Wind and Waterspray

Supervisor

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Summary

In this report we have been working on a particular case, creating a model for a fountain. The fountain is located on a square which is surrounded by terraces. People are sitting on these terraces and they should not get wet due to the fountain. Because the velocity of the wind is a variable, we have to vary the height of the water beam coming out of the fountain. We did research on what the maximum height of the water beam could be at a range of wind velocities. We set some purposes, assumptions, did some calculations and we created a working model. At the end, we took a look back and reflected on everything. Based on these reflections, we have tried to correct the model, where it was possible. At the end, we have been able to create a model of which we think has solved the initial problem.

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Definition phase

A fountain is placed in the middle of a square. Various terraces are surrounding this fountain. In the evening, the fountain is illuminated; this attracts many people. For the tourists, the fountain is the main reason they visit the terraces. At windy days, the water from the fountain might get blown further than meant, which may mean it can wet tourists and visitors. (see appendix A and B)

Problem Definition and Purpose

What is the relation between the water supply and the wind- speed and direction so that the water of the fountain is as high as possible without wetting people?

<u>Purposes that apply to the model:</u>

- **Optimize**: With the help of this model the water will always be as high as possible in different kind of situations without wetting people around it.

- **Predict**: With this model you can predict under the given circumstances (wind speed and direction) with what amount of water you can get the highest possible fountain without wetting people.

- **Control**: The model of the fountain will help the system inside the fountain to control the water pressure in a particular situation at a particular wind speed and -direction

Sub-questions

To make it easier for ourselves to solve this case, we split the problem definition into small problem definitions (sub-questions). In this way we can systematically work through all the different aspects of the problem.

1. Does the temperature of the air influence the speed of the water?

2. How can we find out the distance between the fountain and the people walking around it?

3. What is the highest possible height of the water?

4. Can we find out what the speed of the water leaving the nozzle should be?

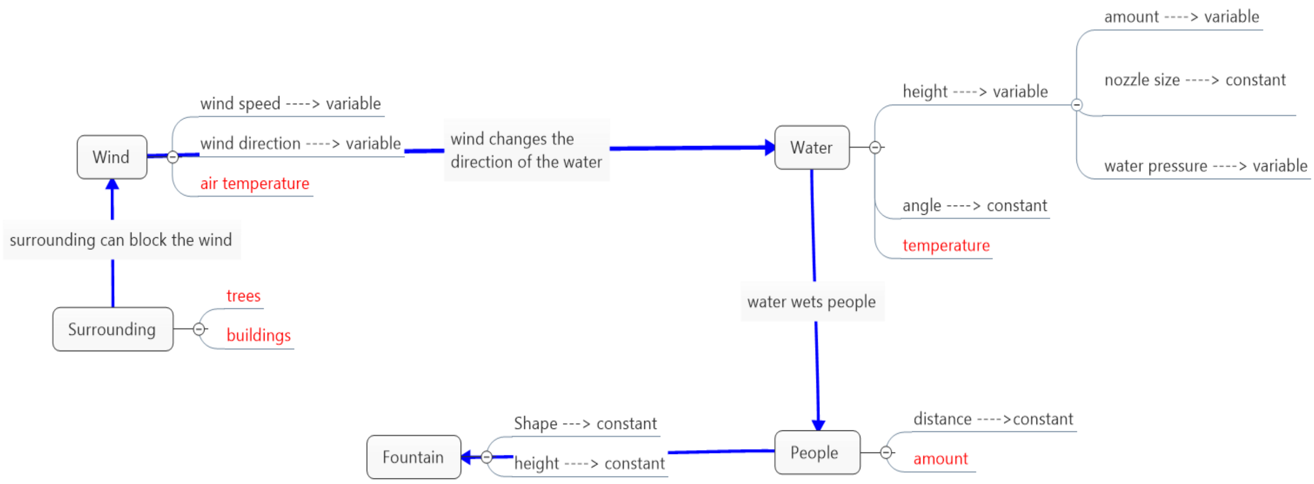
5. Is the wind direction relevant?

6. What are the influences of various types of friction on our model?

Conceptualization

Concepts, properties, values and relations

We made this diagram to see how all the entities with their associated properties, we have chosen, relate to each other. The properties marked red are properties that we will not take into account since we don't want to make our model unnecessarily complicated..



To simplify the case, we decided to skip the nozzle size, water pressure and the amount of water. Instead of these properties we set a constant value for the water speed.
All of the entities and properties we are going to work with are shown below. In order to know which entities en properties we have to focus on, we set their roles.

Entity	Property	Role	Unit
Fountain	Shape	Constant	dimensionless
	Height	Constant	meter
People	Distance	Constant	meter
Water	Height	Variable	meter
	speed out of nozzle	constant	meter/second
	Range	Variable	meter
Wind	Wind speed	Variable	meters/second
	Wind direction	Constant	dimensionless

Formalization phase

Quantities and their Relationships

Entity	Property	Role	Relation
Fountain	Shape	Choose	Definition
	Height	Choose	Definition
People	Amount	Choose	Definition
	Distance	Need	Equation
Water	Height	Need	Equation
	speed out of nozzle	Choose	Definition
	Range	Need	Equation
Wind	Wind speed	From context	Equation

Approximations and Assumptions

we assume..

→ that the temperature of the water and the air is always the same.
→ that the trees (in or surrounding the square) don't have effect on the wind velocity/direction.
→ that the buildings/terraces don't have effect on the wind velocity/direction.
→ that the square is round and therefore the wind direction is neglectable.
→ that people are only on the terraces and not walking around the fountain.
→ that there is no friction at all.
→ that the droplets have the same speed as the wind

We planned not to include all of the previously mentioned factors, due to the limit of time and lack of knowledge. So first of all, we decided that we do not want to take the **temperature of water and air** into account. These values can vary a lot and it will therefore be too hard for us to include it in our model. Besides that we think that they values won't make a huge difference in the outcome. We decided to leave out the **effect of trees in or surrounding the square** in decreasing the velocity of the wind, because the shape of the trees will make the model too complicated. Since we made the square round, the **wind direction** is also negligible. We decided to make the **distance between the people and the fountain** constant. This constant value is equal to the distance from terrace to the fountain. the reason for this is that people walk around all the time. We can not take people who walk around all the time into account. To simplify our case we don't take **friction** into account and assume that droplets of water have the same speed as the wind.

Derivations

Our first derivation assumed that the wind force only worked when the maximum height of the water beam was reached. Also we did not have any calculations involving the initial velocity. When executing this formal model the outcomes were therefore unrealistic and inaccurate.

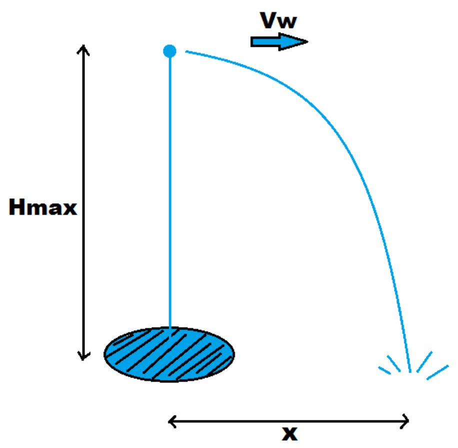
A list with the entire names of the abbreviations that we will use:

X	The range of the water
H_{max}	The maximum height of the water
V_w	The velocity of the wind
g	The gravitational force
t	The time it takes the water to reach the ground

Then we named the inputs and the outputs:

Input:	*Output:*
V_w	*X*

A quick sketch of our situation / problem:



First we need the formulas for projectile motion. These formulas are from the book *University Physics with Modern Physics, 13th Edition - Projectile Motion:*

Then we need change the formulas to fit in our model. We know that:

→ V_w variates between 0 and 14 m/s
→ g is a constant with value 9,81 m/s^2

For the vertical trajectory of the water, we have used the following formula:

$$y = \tfrac{1}{2}gt^2$$

But since we assume the water is only affected after it reaches its maximum height, we have to add H_{max} to it.

To calculate the maximum height, we made a table relating the wind speed and the maximum height. To see the full table, see appendix C..We derived the following linear function from this:

$$H_{max} = 0,7Vw + 0,5$$

This needs to be added to the formula for the free-fall:

$$y = \tfrac{1}{2}gt^2 + 0,7Vw + 0,5$$

Special Cases

- The lower the speed of wind, the higher the beam of the water. This means that if it is wind-still that the beam of water will go infinitely high and this is not what we want. Therefore we set up a limit height of the beam at 10 meters.

- The higher the speed of the wind, the lower the water beam can become. The height of the water beam is 0, when the wind speed is 14 m/s or more.

- When the water is at its highest point (10m in our case) the water won't reach any further than 15 meter horizontally.

Estimates

We needed values to work with. We looked for some information on the Internet and applied the method of "wisdom of the crowd". After this research we came up with the following estimates.

Property	**Value**	**Origin**
Max. height of beam	10 meter	Public domain
Diameter of fountain	8 meter	Mean value
Distance beam to terraces	15 meter	Common knowledge
Max. wind speed	14 meters/second	Public domain

Execution phase

The problem statement in formal terms

→ The quantity $\mathbf{H_{max}}$ should be as big as possible, therefore $\mathbf{V_w}$ is desired to be as small as possible.

→ $\mathbf{H_{max}}$ cannot exceed the value 10 and if $\mathbf{V_w}>\mathbf{V_{w,max}}$, then the quantity $\mathbf{H_{max}}$ should have the value 0.

→ The quantity $\mathbf{V_g}$ is out of all proportion to $\mathbf{V_w}$. The higher $\mathbf{V_w}$, the lower the quantity $\mathbf{V_g}$.

Calculations / Implementation / Simulation

See attached Excel file.

Validation and Verification; Accuracy and Precision

We started to take the wind into account from the point that the water is at his highest, instead of the influence that the wind had from the point that the water was in the air. Also we assumed that the water was a compact beam of water, instead of taking into account that it could divide into small drops. These drops would have probably reacted different to the wind, and may go further than a beam of water. Finally, because we did not implement air resistance, our outcomes are bigger (e.g. the range becomes bigger without air resistance).

Conclusion phase

Presentation and Interpretation

We have chosen to represent our result in a graph. To make things more clear for ourselves and the reader, we have decided to also make a simulation. We started working with Accel, but for some reason it didn't work out the way we wanted it. We were not able to create a proper graph. We decided to start working in Excel instead and we have been able to create a graph with two sliders and a simulation of the water beam there. The graph represents the height of the water beam (H_w), with respect to the velocity of the wind (V_{wind}). The simulation represents the path the water travels as time passes. We have set a maximum wind velocity and a maximum height of the water beam, so we can say:

"For any V_w until and including 14 m/s, the H_w with a maximum of 10 m, is given."

It's a pity that we have not been able to work with Accel, because we do not have access to all the features Accel offers (features like numerical analysis and error propagation). From this we can conclude that we have been able to create a proper graph with which we have solved the initial problem. With diving deeper into our graph and taking a closer look at what happens exactly, we have made it very hard for ourselves. We can say we did the best we could.

Reflections and Discussions

Discussion after the Conceptual Model

Firstly, we chose to leave out the temperature of the air. In hindsight, this was a right choice, since a temperature difference would make an unmeasurable small difference for the height that the water may reach. The same thing holds for the water temperature, which we also did not include. Then, we chose to set a constant horizontal distance between the people and the fountain. After this, we did not include the surrounding into our model.This does make a difference, but since we wanted to keep the model calculable we made the right choice. Furthermore, we set some properties as a constant. These are the dimensions of the fountain and the distance from the people to the terraces. We did this to make the model less complicated for ourselves. Looking back, this was a very wise decision. We chose to do calculations with the height of the water, the range of the water and the wind speed.

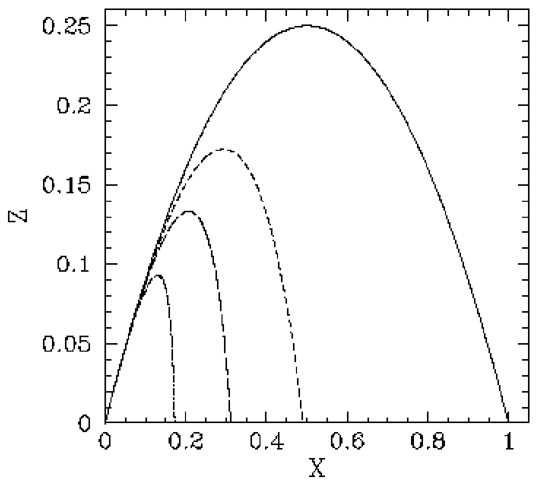
First, we wanted to take the size and the diameter of the nozzle into account. This made the model very complicated because we would also have to take the amount of water and the pressure into account. On the advise of our tutor, we left the nozzle completely out of consideration and chose to see the speed of the water from the ground as a constant.

The direction of the wind will automatically drop because we considered the square as round with all the terraces located at the same distance from the middle of the fountain.

Discussion after the Formal Model

- The assumption concerning the temperature of the water and the air was valid, because a different temperature would make a very small difference to our results.
- We assumed that the environment didn't have any effect on the wind. Actually the environment would have had influence on the direction of the wind, but to keep things simple, we left this out.
- We assumed that the square was round, so that the direction of the wind wouldn't have influence.
- The assumption concerning people not walking across the square was valid, because otherwise it would be up to the people to decide whether they get wet or not. This would have been a variable that we now can leave out of our model.
- We assumed that there was no air resistance. This would have resulted in a path of water that's a little off parabolic. The projectile doesn't actually travel with a constant horizontal velocity; it decelerates. The vertical motion is now under the combined influence of gravity and air friction. They work together on the way up, but work against each other on the way down. Gravity works only downward, while air friction works against the direction of motion of the object. (1)
- We assumed that the droplets of water would have the same speed as the wind. If we would have taken the speed difference between the wind and the droplet into account, we think it would have made a small difference in our outcome

For the maximal height we choose a reach that corresponded with the reach of different nozzles we looked up (see appendix C). For the maximal speed of the wind we looked up average wind speeds in Eindhoven.



(1) *If we would have taken the air resistance into account,*
the beam of water would be close to parabolic, as shown in this figure.

Discussion after the Result

When we first tackled making the actual model, we tried working in Accel. This was fun and challenging at first, but the deadline was approaching so we had to look for another program to work with. We chose to make an interactive model in Excel.

When we had all the sliders working and plotted a graph, we noticed that the formulas from exercise 12 were wrong for our purpose. An assumption for our model was that the water-beam was only affected by the wind after it has reached its highest point, but it is far more realistic that the wind affects the water the moment it leaves the nozzle. So we adjusted the model to fit these new assumptions.
As it turned out, the model was only showing a projectile motion and that was not what we expected, because we wanted the water beam to be most influenced by the wind when the water was at its maximum height. So we went back to our previous assumptions again, but we adjusted the derivations. The model would now adjust its water beam height according to the wind speed. This time the numerical results were very close to our assumptions. So, even though the assumptions sound more realistic, the numerical outcome will not always fit the expectations.

Discussion after the Solution of the Initial Problem

The purposes which are applied to our model are optimize, predict and control. We succeeded to make a optimized model so far, because we modeled that the beam of the water will be as high as possible without wetting the people. We also made a graph in which you can predict which wind speeds are related to the height of the water. This means the height of the water at a certain wind speed. This graph makes our model predictable. The third and last purpose of our model was to set the water speed depending on the wind speed and wind direction. Unfortunately, this was not achievable, because we chose to neglect things such as the water pressure. The reason for this is that we chose to make the initial water speed constant. This would prevent a lot of complexity. We did not take the nozzle into account. The nozzle size determines for example the water pressure.

Reflection on the Assignment

Extension

Instead of simplifying a lot we would work out some extra details and make it more complicated and worked out. For example we would take the nozzle size, the force of the water pushed into the air or the water temperature in consideration. If we would do that, we would have a much more accurate model. We would also try to work more accurate, by dividing the tasks evenly, and keep asking for critical feedback. We also want to look critical at the work done ourselves.
We think that we didn't take enough time to get to know Accel, because we all think it's a hard program to understand. That's why we would start earlier with experimenting with Accel, so we would fully understand it.

<u>Why is the graph deceiving</u>

When the wind speed is 0 m/s, the trajectory of the water is still a curve according to the graph. However, when you look at the axis and at the data, the x values are all 0 meter. Excel still graphs this as a curve, however. Also, when the wind increases, the water gets further. The axis x-axis on the graph is not locked so it will look like it actually decreases. It's important to read the numbers on the axis.

<u>Why does the wind only affect the water on/after it has reached its highest point?</u>

We think we made a reasoning mistake. We accidentally assumed that the water only will be affected by the wind on its maximum point without wetting people. In this not-meant assumption we totally missed the fact that the wind affect the water beam directly from its initial point of squiring into the air. Unfortunately we realised this failure too late and were not able to correct the model. Right now, we have to assume that the beam of the water will be influenced by the wind on its highest point in this model.

<u>Why we decided to go for Microsoft Excel instead of ACCEL</u>

From our experience in high school, we have already some experience working with Excel and applying the *visual basic* programming language. We have tried putting the model in Accel, but we failed to get the plotting correctly. In order to make a working model, we have decided to work in Excel. Another benefit of Excel is the wide range of help you can get from various sources. This resulted in a quicker process of the formalization phase.

Necessity for Improvement

<u>Persuasiveness</u>
We think that we did quite a lot of assumptions. This will make our model not as convincing as it could be. It would have been more convincing if we would have worked out complicated physics formula's about the wind reacting to the surroundings, to look like we know what we are talking about, but this level of physics was too complex for us. We do think that we did create the model to the almost maximum of that what we are capable of with our current knowledge.

<u>Distinctiveness</u>
Again because we did the assumptions, our model isn't incredibly precise. But once again, for the purpose of the model, we think we succeeded to create a model that is precise enough for it's purpose.

Possibilities for improvement

Persuasiveness
If we had the time and/or knowledge, we would spend more time in making a more accurate more complex model. This would make us a lot more convincing, because every result we get then is a lot more plausible and precise.

Distinctiveness
To make the model more distinctive, we would again have to make the model more accurate and more complex. We would do this by studying the behaviour of water under different influences (wind speed and air resistance). We would also study the behaviour of the wind when traveling along buildings, and so on.

The aspects of our work we are proud of

We are proud of reaching the level of applying modeling in real-life situations. This development is useful for making models to solve designing problems in our next projects. We learned a lot about modeling by working out this model ourselves. The several phases helped us to really make our model complete.
We think it was really good that we divided our work in that way that we all developed on all aspects, like making the derivatives and so on.

What have we learned?

Lars Pasch: We have learned how to go through all the steps of making a model. Furthermore, we learned how to apply calculations from our second bachelor college course (physics) into modeling and combine them into our report. We have learned how to go from a very complex context to a concrete model by eliminating all the unwanted data. We also learned various ways of doing estimations like reliable sources or wisdom of the crowd.

Frederique de Jongh: I think the lectures are sometimes very abstract, therefore I think working on this report is a great opportunity to apply the gained knowledge. In this way you can test yourself. I feel the lectures have helped me to stay on the right track while working on this report, but this report has also helped me to understand what was meant with some aspects of the lectures. For example: in the conceptual and formalization phase, I realised why it was important to write these aspects down, after writing them down. While watching lectures, I pay attention and write important things down. While working on this report I think a lot more about the essence of particular aspects and then realise why something is so important and what it’s actually meaning. Furthermore I have been able to apply my already gained Physics and Calculus knowledge during the formalization phase, which helped me a lot. In the execution phase the lectures of chapter 6 helped me most to take a closer look at graphs and where things probably went wrong during the process. I wish I had the time and instruction to learn more about Accel.

Aidan Bundel: In the lectures there were 5 stages (or phases) described in the modeling process: definition, conceptualisation, formalization, execution and the conclusion stage. I found the formalization and execution stages the most difficult ones, because for our report mathematical derivations and topics from physics were involved. Fortunately the modeling lectures helped me through these stages.
The lectures and the report worked well together for me, because they completed each other. If I did not understand a subject that was introduced in the lectures, practicing it in context of the report did help me understand the subject. For example, to get to know the very basics of Accel, the lectures were not sufficient enough. It also helped me to look at some example codes of the demo models.

Bart Leeuwenburg: It was very helpful to see how the process of making a model works. Every concept and every method was of course new for us, so we got all the basics on how to approach a model and what possibilities there are in making it. For instance the 5 stages that you go through were very helpful. All these definitions are to me very important, because especially when this course started, I thought that modelling was very vague. What I also noticed, was that it had again a very close relation to physics and calculus. Doing modelling, I learned about a lot of possibilities to put these mathematical theory into practice. On the other hand, I learned that you can leave a lot of details out of your model, you can select the information that you think is relevant, you can leave out the information that you think is irrelevant and you can come up with numbers that you think is plausible. This way it's a creative and open way of approaching a problem, and me as a designer like that very much.

Olivier van Duuren: During the process of making a mathematical model I really learned how to apply the knowledge gained in the online lectures. Applying those theories and methods, which were explained in the lectures, gave an extra dimension. By looking to the lectures I became more aware of the actual purposes of the methods. During the formalisation process I noticed that I used my other gained knowledge of the previous basic courses(calculus and physics). So what was missing in these other basic courses(applying theories), was especially the main point in building such a model in this report. This report gave me the insight of all the different phases and the process you have to go through. Beforehand I thought it would be very complicated, but the lectures and tutor hours really helped me to go step by step through the modelling process.

Marco Putzu: I have learned to see the value of a model. Before I started the basic course modeling, I already made models subconsciously. Now, after seen all the lectures and putting them into practice with this project, I have learned how to create a more formal model and filter out all the unnecessary data and make educated guesses. I have learned how to apply theories from Calculus and Applied Physics to create a working model.
This course has taught me how much benefit you can have from a model. Even the simplest models give you a clear overview of the process and can give you valuable feedback.
Making a model in Excel and some failed attempts in Accel have taught me how quickly you can make a small model running, which will benefit me whenever I need an overview of a process.

Appendices

Used Literature

http://www.kuijntjes.nl/weer/windsnelheid.htm

Picture of the nozzle size:
http://www.fontanafountains.com/products/spray-systems/fountain-nozzles-heads/geyser-jet

Influence of air resistance on a projectile motion:
http://farside.ph.utexas.edu/teaching/336k/Newtonhtml/node29.html
http://physics.tutorcircle.com/motion/projectile-motion.html

Cannon ball in accel:
http://videocollege.tue.nl/Mediasite/Play/9795a09ca6bd4f12bd4f44fc9736bd491d
http://www.fontanafountains.com/products/spray-systems/fountain-nozzles-heads/geyser-jet

List of Definitions

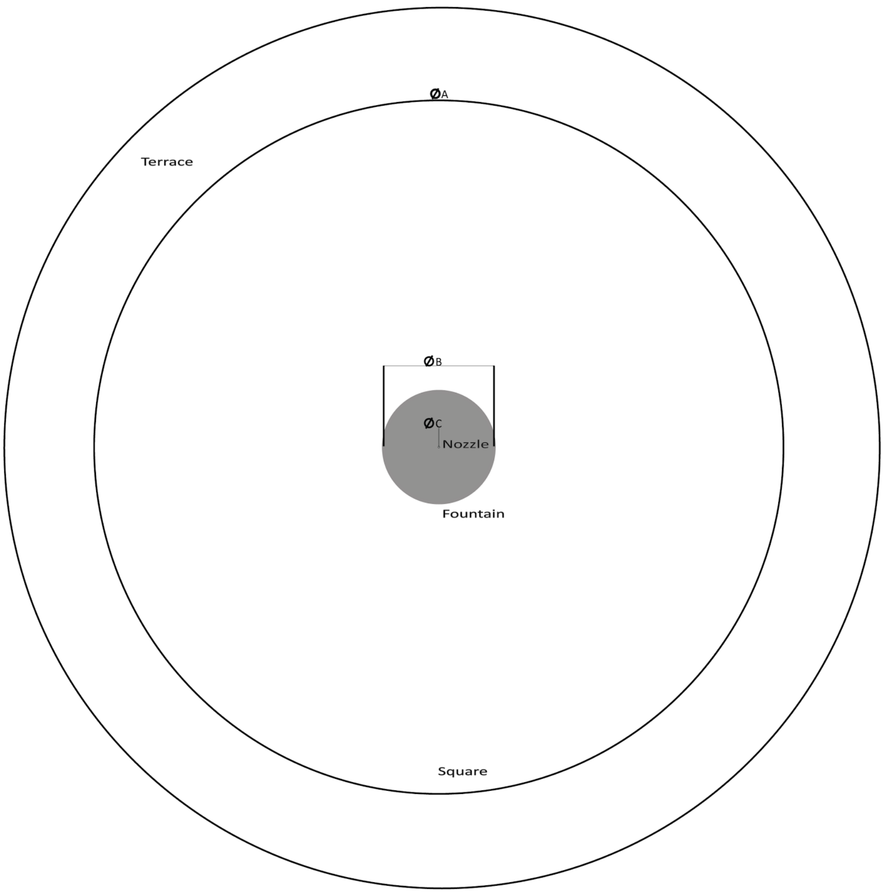
X	The horizontally range of the water
H_{max}	The maximum height of the water
V_w	The velocity of the wind
g	The gravitational force
t	The time it takes for the water to reach the ground

List of Illustrations

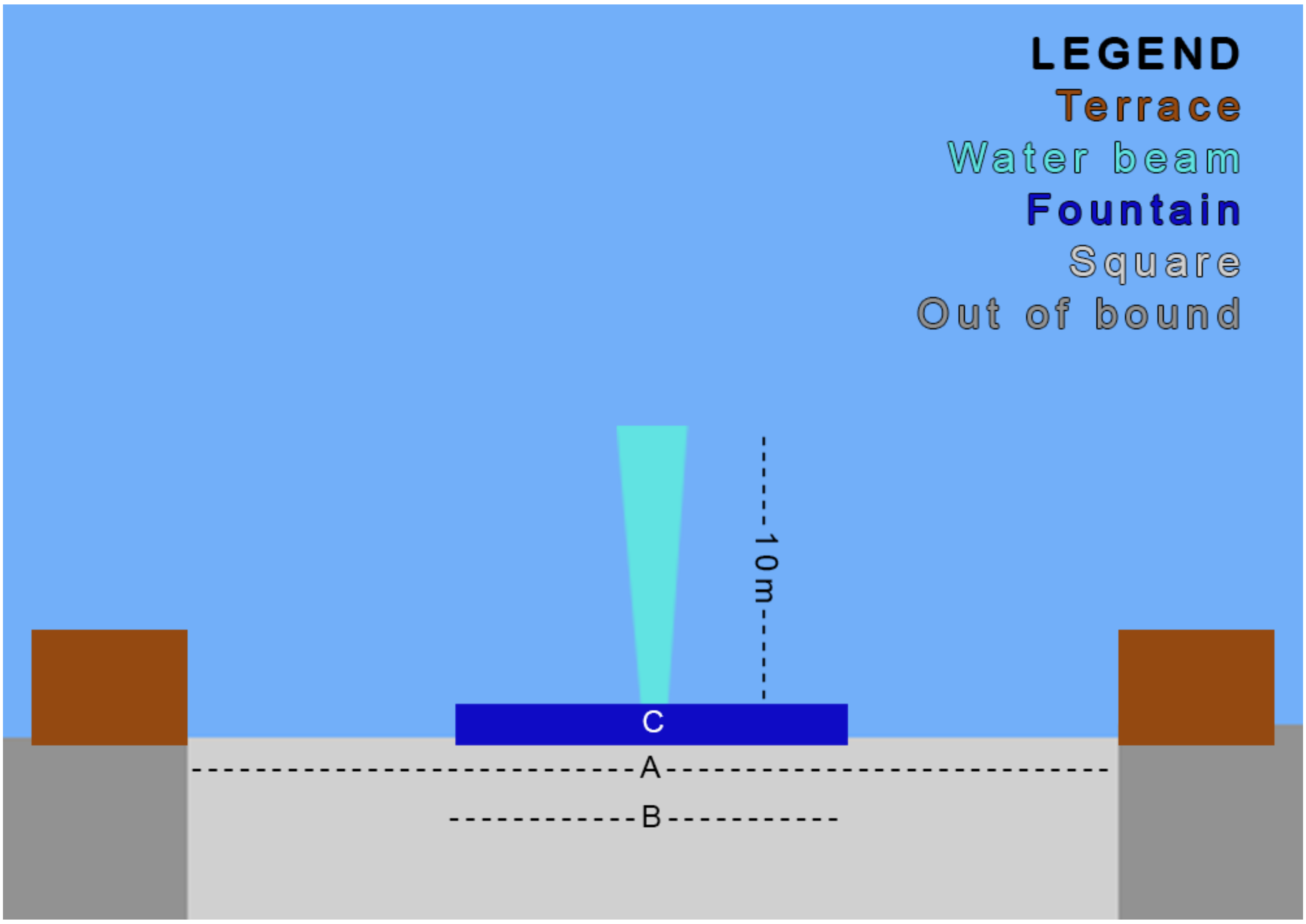
Appendix A:

schematic drawing of the fountain from above

A = 30m
B= 8m
C= 0.5m



Appendix B:



Schematic drawing of the fountain from the side

A = 30m
B= 8m
C= 0.5m

Appendix C:

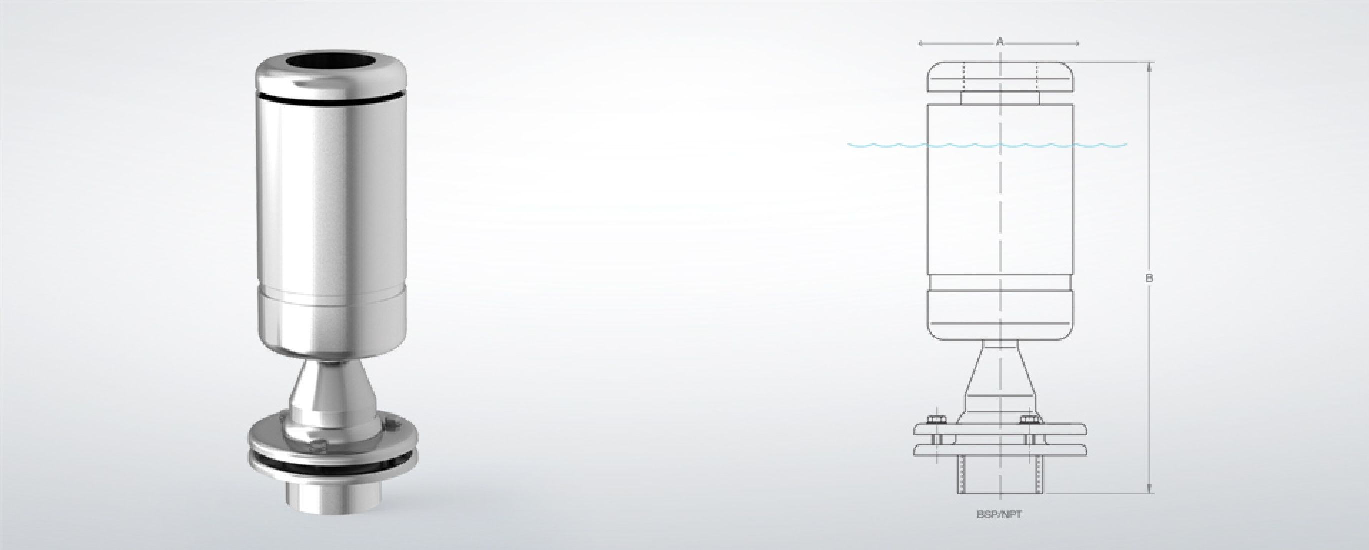
Vw	**Hmax**
0	10.00
1	9.32
2	8.64
3	7.96
4	7.29
5	6.61
6	5.93
7	5.25
8	4.57
9	3.89
10	3.21
11	2.54
12	1.86
13	1.18
14	0.50

Appendix D:

Research on the fountain

We looked at different fountains and squares, and decided that the fountain at the Placa Reial in Barcelona (Spain) will give us satisfying representative initial values. The fountain which we will be looking at has a diameter of eight meters, including the pond around it. The nozzle will be just above water level, and will spray a beam of water straight up (so the angle of the water-jet is perpendicular to the water). We will take a round square with a diameter of 50 meters. Like at the square in Barcelona, there are restaurants placed around it, and it is a cultural attraction. This means that the distance from the water-jet to the restaurants will be 25 meters.

We chose for the following nozzle:



The geyser jet ME 200. This nozzle can squirt up to 10 meters, and squirts one big beam of water. This is what we want. In the picture you find its dimensions A and B. A is 125 mm wide, and B is 333 mm high. The nozzles orifice is 60 mm, and the inlet BSP/NPT is 2’. From the picture you can also see that it sticks out of the water just a little bit.