion of humanity uses electricity on an everyday basis, few people are aware of where or just how the energy is generated. A few years back was the very first moment I really started to notice where power and electricity came from. I had set up ambient lighting for several weeks that month, and from that point on, I had it on each night. My father came up to me and informed me that the energy bill had increased significantly from last month. I had thought this was because I was using the new lighting all the time. This started me on a mental path and made me wonder things like: How is energy produced? In what way can I save costs while using the same amount of energy? At last, our Physics lessons started covering the generation of energy, and I learned about turbines used for hydroelectricity. I was astounded at how potential energy was used to create energy. Brilliant minds had come up with alternate strategies for effectively producing energy. I was hoping to understand greater details about the workings of a hydroelectric plant, which brings me to my topic. As previously stated, a hydroelectric power plant uses potential energy as its primary energy source, that it subsequently transforms into the form of kinetic energy. The vertical height of a point mass has an effect on kinetic energy, which is related to potential energy. Then, a study topic surfaced: How does the speed of the turbine's revolutions per second, which affect the generation of electricity, relate to the head (the variation in level among the water source and turbine)? The purpose of this study is to determine a correlation between the previously listed factors through the use of a self-constructed turbine.

General Information:

A vital element that the majority of energy-generating facilities have is a rotating generator that generates electricity, one among the numerous parts of hydroelectric dams that help in achieving the effective generation of energy. The storage tank functions as a water supply while the other components that make up a hydroelectric dam include height, pressure tunnel which directs flowing water from higher elevations and turbine machinery transforms water energy into electricity before conversion devices distribute electricity through power lines. Figure 1 presents an illustrated hydraulic facility with various components labeled.

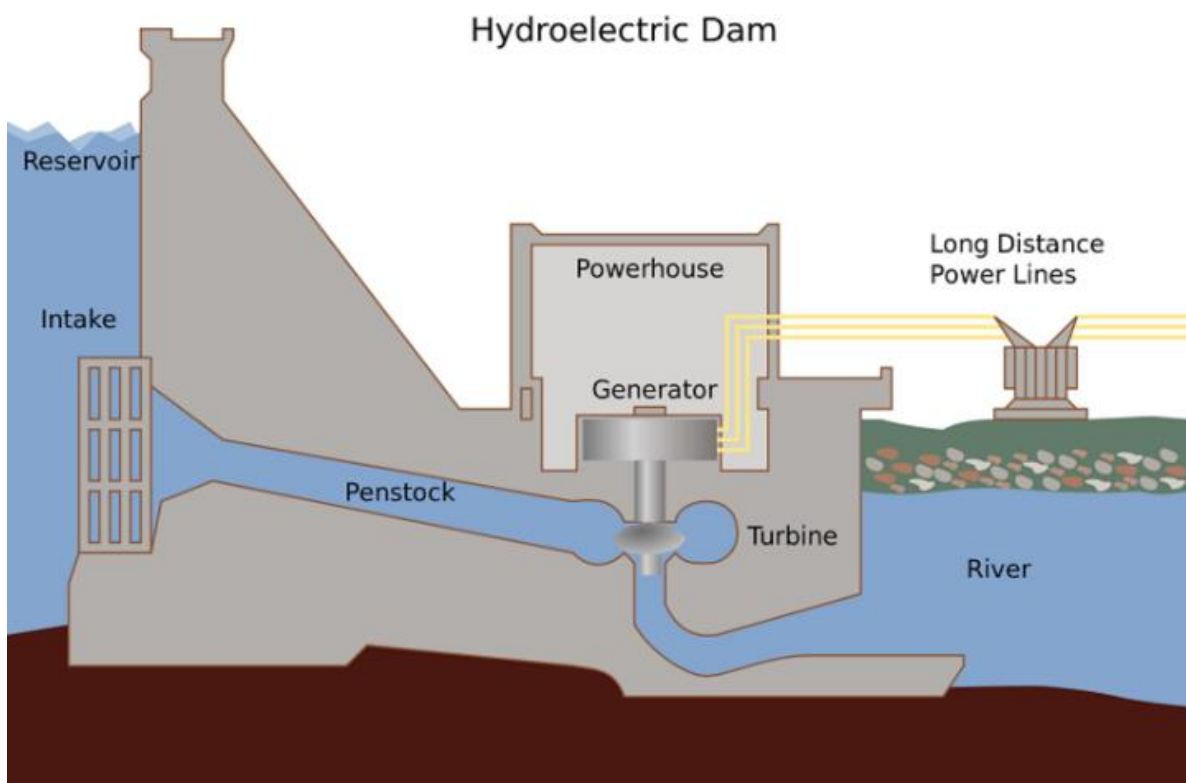


Figure 1: Diagram of a hydroelectric power plant with labels

The first stage of hydroelectric power plant energy generation starts with potential energy storage. An object containing potential energy gets its energy from being at a relative height to another object. The GPE measurement will be used as Gravitation Potential Energy in this experiment based on the following mathematical formula:

$$GPE = mgh$$

The formula for GPE gives Joules (J) as units for gravitational potential energy while mass exists as kilograms (kg) and acceleration due to gravity stays at 9.81 ms^{-2} and height h shows

up as meters (m). The equation uses 9.81 ms^{-2} as the gravitational constant and the variable h represents height measurement in meters (m). A moving point mass possesses kinetic energy as a direct result of its motion. Water from the reservoir moves through the penstock to turn the spinning turbine at hydroelectric power plants. The potential energy of the object enters a chamber containing the turbine to convert potential energy into kinetic energy which enables the turbine spinning. A higher turbine velocity under theoretical conditions leads to greater kinetic energy generation. The turbine speed can be determined through angular velocity measurements that represent the number of turbine rotations in radians.

The mathematical relationship between these parameters appears in the next equation:

$$V = \omega r$$

The rotating object's radius is denoted by r , its angular velocity by ω , and its linear speed by v .

Examining the kinetic energy formula:

$$KE = \frac{1}{2}mv^2$$

Where m is the mass, v is the speed, and KE is the kinetic energy.

The total kinetic energy value will rise in tandem with the expected increase in the spin rate's effect on the point mass's linear velocity. This relates to potential energy because, when allowed to flow freely, potential energy eventually turns into kinetic energy. It is presumed that all potential energy transforms into kinetic energy in order to study the connection between the two.

The essential element of a hydroelectric power plant is the water that flows from the reservoir towards the turbine, which spins the turbine. The first transformation that takes place is the transformation of potential energy to kinetic energy, which starts the procedure for generating energy and leads to the last few steps required for producing electricity.

After establishing the correlation among the height of the water source, the rate of rotations every second, and the electricity generated by the hydroelectric power plant, the connection's examination among the water reservoir's height and the turbine's revolutions every second.

Hypothesis:

The turbine's capacity to rotate more times every second increases linearly with an increase in the height and flow rate differential among the water supply and the turbine.

Dependent, Independent and Controlled Variables:

Independent Variables	Dependent Variables
The height of the water source, expressed in meters (m).	The turbine's spin rate, which was determined using video analysis by timing how long it took the turbine to complete eight full spins.
Flow rate of water source changed with different bottle caps	Weight of water in (g) collected in the bucket that is necessary to spin the turbine seven full spins.

Controlled Variables:

Controlled Variables	Why its Controlled	How its Controlled
Flow of water	The introduction of varied flowrates between trials creates an additional variable which affects spin rate measurements making the results less dependable.	The water bottle's custom caps received the same level of pressure. The water flow rate was also calculated to guarantee that
Number of rotations of the turbine (7)	For easy calculation and direct comparison of each trial in the raw data table.	The spin rate at each height was calculated using the same number of revolutions (7).

Materials:

1. 5 L water bottle
2. Custom designed and printed 3D turbine
3. Phone for recording the procedure
4. Hung adjustable chain system with different levels
5. Measuring tape $\pm 0,0005$ m
6. Scale to measure the mass of water ± 0.01 gr
7. Small bucket
8. Custom 3D printed adjustable bottle caps to control the flow rate of water

Risk Assessment:

- To reduce the possibility of negligence and slips on the water, paper towels were set out for cleaning in the event of spillage.
- The chain system was carefully arranged to reduce the possibility of the water jug toppling over and inflicting injury or damage.

Procedure:

Setup:

- A phone was set up to capture every attempt for each of the 7 heights being measured.
- To ascertain the point at which the water meets the turbine, a specially constructed turbine was created. Additionally, it was used for video analysis to ascertain the turbine's spin rate at the various heights at which the water was dumped.

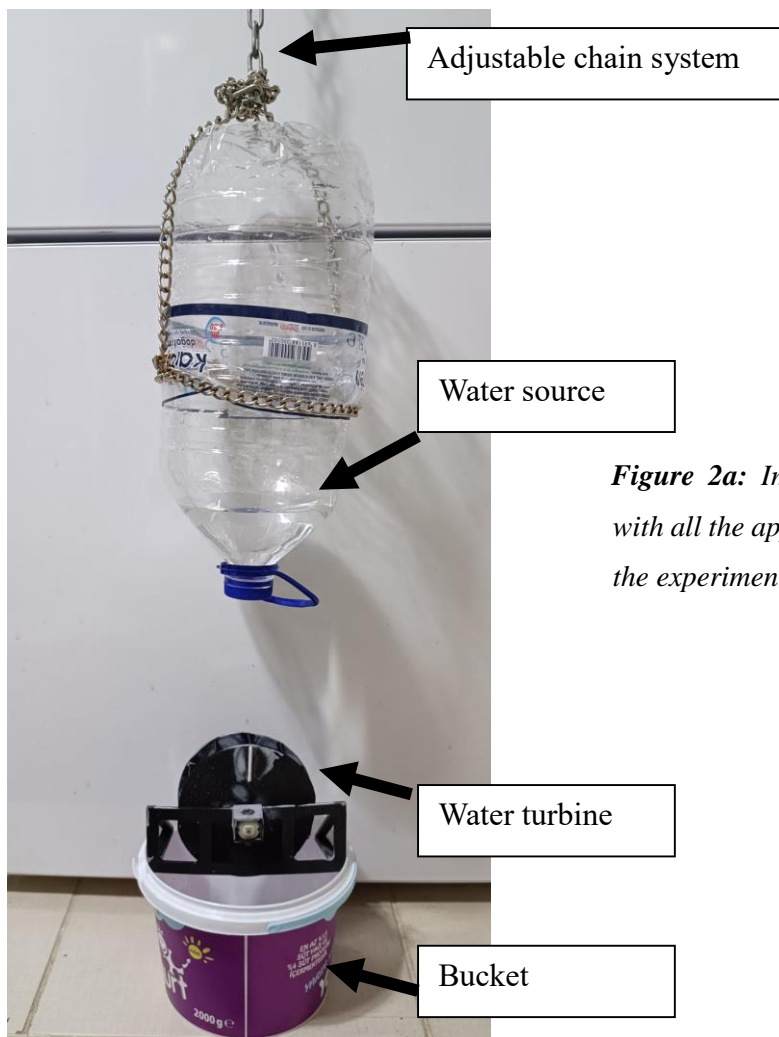


Figure 2a: Image of the experimentation site with all the apparatus set up in order to conduct the experiment



Figure 2b: Image of the custom-built turbine and bottle caps regulating flow rate 1-6 from left to right.



Figure 2c: Image of the custom-built bottle caps regulating flow rate 1-6 from left to right.

Method:

1. In order to collect water and prevent spills, the turbine was set up on the floor beneath the water supply and above a bucket.
2. The water supply was positioned 0.15 meters above the turbine, according to measurements.
3. After every test, the mass of the water in the bucket was measured to determine how much water was needed to spin the turbine seven times.
4. For seven rotations, the water was let to pour unrestricted onto the turbine.
5. Then the cap of the bottle would be changed and a custom cap with larger hole would be attached.

6. The steps 2-5 were carried out again at intervals of 0.25, 0.35, 0.45, 0.55, 0.65, 0.75 meters in height and flow rates of 2, 3, 4, 5, 6.

Raw Data:

Since it makes the math operations easier and has no effect on the relationship, the efficiency will be assumed to be 100%.

Time (s) ± 0.01							
Height (m)	Flow Rates	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
0,15 ± 0,0005 m	1	2,26	2,27	2,27	2,26	2,27	2,27 ± 0,005
	2	2,17	2,16	2,17	2,16	2,17	2,17 ± 0,005
	3	2,05	2,05	2,05	2,06	2,06	2,05 ± 0,005
	4	1,78	1,78	1,78	1,79	1,78	1,78 ± 0,005
	5	1,63	1,64	1,63	1,64	1,63	1,63 ± 0,005
	6	1,41	1,40	1,41	1,41	1,40	1,41 ± 0,005
	7	1,36	1,35	1,36	1,35	1,35	1,35 ± 0,005
0,25 ± 0,0005 m	1	2,47	2,46	2,47	2,46	2,47	2,47 ± 0,005
	2	1,91	1,91	1,91	1,92	1,91	1,91 ± 0,005
	3	1,81	1,80	1,80	1,80	1,79	1,8 ± 0,005
	4	1,69	1,69	1,68	1,69	1,69	1,69 ± 0,005
	5	1,61	1,61	1,61	1,61	1,62	1,61 ± 0,005
	6	1,54	1,54	1,53	1,54	1,54	1,54 ± 0,005
	7	1,40	1,41	1,41	1,41	1,42	1,41 ± 0,005
0,35 ± 0,0005 m	1	2,35	2,35	2,34	2,35	2,35	2,35 ± 0,005
	2	1,85	1,84	1,84	1,84	1,83	1,84 ± 0,005
	3	1,70	1,70	1,71	1,70	1,70	1,7 ± 0,005
	4	1,63	1,63	1,63	1,63	1,62	1,63 ± 0,005
	5	1,52	1,52	1,52	1,52	1,53	1,52 ± 0,005
	6	1,39	1,38	1,39	1,39	1,39	1,39 ± 0,005
	7	1,35	1,35	1,35	1,36	1,35	1,35 ± 0,005
0,45 ± 0,0005 m	1	2,21	2,21	2,21	1,22	2,21	2,21 ± 0,005
	2	1,78	1,77	1,77	1,77	1,76	1,77 ± 0,005
	3	1,62	1,62	1,62	1,61	1,62	1,62 ± 0,005
	4	1,54	1,54	1,55	1,54	1,54	1,54 ± 0,005
	5	1,42	1,41	1,41	1,41	1,40	1,41 ± 0,005

Time (s) ± 0.01							
Height (m)	Flow Rates	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
	6	1,33	1,33	1,34	1,33	1,33	1,33 ± 0,005
	7	1,29	1,29	1,29	1,28	1,29	1,29 ± 0,005
0,55 ± 0,0005 m	1	2,01	2,01	2,01	2,01	2,00	2,01 ± 0,005
	2	1,64	1,65	1,64	1,64	1,64	1,64 ± 0,005
	3	1,52	1,52	1,52	1,51	1,52	1,52 ± 0,005
	4	1,46	1,47	1,47	1,48	1,47	1,47 ± 0,005
	5	1,35	1,35	1,36	1,35	1,35	1,35 ± 0,005
	6	1,19	1,19	1,19	1,18	1,19	1,19 ± 0,005
	7	1,16	1,15	1,16	1,16	1,16	1,16 ± 0,005
0,65 ± 0,0005 m	1	1,79	1,79	1,79	1,78	1,79	1,79 ± 0,005
	2	1,53	1,52	1,52	1,52	1,51	1,52 ± 0,005
	3	1,41	1,41	1,40	1,41	1,41	1,41 ± 0,005
	4	1,35	1,35	1,35	1,34	1,35	1,35 ± 0,005
	5	1,20	1,21	1,20	1,20	1,20	1,2 ± 0,005
	6	1,02	1,02	1,01	1,02	1,02	1,02 ± 0,005
	7	0,93	0,94	0,94	0,94	0,93	0,94 ± 0,005
0,75 ± 0,0005 m	1	1,68	1,68	1,68	1,67	1,68	1,68 ± 0,005
	2	1,43	1,43	1,42	1,43	1,43	1,43 ± 0,005
	3	1,28	1,29	1,29	1,30	1,29	1,29 ± 0,005
	4	1,17	1,17	1,17	1,17	1,18	1,17 ± 0,005
	5	1,09	1,09	1,08	1,09	1,09	1,09 ± 0,005
	6	0,96	0,97	0,98	0,97	0,97	0,97 ± 0,005
	7	0,81	0,82	0,81	0,81	0,81	0,81 ± 0,005

Table 1: Height and flow difference and the corresponding time values to complete seven full rotations

Uncertainty Calculations for Time:

$$Uncertainty = \frac{Maximum - Minimum}{2}$$

Sample Calculations:

Time uncertainty for 0,15 m and stage 1 flow:

$$Uncertainty = \frac{2,27 - 2,26}{2} = 0,005$$

Height (m)	Flow Rates	Mean RPS
0,15 ± 0,0005 m	1	3,0837 ± 0,007
	2	3,2258 ± 0,007
	3	3,4146 ± 0,008
	4	3,9326 ± 0,011
	5	4,2945 ± 0,013
	6	4,9645 ± 0,018
	7	5,1852 ± 0,019
0,25 ± 0.0005 m	1	2,834 ± 0,006
	2	3,6649 ± 0,01
	3	3,8889 ± 0,011
	4	4,142 ± 0,012
	5	4,3478 ± 0,014
	6	4,5455 ± 0,015
	7	4,9645 ± 0,018
0,35 ± 0.0005 m	1	2,9787 ± 0,006
	2	3,8043 ± 0,01
	3	4,1176 ± 0,012
	4	4,2945 ± 0,013
	5	4,6053 ± 0,015
	6	5,036 ± 0,018
	7	5,1852 ± 0,019
0,45 ± 0.0005 m	1	3,1674 ± 0,007
	2	3,9548 ± 0,011
	3	4,321 ± 0,013
	4	4,5455 ± 0,015
	5	4,9645 ± 0,018
	6	5,2632 ± 0,02
	7	5,4264 ± 0,021
0,55 ± 0,0005 m	1	3,4826 ± 0,009
	2	4,2683 ± 0,013
	3	4,6053 ± 0,015
	4	4,7619 ± 0,016
	5	5,1852 ± 0,019
	6	5,8824 ± 0,025
	7	6,0345 ± 0,026
0,65 ± 0,0005 m	1	3,9106 ± 0,011
	2	4,6053 ± 0,015
	3	4,9645 ± 0,018

Height (m)	Flow Rates	Mean RPS
	4	5,1852 ± 0,019
	5	5,8333 ± 0,024
	6	6,8627 ± 0,034
	7	7,4468 ± 0,04
0,75 ± 0,0005 m	1	4,1667 ± 0,012
	2	4,8951 ± 0,017
	3	5,4264 ± 0,021
	4	5,9829 ± 0,026
	5	6,422 ± 0,029
	6	7,2165 ± 0,037
	7	8,642 ± 0,053

Table 2: RPS values corresponding to height and flow difference for the average

The obtained time values were averaged to determine turbine rotations per second (RPS) at different heights. The calculated RPS of the turbine becomes simpler because of this method.

Formula for rotation per second (RPS):

$$RPS = \frac{\text{Number of Rotations}}{\Delta t}$$

Sample Calculation:

RPS calculation for 0,15 m and stage 1 flow:

$$RPS = \frac{7}{2,27} = 3,0837$$

Percentage uncertainty for 0,15 m and stage 1 flow:

$$\% \text{ uncertainty} = \frac{0,005}{2,27} \times 100 = 0,22\%$$

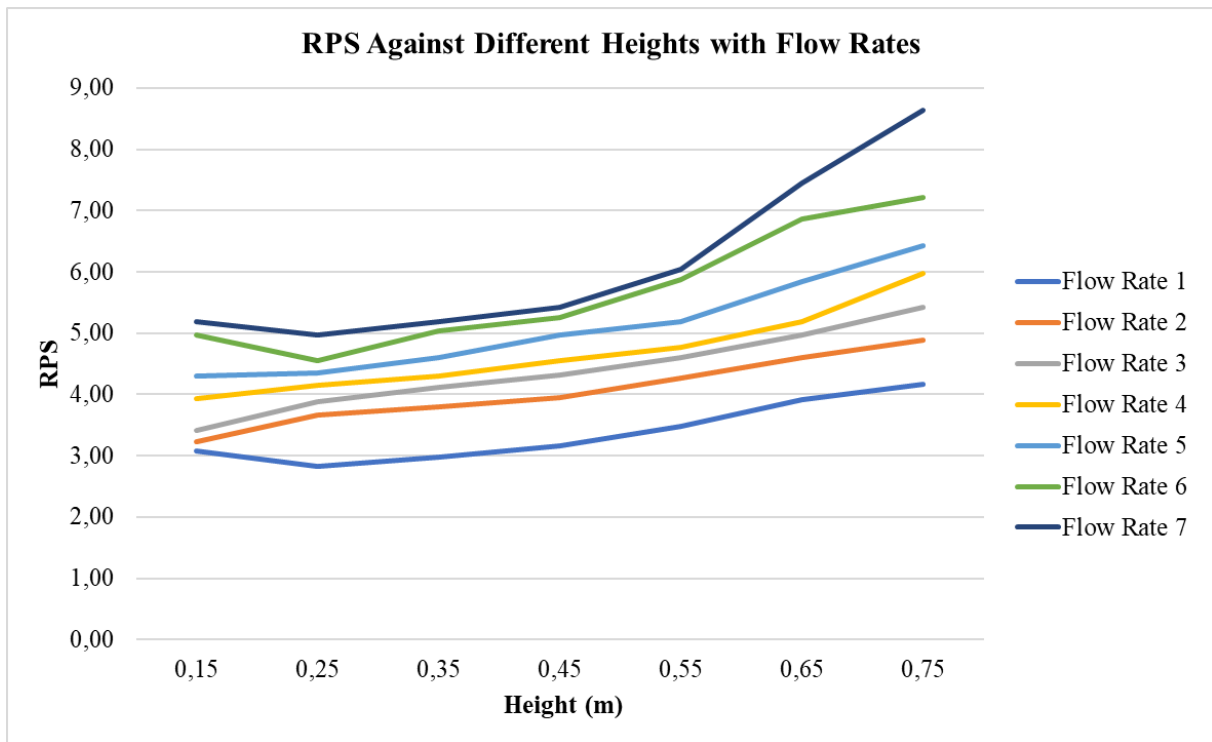
Raw uncertainty for 0,15 m and stage 1 flow:

$$RPS = 3,0837 \pm 0,22\%$$

$$\text{Raw Uncertainty} = 0,0022 \times 3,0837$$

$$\text{Raw Uncertainty} = 0,007$$

$$RPS = 3,0837 \pm 0,007$$



Graph 1: RPS against different heights and flow rates

The rotations per second values against the corresponding height difference values was done. This was done using Excel to create a line of best fit for the collected data. The graph is not linear, and an exponential curve is the closest and most accurate best fit line, according to the average values. This may happen because of my late control of the water. An attempt will be made to linearize the relationship, as there isn't one that can be inferred from the raw data. Testing several value options, such as square rooting or squaring, for the height difference values and RPS values will be necessary to achieve this.

In the following table, the mass of the water poured to spin the turbine 7 times is given. Upon closer inspection to the table, the mass of water necessary for seven full rotations is decreasing in every height but increases proportional to the flow rate.

Mass of water (g) poured in 7 ± 0.01 s, ± 0.01 mg							
Height (m) between turbine and water source $\pm 0,0005$ m	Flow Rates	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean mass of water poured in 7 seconds
0.15	1	384.560	354.220	405.080	350.610	411.230	$381.14 \pm 0.003\%$
	2	470.770	427.420	402.440	375.840	321.770	$399.648 \pm 0.003\%$

Mass of water (g) poured in 7 ± 0.01 s, ± 0.01 mg							
Height (m) between turbine and water source $\pm 0,0005$ m	Flow Rates	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean mass of water poured in 7 seconds
	3	793.210	831.140	593.570	533.620	866.690	$723.646 \pm 0.001\%$
	4	1128.580	1005.760	931.350	1075.620	1156.260	$1059.514 \pm 0.001\%$
	5	1227.310	1263.360	1242.580	1031.060	1155.610	$1183.984 \pm 0.001\%$
	6	1496.520	1425.360	1194.150	1048.280	1328.210	$1298.504 \pm 0.001\%$
	7	1574.910	1680.210	1439.320	1494.110	1766.530	$1591.016 \pm 0.001\%$
0.25	1	219.030	239.690	244.760	255.740	231.720	$238.188 \pm 0.004\%$
	2	382.490	340.440	310.290	369.470	347.110	$349.96 \pm 0.003\%$
	3	592.670	597.020	576.320	559.350	561.430	$577.358 \pm 0.002\%$
	4	701.240	840.720	698.080	710.140	726.460	$735.328 \pm 0.001\%$
	5	846.430	757.290	821.130	863.210	839.040	$825.42 \pm 0.001\%$
	6	917.380	903.270	1070.930	1071.950	937.120	$980.13 \pm 0.001\%$
	7	1081.730	1119.110	1317.290	923.170	991.830	$1086.626 \pm 0.001\%$
0.35	1	255.500	239.790	202.210	252.040	238.680	$237.644 \pm 0.004\%$
	2	311.400	341.490	332.370	301.480	298.670	$317.082 \pm 0.003\%$
	3	631.220	620.940	529.820	507.840	581.930	$574.35 \pm 0.002\%$
	4	555.330	575.690	848.670	781.190	673.770	$686.93 \pm 0.001\%$
	5	915.480	896.510	692.880	1057.070	825.290	$877.446 \pm 0.001\%$
	6	907.640	1256.660	1042.830	1167.940	1047.030	$1084.42 \pm 0.001\%$
	7	1072.230	1261.160	1168.570	1341.010	1203.580	$1209.31 \pm 0.001\%$
0.45	1	247.650	224.160	245.830	232.510	227.690	$235.568 \pm 0.004\%$
	2	299.290	293.020	305.480	325.120	301.480	$304.878 \pm 0.003\%$
	3	401.360	415.750	397.130	418.780	400.870	$406.778 \pm 0.002\%$
	4	470.220	514.960	481.980	528.590	483.640	$495.878 \pm 0.002\%$
	5	715.800	761.710	688.420	704.310	697.520	$713.552 \pm 0.001\%$
	6	948.560	1001.840	969.530	960.710	953.470	$966.822 \pm 0.001\%$
	7	1062.530	1159.280	1088.860	1132.790	1039.830	$1096.658 \pm 0.001\%$
0.55	1	176.590	190.560	200.090	207.980	181.430	$191.33 \pm 0.005\%$
	2	292.760	272.310	289.230	280.340	284.790	$283.886 \pm 0.004\%$
	3	405.620	382.510	373.180	399.910	387.610	$389.766 \pm 0.003\%$
	4	455.850	435.280	493.070	471.670	469.910	$465.156 \pm 0.002\%$
	5	602.460	598.650	584.010	623.320	607.800	$603.248 \pm 0.002\%$
	6	811.640	894.890	791.740	793.940	803.560	$819.154 \pm 0.001\%$
	7	959.570	939.330	993.410	905.130	943.670	$948.222 \pm 0.001\%$
0.65	1	168.870	161.720	187.940	175.860	173.430	$173.564 \pm 0.006\%$
	2	246.390	263.980	261.890	258.830	249.510	$256.12 \pm 0.004\%$
	3	363.850	360.400	385.080	359.050	367.120	$367.1 \pm 0.003\%$

Mass of water (g) poured in 7 ± 0.01 s, ± 0.01 mg							
Height (m) between turbine and water source $\pm 0,0005$ m	Flow Rates	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean mass of water poured in 7 seconds
	4	412.530	423.570	439.410	453.950	431.940	$432.28 \pm 0.002\%$
	5	525.140	553.630	523.280	547.590	537.380	$537.404 \pm 0.002\%$
	6	765.510	726.320	751.770	744.380	729.650	$743.526 \pm 0.001\%$
	7	849.050	814.020	856.780	865.270	821.690	$841.362 \pm 0.001\%$
0.75	1	164.950	151.810	150.630	166.280	147.050	$156.144 \pm 0.006\%$
	2	254.470	234.900	244.390	241.860	246.730	$244.47 \pm 0.004\%$
	3	330.910	345.750	340.280	329.470	324.880	$334.258 \pm 0.003\%$
	4	415.180	427.810	403.940	416.260	407.060	$414.05 \pm 0.002\%$
	5	506.590	498.130	501.550	493.410	499.010	$499.738 \pm 0.002\%$
	6	734.860	728.410	703.820	714.370	689.140	$714.12 \pm 0.001\%$
	7	805.810	823.980	800.070	804.640	813.270	$809.554 \pm 0.001\%$

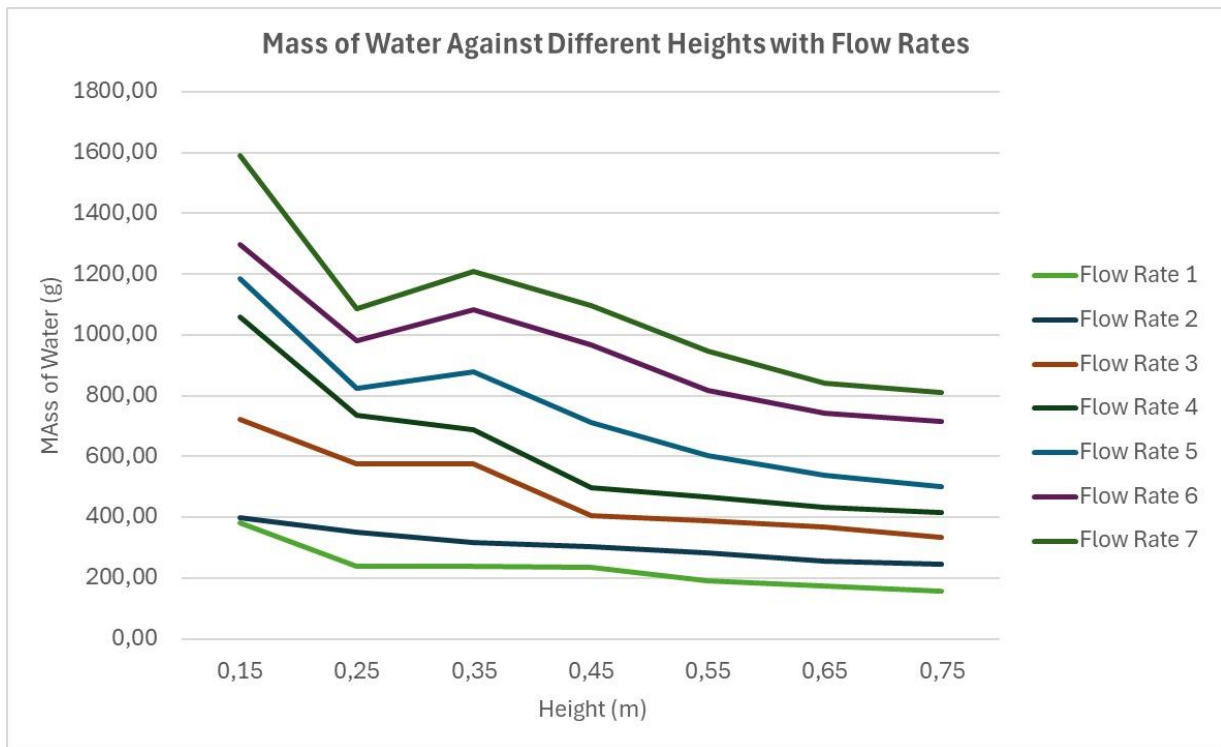
Table 3: Height and flow difference and the corresponding weight values to complete seven full rotations

Uncertainty Calculations for the Average Mass Poured to Spin the Turbine 7 Rotation

$$\text{Percentage Uncertainty} = \frac{0,01}{\text{Average Mass Poured}} \times 100$$

Uncertainty Calculations for 0,15 m and Flow 1,

$$\text{Percentage Uncertainty} = \frac{0,01}{381,14} \times 100 = \pm 0.0262\%$$



Graph 2: Mass(g) of water poured in different heights and flow rates

It is safe to say that according to the graph above, the necessary amount of water to spin the turbine 7 times mostly decreases despite the non-linear graph. The reason of fluctuation seen in the graph could be due to my inconsistent control of the water flow. In conclusion my theory is supported, and it is consistent with potential energy formula because while the height of the water source increases, the mass required mostly decreases.

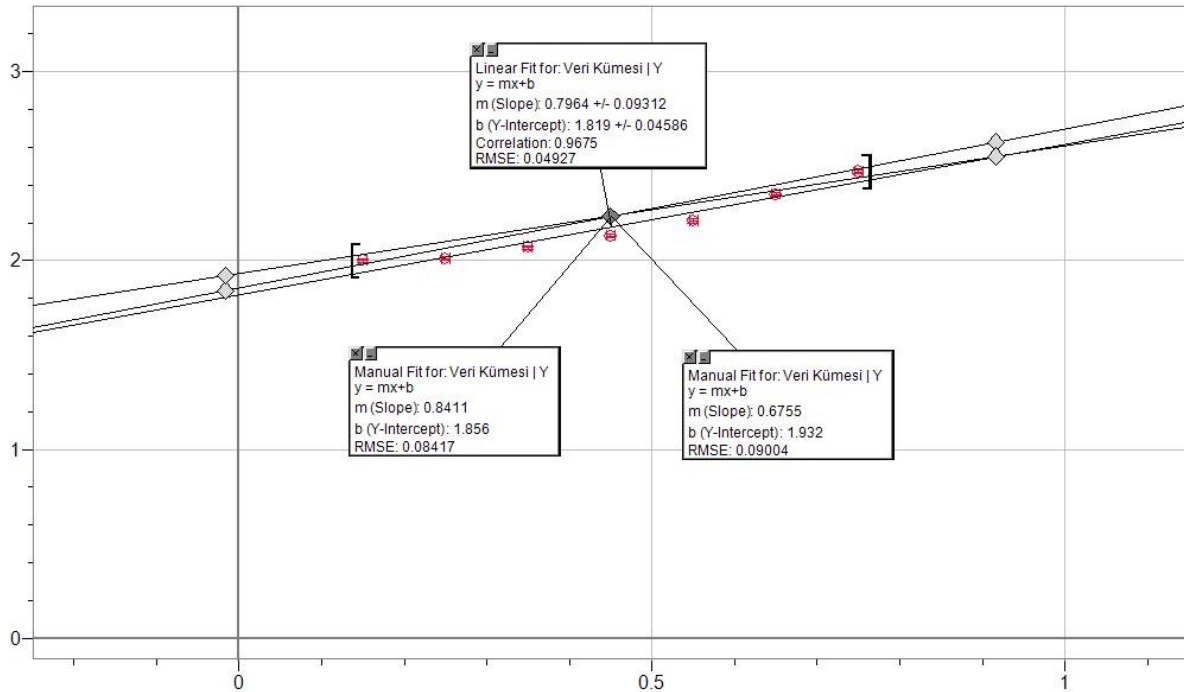
Processed Data:

Height (m) $\pm 0,0005$ m	Flow Rates	$\sqrt{\text{Rotations per second (rps)}}$
0.15	1	1.76 ± 0.007
	2	1.8 ± 0.007
	3	1.85 ± 0.008
	4	1.98 ± 0.011
	5	2.07 ± 0.013
	6	2.23 ± 0.018
	7	2.28 ± 0.019
0.25	1	1.68 ± 0.006
	2	1.91 ± 0.010
	3	1.97 ± 0.011

Height (m) $\pm 0,0005$ m	Flow Rates	$\sqrt{\text{Rotations per second (rps)}}$
	4	2.04 ± 0.012
	5	2.09 ± 0.014
	6	2.13 ± 0.015
	7	2.23 ± 0.018
0.35	1	1.73 ± 0.006
	2	1.95 ± 0.010
	3	2.03 ± 0.012
	4	2.07 ± 0.013
	5	2.15 ± 0.015
	6	2.24 ± 0.018
	7	2.28 ± 0.019
0.45	1	1.78 ± 0.007
	2	1.99 ± 0.011
	3	2.08 ± 0.013
	4	2.13 ± 0.015
	5	2.23 ± 0.018
	6	2.29 ± 0.020
	7	2.33 ± 0.021
0.55	1	1.87 ± 0.009
	2	2.07 ± 0.013
	3	2.15 ± 0.015
	4	2.18 ± 0.016
	5	2.28 ± 0.019
	6	2.43 ± 0.025
	7	2.46 ± 0.026
0.65	1	1.98 ± 0.011
	2	2.15 ± 0.015
	3	2.23 ± 0.018
	4	2.28 ± 0.019
	5	2.42 ± 0.024
	6	2.62 ± 0.034
	7	2.73 ± 0.040
0.75	1	2.04 ± 0.012
	2	2.21 ± 0.017
	3	2.33 ± 0.021
	4	2.45 ± 0.026
	5	2.53 ± 0.029
	6	2.69 ± 0.037
	7	2.94 ± 0.053

Table 3: Square root of RPS values (rps) corresponding to height and flow difference

The final derivation of a straight line appeared from many failed attempts to linearize the RPS against height difference graph. As a result, I have square rooted the RPS values at each height and flow rate to generate graph that mostly resembles a linear graph.



Graph 3: RPS versus the flow rates and RPS against the height difference between the water source and the turbine

The gradient of the best fit line, the maxima line and the minima line:

Best fit line = 0,7964

The maxima line = 0,8411

The minima line = 0,6755

The uncertainty of the best fit measurement amounted to $\pm 0,09312$. The following equations enabled the determination of the uncertainty value

$$\text{Uncertainty gradient} = \text{Maxima line gradient} - \text{Best fit line gradient}$$

$$\text{Uncertainty gradient} = 0,8411 - 0,7964 = 0,0447$$

$$\text{Uncertainty gradient} = \text{Minima line gradient} - \text{Best fit line gradient}$$

$$\text{Uncertainty gradient} = 0,6755 - 0,7964 = -0,1209$$

$$\text{Final gradient} = 0,7964 \pm 0,0447$$

Given the greater distance between the minima and the best fit line, that uncertainty will be chosen as the uncertainty for the line that fits the best.

Analysis:

I have previously expected a positive linear relationship to exist between height differential variables and revolutions per second of the turbine, however, the line of best fit demonstrated a quartic function pattern instead of establishing a straight-line relationship with the error bars as shown in the previous graph from the raw data section. Upon seeing this, I made a linearization effort because the raw data failed to generate a proper linear relationship. The line of best fit displayed a linear relationship that passed through each error bar after I calculated the square root of revolutions per second.

This graph indicates that for every meter of height the RPS square root will increase its rotational speed by 0,7964 revolutions per second.

A power output of zero was predicted at the origin because no potential energy exists within the water mass to become kinetic energy when height reaches zero meters. The linearized graph also shows a square root value of 0 at the x-axis point 0. Since the trend has been verified it raises the question “Does the current observation match the hypotheses developed before the experiment?” The answer is no because the raw RPS data graph against height difference does not show complete compatibility with a linear connection. The data points from the square root of RPS versus height measurement displayed linear behavior.

Conclusion:

In conclusion, it was discovered that there was a positive linear relationship between the height differential and the square root of the turbine's spin rate. The study established a direct linear connection between the height difference variable and the square root value of turbine rotational speed. The square root of the number of rotations per second produced grows linearly with the magnitude of the height difference.

Evaluation:

Systemic Error: The number for gravitational acceleration, measured at 9.81 ms^{-2} , actually falls slightly as height increases. As a point mass gets farther away from the earth, the gravitational pull gets weaker.

Importance:

This inaccuracy is minor because rounded calculations won't be affected by the tiny variation in g at the scale of this particular experiment.

Improving Method:

Because I was regulating the flow of water,

Random Error	Importance	Improving Method
In addition to the ambiguity, the experimenter's reaction time may have affected the stopwatch's targeted time because it was manually started and stopped.	Due to fluctuating reaction times across trials, it is possible that the 7 full spins that were assumed to be recorded during computations were not fully recorded, which makes this inaccuracy extremely significant.	A more accurate reading might be obtained by using a timer rather than data collected from videos. The partner could record the time because their complete focus would be on operating the stopwatch instead of managing the tap during the procedure.
The recorded height may be somewhat less or longer than the assumed height, which could cause the points on the graph to slightly shift. The meter stick's uncertainty is 0.0005 meters.	Since there is little ambiguity and more accurate outcomes, this mistake is negligible. Additionally, the graph's error bars are rather tiny.	Not much uncertainty necessitates advancements.
The mass recorded may be slightly before or after the ideal, which could cause the points on the graph to slightly shift.	Since there is little ambiguity and more accurate outcomes, this mistake is negligible. Additionally, the graph's error bars are rather tiny.	Closing the water flow when the turbine is near to complete its seventh rotation can reduce the mass of water used in calculations.

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