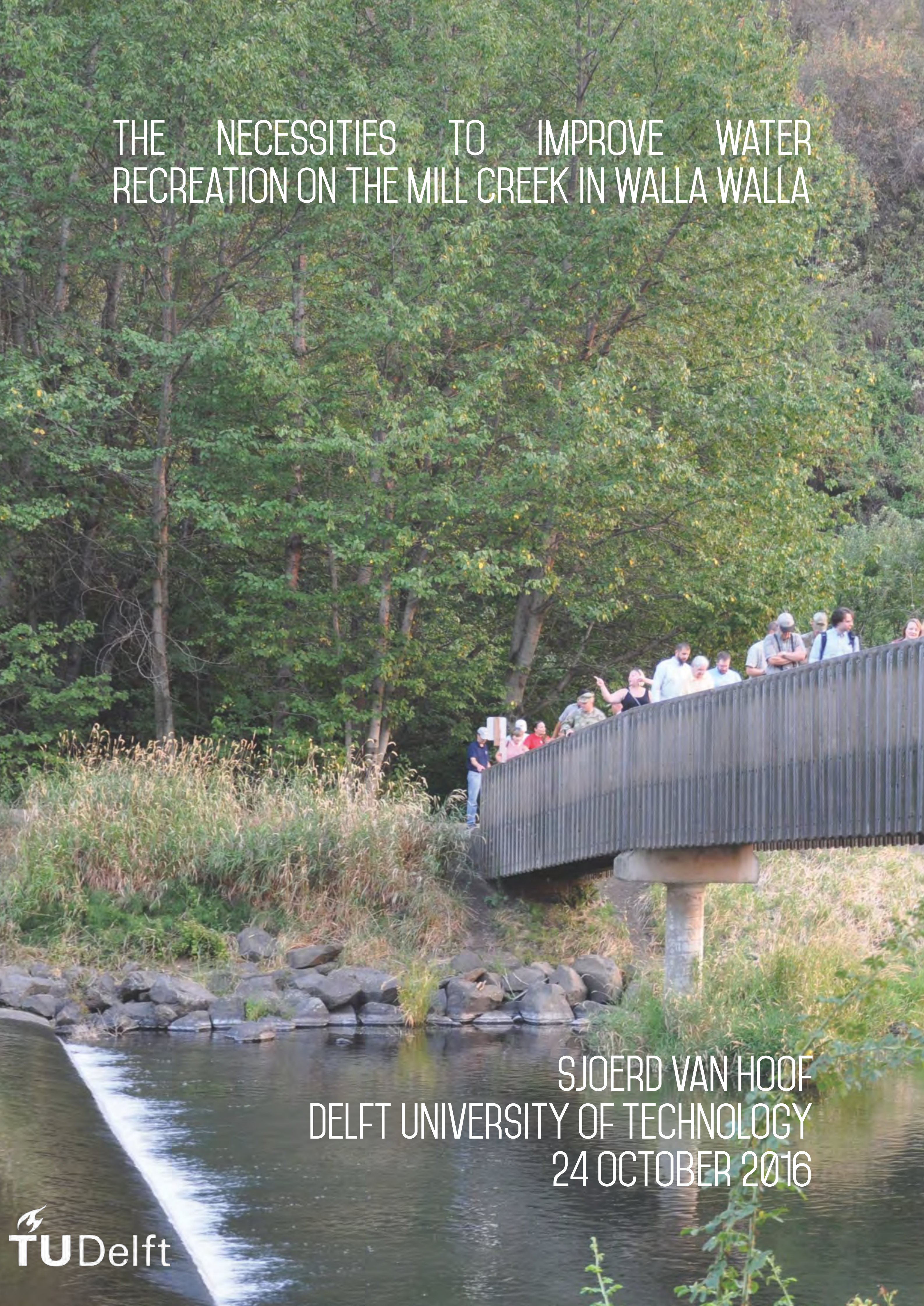
THE NECESSITIES TO IMPROVE WATER RECREATION ON THE MILL CREEK IN WALLA WALLA



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THE NECESSITIES TO IMPROVE WATER RECREATION ON THE MILL CREEK IN WALLA WALLA

BY

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ABSTRACT

In Walla Walla, Washington the Mill Creek flows through an outdated concrete spillway that needs renovation. The city council of Walla Walla saw this as an opportunity to further develop this channel. Their desires include conservation of the fish ladder, enabling to sail by boat and to prettify the spillway.

A Sobek 1D model was built to give a proper insight of the current situation. To verify the model calibration was done by using USGS data and GIS maps of the Walla Walla council. Also various design alternatives were specified to see which form of recreation is most feasible.

The results from the model in the current situation showed that the water depth was too low while its velocity was too high for the different vessels. To solve this issue, an upgrade for the concrete spillway was proposed. By roughening the riverbed and placing groynes into the creek, the water depth increased and the water velocity dropped, according to the improved model.

However, the design is a rough sketch that forms the base for a more detailed study. It is recommended to continue improving the model to verify the results which are presented in this report to be sure the proposed upgraded design will contribute to the desires.

INTRODUCTION

In the United States of America, there is a little city in the state Washington called Walla Walla. A creek flows through this city called the Mill Creek. This creek starts in the mountains East from Walla Walla. The water meanders through the green nature and offers a breeding place for fish such as salmon. But as soon as the creek arrives in the city, the water is transferred into a concrete spillway.

The US Army Corps investigated the channel several decades ago and reviewed the weak spots of the channel. (Robinson & Copeland, 1986) During a council meeting in August 2016, there was a discussion to make plans and goals for the channel in Walla Walla. The conclusion of this meeting between the Walla Walla tribe chief and the Corps of Engineers was that it is indeed necessary to invest in the channel to significantly improve it.

The result in one of their meetings included some wishes. One of the wishes is to be able to realise water recreation on the Mill Creek in the city centre, such as a water taxi. At the same time the fish that swim upstream to their breeding spots should not be hindered.
In order to help the community of Walla Walla Sjoerd van Hoof was asked to take a look into the plans of the council. This report investigates the opportunities of water recreation are possible on the Mill Creek using a model made in Sobek; a water modelling tool.
In the report different design alternatives are discussed and recommendations have been written to inform the Walla Walla council at best.

The calculations will be done in SI standards, as Sobek is only able to calculate in the metric system. However, textual explanation and conclusions will also be given in imperial units.

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1 – PROBLEM DEFINITION

The research question of this report reads: What is needed to improve water recreation on the Mill Creek in Walla Walla?

At this moment the Mill Creek runs through Walla Walla tubed in a concrete spillway. This channel consists of a deep small centre with a shallower surrounding. This is a very useful way to create a minimum water depth with a relatively low water intensity. But as soon as the water intensity rises, one is able to guide this extra water securely, as the wider gutter is being used. However, the discharge in the channel varies quite significantly, which can also be seen in Figure 1. While it has peaks up to 600 ft³/s in April, it reaches very low values with only 30 ft³/s in September.

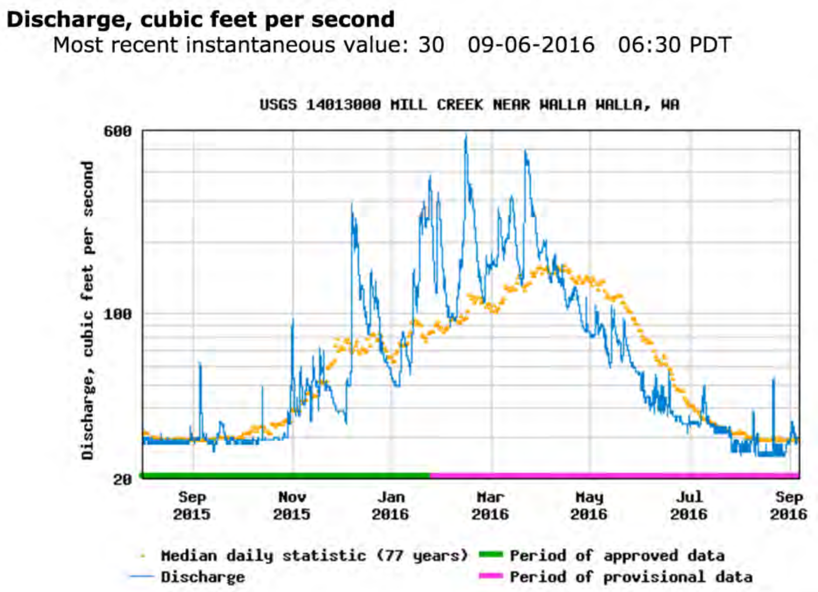

Figure 1; Discharge near Mill Creek (USGS, 2016)

This fickleness of the discharge makes it hard to recreate on the water throughout the year. The salmon would benefit from a more constant flow rate and water depth. Another issue is the gradient of the Mill Creek. The water runs very rapidly downstream as the surface is very steep.

How will the fish not be hindered?

Baffles (see Figure 2) have been built in the channel to help upstream migration for fish. These baffles divide the channel into small surmountable steps. This enables fish to climb the channel more easily, compared with one big slope of several kilometres long. (Robinson & Copeland, 1986)

Figure 2; Fish ladder Mill Creek (Google Maps, 2016)

How could the spillway be prettified?

The channel should look attractive and have a positive appearance that fits its environment. In contrast, the old concrete does not look attractive at all and is at the end of its tether.

The improvement consists of several parts. First of all, replacement of the concrete spillway should give space for a better, more attractive alternative that is ideal for sailing with small boats. Besides the reconstruction there needs to be a plan to control the discharge in the channel. This should be accomplished by regulating the dam differently than is done at the moment. Eventually, the flow rate of the water should be limited. This can be obtained by building low flow structures. It is however important that these structures do not hinder the boats and at the same time, the boats should not disturb the fish.

These problems should be overcome to give great boost to the local community. A good-looking spillway where salmon swim upstream and little ships with names of the Walla Walla tribe sail up and down attracts a lot of attention. Restaurants settle on the shores, tourists take boat trips, fishing activities are organised. All abovementioned factors will result in a better place to live or stay.

2 – CURRENT SITUATION

DIMENSIONS

A few kilometres upstream of Walla Walla there is a dam. At the dam the in- and outflow of the Mill Creek is controlled. If there is too much water, the surplus will be transferred towards the Bennington Lake. Downstream of the dam, the Mill Creek flows with a width of about 60 feet (18 m) for 3.0 miles (4.8 km). Then it reaches the city of Walla Walla where the creek becomes a concrete spillway with a 45 feet (14 m) cross-section that flows through the city centre.

FLOW RATES

The discharge of the Mill Creek is essential. The quantity of water passing by every second determines the velocity and water depth. There should be enough water to sail on, but on the other hand not too much, as the flooding could appear.
The flowrate of the channel in Walla Walla highly fluctuates over the year. Last year's graph shows (see Figure 16) the discharge with a blue plotted line on a daily basis. The yellow line shows the mean flowrate over 75 years. The months between December and June have the highest discharge of the year, surpassing the 100 ft^3/s boundary.

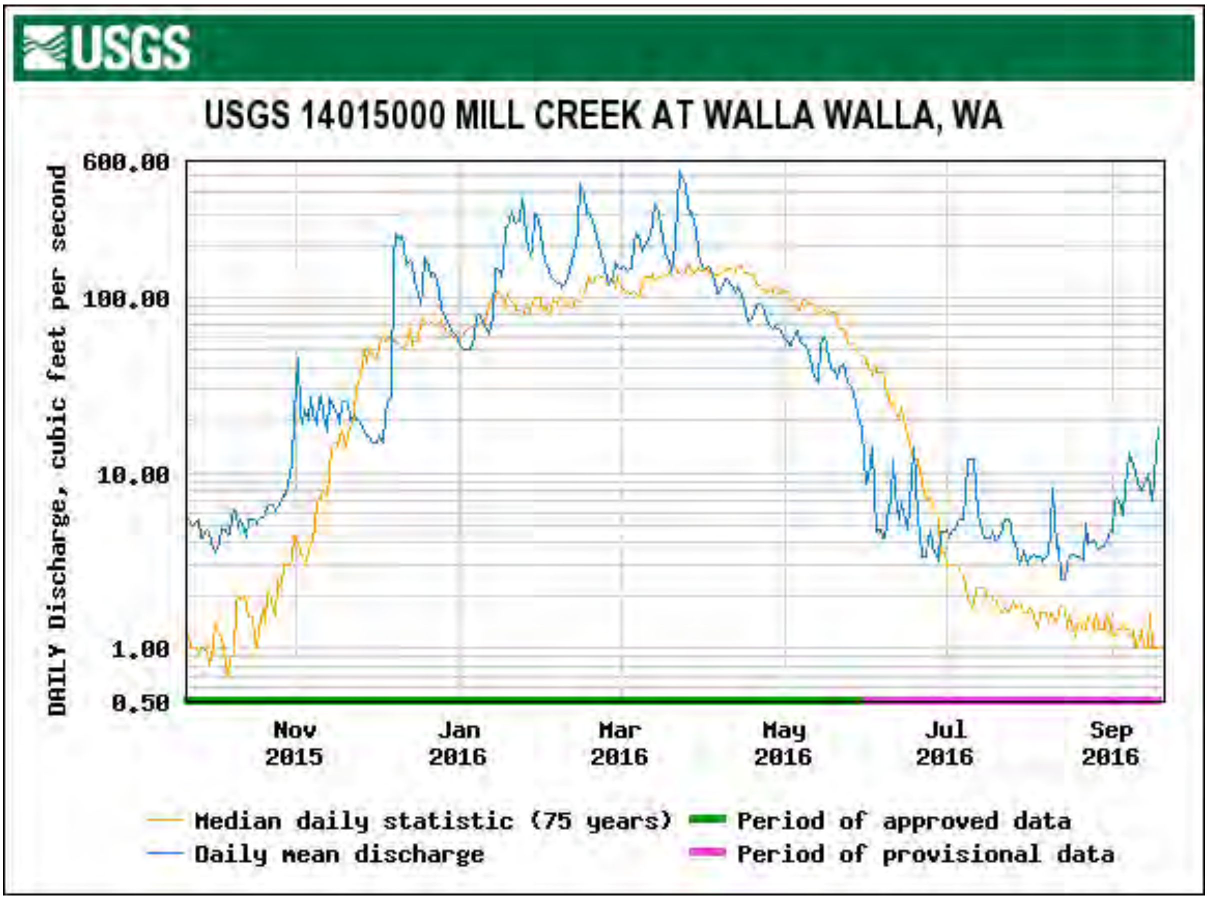

Figure 3; Daily mean discharge Mill Creek at Walla Walla (USGS, 2016)

GAGE HEIGHT

According to USGS's data, the minimum gage height ever measured 1.69 ft. At the same time the discharge was almost zero. (USGS, 1997) This is a good estimator to convert the gage height to a water depth. The gage height will always be 1.69 ft higher than the water depth.

$$d = h_{gage} - 1.69$$

GRADIENT

The gradient of the concrete spillway is very high. In the few miles' length of the spillway, the ground level lowers by more than 120 ft (37 m). This is why the water in the creek runs very quick and complicates sailing on it.

FISH

The fish in the Mill Creek consist of Chinook Salmon that need to be able to swim up the river all year long. This means that throughout the year, there should always be enough water in the spillway to have the Chinook swim in the upstream direction. This requires a maximum water velocity and enough rest places for the fish to relax during their trip. Depending on the distance of the intervals the fish have to swim the maximum speed changes. In Table 1 can be seen how these lengths correspond with the maximum velocity. Apart from the speed, the minimum depth in order to have the fish pass is one foot. (Phillips, 2001)

Swimming Length (ft)	Maximum water velocity (ft/s)
10 – 60	6.0
60 – 100	5.0
100 – 200	4.0
> 200	3.0

Table 1; Max water velocity (Phillips, 2001)

3 – MODEL

For the current situation it is not obligated to use a model per se. The situation is this straightforward that a calculation by hand would suffice. However, as the current situation needs renovation, there will be added civil structures in the renovation design which make the design too complex to calculate by hand. For time efficiency there has been chosen to start using the model from the beginning.

SOBEK

What is sobek?

Sobek is part of the Delft3D Flexible Mesh Suite which is a simulation software product that enables people to model coastal waters, lakes and specifically in this case rivers. Sobek was developed by the independent non-profit institute called Deltares. The Dutch organisation employs over 800 people and is based in Delft and Utrecht. Sobek is a very useful tool to simulate reality in a 1D, 2D or 3D environment. (Deltares, 2016)

Why Sobek?

There are several reasons to choose for Sobek. First of all, this software tool very often used in international projects all over the world. A few recent projects include a flood and drought risk management in South Florida, combating subsidence in New Orleans and safe navigating on the Port Loko river in Sierra Leone. (Deltares, 2016)

Furthermore, it has the option to model rivers in a 1D environment. That means that the river is modelled as a line without a width. Although the cross section is dimensioned and does have a width, the output data will only be one velocity value per data point and a certain height. The width of the cross section is only necessary to convert the discharge to a one-dimensional unit. The model also assumes that the velocity at a certain point in the river is equal in width. There will be no speed differences along the same flow area.

Very complex networks can be modelled with the 1DFlow component of Sobek. A good example can be seen in Figure 4. Here a whole water network of Hong Kong is modelled in only one dimension. On the left side of the picture, one sees that this model includes various complex nodes, such as culverts, weirs and manholes. Finally, a 1D model is significantly easier to develop. 2D models also describe width currents, which is in this case not important, as there are barely width flows. It is also much more time intensive, so in the given time frame of nine weeks, it is wise to choose the 1D model over the 2D alternative.

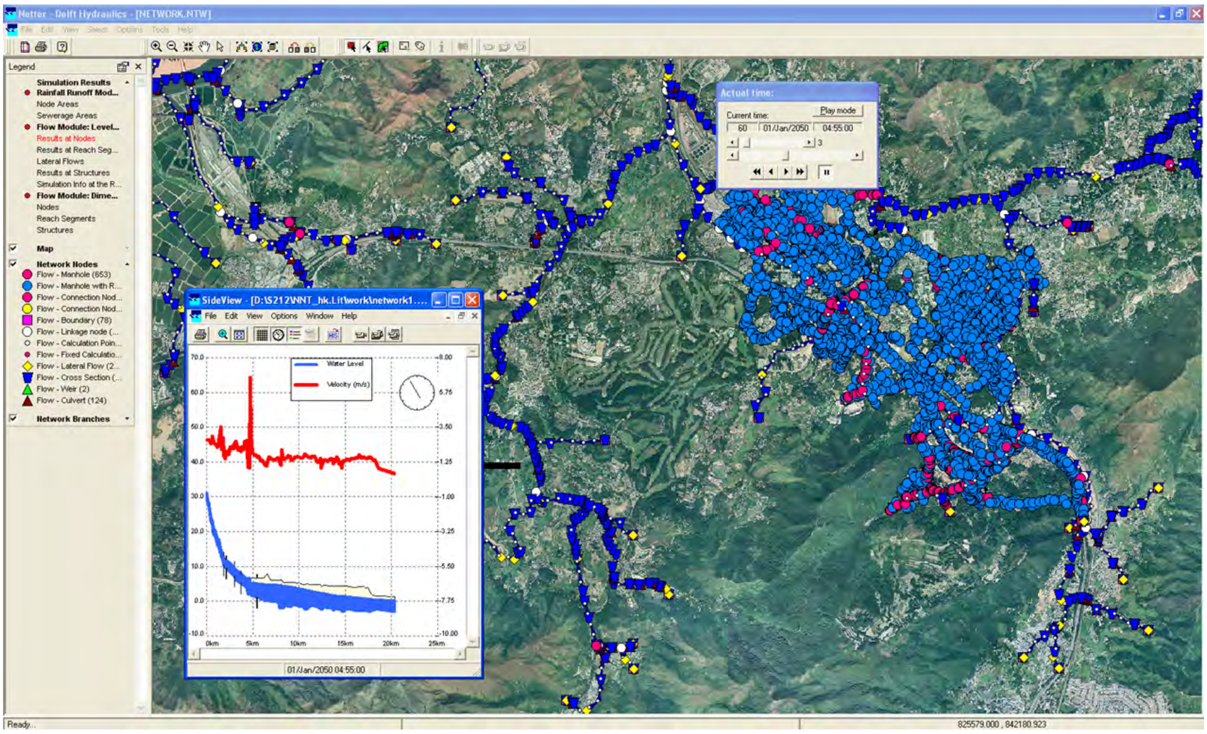

Figure 4; SOBEK-2-Hong-Kong2 (Deltares, 2016)

TECHNICAL SPECS

The two main aspects that are measured in the Sobek model are: the water depth and the flow rate of the water.

The water depth (d) is calculated by the distance between the water level (h) and the bed level (z_b). The water level is the difference between the reference level and the surface of the water. The bed level is the lowest point in the cross section, which all can be seen in Figure 5. (Deltares Systems, 2014)

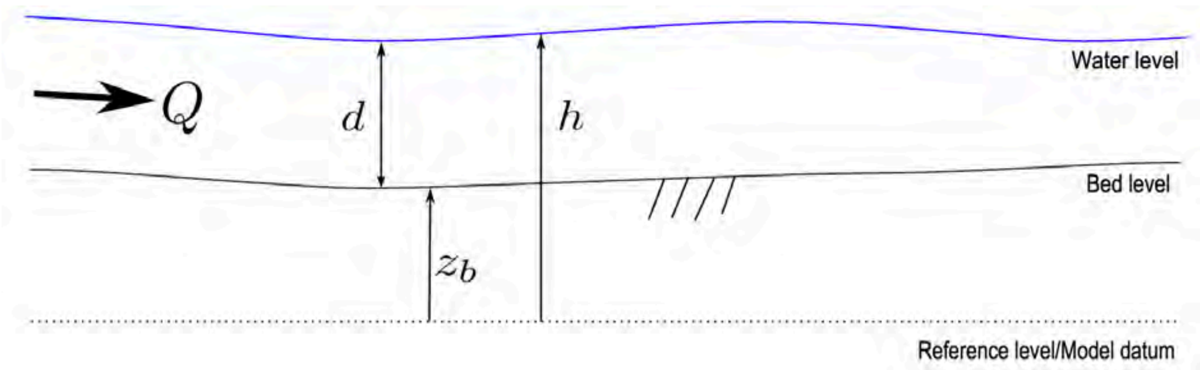

Figure 5; water, bed and reference level (Deltares Systems, 2014)

To calculate the velocity of the water, the area of the river is needed, as well as the discharge. Sobek distinguishes the difference between the flow area (A_f) and the storage area (A_s). The flow area is the area where the water actually flows, whereas the storage area consists of stagnant water, also see Figure 6. The user defines the distinction between those two while dimensioning the cross section ns. The velocity (u) is calculated by dividing the discharge (Q) by the flow area. (Deltares Systems, 2014)

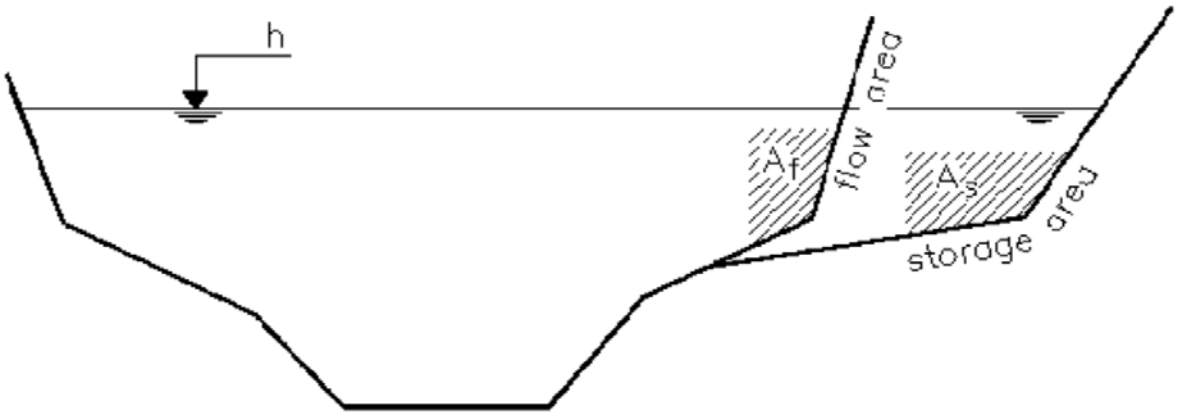

Figure 6; Flow and storage area (Deltares Systems, 2014)

1D FLOW

In comparison to the model of Hong Kong earlier mentioned, the model in Walla Walla will be much less complex. The model consists of an inflow located at the dam. A split vector is drawn on the map which follows the real spillway. Its discharge varies over time, based on historical data. The cross-sections are dimensioned and the gradient is set. This will result in a water depth with a corresponding water velocity.

As can be seen in Figure 7, the Mill Creek and the spillway have been modelled in Sobek. On the right side where the dam is located, there is a dark blue marker which is the start of the model. At this point the discharge is set and the water will flow via the dotted line towards the pink marker on the left side. However, in the middle of the picture there is another dark blue marker. This is where the concrete spillway begins. The blue markers tell the model which size the cross section has. Every time the cross section changes a blue marker is present.

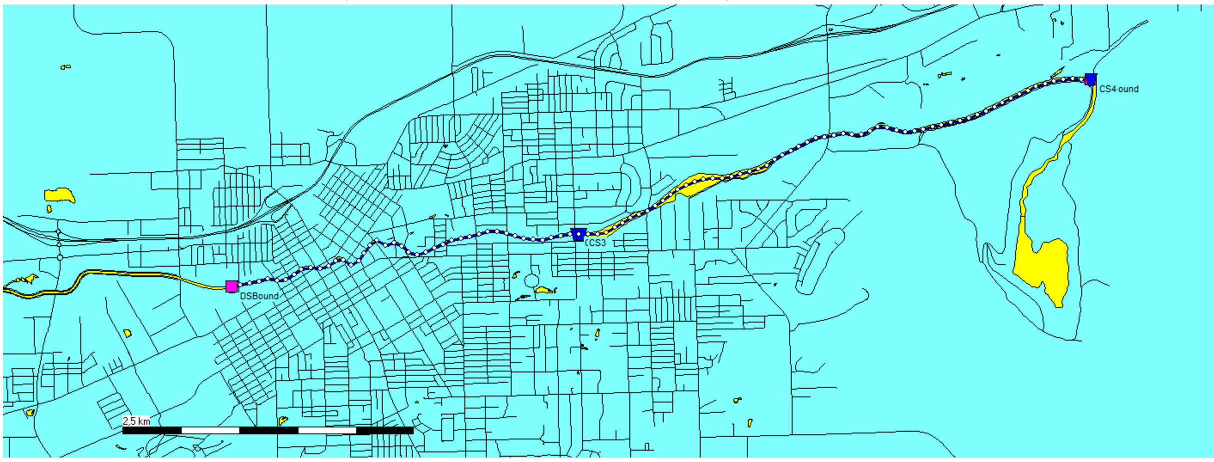

Figure 7; Overview Sobek model

CALIBRATION

In order to check whether the model is accurate, output values of the simulation have been compared with measured data in the Mill Creek. The discharge was chosen as input value and the water depth could be checked.

The available data from the USGS are the discharge and the corresponding gage height every fifteen minutes. As explained above, the gage height is 1.69 ft higher than the actual water depth. This way the gage height can be converted to the water depth.

For calibration of the model the data of the first two months of 2015 have been used. These months have been chosen, because they include very high as well as very low discharges. This makes it ideal to check if the model is accurate at all scenarios.

In Table 2 the real data is compared with the modelled data when. During the 1st of February in 2015 there was almost no discharge, while on the 10th there was a huge amount of water to be flowed away.

To properly calibrate the model, there has made use of several sources. First of all, the dimensions of the spillway were needed. These could be found in the US Army Corps of Engineers report from 1986. The report reads that the width of the concrete channel is 40 ft (12.19 m). (Robinson & Copeland, 1986) This was the starting point of dimensioning the model. Using photographs of the spillway, it was estimated that the inner gutter has a width of 8 ft (2.5 m) and a height of 0.82 ft (0.25 m). This means that the remaining 32 ft (9.75 m) is split into two on both sides of the gutter. The gradient in the width direction seems very low, so there has been estimated that the concrete sides will be 1 ft (0.30 m) higher on the edges than in the middle. Then a concrete wall is designed to be 11.5 ft (1.5 m).

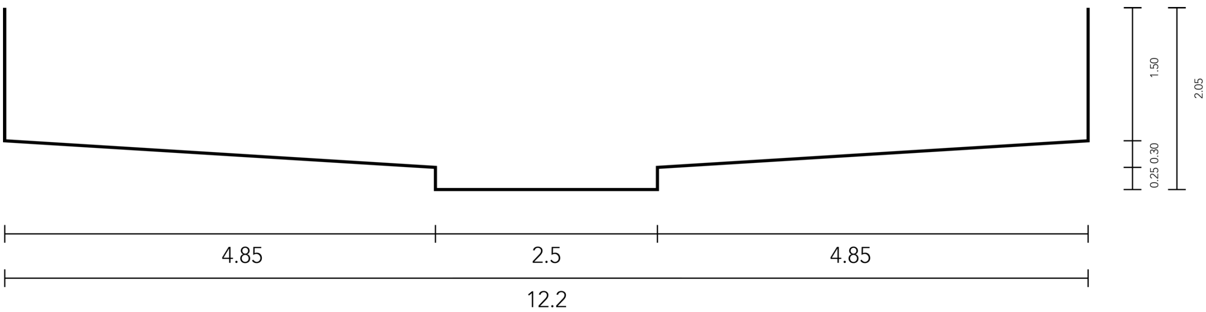

Figure 8; Cross section concrete spillway in metres

These dimensions seem very plausible and from this point the roughness of the channel could be calculated. To determine the roughness of the spillway the Chézy coefficient should be calculated. To read the full calculation, see 'A – Chézy coefficient calculation' in the Appendices. From the calculation follows a Chézy value of 71 $m^{1/2}/s$. This value is part of the input data for Sobek.

Time	Water depth model (m)	Water depth measured (m)
01/02/15 18:00	0.249	0.17
01/02/15 18:15	0.246	0.17
01/02/15 18:30	0.248	0.18
01/02/15 18:45	0.253	0.18
01/02/15 19:00	0.255	0.18
01/02/15 19:15	0.255	0.18
01/02/15 19:30	0.255	0.18
01/02/15 19:45	0.255	0.18
01/02/15 20:00	0.255	0.18
…	…	…
02/10/15 16:00	0.824	0.82

02/10/15 16:15	0.825	0.82
02/10/15 16:30	0.827	0.82
02/10/15 16:45	0.827	0.82
02/10/15 17:00	0.826	0.82
02/10/15 17:15	0.824	0.82
02/10/15 17:30	0.823	0.81
02/10/15 17:45	0.818	0.81
02/10/15 18:00	0.818	0.81

Table 2; Model data compared with actual data (USGS, 2016)

During the calibration there has been focussed on getting the right output data at higher discharges. During very low discharges the model seems a little bit more inaccurate. But in these periods, there is too little water to sail anyway, so these datasets are much less important.

Apart from numbers, Sobek is also able to produce a visual output (see Figure 9). The figure shows the height of the Mill Creek relative to the end point, which is in this case the end of the concrete spillway. It also shows the water level in the channel, which is filled with blue.

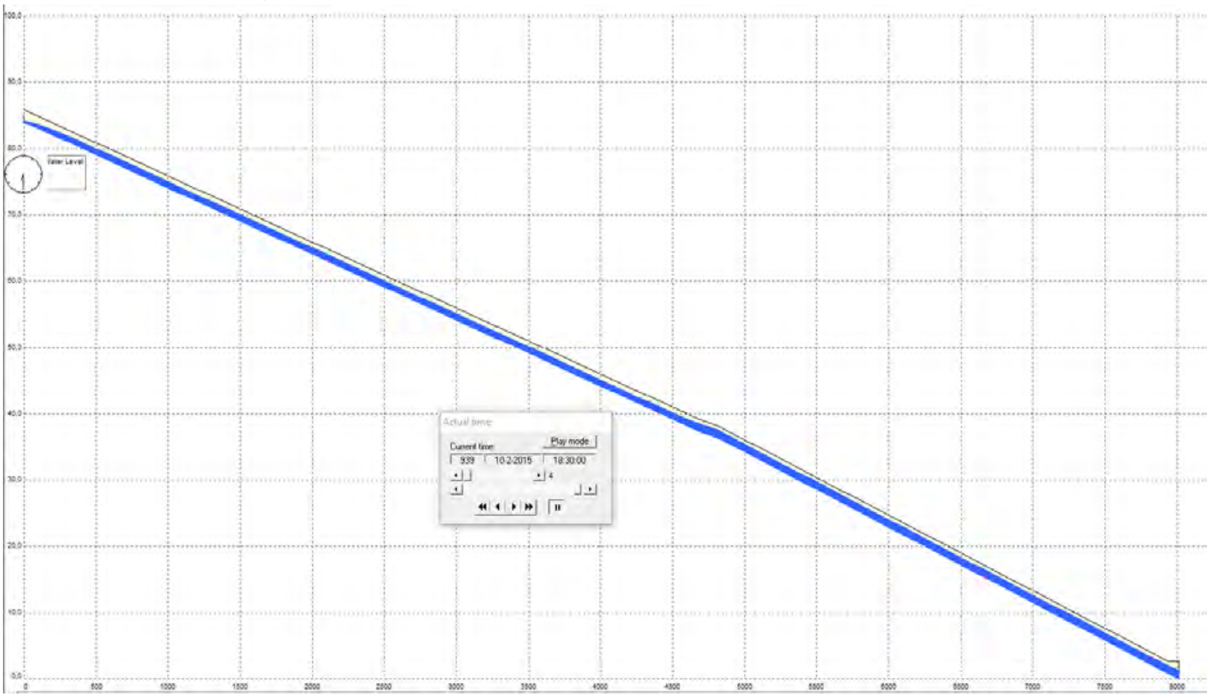

Figure 9; Visual output Sobek model

4 – DESIGN ALTERNATIVES

Boats are available in all kinds of forms. This could be as big as an engine powered water taxi or just a humble human driven pedalo. To come up with the best suitable type of boat to sail on the Mill Creek, different kinds of crafts are taken into account and their characteristics are being discussed. The main specifications which are important to check if the vessel is applicable are: the draught, size, speed and power. The draught and size are required to dimension the spillway. The speed and power give an estimate if the boat is able to sail downstream, upstream or both ways.

WATER TAXI

For the water taxis the model MSTX 6 is used in this calculation. This boat is used in Rotterdam to sail on the Meuse. It is a motorboat with two 140 kW motors. It reaches its top speed at 50 km/h and has a maximum draught of 0.40 m. The vessel's size is 9x3 m. (Watertaxi Rotterdam, 2016)

Figure 10; Water taxi (SilentSpotter1, 2015)

SUP

Stand up paddle boarding or shorter SUP is a recreational and more active way of paddling. They are suitable for racing or wave surfing, but also for touring on a river or a lake. An average SUP board is about 3.4 metres long and has a width of 0.79 m. Its draught is determined by the length of its fin, which is about 0.2 metres. The board is driven by human power, so that means that the maximum speed one will reach is about 10 km/h, depending on the current. (REI, 2016)

Figure 11; Stand Up Paddling (Coastline Algarve, 2016)

DINGHY

A dinghy is a small boat with a small engine. Dinghies are excellent for recreational use and tours. They offer the comfort to spend a day on the water without difficulties. For this feasibility check there has been chosen to use the Corsiva 490 Classic. This dinghy is not very large with length of 4.9 metres and a width of 2.0 m. Its draught is similar to the water taxi's, which is 0.40 metres. Powered by a 22 kW engine it will reach its top speed at about 20 km/h. (Krijgsman Watersport, 2016)

Figure 12; Dinghy (Krijgsman Watersport, 2016)

KAYAK

Just like SUPing, kayaking is more sportive way of sailing the Mill Creek. Kayaking can be done either by two people in a boat or just one. Especially when there are high discharges it could be much fun to have more challenging approach to water recreation. Kayaks have almost no draught (0.10 m) and their dimensions are 3 by 0.7 metres. A kayak is powered by human strength and will reach a velocity not higher 15 km/h. (Guillemot Kayaks, 2016)

Figure 13; Kayak (Oklahoma Road Trips, 2011)

PEDALO

The pedalo is a boat where one cycles to move in the desired direction. This could be a great way of seeing the city from the water. The boat offers a perfect space for a family, with a size of 3.6 by 1.8 metres. Its draught is lower than a water taxi, but higher than a kayak with 0.30 metres. As human legs are needed to move the pedalo, the vehicle will not go faster than 10 km/h. (Aquafunrent.nl, 2016)


Figure 14; Pedalo (Pioner Boats, 2016)

PULL FERRY

The pull ferry is not actually a boat, but more of a recreational tool for crossing the Mill Creek. It consists of a wooden platform with ropes across the channel. This limits the ability of sailing on the creek, but offers great fun when the weather allows it. The big difference with this alternative compared with the other is that this one sails the Mill Creek in lateral direction. The pull ferry goes from edge to edge and functions as an exciting bridge. There has been chosen for a platform of 4 by 3 metres with draught of 0.25 m. Man power pulls the ropes while slowly moving forward with speed of about 5 km/h.


Figure 15; Pull Ferry (IJreka, 2016)

SUMMARY

In Table 3 the differences per alternative are briefly stated.

	Length (m)	Width (m)	Draught (m)	Top speed (km/h)	Power (kW)
Water taxi	9.0	3.0	0.4	50	2 x 140
SUP	3.4	0.8	0.2	10	man power
Dinghy	4.9	2.0	0.4	20	22
Kayak	3.0	0.7	0.1	15	man power
Pedalo	3.6	1.8	0.3	10	man power
Pull Ferry	4.0	3.0	0.25	5.0	man power

Table 3; Specifications summary of design alternatives

TEMPERATURE

In order to recreate in a decent way, the temperature should be at least acceptable or ultimately pleasant. A minimum temperature of 60 °F (15 °C) should suffice for outdoor activities on the water. The US climate data shown in Figure 16 informs that the period between April and October is ideal for recreation on the water concerning temperature only.

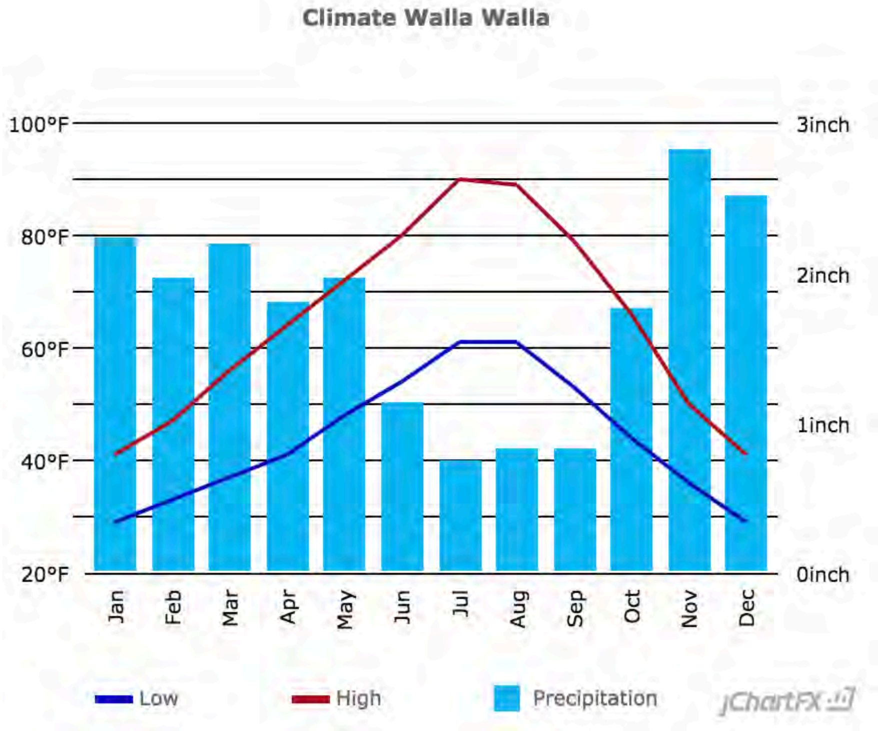

Figure 16; Monthly Climate Walla Walla, WA (US Climate Data, 2016)

5 – SIMULATION CURRENT SITUATION

The calibrated Sobek model has been used to get additional information including the velocity of the water concerning the concrete spillway. This data is very useful to assist considerations made if certain design alternatives are feasible in the current situation.
Important factors to test if the designs are possible are the water depth, flowrate and therefore the minimum discharge from the dam.

WATER DEPTH

The water depth varies over the width of the cross section, as the middle is 0.55 m deeper than the edges. There needs to be a different minimum water depth for each design alternative depending on the size of the boat. However, for a lot of activities not the full width of the spillway is needed to still execute it. Therefore, it is also tested how the circumstances are if only two third of the channel fulfils the desired water level.

FLOW RATE

The velocity of the water should not be too high as it becomes impossible to sail upstream or the activity becomes too dangerous.

DISCHARGE

In order to reach a certain water depth in current scenario, a change of discharge of the dam is the only aspect to consider. More water will immediately have the water level rise.

RESULTS

Design Alternative	Draught (m)	Water velocity (m/s)	Discharge needed (m^3/s)	Water depth (m)	Upstream	Downstream
Water taxi	0.40	5.90	48.0	0.95	Yes	Yes
SUP - Minimum - Ideal	0.20	 4.65 5.09	 19.9 28.3	 0.65 0.75	No	Yes
Dinghy	0.40	5.90	48.0	0.95	Yes	Yes
Kayak - Minimum - Ideal	0.10	 4.17 4.65	 12.6 19.9	 0.55 0.65	No	Yes
Pedalo - Minimum - Ideal	0.30	 5.09 5.43	 28.3 35.7	 0.75 0.85	No	Yes
Pull ferry	0.25	5.30	32.8	0.80	DNA	DNA

Table 4; Results from Sobek model

A brief summary of the results of the Sobek model are stated in Table 4. For further explanation of this table and how these values have been retrieved, see appendix 'C – Model Results of Design alternatives current situation'.

CONCLUSION

After having gathered all the useful information for each design alternative, it turns out that kayaking is the most feasible option for the current situation. However, even for kayaking the velocity of the water is still very high and could be dangerous. It has become clear that the current spillway is not very optimal for any of these forms of recreation. That is why there has been taken a look to improve the spillway by renovating the current one. This will be explained in the next chapter.

6 – RENOVATION DESIGN

During the simulation of the current situation, two things came forward that need to be changed. First of all, the water depth is often not high enough for most design alternatives. Next to this the water speed is quite high. Reaching values of up to 5 m/s makes this creek a wild water system.
There is a way to solve these two problems at the same time. If the discharge and the width of the cross section stay the same, and the velocity of the water decreases, then the following formula shows that the water depth will increase.

$$Q = A * v$$

Where:

$$Q = discharge$$
$$A = cross\ section\ area\ \approx width * height$$
$$v = velocity\ of\ the\ water$$

INCREASE OF ROUGHNESS

Decreasing the water speed can be realised by increasing the roughness of the cross section. If a calculation of the Chézy coefficient is made using the following formula with an increased roughness constant (k), the Chézy coefficient will be lower, as the hydraulic radius (R) stays almost the same.

$$C = 18 * \log\left(\frac{12R}{k}\right)$$

Where:

$$R = hydraulic\ radius$$
$$k = material's\ roughness\ constant$$

If the Chézy value is lower, the velocity will also decrease; given that the gradient (i) will not change. (Chow, 1959)

$$v = C * \sqrt{R * i}$$

Where:

$$v = velocity$$
$$C = Chézy\ coefficient$$
$$R = hydraulic\ radius$$
$$i = gradient$$

The roughness index k is determined by the material of the spillways. At the moment, the spillway is made out of concrete and has, according to Nikuradse, a k-value of 0.001 m. By using pebbles on the bottom of the spillway the Nikuradse's k-value is increased to 0.050 m.

$$C = 18 * \log\left(\frac{12 * 0.72}{0.050}\right) = 40\ \frac{\sqrt{m}}{s}$$

This results in a Chézy coefficient of 40 $m^{1/2}/s$.

IMPLEMENTATION OF GROYNES

A second change that will be made is the construction of groynes in the spillway. These groynes will be placed alternately on the left and right sides. These walls make the water break down, as it is forced to meander around them (see Figure 17 in appendix 'D – Upgraded spillway'). The groynes will have length of 8.1 m, leaving 4.1 m space for the boats to cross. This is one metre wider than the largest design alternative, which should be a safe approach. The fish ladder will be maintained as it is at the moment. The groynes will be built over the fish ladders (see Figure 18 & Figure 19 in appendix 'D – Upgraded spillway'). As this hole in the groyne is relatively low, this will not affect its function significantly. The groynes consist of very large rocks that are put into the creek.

MODEL

To calculate the new water depth and water speeds, the increase of the roughness of the spillway and implementation of the groynes have been modelled in Sobek. This has been done by entering a Chézy value of 40 over the entire cross section of the concrete spillway. The groynes have been modelled by setting the Chézy value to 25, alternating sides every 100 metres. This Chézy value is achieved by choosing a k-value of 0.5 m and a hydraulic radius of 1 m. At the places where the groynes have been installed a Chézy value of 15 is modelled. Figure 20 in appendix 'D – Upgraded spillway' gives a graphical explanation of how the Sobek model calculates this setup between the data nodes.
The Chézy value in the fish ladder could have been modelled with values of 40 instead of 15 or 25 at the groynes or in the main flow respectively. However, as the height of the fish ladder is relatively low compared with the total height of the spillway, this is considered to be neglected.

From the output data of the Sobek model it shows that at lower discharges the minimum requirements for the design alternatives are reached. As there is a lower discharge needed for the same water depth, the option to implement several designs increases. Next to this, the possibility to sail on the Mill Creek will be higher during a longer period of the year. This makes the business plans of starting a recreation facility much more feasible.

Table 5 gives a comparison of the water depth in the current and new situation. This data shows that during a high discharge the water level increases with more than 50%.

Time	Water depth model new (m)	Water depth model current (m)
02/10/15 16:00	1.254	0.824
02/10/15 16:15	1.255	0.825
02/10/15 16:30	1.259	0.827
02/10/15 16:45	1.259	0.827
02/10/15 17:00	1.258	0.826
02/10/15 17:15	1.254	0.824
02/10/15 17:30	1.252	0.823
02/10/15 17:45	1.243	0.818
02/10/15 18:00	1.243	0.818

Table 5; Comparison of current situation with the new

Table 6 shows the discharges and water speeds that correspond with water depth that is required for each design alternative. The water depth should be at least 0.55 m deeper than the draught of the vessel. This demand is based on the fact that the edge of the spillway is 0.55 m higher than the middle of the creek.

Design Alternative	Draught (m)	Water velocity (m/s)	Discharge needed (m^3/s)	Water depth (m)
Water taxi	0.40	2.49	19.9	0.95
SUP	0.20	1.82	7.3	0.75
Dinghy	0.40	2.49	19.9	0.95
Kayak	0.10	1.86	7.9	0.65
Pedalo	0.30	2.29	15.4	0.85
Pull ferry	0.25	2.19	13.5	0.80

Table 6; Water velocity and discharge at required water depth

CONCLUSION

As one can see from the results of the model, the velocity of the water has decreased and the water depth has increased. These two factors provide opportunities to have the design alternatives succeed. However, still not all of them are safe to use in the upgraded scenario.
The pedalo will not be able to resist the flow rates and the groynes make it also dangerous. The dinghy is able to sail up and downstream the creek, but as its reach is limited to the concrete spillway, it will not be a feasible concept. The trips are simply too short. Also SUPing might be a dangerous exercise. The chance of falling off the board is realistic. With many rocks and a constant current in the creek, this could easily go wrong. These three activities could better be executed at the Bennington Lake instead.

The three remaining design alternatives look attractive and safe to implement. The water taxi is now able to sail across the Mill Creek much more often than previously due to a higher water depth. The improved spillway has become an exciting playground for kayakers and even the pull ferry could be implemented. The ropes could however conflict the passing boats. Perhaps it would be better to build the pull ferry upstream of the concrete spillway where the creek flows in free nature.

7 – RECOMMENDATIONS

In the last nine weeks the current situation has been mapped. A Sobek model of the Mill Creek at Walla Walla has been made and calibrated to see if improvements were necessary. The water depth was too low for various design alternatives and an upgrade for the spillway was proposed.

This upgrade has been modelled by using different roughness indices at segments in the cross sections of the creek. This was a way to simulate the groynes in the spillway. However, due to interpolation over the data cells, this may be not the most accurate way to do it. Therefore, it would be wise to further develop the model in further studies to verify the results of the water depth and water velocity.

The design is also a rough sketch that forms a base for a more detailed study. Perhaps, a physical model helps to see how the water in this new design actually flows, as the Sobek model only gives a 1D result.

Next to this, another important factor to obtain a feasible recreation playground is to have a constant discharge from the dam. Research should be done to see if water from the Bennington Lake can be used to keep a constant discharge in the Mill Creek.

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APPENDICES

A – CHÉZY COEFFICIENT CALCULATION

The Chézy coefficient is part of the Chézy formula which is devised by Antoine de Chézy in 1775. (Chow, 1959) The formula reads:

$$v = C * \sqrt{R * i}$$

Where:

$$v = velocity$$
$$C = Chézy\ coefficient$$
$$R = hydraulic\ radius$$
$$i = gradient$$

To calculate the Chézy coefficient, one uses this formula:

$$C = 18 * \log\left(\frac{12R}{k}\right)$$

Where:

$$R = hydraulic\ radius$$
$$k = material's\ roughness\ constant$$

The hydraulic radius is the ratio between the flow area (A_f) and the wetted perimeter (P) and is described in the following formula:

$$R = \frac{A_f}{P} = \frac{h * b}{b + 2 * h}$$

Where:

$$h = water\ depth$$
$$b = width\ of\ channel$$

According to Nikuradse, for concrete the k value lies between 0.0005 – 0.002 m. Because the exact value of the specific concrete is unknown, the k value is estimated to be 0.001 m for these calculations.

The chosen water depth is equal to 0.82 m which has been measured at 4 pm on 2nd February 2015. (USGS, 2016) The channel's width is found in the US Army Corps report and is 12.19 m. (Robinson & Copeland, 1986)

This results in a hydraulic radius of:

$$R = \frac{0.82 * 12.19}{12.19 + 2 * 0.82} = 0.72\ m$$

And a Chézy value of:

$$C = 18 * \log\left(\frac{12 * 0.72}{0.001}\right) = 71 \frac{\sqrt{m}}{s}$$

B – PULL FERRY CALCULATION

The pull ferry is a wooden raft that floats the water. To correctly dimension the raft one should take Archimedes' principle into account, which states that "*Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.*" (Archimedes, 250 BC)

The used wood is pinewood which has a density of 580 kg/m^3 (OSBExact, 2006) The water of the Mill Creek has a density of 1000 kg/m^3. Which means that the raft is for 58% underwater.

$$\frac{580}{1000} * 100\% = 58\%$$

Apart from its own weight, there is an external force applied on the raft, as people stand on it. To keep it safe and comfortable on the 12 m^2 there is a maximum of six people allowed on the raft, or a maximum of 600 kg.

The external force is the product of the mass times gravity constant which results in a force of about 6.0 kN. The desired draught of the raft is 0.20 metres. To create an equilibrium, the downward forces should be equal to the upward forces.

Downward forces:

$$F_{own} + F_{ext} = 10 * 0.58 * 3 * 4 * x + 6\ kN$$

Where:

$$x = desired\ height\ of\ the\ raft$$

Upward forces:

$$F_{water} = 10 * 1.0 * 3 * 4 * 0.25 = 24\ kN$$

Equilibrium:

$$F_{own} + F_{ext} = F_{water}$$
$$69.6 * x + 6 = 30 \rightarrow x = 0.34\ m$$
$$0.34 * 58\% = 0.20\ m$$

The total height of the raft is 0.34 m and will have draught of 0.25 m when it is fully loaded and a draught of 0.20 m if there is no external load at all.

C – MODEL RESULTS OF DESIGN ALTERNATIVES CURRENT SITUATION

Water taxi

The water taxi has a draught of 0.40 metres. This means that in order to sail or dock the taxi a water depth of at least 0.95 m is necessary. This only happens during a very high discharge of 48.0 m^3/s.

The water speed at this discharge is 5.90 m/s. This is rather high and makes it harder for a captain to gently sail the taxi in either way. The water is very rough and a pleasant trip on the water in the current situation in not likely. However, as the top speed of the water taxi is 14 m/s, it is powerful enough to sail upstream.

SUP

The draught of a SUP raft is 0.20 m. To be able to SUP across the whole width of the spillway a water depth of at least 0.75 m is necessary. With a discharge of 28.3 m^3/s this height is obtained, with a velocity of 5.09 m/s. However, if two third of the channel complies to the desired water level, it is also possible to do the activity. This means that a water depth of 0.65 m is acceptable. At discharges of 19.9 m^3/s with a corresponding velocity of 4.65 m/s this water depth is reached. The velocity of the water is in both cases too high to sail upstream, as SUPing does not involve any power other than man power.

Dinghy

The dinghy has the same draught as the water taxi of 0.40 m. This means that the conditions for the dinghy are similar as for the water taxi. The minimum water depth should be 0.95 m which is achieved with a discharge of 48.0 m^3/s with a corresponding water speed of 5.90 m/s. However, while a trip with a water taxi only takes a short amount of time, a dinghy is meant for longer trips. With these flowrates, a form of recreation with a dinghy is not recommended in the current situation.

Kayak

The draught of a kayak is only 0.1 m. For a full width experience the water depth needs to be 0.65 m. With a discharge of 19.9 m^3/s this height is obtained, while the velocity of the water is 4.65 m/s. A two third compromise results in a depth of only 0.55 m, where a discharge of 12.6 m^3/s is needed at a water speed of 4.17 m/s. These water heights are very often realisable. In addition to the fact that kayaking becomes more exciting as the water speeds increase, this makes it a very feasible option in the current situation. There is only one slight issue. Kayaking will only be workable downstream but it is common practice for a kayaking company to return the boats back to the starting point by car.

Pedalo

As the pedalo's draught is 0.3 m, it needs a water depth of 0.75 m for a two third compromise and a depth of 0.85 m in the desired scenario. To achieve these heights there should be a discharge of 35.7 m^3/s or 28.3 m^3/s respectively. The corresponding respective water speeds are in these cases 5.43 m/s and 5.09 m/s. As a pedalo is man power driven, the forces of the water in the Mill Creek are too high to safely sail on the water. Steering becomes very difficult as well as braking. This makes it a dangerous activity in the current situation.

Pull Ferry

The pull ferry sails in contrast to the other design alternatives in the lateral direction from shore to shore. It has the function of a bridge, but is more fun and exciting than a regular one. As one needs to cross the whole channel and the pull ferry having a draught of 0.25 m, the water depth needs to be 0.80 m. This is achieved by discharges of 32.8 m^3/s. The water speed will be 5.30 m/s. These currents are rather high and falling off the raft is likely to happen once in a while. This makes it not ideal to realise this concept in the concrete spillway.

D – UPGRADED SPILLWAY

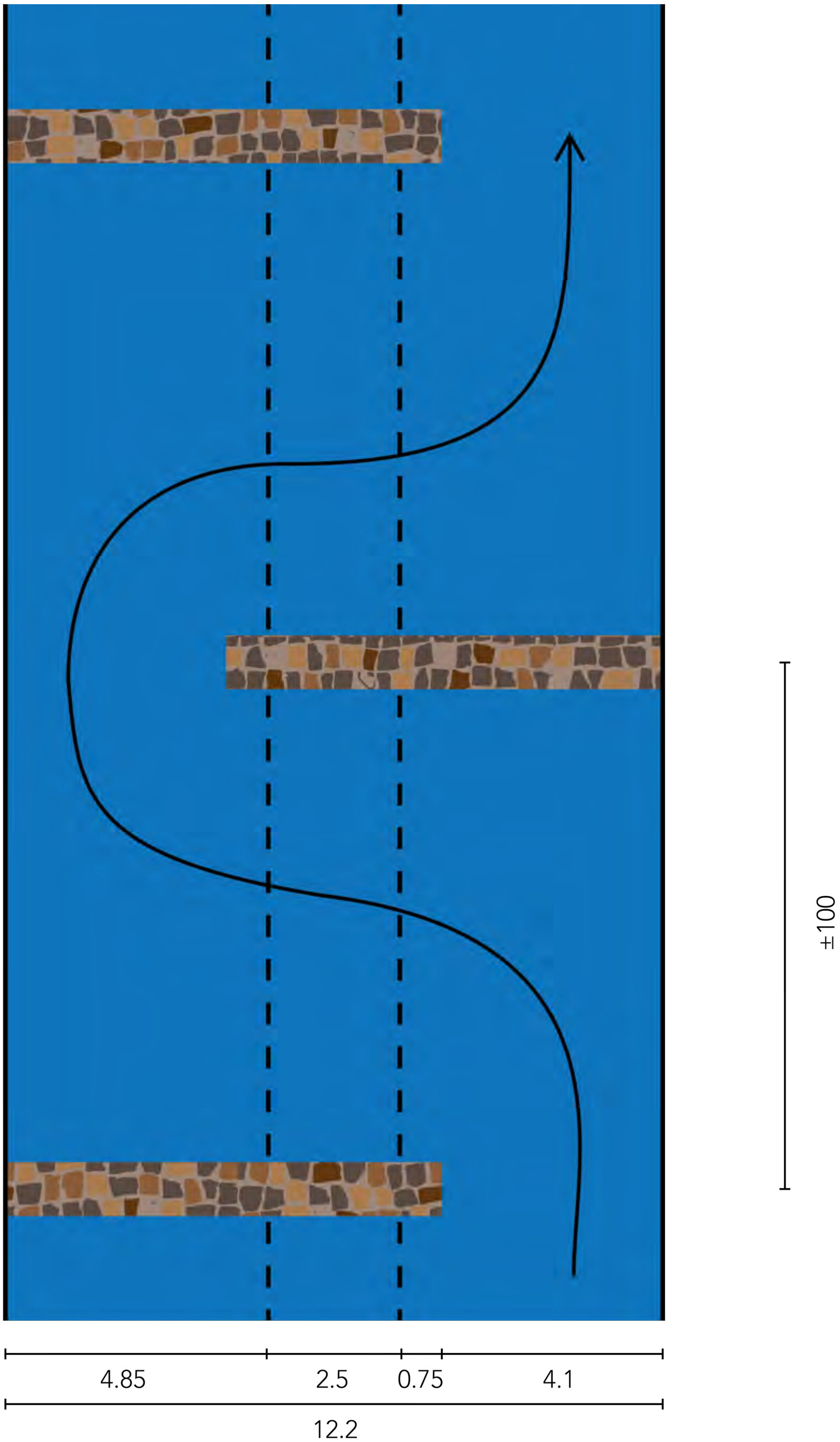

Figure 17; Upgraded Mill Creek top view (in metres (not to scale))

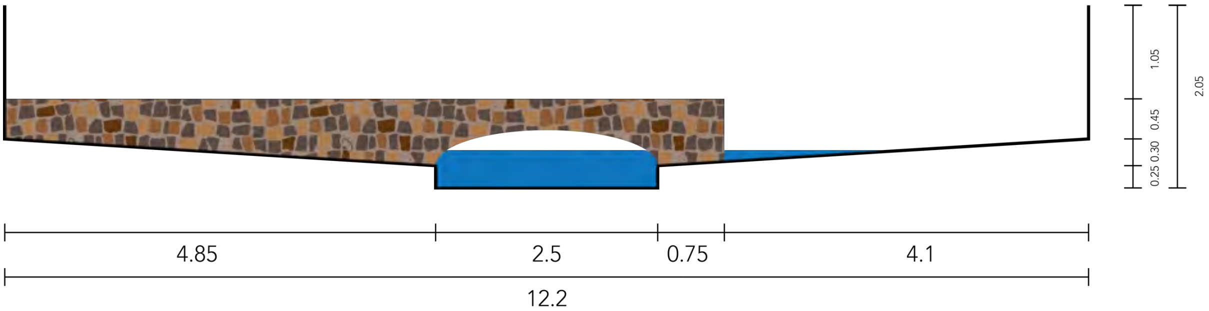

Figure 18; Upgraded Mill Creek front view low tide (in metres)

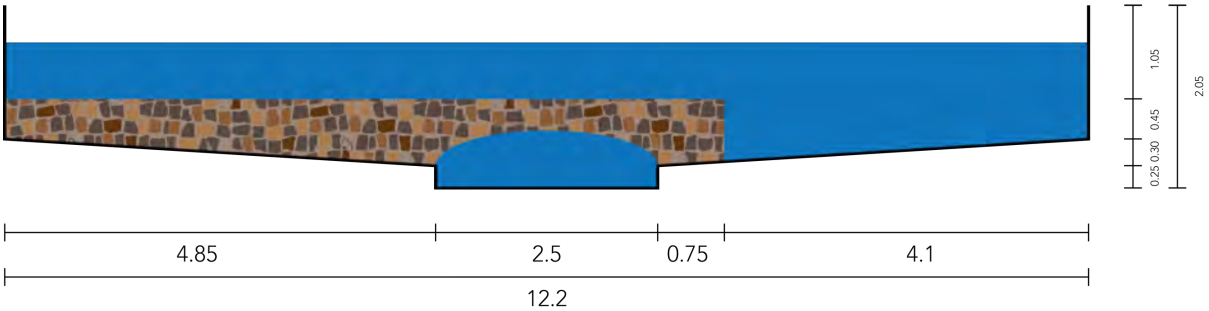

Figure 19; Upgraded Mill Creek front view high tide (in metres)

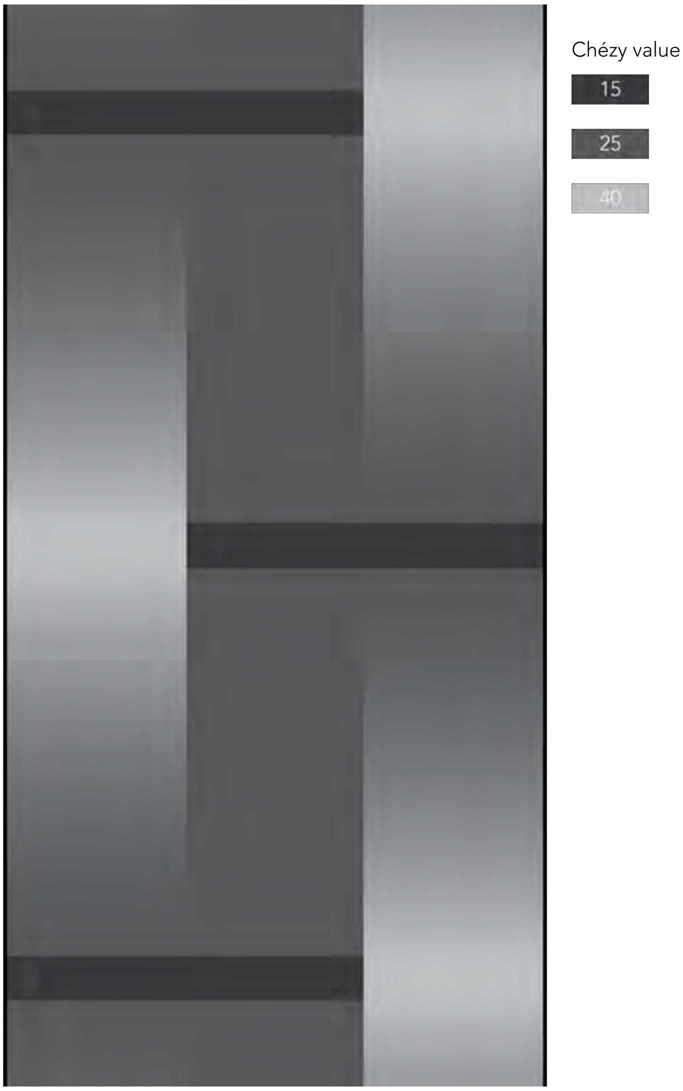

Figure 20; Chézy values in the Sobek model of the upgraded spillway