RAPID ASSESSMENT OF ZALUN BANK EROSION (DRAFT)

field inspection, diagnosis and first recommendations

RVO in collaboration with DWIR

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Photo on front page: river bank erosion 8 km north of Zalun (photo taken from boat on 27 January 2020)

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1 INTRODUCTION

The Ayeyarwady river is a dynamic, largely undisturbed river in Myanmar characterized by constantly moving channels and sand bars. One of the many locations where this meandering moved far into the river's floodplain is near a small village named Du Ya (see Figure 1), located north of Zalun. Here, the meandering of the most westerly river channel has caused severe erosion in the past.

Along parts of the west bank of the Ayeyarwady River, starting from north of Hinthada, a so-called horseshoe dike, or U-dike, was constructed long ago (before 1900) to protect the hinterland of the upper delta from being flooded during high river discharges. The here-considered part of this U-dike is the Zalun – Myoma Section with mileages starting at 15.5 in the north to 28.6 at Zalun.

Figure 1 Map of the area

The strategy in Myanmar to deal with meandering channels is as follows. Once the moving river channel approaches the embankment within 30 m, a secondary embankment is constructed at some (inland) distance from the primary embankment. This was also the situation in 2015 at Du Ya, and many attempts were made to stop the ongoing erosion, including the placement of flow diversion screens, and the placement of sandbags (see photo taken by the author in September 2015). By the time, it appeared difficult to maintain the new embankment and the local bank erosion continued. To better control it, DWIR dredged a meander cut-off channel in 2016/2017. The plan for this system intervention was discussed during the DRR mission in 2015 when author advised to first analyse the hydro-morphological response before opening such new channel. However, proper tools to do so were not available at the time and the works were carried out according to plan, which comprised the construction of training walls, closing of branches and the excavation of an approximately 14 km long, 35 m wide and 2 m deep (below low water level) channel in a straight line through the centrally located sand bar (see Figure 2 below obtained from DWIR in 2015 - the work has been carried out in 2016/2017).

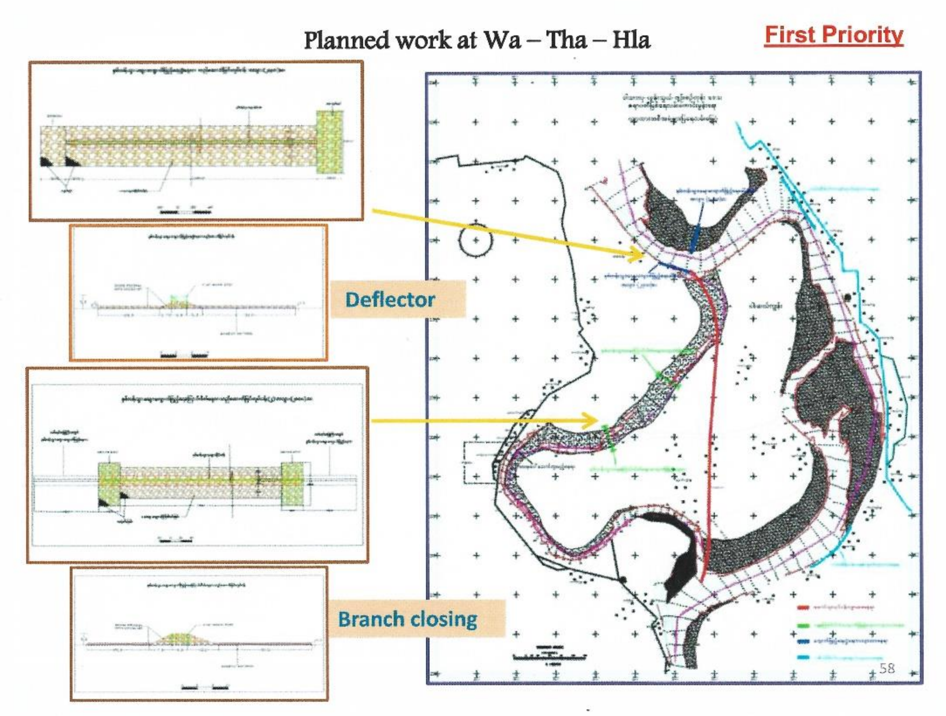

Figure 2 Planned and executed river work north of Zalun (2017)

The morphological response of the river to these interventions was intense: the new cut-off channel quickly deepened and widened, started to meander itself and extended southwards, resulting in significant erosion of the floodplain downstream. Intense erosion was also observed along the primary west embankment, around mileage 22.0 (some 8 km north of Zalun) – see right two photos taken from the boat during the field inspection on 27 January 2020. Today, the erosion has reached the city of Zalun, where the existing revetment is already undermined and damaged (left photo below in Figure 3).

Figure 3 photos taken during field trip on 27 January showing serious erosion on west bank

DWIR and IWUMD requested the Dutch government to provide expert advice on the situation, more specifically:

- what caused the bank erosion near Zalun and how is this related to the executed river works,
- what can be expected on short term,
- How effective are the emergency measures that are currently being undertaken by DWIR, and
- what alternative measures can be considered to limit the impacts.

On their turn the Dutch government, through their executing agency RVO, requested Arcadis to deliver the following services:

- Collection of all available data (to be obtained from DWIR and IWUMD);
- Analysis of the collected information, including the calculation of erosion and deposition volumes and bank retreat distances.
- Two-days field visit (one overnight stay in Hintada) to inspect the site, take sediment samples, hold meetings with local DWIR officials and interview local people to learn from their local knowledge, concerns and understanding of the situation (Appendix A).
- Verbally present the findings of the analysis to DWIR and IWUMD staff, and
- Prepare a brief report on the main findings (this report)

A total of 7 mandays for international experts and 5 mandays for local support were agreed to carry out these tasks. The activities were carried out by the following experts, who all four participated in the field mission that took place on 26 and 27 January 2020:

- Rob Steijn – senior morphologist and team leader (analysis and reporting)
- Brecht d'Haeyer – junior morphologist (data processing and analysis)
- U Khin Latt – senior advisor and former Irrigation Department head Zalun region (historical perspectives)
- Hnin Nandar Aye – junior river engineer (coordination field trip; stakeholder engagement and reporting)

This report has been structured as follows. Based on the observations from the field survey and bathymetrical data obtained from DWIR, a first assessment of the situation is given in Chapter 2. The data analysis results in a general description of what happened (hindcast) as well as a prediction of possible changes on short term in case no action is being taken (forecast).

DWIR is currently taking precautionary action with limited available funds. This includes the excavation of a new channel (70 m wide, 5 m deep) and a provisional slope protection near mileages 22 to 24. In Chapter 3 a first assessment is given of the possible effect of these measures on the predicted short-term bank erosion.

Chapter 4 describes alternative options for short term action aiming to minimize the short-term river bank erosion, particularly near Zalun.

2 DIAGNOSIS

2.1 What happened?

Figure 4 shows the situation north of Zalun, which city is marked with the yellow pinpoint, in 1984, 2016 and 2019. By comparing 1984 and 2016 it can be seen how the main channel split up in two channels with the smaller one meandering far westwards. This smaller channel caused the severe erosion problems near Du Ya, which was the motivation to excavate the cut-off channel visible in 2019. Note that the situation in 2019 is much different than shortly after the excavation in 2017 when the channel was initially straight and narrower.

Figure 4 Satellite images 1984, 2016 and 2019

One way to analyze satellite information is presented in Figure 5. It compares the situation in 2015 and 2019:

- red areas are 'dry surface' in 2015 and 'water surface' in 2019 (so eroded land),
- blue areas are 'water surfaces' in both 2015 and 2019 (so remained part of the river flow), and
- yellow areas are 'water surface' in 2015 and 'dry surface' in 2019 (so silted up).

The new channel that was dredged in2016/2017 can be clearly recognized, but also its southward extension into the flood plain (indicated with the white arrow). What also can be seen is the abandonment of the old river meander that in 2015 still caused the erosion problems near Du Ya (see yellow colored remnants of the old meander). The meander cut-off was clearly very effective in stopping the erosion at Du Ya.

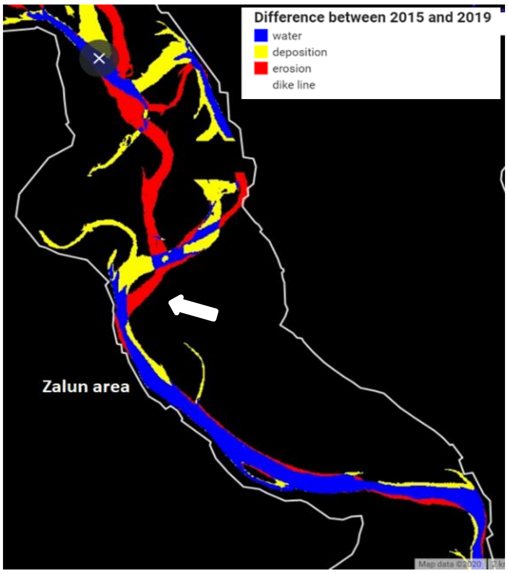

Figure 5 Satellite difference map 2015-2019 showing areas of erosion and deposition

DWIR has carried out bathymetric surveys in November 2017, November 2018 and November 2019, which data provides the opportunity for a more detailed analysis of the morphological changes. The original measured depths were interpolated using Triangular Irregular Network method (TIN) using 0,5 m gridding distance, resulting in the bathymetry maps shown in Figure 6 below.

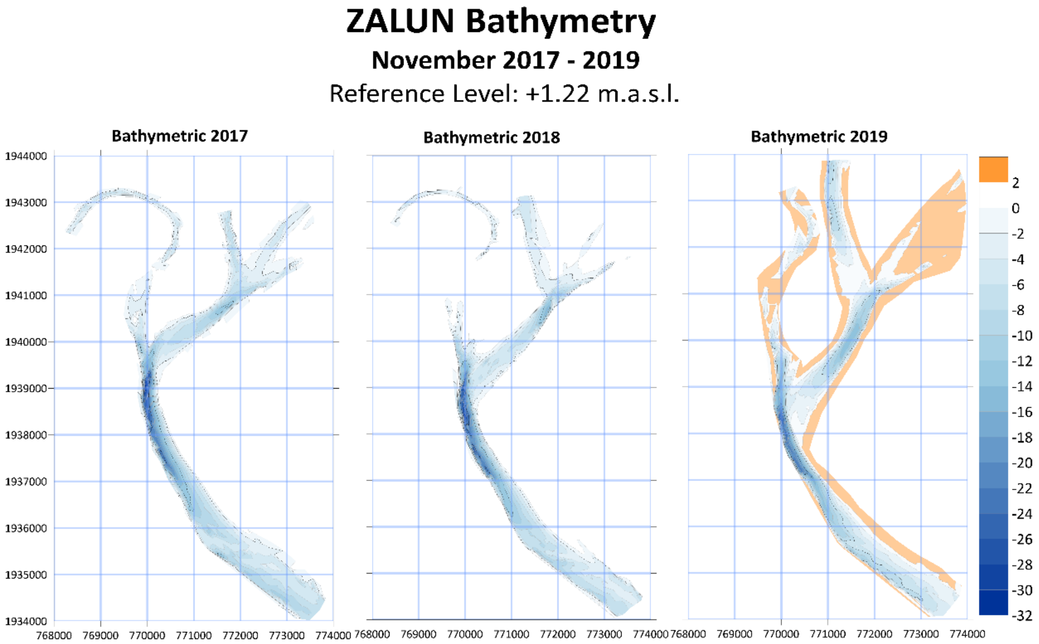

Figure 6 Bathymetry maps 2017, 2018 and 2019

With all information now available at the same 'grid points', it becomes possible to produce "bed difference maps" by subtracting depths between successive years. The results are shown in Figure 7 with the differences between November 2017 and November 2018 in the left panel and those between November 2018 and November 2019 in the right panel. Blue and red colored areas indicate locations that respectively have eroded or accreted. The darker the color, the larger the erosion or accretion (in m). Note that the red "spike" on the left panel (indicated with "2") is a triangulation error with no further impact on the results.

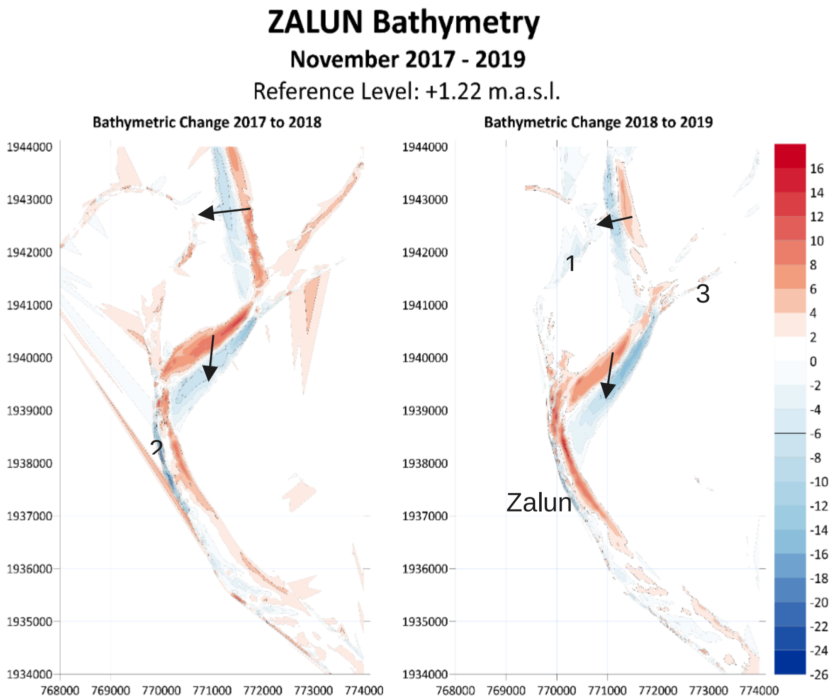

Figure 7 Patterns of erosion and accretion 2017-2018 (left) and 2018-2019 (right)

The arrows in Figure 7 show the westward migration of the cut-off channel over a distance of hundreds of m over the period 2017 – 2019. What can also be observed is that the cut-off channel is no longer straight but curved, with a tendency to develop a new meander to the left, i.e. to the west. The location indicated with nr “1” in the Figure suggests that erosion is taking place in an older river channel that may further develop into a new channel after some time.

The lowest two arrows in the Figure show how the cut-off channel has eroded the sand bank on the east side of the river. The northern bank has already moved southwards over a distance of more than 1 km in just two years’ time. This is not a surprise because the flow from the cut-off channel approaches this bank almost “perpendicular” (in reality flow curves bend) leading to high erosive forces. The new cut-off channel outflow consequently moved southward and re-orientated in counterclockwise direction. This is not positive for the stability of the riverbank at Zalun, because it will become more attacked by river flow if this continues.

Figure 8 shows a detail of the calculated sedimentation / erosion patterns. It shows the strong scouring along the riverbank north of Zalun in the period 2017-2018 with erosion rates of locally 10 -15 m. The erosion zone shifts gradually southwards (downstream) in the next year and starts to reach Zalun. The area that eroded most severely in 2017-2018 now seems to start accreting again (indicated with “1” in Figure 8). Both observations are the consequence of the southward movement and re-orientation of the outflowing discharge from the cut-off channel (illustrated with the two arrows below).

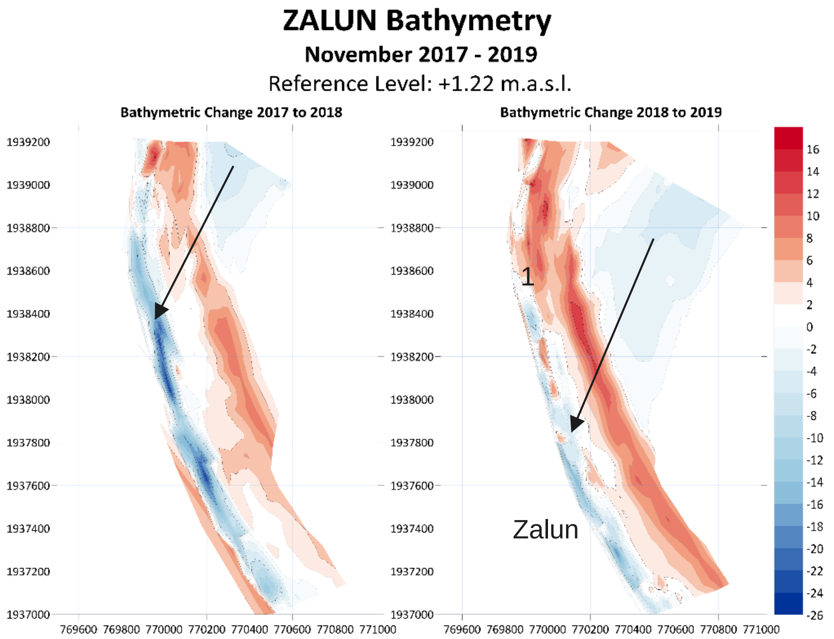

Figure 8 Patterns of erosion and sedimentation 2017-2018 and 2018-2019 – detail

Also an analysis of river cross-sections can help to understand what is happening. Figure 9 shows cross-sections of the riverbed for each year (the locations of the cross-rays are indicated in the included 2019 bathymetry map). Cross-section “1”, which is located near Daung Gyi, shows how the channel is silting up.

The middle cross-section (“3”) shows how the channel moves westwards. The channel slope on the west side is approximately 1:1,5 (vertical : horizontal). Such steepness can only occur when the bed material consists of clay, which is much less erodible than sand. To check the riverbed composition, a bed sample was taken by using a Van Veen grab. The sample confirmed that the composition of the riverbed is clay. Observations from the landside also confirmed the presence of clay layers around the water line (see photo in Figure 3 and further details of collected sediment samples in Appendix B). If no such clay layers would have been present, then it is likely that the erosion would have been many hundreds of meters having destroyed all local primary and perhaps even secondary embankments.

The lowest cross-sections ("2") in Figure 9 show how the river has moved towards the west bank. This cross-section is near Zalun, and shows how the depth in front of the city's waterfront increased with locally more than 10 m (!). Clearly this is a serious threat for the local embankments and revetments. It also increases the probability of a landslide given the likelihood of clay layers in the underground (similar as what happened in January 2020 at the city of Nyaungdon at the Pan Hlaing River bifurcation).

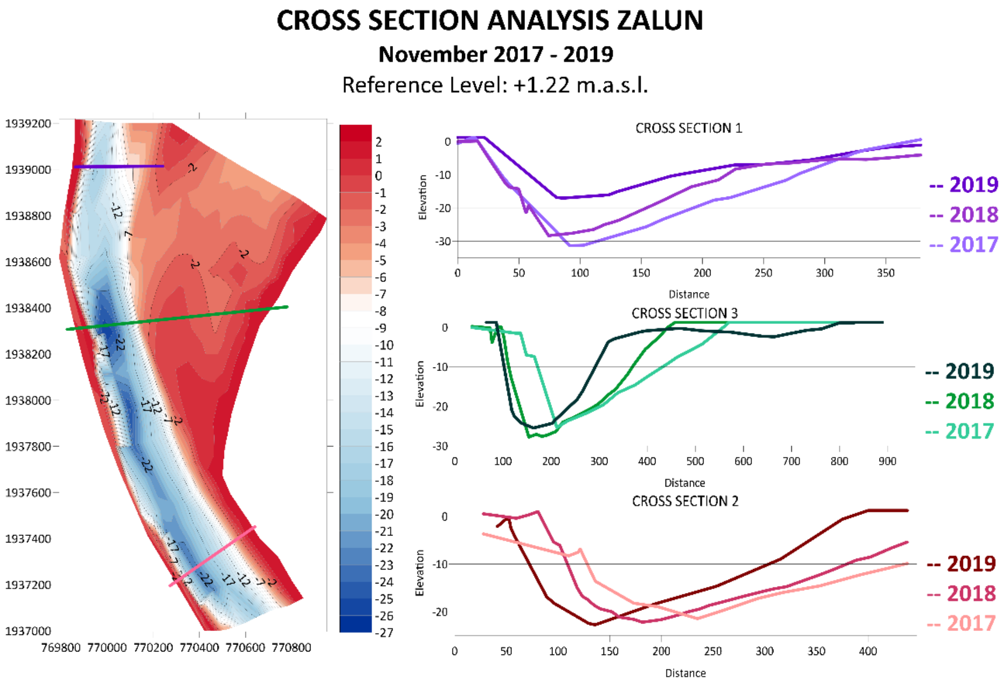

Figure 9 Cross sections 2017, 2018 and 2019

The so-called "cross-sectional flow area" (in m²) almost linearly depends on the discharge that flows through that cross-section. This means that if twice as much water flows through a cross-section, that the total surface area will also double. Five cross-sections were selected (see Figure 10) and for each of them, the cross-sectional flow area below the local reference datum (0.00 m) was calculated. The results are given in the table below:

CROSS SECTION SURFACE AREA (m2)			
CROSS SECTION	YEAR		
	2017	2018	2019
1	5860	6217	5146
2	5520	5648	4610
3	5648	5428	4290
4	5792	4967	4041
5	5517	5209	4454

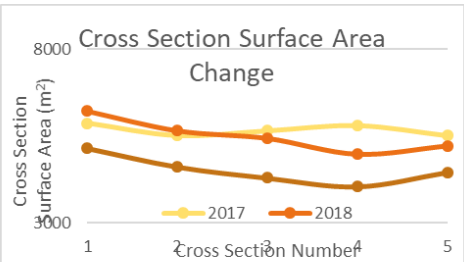

Table 1 computed cross-sectional flow area

What follows from this analysis is that in 2017, when the morphological changes near Zalun were not as manifest as in 2019, the cross-sectional flow area varies maximum 4 percent between the five cross-sections. This suggest a relatively stable situation. In 2018 not much changed, but in 2019 the five cross-sectional areas reduce with some ten percent with smaller flow areas going from north (cross-section "1") to south (cross-section "5"). Although year to year differences in river discharge will also have an impact, this may suggest that the flow velocities towards the south, so towards Zalun, increases (roughly with some 10 %). After all, the same volume of water that goes through cross-section "1" also needs to pass cross-section "5". If the riverbed would entirely consist of erodible sediments such as sand, this increase in flow velocity would lead to bed erosion, which, however, is probably prevented due to the presence of less- or non-erodable clay layers at the river bed.

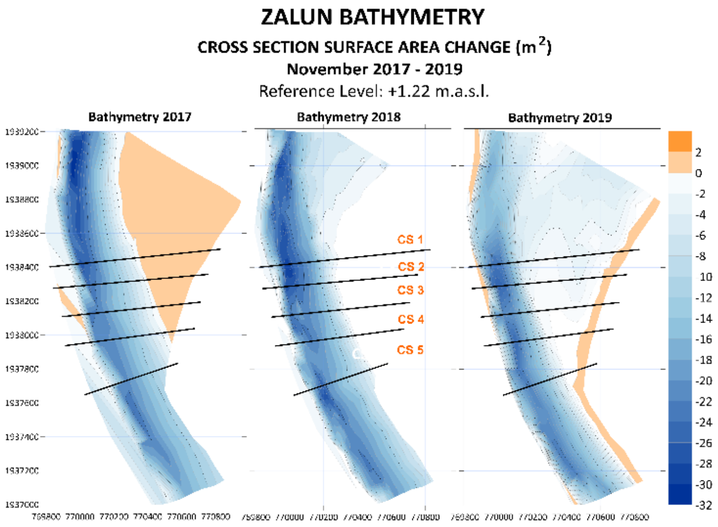

Figure 10 Locations of five cross-sections for calculation of cross-sectional flow area

Based on the above data analysis, the answer to the question "what happened?" can now be summarized as follows:

1. The cut-off channel that was dredged in 2017 rapidly developed into the dominant river channel.
2. This led to a significant erosion of the north bank of the sand bank on the eastside of the river as well as a largely east-to west flow direction towards the westbank around mileage 22.0 - See Figure 7.
3. This changing flow pattern caused serious erosion along the west bank which remained relatively limited thanks to the presence of clay layers on the riverbed and bank.
4. Due to the fast migration and re-orientation of the new river channel, the most exposed part of the west bank moved southwards and has reached Zalun in 2019 – see Figure 8.
5. There is a serious threat to the stability of the embankment and revetment at Zalun, partly because of the erosion and partly because of increased probability for landslides.

2.2 What will happen?

The more complex a system, the less predictable it becomes. Or in other words: the time horizon on which morphological changes can be predicted becomes shorter for more complex systems. It may be possible to predict the situation as this may occur after a few weeks, but certainly not over a period of a few years. With this in mind, an attempt was made to predict the situation for November 2020. It has been assumed that no measures are implemented in the meantime that significantly change the river system. In the next Chapter it is explained that the measures currently underway are not expected to have such significant impact.

To make a prediction it is important to recognize "signs of change". These are morphological changes that may alter the current morphological developments: "game changers", so to speak. One of these signs is the formation of sand bars at the southern end of the cut-off channel. This could be a sign for relatively less river discharge going through this channel, which can be a sign of channel instability. On the other hand, this situation may also change in the wet season when water levels are generally 7 m higher and most sand banks are completely flooded and overflown.

Another possible "sign of change" can be the observed erosion near location "1" in Figure 7. It is possible that here a new side-branch of the cut-off channel develops, which may divert part of the river discharge away from the cut-off channel. This would then result in further shallowing (and narrowing) of the cut-off channel. It is possible that this new side-channel may further grow and develop into a major river branch which may meander towards the west as this has occurred for many decades in the past. Figure 11 shows how this may look like in November 2020. It would give some relief to the erosion along the west bank because the direction of the flow then becomes more parallel to the river axis instead of under an angle to it.

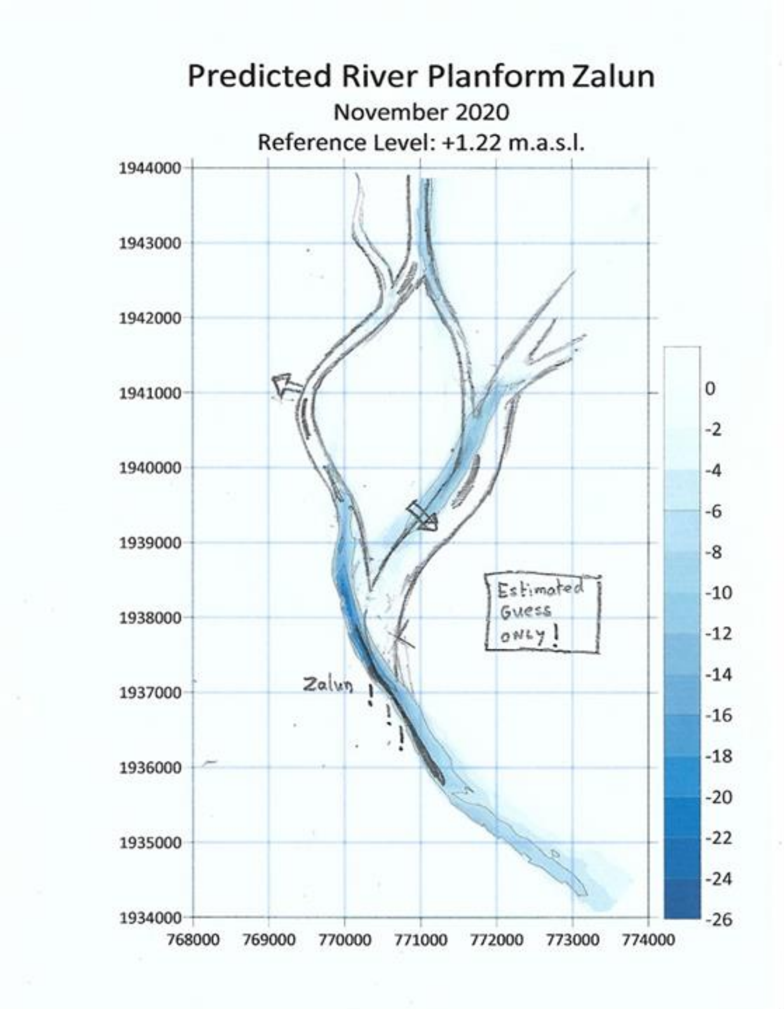

Figure 11 Estimated guess of bathymetry November 2020

Although this possible development seems promising, it will not give immediate relief to the erosion situation at Zalun. Thanks to the presence of poorly-erodable clay layers, the erosion will be limited, but can at some place still be several meters. However, the safety situation is already urgent today because the revetment has already been damaged, and because landslides can occur due to unstable riverbank (underwater and above water profile).

The erosion along the west bank is expected to continue to shift southwards in front and south of the city of Zalun. The bank sections north of Zalun which currently experience the heaviest erosion, may then experience sedimentation again. This means that protecting the currently eroding sections may not be the best strategy as the erosion zone gradually shifts southwards.

On an even smaller scale, and on very short notice (i.e. coming wet season), the revetment at Zalun is under serious threat. The left photo in Figure 3 clearly shows the current structural damage. When the water level rises again from May onwards, the river flow will most likely further damage the structure.

It is difficult to predict what will happen on the east bank of the river. On the one hand more sediment will be deposited which is eroded away from the various sand bars and floodplain. The whole east bank has been built with such eroded sediment because the east bank is the inner bank of the river channel where sediments are being deposited. Most likely the east bank will continue to grow in size on the short term, but if the re-organization the main channel pattern upstream continues (illustrated in Figure 11), then the deposited sediments may also be washed away resulting in bank erosion on the east side. The latter, however, will not be experienced as a problem because this sand bar is not inhabited nor used.

In summary, it can be concluded that the erosion problems along the riverbank at Zalun remain critical for at least one more year, with a potential natural relief later when the erosion may (partly) shift to the east bank. However, such relocation of erosion area remains highly uncertain and regular (quarterly) monitoring and analysis of the morphological changes are important to regularly update the prediction and adjust planned interventions. The latter requires an adaptive approach towards intervening in the river system based on regular updates, which however, is not the way to plan and finance (emergency) measures in Myanmar.

3 REVIEW OF PROTECTIVE ACTIONS CURRENTLY IN EXECUTION

To avoid undermining of embankments on the west bank in the coming wet season, DWIR is currently undertaking various precautionary measures with very limited funds (understood to be less than 180,000 USD, or 270 M MMK)).

Figure 12 shows the planned activities at two key locations (indicated with A and B), i.e.:

- the construction of provisional slope protection using sand-filled barrels near mileages 22 to 24 as an outer-bend erosion prevention measure (A); and
- the excavation of a new 70m long and 5 m deep channel through the sand bank on the east river bank (B).

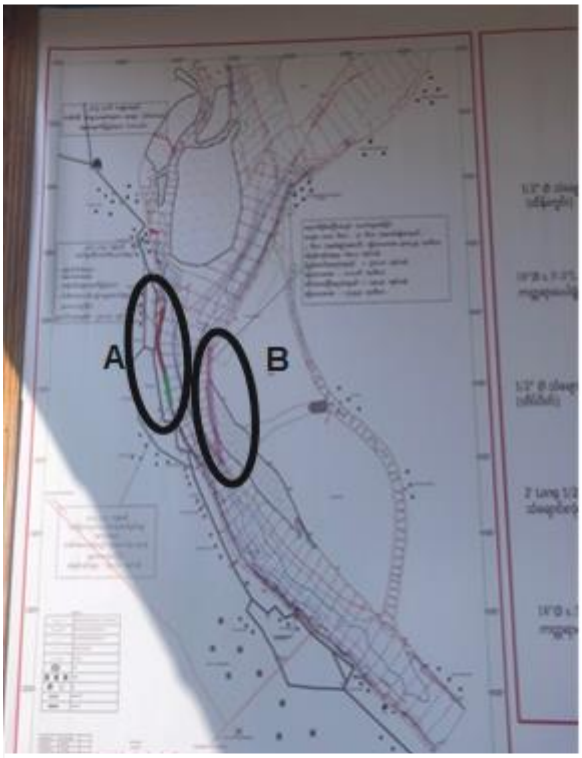

Figure 12 Emergency measures currently undertaken

The “barrel measure” (A)

The outer-bend erosion protection (A), referred to as the barrel measure hereinafter, consists of old (rusty) barrels that are filled up with sand using polyethylene woven bags. The barrels are either placed in a triangular formation or are stacked on top of each other (Figure 13, left). Subsequently, the barrel-constructions are placed at 5 feet intervals (10 feet spacing if measured from centre to centre) and are fixed at the head of the slope around a wooden pole (Figure 13, middle). The downslope situated barrel constructions are attached to the topmost barrels using thick ropes, this prevents the barrels to shift downward during the (monsoon) flows and aims to optimize the slope protection.

Whereas the applied barrel measure is possibly the only possible measure given the limited budget (said to be 30.000 USD), the local DWIR staff indicated that some barrels were found at the toe of the slope, hence the protection measure might not last throughout the full wet season.

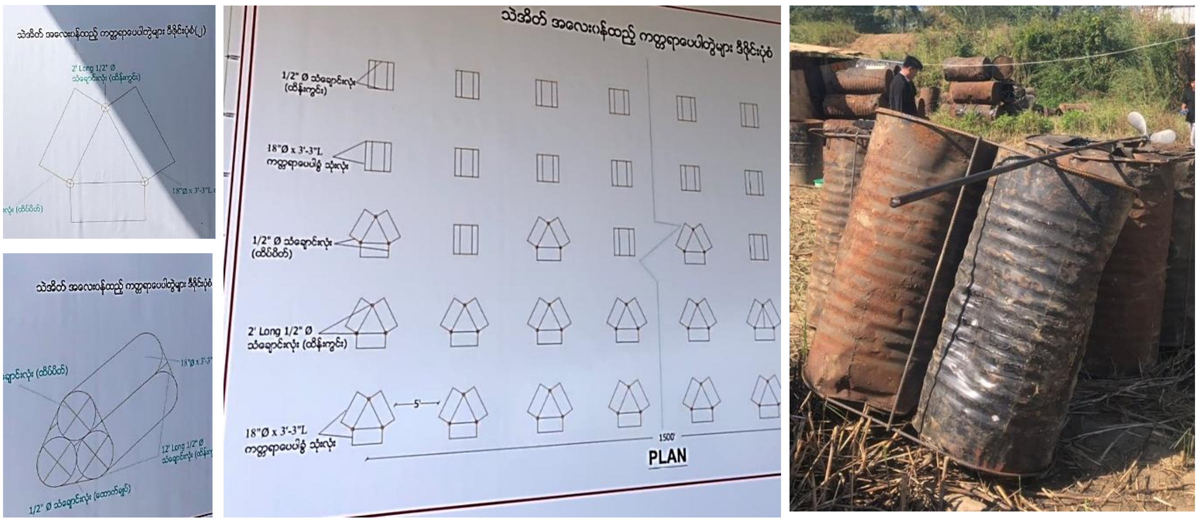

Figure 13: Barrels in triangular formation (top left); Stacked Barrels (bottom left; right); Overview of the barrel measure (middle).

Additionally, considering the use of sparsely distributed protection elements (the barrels), rather than full slope covering protection works (such as revetments), one could argue that the subsequent flow turbulence around the barrels could worsen the slope stability. However, following soil sampling of the river bed and bank during the field inspection (Figure 14 and Appendix B), various silt/clay layers were found indicating that the impact of turbulence might be limited as compared to dominant sand-bed river systems.

Figure 14: Clear Clay formation found along the riverbank

In addition to the possible problems following the construction method of the barrel measure, it is argued that more is required than post-erosion attack mitigation measures (emergency adaptation). This is especially pivotal as major rivers, such as the Ayeyarwady, are characterized by continuously shifting location of erosive attack (Figure 15, left).

In addition to these inherent characteristics of erosion behavior in major rivers, the actual erosion prevention/mitigation measures should also be sufficiently long so that the measure itself does not lead to a direct shifting of the erosive attack as illustrated in Figure 15 (right).

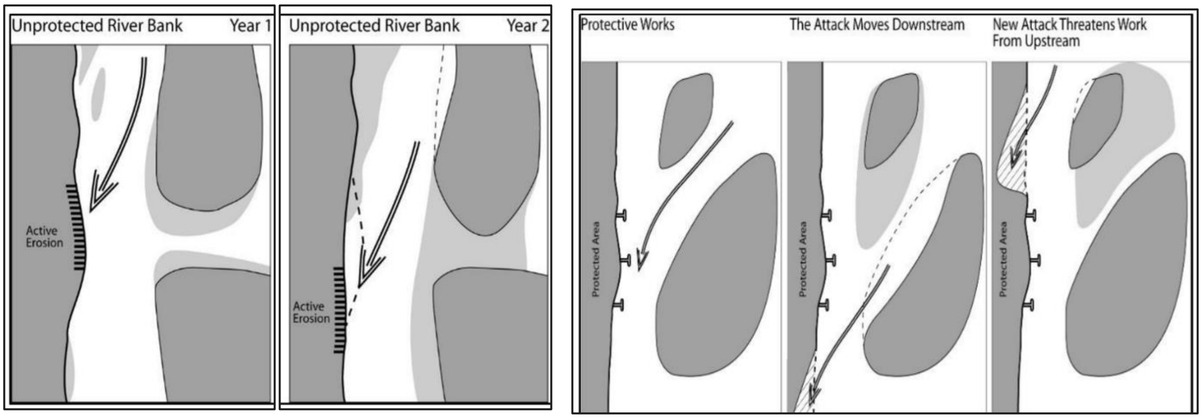

Figure 15: Major rivers are characterized by permanently shifting locations of erosive attack on riverbanks (left); Frequent problems with too short riverbank protection (right).

Therefore, the Zalun riverbank erosion prevention requires - apart from careful preparation and implementation - extensive and effective monitoring and surveying so to keep track of whether the barrel construction remain in place throughout the wet season. This could be realized by multi-beam surveying. Effective surveying and bathymetric analysis will allow DWIR to better cope with the unpredictability inherent to major river systems. This is especially relevant as in monsoon dominated river systems, where the difference between dry season and wet season flows is significant, designs and planning can only be realized one year at a time, i.e. what is built in year one, will change the river morphology in year two. Hence the design for riverbank protection in year two can only be made once the response to the year one construction is visible, measured and presented. This asks for a more adaptive approach towards river engineering works.

The new channel (B)

The second measure that is currently implemented is the excavation of a new channel across the sand bank on the east bank. The actual dredging is done by a cutter suction dredger with the sediment disposal site at some 30 m distance into the river. The idea is that the disposed sediment is transported away by the river flow (Figure 17). In addition to the actual dredging, excavators and bulldozers clear and level the ground to be dredged.

The impact of the new channel is not certain. In the wet season the sand bank will be flooded and flow will go over it most likely under an angle with the dredged new channel. Given the expected high sediment transport rates (which is proven by the rapid growth in the past of the whole sand bank) and the relatively small dimensions of the newly dredged channel, it is likely that the new channel will completely silt up during the wet season. In addition to this it is also likely that on both ends of the new channel strong sedimentation will block the in- and outflow which will accelerate the abandonment of this new channel. As such, therefore, it is unlikely that the new channel (intervention B) will have much impact on reducing the flow velocities near the river's west bank or near Zalun.

If, on the other hand, the new channel would indeed attract flow and play a role in the river run-off, then the new channel may also develop into a larger river channel. And if that happens, then a portion of the river discharge will be directed towards the westbank at Zalun, in theory worsening the local safety situation (Figure 15 – left, and Figure 16).

Figure 17 (left to right); formed sand point-bar across mileages 22 to 24; dredger pipeline; dredged sand/water being released back into the Ayeyarwady River.

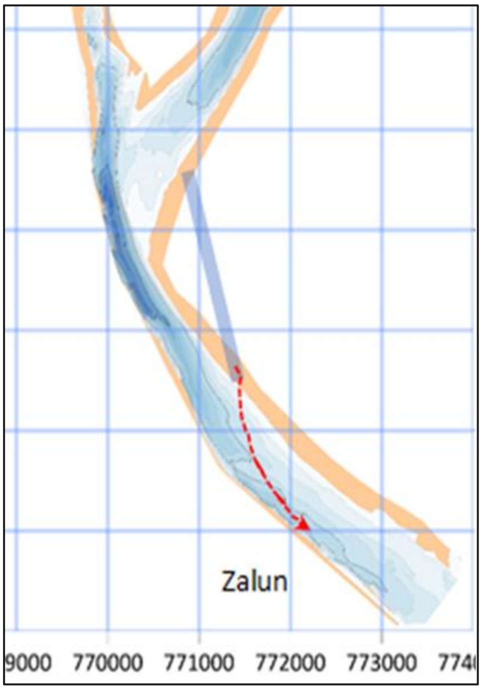

Figure 16 The possible erosive attach on the Zalun west bank following the new excavated canal

Hence, it has been observed that the current measures taken to overcome the challenges arising from river bank erosion are mostly emergency related rather than being part of a long-term vision and strategy. Whereas part of this can be contributed to the planning and financing rules (i.e. money is assigned to emergency cases mostly and is very limited in general), it would be in the interest of the Ayeyarwady River and its surrounding riverbank communities if a more long-term plan is to be developed in which monitoring and evaluation play an important role in the decision-making.

4 RECOMMENDATIONS

In order to overcome the annual erosion/sedimentation induced problems that are likely to continue to occur if no long-term planning is done, a set of holistic measures is presented below. Whereas in ideal circumstances all recommendations should be considered and accounted for, some of them have a higher priority. Figure 18 presents an overview of the proposed alternative options which are explained below.

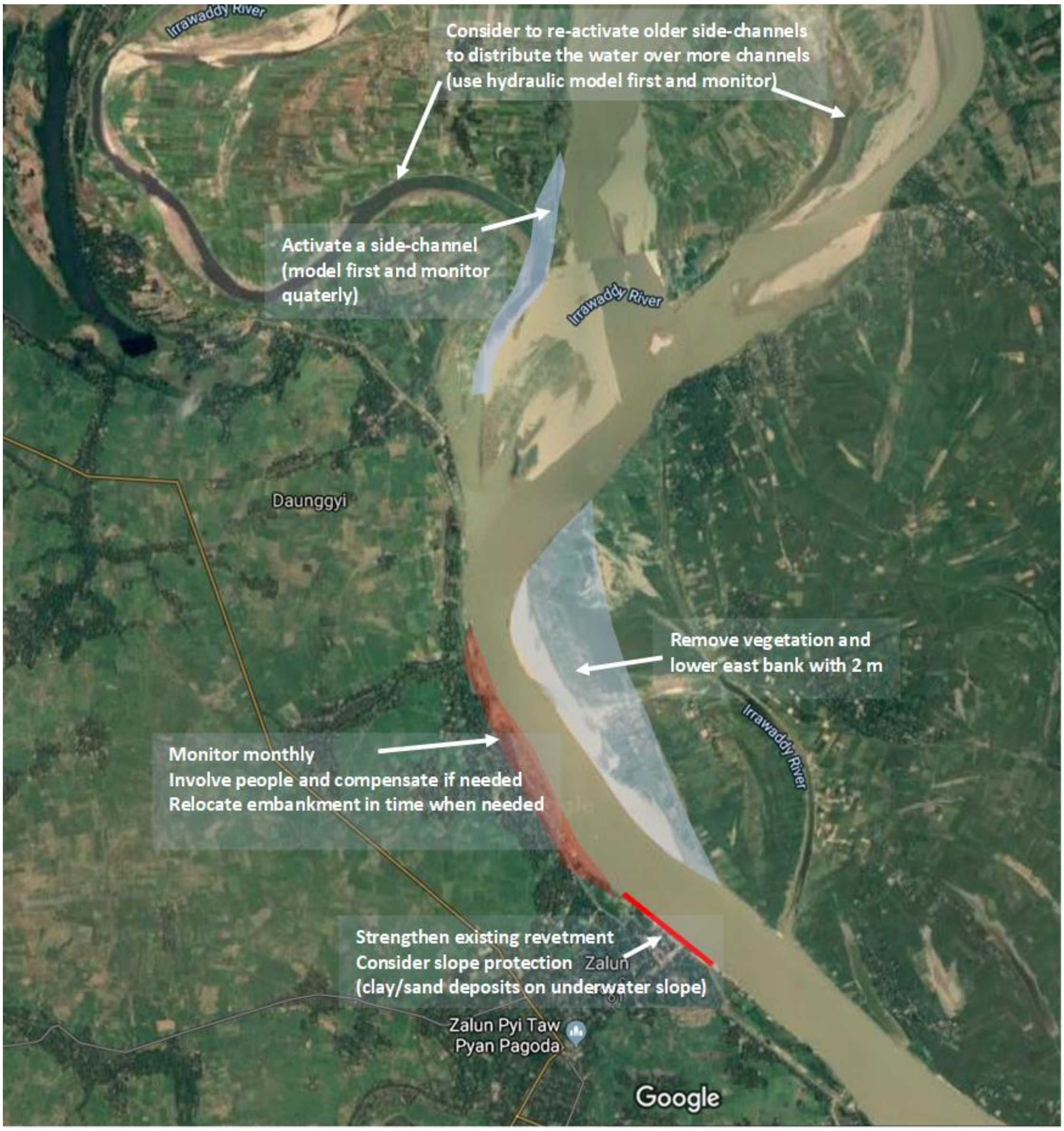

Figure 18 summary of proposed alternative options

The first, and foremost most important measure that should be taken is the rehabilitation of the failed revetment near Zalun so that the coming 2020 flood season does not deteriorate the current situation. Best option to do this is by covering the failed revetment works with sand-filled geobags. This is a cost-effective solution given the required urgency. In the long run a strong revetment at Zalun, built both above and under water with a sufficiently long falling apron, is the only way to stop the local bank erosion. However, it is hardly possible to build (17 m deep and 8 m high with already very steep slopes 1:2) and it will be very expensive (estimated at least 6000-10000 USD/m). In case the latter would be preferred in the long run, it is uncertain whether such a project has a feasible cost-recovery which implies that the avoidance of (monetary) damage to be larger than the costs for preventing this damage. We are not convinced this to be the case at Zalun.

Whereas a revetment in front of Zalun may be considered, constructing such expensive bank protection measure for the largely agricultural area north of Zalun is not anticipated to be cost-effective. Here, the economic value of the hinterland and its households is not likely to balance with the cost of potential avoidance of damage. This is related to the fact that the area comprises mostly out of agricultural areas and smaller community villages.

Some of these villagers already have been relocated in the past after the construction of (locally) secondary embankments. In Appendix A their main concerns are reported from the held interviews. Nonetheless, not stopping the bank erosion here, must not lead to the risk of flooding of the hinterland. Consequently, it is recommended to closely monitor the bathymetric development at these sections (every month). An alternative option here is to build a secondary or tertiary embankment at sufficient distance to secure flood safety of this hinterland while limiting the investment cost.

It is recommended that quarterly single-beam surveying of the full river channel and lower-economic critical sections surrounding Zalun is done (same area as in Figure 6). In addition, monthly multi-beam monitoring of the riverbed of the specific locations where measures are implemented is required. For example, the multi-beam bathymetry would allow to detect before, during and after the wet season how the barrels are positioned on the slope and whether they are changing position over time. In addition to bathymetric data, it is helpful if ADCP data is collected as it will allow to relate any bathymetric changes to specific current flow patterns. These two types of monitoring, if done consistently, will yield a better understanding of the annual river morphology and will allow to better capture the effectivity of current and to-be implemented measures.

Whereas the above measures are potential game changers effective in the short run, the other proposed measures as depicted in Figure 18 will help resolve the current threats in the long run. Hereto, it is pivotal that the river gains more space in both horizontal and vertical direction.

We consider the current dredging of the channel through the east sand bank not desirable because (i) we expect the channel to silt up soon after its construction in the first months of the wet season, or in contrast (ii) the event that the channel does become a significant flow channel, this channel may further aggravate the erosion at the Zalun bank as more river discharge will approach its west bank more directly. As an alternative option, it may be considered to remove the current vegetation on the flood plain/sand bank on the east and to lower it with say 2 m. This gives another 2000 m^2 cross-sectional flow area which is significant compared to the cross-sectional flow areas presented in Table 1 (between 5000 and 6000 m^2). Note that the flow resistance will be higher due to shallower depths, but nevertheless it can be expected that it has a noticeable impact on the flow distribution on the short term. If the quality of the sand is good enough, this sand can also be removed from the river system and sold to compensate for the costs via a Public Private Partnership (PPP). The advantage of such eastern bank modification is that water from the upper cut-off channel can flow over it more easily (decreased flow resistance) and enter the main channel more gradually thereby decreasing the impact of erosive attack on the west bank near Zalun as it may lower the flow velocities directed under an angle towards the west bank.

To “help nature a bit”, we recommend to investigate the impact of excavating a connection channel between the “old” cut-off channel and a possible new side branch (“1” in Figure 7). This would lead water more parallel into the river and therefore decrease the flow attack on the westbank near Zalun currently induced by dominant flows coming from the eastern two current dominant channels.

Lastly, and of lesser importance/urgency compared to the above recommendations, is the possible re-activation of some of the upstream side-channels north and next to the cut-off channel.

As the above two branch redirecting measures are guesses based on the analysis of a few bathymetric maps and a field inspection only, we advise to make a model in which the suggested morphological adjustments are being modelled to see how flow patterns and velocities indeed may change.

Whereas the above recommendations are directly related to the problems observed near and surrounding Zalun, it would be in the interest of DWIR to consider that the changes implemented near Zalun will have an impact on the upstream and particularly downstream Ayeyarwady areas. Therefore, we recommend to discuss different planning and financing options for river & embankment maintenance & repair works by enabling frequent monitoring, modelling and analysis of and on the Ayeyarwady River. Subsequently, the time-series monitoring data can allow to make predictions and establish forecasts that can be (say twice a year) adjusted as more monitoring surveys become available. With these predictions and forecasts, design plans can be formulated which will strengthen the implementation of new measures. It is pivotal that this monitoring and holistic planning translates into a step-by-step guidance, adapting the river system from upstream to downstream direction, on projects. Hence, not a project by project approach which therefore requires a budget that can be used to focus on specific areas based on the made predictions. In such budgeting and planning, PPP for sand-mining could be combined with strategic dredging solutions.

On a river-planform scale, such monitoring and planning could allow to come up with a holistic plan in which a low and high flow corridor are established. Such a high flow corridor would allow to carry the monsoon flows while enabling the use for agriculture/livestock during the dry season. In addition, such corridor establishment requires good understanding of the river dynamics and therefore the monitoring is key. For the high flow corridor to be determined, the set-back line, i.e. the line behind which no meanders would be expected, needs to be defined and a policy limiting the construction of hard infrastructure in this area need to be enforced. In case towns, cultural heritage and/or other critical infrastructure is already in between these two river corridors, these could be protected with strong revetments that connect underwater and above water profiles. Costs for such strong revetments will be in the order of 5 – 10 M USD per km depending on local situation.

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APPENDIX A STAKEHOLDER CONSULTATION

The field inspection took place on 27 january 2020. The area was inspected by boat, by car, by scooter and by foot. A number of local people were interviewed to understand their concerns and their knowledge about the erosion situation. At three locations more in-depth interviews were held, the outcomes of which are presented below.

Conversation Point 1

- When the primary embankment broke down, this family moved behind the secondary embankment. They were not provided with any kind of relocation area nor compensation for their lost livelihood. They searched and purchased their new home and cultivated the new land themselves. The area nearby the river from which they had to move, is still their own property and they continue to grow vegetables until it is fully eroded.
- They are concerned that there will be erosion near the secondary embankment as well. They mentioned that if a failure of the second embankment would occur, and if as a consequence a new (third) embankment is to be built on their lands, the government will provide only 500,000 mmk as compensation. The interviewed persons find this compensation much too little.
- The interview persons further argued that they do not want any sort of erosion on any side of the river. They think that the other bank of the river will start to erode when their river side is prevented from erosion. They do not want anyone to be in trouble following the on-going riverbank erosion and therefore they would rather have a straight channel.

Conversation Point 2

- This and other (around 5) families are still living on the riverbank. They have observed that for the past two years the area has been undergoing deposition rather than erosion (which was last observed in 2017). Therefore, this household does not have a current concern regarding bank erosion.
- They will stay there for as long as possible as they have nowhere else to move.
- They thought that the old boat filled with stones might slightly prevent the on-going riverbank erosion.

Conversation Point 3

- The nearly 15 houses are located between the embankment and the riverbank, on top of the old embankment. Most of them are sued by IWUMD officers because they have broken the rule which prohibits anyone to live within 100 feet of the embankment.
- Although they have been sued, they have to stay in this area and cannot move to other places. While compensation to move has been offered, they still want to live near this place where no erosion occurs as they know how to live and earn money in this area only.
- They have seen the river bank protection with the old boats filled with stones, so they thought that it might save the river bank.

APPENDIX B SEDIMENT SAMPLING

On 27 January 2020 five river bed (with Van Veen grab) and river bank (by hand) sediment samples were taken and visually analysed. The five locations are shown in the map; photoos of the collected samples with a brief description is given below.

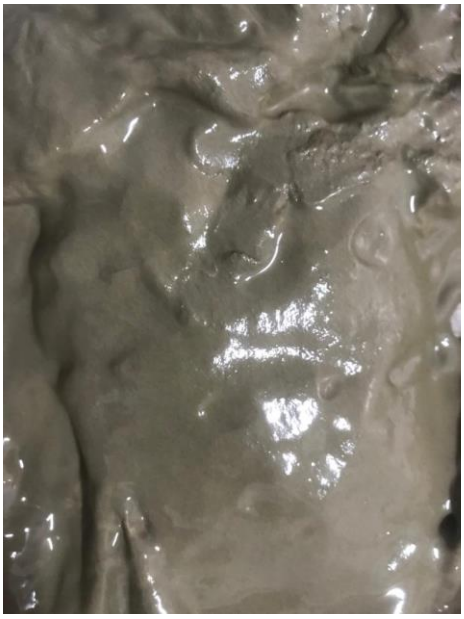
<u>From the river bank at eroded section (near mileage 22.0):</u>

Dark Grey Silt with Sand

Brown Yellow Fine Sand

From the river bed:

in front of the eroding west bank: near the south end of the cut-off channel:



River bed in front of eroding section: Soft Clay Coarse Sand (>0,500 mm) with Gravel

Near Zalun revetment

Brown Grey Silt

COLOPHON

RAPID ASSESSMENT OF ZALUN BANK EROSION
FIELD INSPECTION, DIAGNOSIS AND FIRST RECOMMENDATIONS

CLIENT
RVO in collaboration with DWIR

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