Forecasting, Communication and Trust of Day Zero:

A Case study on Cape Town

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30th of May, 2018

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Introduction

Cape Town has been dealing with severe droughts for several years now, which strongly presses on the availability of water and drinking water for its citizens (Poplak, 2018) . The city has been coming closer to the day that taps start running dry, the so-called Day Zero, with its ever growing population and warming climate (Welz, 2018). Currently the water restriction level is at 6b, which means a maximum of 50 liters of water for home consumption and more restrictions (Residential water restrictions explained, 2018), in accordance to predicted water production and usage. Furthermore, the water restrictions are aligned with the moment when water security falls underneath a critical point, Day Zero. The date of which Day Zero would occur has been pushed back over five times as predicting it fluctuates with short-term water consumption levels.

Therefore, this mitigation paper addresses the need of better prediction of the water levels at the dams around Cape Town, for this is of crucial value for the way the people and Government of Cape Town have to adapt their behaviour. The paper is twofold: A technical analysis on how to improve the accuracy of Day Zero forecasting systems using machine learning and a social approach on communication from the government to the stakeholders. For both disciplines, the related work in the academic field has been explored. Then, an in depth analysis of the disciplines is performed separately. Finally, there is an integration part which concludes with the implications of this socio-technical mitigation solution, which explains how the social and technical parts fit together by a view which integrates and technology into one system.

The main questions that will be addressed in this paper are how the water levels at the dams around Cape Town can be better predicted using machine learning algorithms and how the communication about the resulting predictions can be done best, taking into account the insecurity about predictions and the influence this might have on the audience.

Several stakeholders have to be taken into account, both when designing a technical solution and designing the communication solution. The most important are stated below:

- Government of Cape Town,
- Department of Water and Sanitation (DWS)
- University of Cape Town (UCT)
- Dam management actors
- Consumers: the people, agriculture and businesses
- The Independent Electoral Committee (IEC) as potential stakeholder

The most direct stakeholders are government entities, like the general Cape Town government and the more specialised Department of Water and Sanitation. The more technical actors UCT and the dam management actors are relevant for providing data and implementing changes. Last, the consumers are very relevant, especially for the social part of the mitigation strategy, as this is the group of people that the communication plan based on the improved predictions aims for.

Now follows first the part on communication and trust, explaining the social implications of inaccurate communication and plans to improve this. Next, the part that explains the machine learning and model development for the improved predictions. And lastly, the discussion will cover the integration and conclusions.

Communication and trust

Analysis

When communicating risks or designing crisis communication, there are three major characteristics that should be taken into account: audience, the source and the content of the message (Breakwell, 2000).

The audience is in the end the group of people that should be reached or influenced and has therefore a big influence on how successful the communication will be. The audience can have many characteristics that should be taken into account, like demographics (e.g. income level, gender, ethnic background), religion, personality profile, past experiences (e.g. with the source of the message, the content of the message or the means of communication being used) and ideological orientation (Breakwell, 2000; Twigger-Ross and Breakwell, 1999).

The factors that might be especially relevant in the case of water consumption in Cape Town are income level, religion and past experiences with the government. The wage gap and therefore difference in level of income and financial wealth in South Africa is one of highest in the world (UN News, 2016), which means that, while designing communication and suggesting possible solutions to the audience, it needs consideration that different incentives (e.g. higher water price or subsidies on water tanks) might influence different groups in different ways. Also religion can play an important role as almost 80% of the South African population is Christian (Government of South Africa, 2012) and religion can tell much about people's values and view on the world as part of their mental models (Atman et al., 1994; Bostrom et al., 1994). The relationship with the government in previous cases, also depending on the sub-group of the audience, have not always been positive (e.g. corruption, discrimination) and might therefore very much influence the willingness of people to believe messages and to adopt suggested changes.

As mentioned above, the source of information also greatly influences how people perceive information from messages. In theory, the source should be trusted for messages to be effective. The source should display expert knowledge, be knowledgeable, unbiased and should have no vested interest in the hazard and is not looking to sensationalise the hazard (Breakwell, 2000).

The South African government might not have the best reputation, seen the corruption and discrimination that has happened in South Africa. Also, previous and current projects that have been executed may have focused on the wrong methods (e.g. a publicly available map that shows for every individual house how much water is used, “naming and shaming”) (City Water Map, 2018), which does not make the audience more perceptive of new messages from that source. To solve this problem, the more favourable image of university scientists or NGOs might be useful.

The content of the message finally determines if people will perceive a risk at all. Important factors are the controllability, if exposure is (in) voluntary, if it consequences are globally catastrophic, the impact on future generations, if there is an increasing probability of occurrence, novelty and naturalness of the risk (Breakwell, 2000). If the audience feels like there is no way at all that they can influence the risk, it is not really interesting because the bad event will probably happen anyway. If the risk is easy to avoid, people will also pay less attention. When there is a lot of involuntary exposure, however, this might really engage people especially when it concerns their (future) (grand) children. Increasing occurrence might make people decide that a risk that, until that moment, was bearable, will now become too much of a problem to sit still and do nothing. Novelty seems straightforward, as it makes sense that new threats and risks attract more attention than old ones people have got used to. This may be cause of problem in the Cape Town case, because people are used to droughts and water restrictions. Therefore, it will be harder to establish a feeling of urgency. High naturalness of the risk may give people the idea that ‘it is supposed to be this way’, especially with strongly religious people. Therefore it might be important to create the feeling that the droughts around Cape Town are not (only) because of natural causes, but also because of the way people in Cape Town exploit their resources.

Further problems that might arise are that the content of the risk communication should not only attract attention, but also achieve comprehension, be definitive and unambiguous (Breakwell, 2000). Achieving comprehension might be done by providing enough information in a way that is easily understandable for all subgroups of the audience. Also reaching unambiguity can be done, as usually the solution to the problems will be to use less water. Still, communication a definitive message that also triggers the attention will be hard. For example, ‘Day Zero’ (the day no water will be available anymore) for sure triggers the imagination, but, as it turns out, the predictions are too inaccurate and Day Zero has been postponed several times. This might lead to loss of trustworthiness of the source and loss of novelty of the risk. In the other hand, the message ‘use less water as there are water shortages’ could definitely serve as a definitive message as the water shortages will not be over soon, but it lacks almost all trigger to the imagination. To solve this part of the problem, improved accuracy of the water level predictions is needed. Also, the communication has to be designed while taking into account the effect that inaccurate/non-definitive communication has on the audience. A possibility is to admit that there is a factor of uncertainty about the predictions, which, in case of a trusted source, might add to the credibility of the source but decrease absolute authority, but in the case of an untrusted source lead to expectations of facts being hidden (Miles et al., 1998).

Very generally, 3 steps that have to be taken in the process of communication risks are (Breakwell, 2000):

1. Analysing the audience and its characteristics and mental models
2. Bridging the knowledge gap and correcting incorrect knowledge amongst the audience
3. Providing the audience with a good, realistic mitigation strategy

In this, attention has to be paid especially to the fit between the level of understanding of the risk by the audience and the message. In order to do this properly, mapping of the audience, in this case probably audiences (sub-groups of the population of Cape Town), and their mental models has to be done thoroughly and is crucial in making the right fit (Bostrom et. Al, 1992; Jungermann et al., 1988). Also, attention should be paid to informing the people of Cape Town about the modes by which the predictions for water availability and decisions for water restrictions are made, as to be more transparent and to make people feel more involved.

Advice

The advice towards the government of Cape Town is to follow the above mentioned 3 steps and very much focus on analysing the different parts of the audience, so the right information that fits with the believe systems and mental models of the audience groups can be achieved, and informing the audience about how predictions and decisions about water restrictions came about. Therefore, different messages with different information could be sent out to different groups of the audience (e.g. more wealthy people might get the advice to invest in water tanks and use less water for watering their lawns and filling their swimming pools, while less wealthy people may get less capital intensive advice). Also providing people with information that fills their knowledge gap and gives positive and constructive feedback on how to improve, instead of the 'naming and shaming' map that is currently being used, may lead to better adoption of mitigation strategies.

Next to that, it may be very important to focus on establishing the feeling of urgency of the risk, as the people of Cape Town might have got used to the droughts, as well as 'Day Zero' being postponed. This might lead to people underestimating the risk when 'Day Zero' is actually close and not being postponed.

Furthermore, the credibility of the government might not be optimal for communicating the risks and solutions, as the reputation is not always best. There has been a similar case with a Social housing provider in Enschede, which wanted to increase sustainability of its houses but needed to convince their mistrusting inhabitants first. They came up with the solution of setting up a daughter business solely for promoting sustainability amongst their tenants, which found these same tenants to be much more perceptible of the exact same ideas and offers, just because they trusted the daughter business more than the social housing provider. For Cape Town, a similar construction could be designed, for example a cooperation between the government and a university (which usually has a high credibility and trust level) or an NGO.

One last idea that may be taken into account is to explain the audience how the people of cape town are part of the technological system. If they change their behaviour, this may mean that ‘Day Zero’ can get postponed. This explanation might change possible annoyance amongst the audience about the inaccuracy of the predictions into a feeling of accomplishment. This could solve the credibility and trustworthiness issue, but it could also make people feel more like they are part of the solution and therefore engage them more, which actually makes them contribute more to decreasing the water usage.

Forecasting Day Zero Methods

Accurately forecasting Day Zero is important for strategic resource planning and efficient and effective communication. The government of Cape Town and the Department of Water Security (DWS) show reluctance to media to give away much details on how Day Zero is calculated (Jones & Geffen, 2017). The only insight provided by X. Limberg, chairperson for the Water Resilience Advisory Committee of the government of Cape Town, is that Day Zero is calculated by subtracting the expected usage of water from the Western Cape Water Supply System current dam volumes. This source seems to neglect any water income, or silently assumes that no more rain will fall. Either way, this method of forecasting is limited in the sense as it neglects some important events i.e. expected rainfall, evaporation and water leakages. In addition, the government has not provided spreadsheets or computer programs that calculate Day Zero (Jones & Geffen, 2017).

Piotr Wolski (2018), a water researcher at the University of Cape Town, has created an online tool to assess dam levels in the Western Cape called the Big Six Monitor. The tool allows the user to predict future dam levels by changing the variable (Q) for water consumption. The projection is found by calculating water balance of the dams that takes the following form:

$$S_{t+1}=S_t-Q(use)_t-E_t$$

In which S is storage of all dams together, variable Q is total usage of water and E is the predicted evaporation loss, based on the water surface area of the dam. Thus, Wolski takes into account the extra variable of water evaporation. Furthermore, in the model Day Zero is reached when the dam levels have reached 10% capacity. According to the City of Cape Town government (2018), the water is hard to access for most dams when the capacity goes below 10%.

In addition, some unverified methods to calculate Day Zero for Cape Town can be found on the web, on forums and news articles. These approaches can still provide inspiration for further research. This paper explores a blog post which present a model that can calculate Day Zero by Tom Brown (2018), a retired international businessman and fruit farmer in the Klein Karoo. For the forecast the assumption is made that in reality the last 10% for various dams is available till almost 0% with minor intervention or filtration. Brown averages the real inaccessible water drops to 7.5%, as illustrated in Figure 1. Another insight Brown highlighted was that the City of Cape Town only has to postpone Day Zero till June, when the seasonal rainfall is expected to start.

However, the prediction is not based on average water consumption throughout. But alters the water consumption based on the restrictions the city of cape town put in place on the population and farmers over time. Such a method allows a government to test what interventions are necessary to push further Day Zero. Brown's model allows insight for further research to the accessible water threshold and the validity of the calculations and assumptions remain untested.

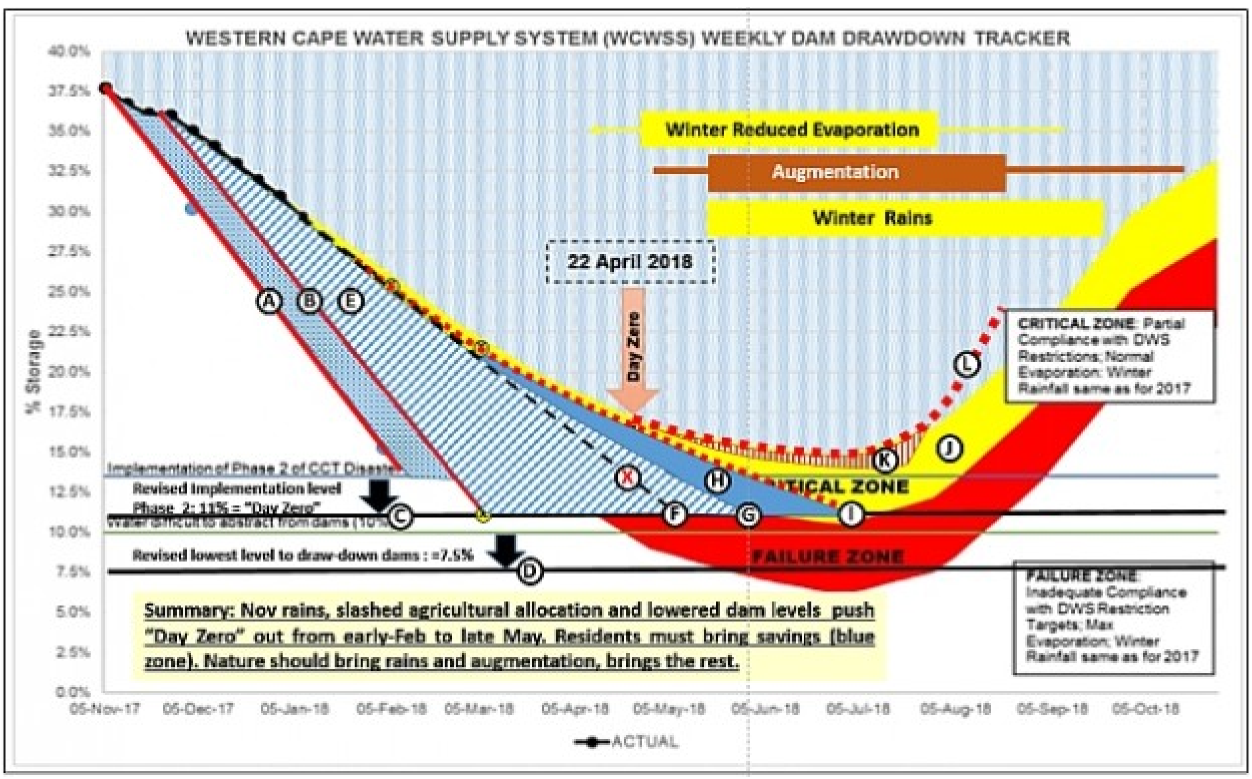


Figure 1: graph of Brown's model retrieved from: ShowMe.co.za/paarl

In conclusion, related work on how to calculate Day Zero have similarities to the assumption that the last percentage of the dam capacity is not accessible, but differ in the hard line or range in percentage they set on the actual capacity. Both vary the future water consumption, either as a constant or make the consumption decrease over time. They both covered water evaporation in some way, however Brown allows for seasonality. The main difference is adding expected seasonal rainfall in the calculation.

Improvement via Machine Learning

Assessing the limited insights the government provides on the forecast of Day Zero, it seems as is the only variable the City of Cape Town uses in prediction Day Zero is the expected consumption versus the current dam levels. A model based on water consumption is not useless, since water consumption one of the few variables the government of Cape Town has influence on. However, this does raises the question whether a more accurate forecast can be made by adding related (expected) attributes, e.g. predicted rainfall, temperature, etc.

Technical Report - Machine Learning

Data Preparation

The dataset used in the development of a machine learning pipeline is provided by the City of Cape Town's Open Data Portal. The data is verified and collected by the City of Cape Town and consists of Dam levels for major and minor dams in the Western Cape water supply system from 2012 to 2018. The dataset is updated on a daily basis. In this research, the data stream was cut off at 19th of April, 2018. There's 2301 data points.

Methodology

The methodology follows Box-Jenkins forecasting method that refers to the set of procedures for identifying, fitting, and checking Autoregressive Integrated Moving Average(ARIMA) models with time series data. The reason for choosing Box-Jenkins is due to its ability to use autocorrelation to detect stationarity and seasonality. This method is chosen due to its appropriate use for time series of medium to long length (at least 50 observations). Usually, the nonstationarity is due to a trend, a change in the local mean, or seasonal variation. Since the Box-Jenkins methodology is for stationary models only, some adjustments have to be made before one can model the non-stationary data. As the data from the dams incorporates a seasonal pattern, Box-Jenkins recommends the following general model:

$$\phi_p(B)\Phi_P(B)(1-B)^d\left(1-B^s\right)^D X_t = \theta_q(B)\,\Theta_Q\left(B^s\right)a_t$$

where d is the order of differencing, s is the number of seasons per year, and D is the order of seasonal differencing. The operator polynomials are

$$\phi_p(B) = \left(1-\phi_1 B - \cdots - \phi_p B^p\right)$$

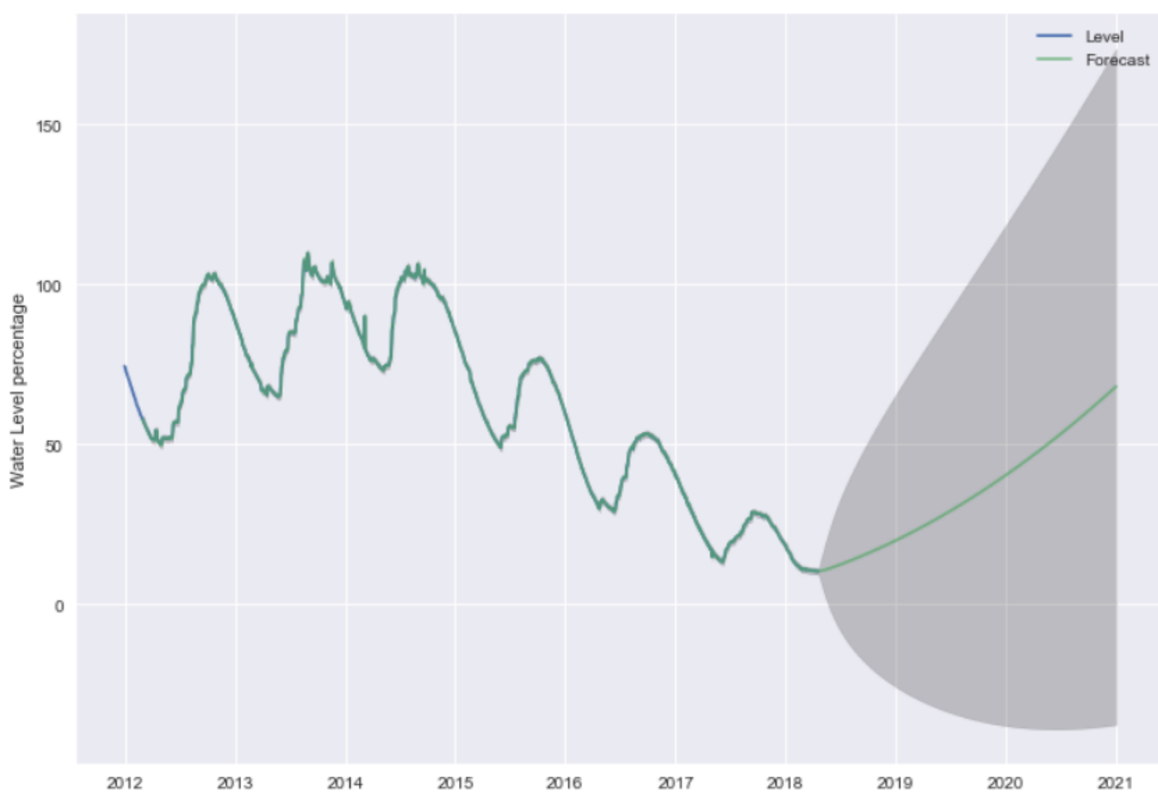
$$\theta_q(B) = \left(1-\theta_1 B - \cdots - \theta_q B^q\right)$$

$$\Phi_P\left(B^s\right) = \left(1-\Phi_1 B^s - \cdots - \Phi_p B^{sp}\right)$$

$$\Theta_Q\left(B^s\right) = \left(1-\Theta_1 B^s - \cdots - \Theta_Q B^{sQ}\right)$$

Results

The results with no variable besides time yield the following prediction for the largest dam of Western Cape (Theewaterskloof Dam):



The shaded grey area represents 95% confidence interval. The algorithm fails to convene and capture a trend due to multiple reasons. Firstly, the data is limited to only 8 years with only monthly data points resulting in 2301 points of data. For having a successful time series forecasting algorithm, it is generally required to have tens of thousands of data points available. Especially when the trend is fluctuating, like in this case. Moreover, the area of Cape Town is experiencing a water crisis due to a three-year drought. This introduces an unprecedented anomaly to the dataset that is impossible for the algorithm to detect and use it as a reference point as it hasn't occurred previously in the training data.

Furthermore, as weather data in regards to rainfall and hours of sunshine are behind a paywall, these features are not introduced in this dataset. Finally, if water consumption would be added to the data, the prediction accuracy would improve. However, the City of Cape Town does not release water consumption levels on a daily basis, but does monthly updates within smaller regions within Cape Town. This results in unusability of water consumption data, which would be crucial for training the algorithm.

Consequently, an alternative research was carried out to establish a methodology that would mimic the requirements for predicting water levels in Cape Town. If the data was available, then the methodology could be transposed to predicting Cape Town's water levels.

Data Preparation

Another data set is provided by the California Independent System Operator (CAISO), which is a non-profit Independent System Operator (ISO) serving the state of California. It is the overseeing authority of California's energy supply system's electric power, transmission lines, and electricity market. CAISCO is an adamant supporter of open data and has consequently authorised open data regarding the production means of electricity. The data in this report will be directly derived from CAISIO and will contain hourly reports on the power production from renewable energy sources (measured in megawatts). The given data include the following: geothermal, biomass, biogas, small hydro, wind total, and solar thermal. The data has already been processed by CAISIO and consequently requires no further manipulation except removal of missing values. The data was hourly and consisted of 67584 data points.

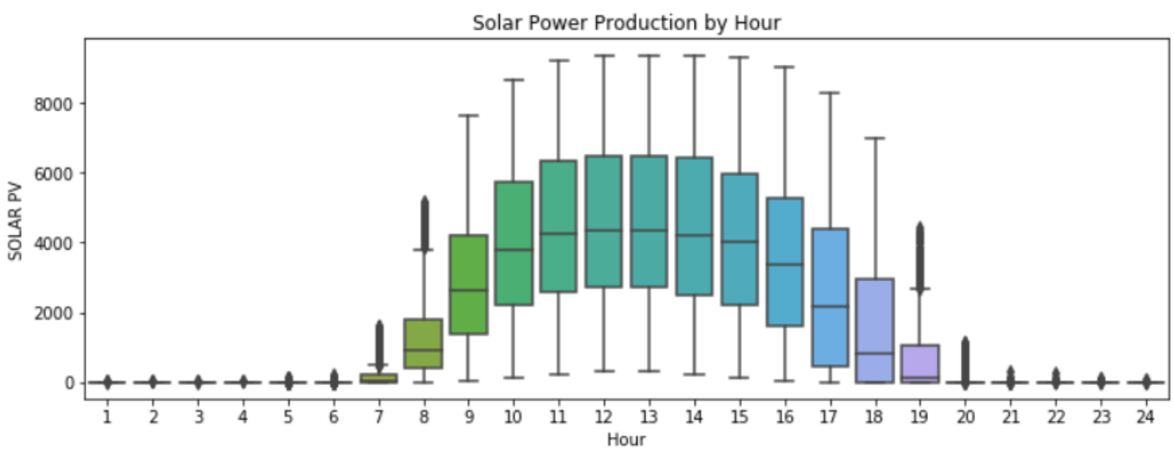
Methodology

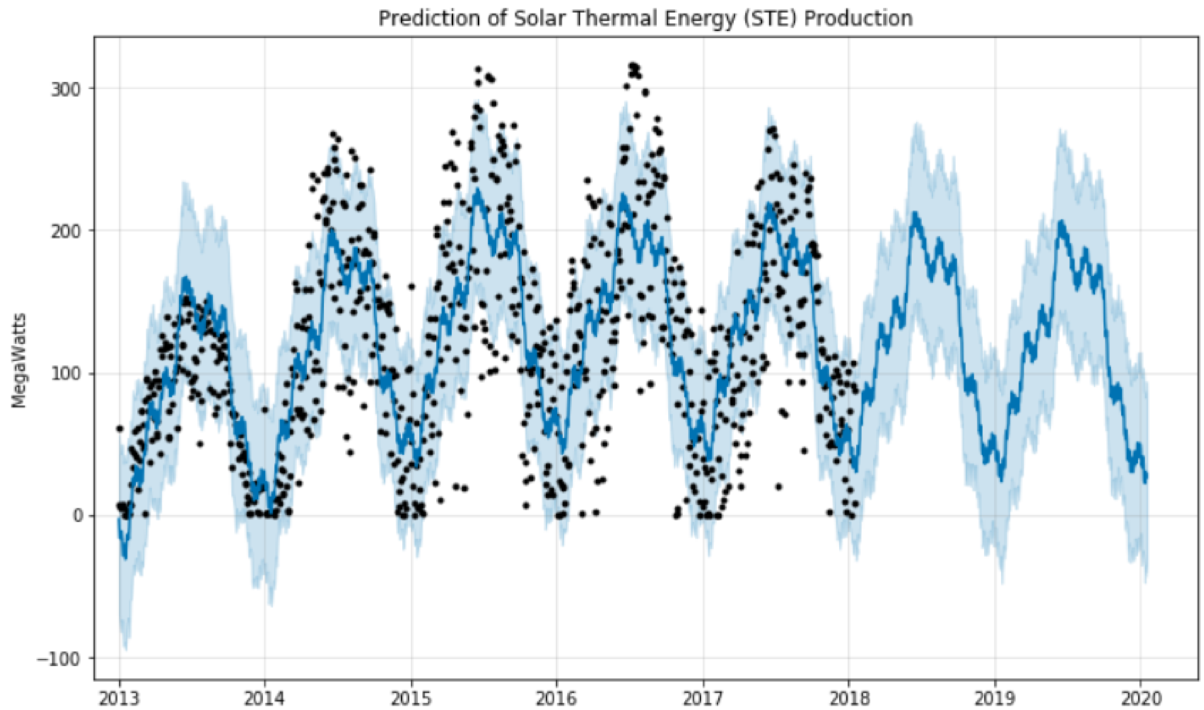
The machine learning follows Facebook's Prophet algorithm (Taylor & Letham, 2017). This is due Prophet's ability to capture seasonal trends and capability to handle irregularly sampled data. Prophet is an additive regression model with four main components of logistic growth curve, yearly seasonal component using Fourier series, and weekly seasonal component using dummy variables. The four model parts fit to time series data and consequently minimize the misfit to data within an internal trade-off between model parameters. The four constituents in additive regression model are as follows:

$$\underbrace{y(t)}_{\text{signal}} = \underbrace{p(t)}_{\text{piecewise trend}} + \underbrace{s(t)}_{\text{periodic variations}} + \underbrace{i(t)}_{\text{irregular variations}} + \underbrace{\epsilon_t}_{\text{Gaussian residual}}$$

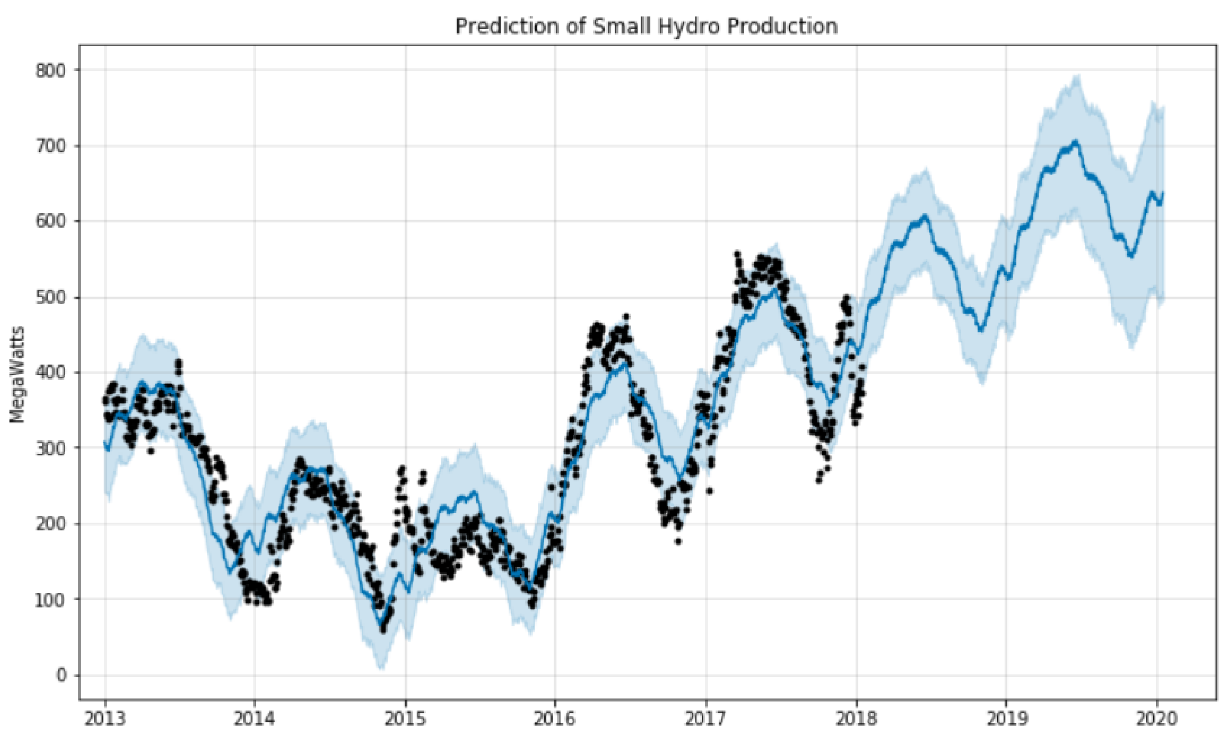
Results

The following graphs represent solar production by hour and the predictive analysis on a yearly basis. On both graphs there is a presence of seasonality both in an hourly and yearly form. This is a consequence due to solar power being present during the days and lack of sunlight during the winter.

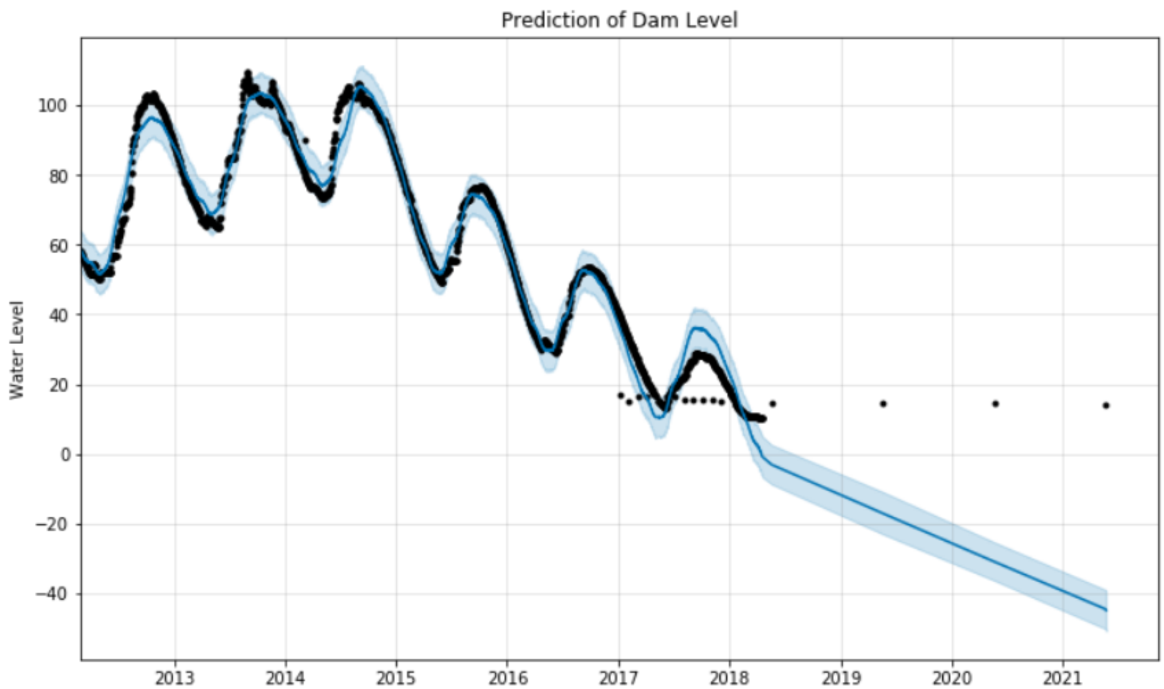




Same type of seasonality can be witnessed for small hydro production with a distinct difference of an upwards trend. This is due state of California's increase in hydroelectricity production. (Upchurch & Peterson, 2017)



Same type of data seasonality is found in dam levels. Consequently, the author proposes that the methodology allows for replication and extrapolation of the Prophet's prediction to a time series data with seasonality with a sufficiently sized data set.
This methodology was also implemented to original dataset from Cape Town with the following result.



The primary reason for the failure of Prophet on Cape Town's dataset is due the low data points (2301) compared to California's dataset of 67584 data points. The algorithm fails to capture the underlying trend in the dataset.

Ethical analysis

The ethical challenges around this mitigation plan can mainly be found in the technical part and concern data security. The data that will be collected and processed is of big importance, as the water levels at the dams are of vital importance for the city of Cape Town and its inhabitants. Therefore, the security needs to be on point. If too much data about water usage or dam levels or about the construction of the dams itself may become publicly available, this might cause risks for the water security and might make the dams vulnerable to sabotage.

Furthermore, if in future models more data will be used, the data security data of a more personal, and therefore more sensitive, nature (e.g. household level water usage) will be of greater relevance. Privacy concerns may play a bigger role then. Important in this case will be that the households need to give an informed consent where they state that they have been properly informed about the way that their data is being collected, saved and secured, and that they give permission to do so. In this way, the benefits of providing everyone with enough water outweigh the privacy concerns and people are treated well and are provided with the necessary information to make an informed choice. This is to avoid controversy as the one around the City Water Map (2018), with its ‘naming and shaming’ character.

For the social part, less ethical issues will arise. Still, as the communication will have to be very much specified at certain groups, the analysis and collection of data on groups might lead to some privacy issues. Also the decision in which group people will be put might lead to issues, as they will receive different messages than people in other groups. Still, the need for providing most people with the best suited information (as opposed to fairly inaccurate ‘one size fits all’ information in the case when there are no personalized/group-tailored messages) will outweigh the negative consequences of possible less-than-optimal messages for some people.

General discussion and conclusion

Accurate forecasting of Day Zero is key in finding a sufficient strategy to mitigate the water shortage. However, the success of any mitigation solution strategy is closely knit in with the communication by the government to the other stakeholders (e.g. consumers, agriculture sector.) with regard to trust and behavioural change.

Seasonal variables can contribute to a machine learning algorithm to predict future droughts if the use of potable water is unchanged. However, due to the complex nature of the Day Zero problem, predictions about water levels will always have a significant level of uncertainty e.g. predicted rainfall, water consumption. Besides, there has to be enough historical data on these variables for the algorithm to find the seasonality and trends. Additional limitation is the difficulty for a machine learning algorithm to predict the effects of droughts and the respective water consumption. Especially when there is a lack of historical data.

The implications for the communication of the risk towards the people of Cape Town are that the inaccuracy of the predictions and the postponing of Day Zero may lead to less sensitivity to the message. Key in this will be to make a decision how to use the information from the prediction model to phrase the right risk communication. Also making clear to the people of Cape Town how they are part of the total socio-technical problem, may help them understand how the predictions might sometimes be inaccurate, how they can help to reduce water usage and how the inaccuracy of the predictions does not mean that the measures they take are not effective or relevant. In a way, they should see postponing Day Zero as an accomplishment for being successful at saving water, and feel pride instead of annoyance when this happens.

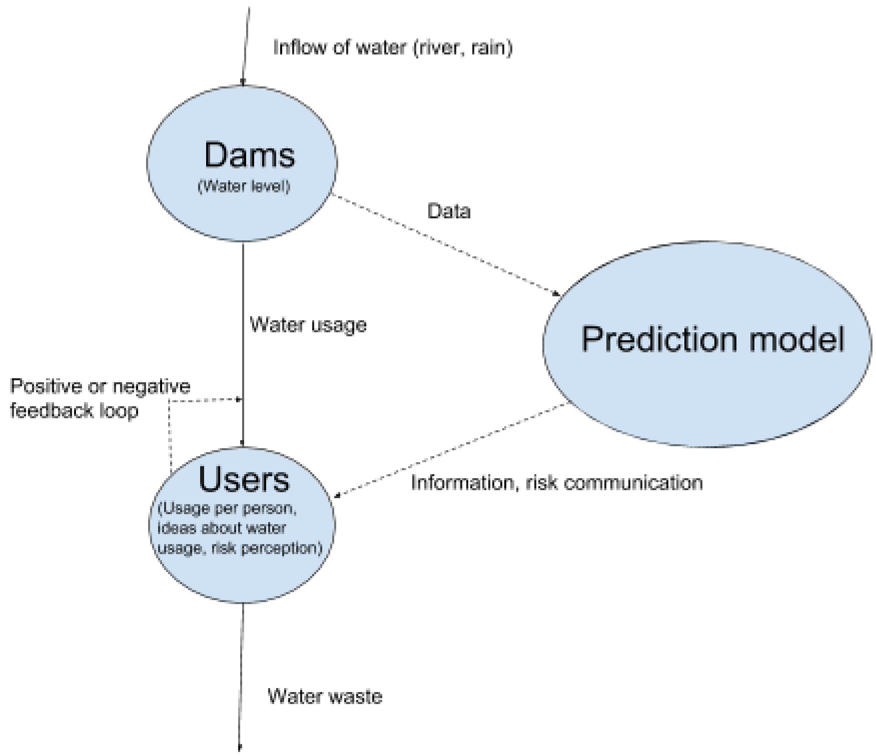


Figure 3: Integration of forecasting model and social effects

The Figure 3 explains how the social and technical part of the paper fit together, as the users and dams are a crucial factor in the water usage and the prediction model takes data from the dams to make predictions that influence users and therefore the water level. The solid arrows depict water flow and the dotted arrows depict flow of information or influence. For example, the characteristics of users influence their water usage and information from the prediction model influence the characteristics of the users.

The relation between more accurate real-time forecasting of Day Zero and the communication of both this day and the numbers from the variables used in the forecast e.g. water consumption etc. is complementary. Because, better forecasting allows for better governmental strategy and decision making to postpone Day Zero, but leaves out involving the people in the problem, which might lead to resistance. And more transparency on real-time information, open-source data sets on water consumption and risk communication can involve and move the people in contributing to the solution and mitigate the problem on own initiative. Or at least see the reasons for water restrictions for themselves.

Therefore, the advice is to implement the proposed machine learning forecasting model and grant more transparency in the prediction of Day Zero and open numbers and data sets on consumption to the inhabitants, which will allow more understanding of the water restrictions and involvement will lead to creative initiatives to save or win water.

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