Tat Lan Hydrological Masterplan

Volume I: Introduction and design standards

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CDN
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CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

One of the main focus areas of the Tat Lan programme, funded by LIFT and to be implemented in the coming years, is the rehabilitation of embankments and other water-related infrastructure. During the development of the call for proposals, a group of NGOs conducted an extensive assessment of embankments that need rehabilitation in the targeted townships (it was included as Annex D in the Tat Lan documentation). The conclusion of the embankment study is that approximately 640 km of embankments in the area still need repair, and that 304 new sluicegates need to be constructed.
While the embankment study has generated a large amount of valuable information, highlights a number of key lessons learnt, and correctly points to the importance of solid compaction and of adequate sluices, there is a need for more understanding on several topics:

- First of all, the data are not complete. The list of villages studied in the embankment study and the villages mentioned in the Tat Lan village list are not entirely the same – some villages in the embankment study are not on the Tat Lan village list (including a large area in the south of Myebon Township), while some villages on the Tat Lan village list were not included in the embankment study[1].
- Secondly, any embankment construction must be based on a solid hydrological understanding of its surroundings. In quite a few locations, multiple villages have their fields in the same catchment. Repairing a stretch of embankment in one village may be pointless if embankments in adjoining villages are not repaired: the water will simply flow through the other gaps and still affect the polder. Also, in some cases it may be less work to combine adjoining polders and repair/create a single embankment around them than to repair embankments around each individual smaller polder. The planning of embankment repairs must be done based on the selection of hydrological units (polders / catchment areas), rather than on the selection of individual villages.
- Thirdly, the embankment study rightly points to the importance of having enough sluices to allow drainage of excess water. Overtopping from inside the embankments due to excess rainfall is mentioned as an important cause of embankment failure apart from embankments being damaged by the sea. However, there is no hydrological analysis underlying the embankment study's recommendations for which types/sizes of sluices must be constructed in which location. In order to ensure sustainability of the embankments and sluices, is absolutely essential that sluice designs are based on an analysis of expected peak outflow volumes for each specific polder.
- Fourthly, the Tat Lan documents speak not only of embankment repair, but also of other water-related infrastructure: irrigation / water harvesting for dry season crop production, and drinking water ponds. These were not included in the embankment study.

In order to address these issues, LIFT asked CDN to conduct a masterplan study of water-related infrastructure development in the Tat Lan project area. This report presents the findings of that study.

This study provides inputs for the village-based planning processes that lies at the heart of the Tat Lan programme implementation methodology. It will also help the implementing partners make informed decisions about the allocation of scarce resources in such a way that it genuinely contributes to improved agricultural production, and not only to a short-term increase in income through cash-for-work activities.

[1] Note however that the Tat Lan village list (Annex E to the call for proposals) is not entirely unambiguous, especially for Kyaukpyu. For this reason, LIFT developed a new list for Kyaukpyu Township.

1.2 METHODOLOGY

The master plan study has been conducted using a combination of methods:

First, an analysis was done of available Google Earth imagery for each village, in combination with information (if available) from the embankment study. Possible sites for water harvesting / irrigation development were identified, and coordinates were marked. Where several villages together are located in one hydrological unit (a stream catchment, a polder, or an island), the analysis was done jointly for these villages.

This analysis was shared with the teams that did the field assessment. These field teams visited the respective hydrological units. There, they had discussions with people from the area and inspected specific interesting locations (embankments, sluices, possible dam sites, etc.). Details on these inspections were recorded on a set of standard forms.
See the annexed documents for more details on the field assessment.

Separately, available rainfall data was analysed and design values for peak rainfall and peak outflow from catchment areas were worked out. These design values were then used for making polder-specific recommendations for sluice sizes.
For those potential reservoir locations that were found to be interesting enough for further study, the estimated annual inflow into such reservoirs and the estimated acreage that can be irrigated from such reservoirs were calculated.

1.3 STRUCTURE OF THE REPORT

The report consists of three volumes, with the following table of contents:

- **Volume I: Overall analysis**
  - Chapter 1: Introduction
  - Chapter 2: Sea water levels and embankment designs
  - Chapter 3: Rainfall, runoff and design sluicegate capacities

- **Volume II: Detailed analysis of areas assessed until December 2012**
  - Chapter 4: Minbya Township

- **Volume III: Detailed analysis of remaining areas assessed:**
  - Chapter 5: Myebon Township
  - Chapter 6: Kyaukpyu Township
  - Chapter 7: Pauktaw Township

If the discussions around the selection of target villages for the Tat Lan programme will generate new villages to be assessed, an extra round of assessments will need to be done, and this will be reported on in Volume IV (with a chapter per township).

2 SEA WATER LEVELS AND EMBANKMENT DESIGNS

2.1 FACTORS AFFECTING SEA WATER LEVELS

The main function of embankments is to keep the sea water out. This means that they must have a crest level that is higher than the highest normally expected sea water level.

The sea water level in each location is influenced by different factors: tides, wave height, storm surges and discharge from inland catchment areas.

2.1.1 TIDES

Tides vary from place to place. At Sittwe, the difference between spring high tide and low tide is about 2.6 m. At Kyaukpyu, a difference of about 4 m is found.[2] Field observations in Myebon and Minbya indicate that the tidal difference is around 4.5 m in much of Myebon, about 3 m in much of Minbya, and about 1.5 m in parts of Minbya near the Ann-Sittwe road.

Because the monsoon pushes large volumes of water inland, an additional 0.2 m must be added to the tidal cycle to come to water levels compared to mean sea level (MSL). This gives the following rough estimates for spring high tide and low tide in different areas:

Location	Spring High Tide (+MSL)	Low Tide (+MSL)
Sittwe town	1.5 m	-1.1 m
Kyaukpyu town	2.2 m	-1.8 m
Coastal parts of Kyaukpyu, Myebon and Pauktaw	2.45 m	-2.05 m
Minbya and interior Myebon	1.7 m	-1.3 m
Interior Minbya (near Ann-Sittwe road)	0.95 m	-0.55 m

Very roughly, the area can be divided into three tidal zones as indicated on the figure below.

Figure 1. Estimated boundaries of tidal zones in the Tat Lan program area.

[2] http://www.tides4fishing.com/as/myanmar/kyaukphyu and http://www.tides4fishing.com/as/myanmar/sittwe [accessed 31-12-2012]

In most polders, the average land level is 1' – 2' (0.3-0.6 m) above mean sea level. This means that the highest spring high tide level can be as much as 6' (1.8 m) above the land level in tidal zone I, and as little as 2' (0.6 m) in tidal zone III.

2.1.2 WAVE HEIGHT

On top of the tides, there are waves. During the monsoon, the sea can be very rough. Along the coastlines facing west, and with at most one other island between it and the ocean, wave tops can easily be 0.5 m higher than the spring high tide level. Along coastlines facing east, north or south and along all interior coastlines, the design wave height will not be more than 0.3 m on top of the spring high tide level

2.1.3 STORM SURGES

During cyclones, the wind may push a large volume of water towards the shore, causing an extra increase in the water level. During cyclone Giri, the storm surge was reported to be several metres high in some locations (although these levels may have been combined with high tide levels).
In principle, storm surge levels should be the key factor determining coastal embankment levels. However, the costs of such embankments are so high that it becomes almost impossible to build and maintain them. Due to the lack of resources, storm surges are not taken into consideration for the design of embankments that are constructed under the Tat Lan program. Where embankments are particularly vulnerable or where villages/towns are endangered, the agencies implementing the Tat Lan program should advocate with the Myanmar government for allocating resources for upgrading them.

2.1.4 DISCHARGE FROM INLAND CATCHMENT AREAS

During periods of high flow, estuaries and creeks will act as rivers, and the water level will increase. This increase varies from stream to stream, depending on the cross-section of the stream and the characteristics of the catchment area.

2.2 EMBANKMENT DESIGNS

The embankments will be constructed using locally available soil. In most areas, this will likely be heavy clay. In some areas near hills, it is important to verify the soil type. Soils with a lot of sand and/or silt will require flatter side slopes.
There are three factors that determine the shape of the embankment: crest level, side slopes and crest width. These are discussed in the section below. After that, a section is added on compaction.

2.2.1 CREST LEVEL, CREST WIDTH AND SIDE SLOPES

In order to keep the embankments stable, it is important that no water flows over the embankment.
To ensure this, the embankment must have a **crest level** as high as the annual maximum spring high tide[3] plus a freeboard. Along creeks, the maximum water level may be more related to runoff than to tides. In that case, the crest level must be as high as the high water level plus freeboard.
The embankment study recommended a uniform freeboard of 2 feet. In most cases, this is indeed enough. For some important embankments however (for example along the sea shore, or embankments that protect a village), a freeboard of 3 or 4 feet is needed (more if the damage in case of failure is higher).

The **crest width** depends on the other uses of the embankment. Normally, a crest width of 3 feet will be enough. However, if the embankment is used as a foot/bicycle path, a crest width of 4 feet is needed. If there is motorbike traffic, a crest width of 5 feet is needed. Ox carts and vehicles (if they are there) should be kept off the embankments.

[3] Tides vary throughout the month. Spring tide occurs during full moon. On top of that, there is annual variation in spring high tides, with the highest spring high tide occurring in the middle of the year.

The embankment study recommended **sideslopes** of 1:1, considering this to be an acceptable middle between much steeper slopes constructed by farmers and much flatter slopes (up to 1:3) recommended by government engineers.
For the stability of embankments, it is also essential that no water seeps through the embankment and flows out on the other side above ground level. As a practical rule of thumb, the slope between the maximum spring high tide level and the toe of the embankment on the other side must be at least 1:4 for a clay embankment (provided that there is adequate compaction!). For soils other than clay, a more detailed analysis is needed. If this slope is not available, embankments may fail even if the freeboard is enough, and even if there are enough sluices.
An analysis of the maximum embankment height with given values for crest width (C), freeboard (F), and sideslopes (m) is given in the table below.

	C=3', F=2'	C=4', F=2'	C=5', F=2'	C=3', F=3'	C=4', F=3'	C=5', F=3'	C=3', F=4'	C=4', F=4'	C=5', F=4'
m=1:1	H_{max}=4'4"	H_{max}=4'8"	H_{max}=5'	H_{max}=6'	H_{max}=6'4"	H_{max}=6'8"	H_{max}=7'8"	H_{max}=8'	H_{max}=8'4"
m=1:1.5	H_{max}=5'7"	H_{max}=6'	H_{max}=6'5"	H_{max}=7'9"	H_{max}=8'2"	H_{max}=8'7"	H_{max}=10'	H_{max}=10'5"	H_{max}=10'9"
m=1:2	H_{max}=7'6"	H_{max}=8'	H_{max}=8'6"	H_{max}=10'6"	H_{max}=11'	H_{max}=11'6"	H_{max}=13'6"	H_{max}=14'	H_{max}=14'6"
m=1:2.5	H_{max}=10'8"	H_{max}=11'4"	H_{max}=12'	H_{max}=15'	H_{max}=15'8"	H_{max}=16'4"	H_{max}=19'4"	H_{max}=20'	H_{max}=20'8"

Because of the risk of damage by waves and (along creeks) the risk of damage from water flowing quite fast, **the minimum sideslope must be 1:1.5 in almost all locations**. A sideslope of 1:1 can only be considered in situations where the embankment is not along a creek that carries high runoff during the rainy season, and where the embankment is protected against waves by at least 50' of thick mangrove.

If embankments are higher than the values indicated on the lowest line in the table, a custom design is needed.

2.2.2 COMPACTION

As very rightly mentioned in the embankment study report, proper compaction is essential for ensuring the safety of the embankments. This means that the existing embankment must be properly cleaned and the existing sideslopes must be turned into steps. That will ensure that the new soil will bond properly with the existing embankment.
New soil must be added in layers of 6" thickness, and properly compacted. Only after a layer has been compacted can a new layer of soil be added. The embankment study suggested to let added soil settle by itself (thus providing a form of passive compaction). However, if there is heavy rain during the first season after construction, this will likely cause damage to the embankments. Because of that, compaction must be active (using either hand tools or rollers pulled by buffaloes).

This has two important consequences:

- For calculating the volume of earthwork required (design cross-section minus existing cross-section), a factor 1.15 must be added. After compaction, the soil has less volume that the soil had when it was excavated.
- For calculating the cost of embankment works, a factor 1.2 must be applied to the total cost of soil excavation to cover the cost of compaction.

2.2.3 COST CONSIDERATIONS

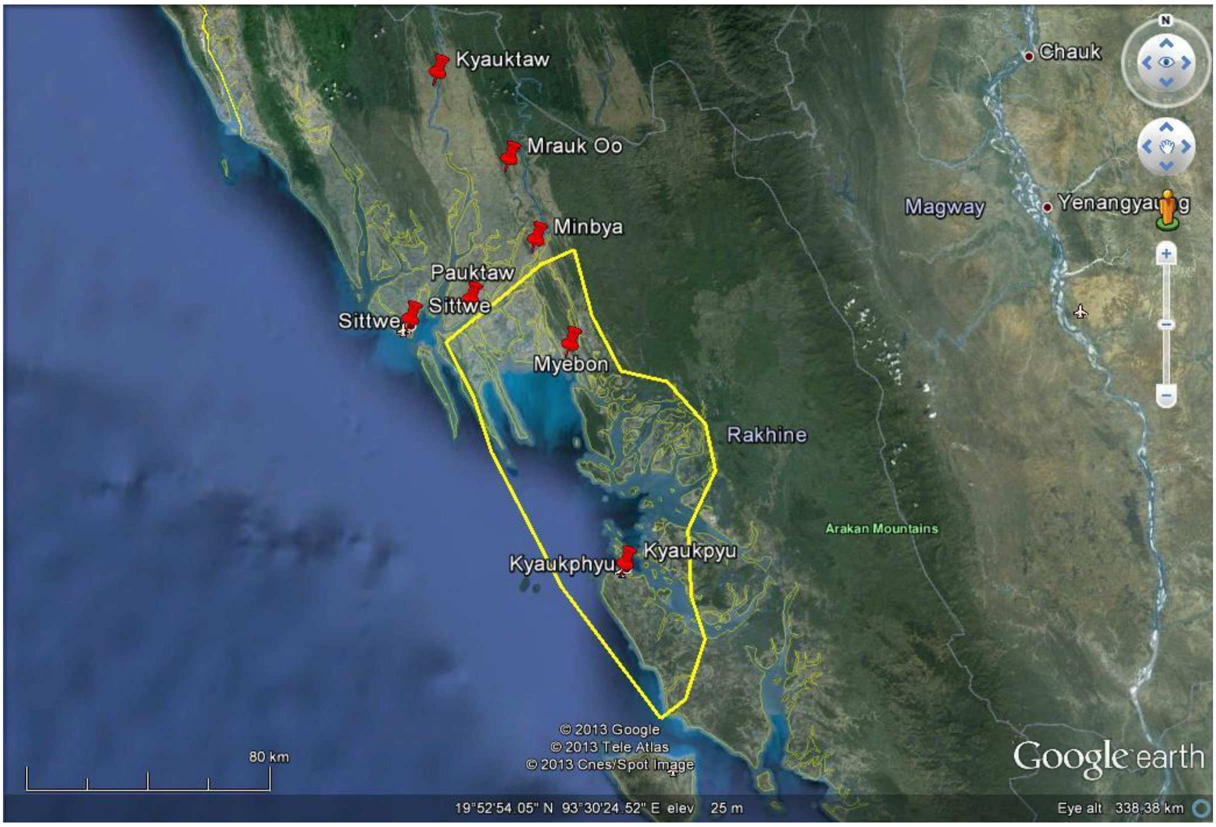
The labour charge for excavating 1 sud (100 cubic feet) of soil is 4,000 MMK. The cost of adding 100 cubic feet to an embankment is 4,000 x 1.15 x 1.2 = (about) 5,500 MMK. This comes to an additional cost of about 38%. This is 8% more than estimated in the embankment study. More importantly, the flatter design side slopes mean that a lot more earthwork is needed in general.
Where the embankment study estimated the average cost of embankments to be 130% x USD 1.8 = USD 2.34 per foot of embankment length, the revised cost estimate calculated by this study is between USD 5 and USD 6.5 per foot of embankment length.
Constructing all the 2.16 million feet of embankments listed in the embankment study would thus cost roughly USD 11-14 million; double the amount budgeted for infrastructure rehabilitation.

3 RAINFALL, RUNOFF AND SLUICE DESIGNS

3.1 RAINFALL

For this assessment, daily rainfall data were obtained for two locations: Sittwe (16 years) and Kyaukpyu (17 years). Monthly rainfall data were collected for these two stations and for five other stations: Minbya, Myebon, Kyauktaw, Pauktaw and Mrauk Oo (11 years, from January 2002 until September 2012). The rainfall data for Pauktaw show an unusual increase in the annual rainfall for 2010, 2011 and 2012 (about 8000 mm in 2011, 3000 mm more rainfall than all other stations in the same year). Because this trend is not followed for other stations, it is assumed that this data is not reliable.

The locations are shown in the figure below. The project area is roughly the area inside the yellow line.



3.1.1 MONTHLY AND ANNUAL RAINFALL

The average monthly rainfall over the period 2002-2011 is shown in the table below (values in mm).

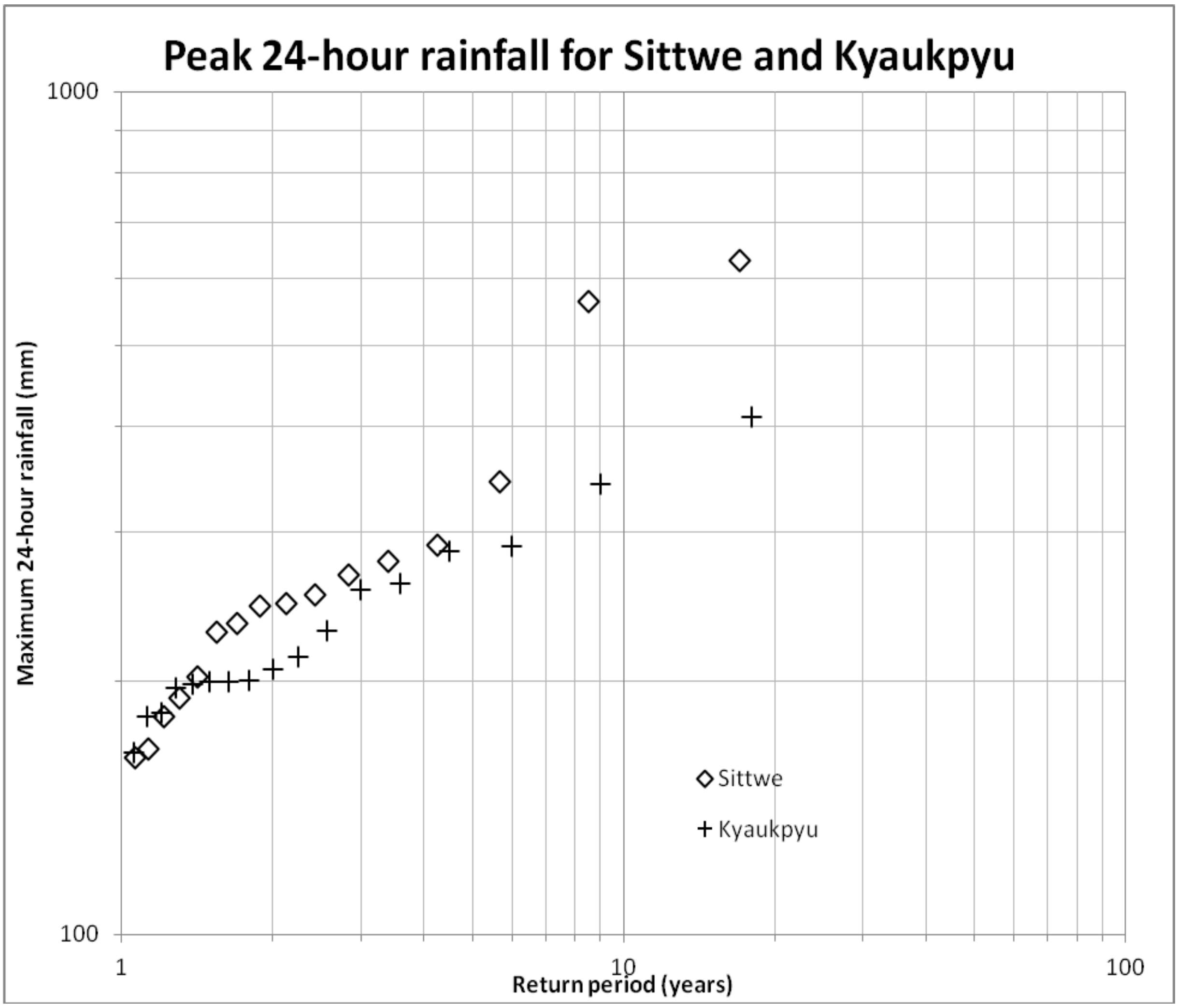
Month	Kyauktaw	Mrauk Oo	Minbya	Sittwe	Myebon	Kyaukpyu
January	7	5	1	1	2	12
February	1	1	1	2	1	1
March	18	7	1	1	5	2
April	57	44	11	23	16	17
May	417	364	351	389	488	427
June	1,039	893	882	1,059	1,024	1,143
July	1,079	1,036	1,069	1,396	1,328	1,325
August	873	739	714	916	1,019	1,094
September	537	503	499	646	650	630
October	300	263	242	370	286	371
November	34	23	42	61	39	94
December	34	27	20	26	34	39
Total	4,395	3,905	3,833	4,891	4,893	5,153

Several conclusions can be drawn from the rainfall data:

- In general, rainfall is exceptionally high in this area.
- Rainfall is concentrated in the rainy season. Outside this period, there is almost no rainfall at all.
- Rainfall along the coast is about 20% higher than in the interior parts of the program area (Minbya)
- The monsoon moves from north to south, which creates a time lag of about two weeks between the north and the south of the program area. In Kyauktaw and Mrauk Oo, the rains begin already in late April, and peak mostly in early July. In Myebon and Kyaukpyu, the rains begin in early May, and peak in mid- to late July.

3.1.2 PEAK RAINFALL

For Sittwe and Kyaukpyu, the maximum rainfall in each year was used to determine how much rainfall can be expected to fall within a period of one, two, three, four and five days. This information is needed to determine drainage capacities of polders and catchment areas (see sections 3.2 and 3.3). A plot of one-day rainfall maxima is presented below.



Using the Log-Pearson type III distribution (corrected for outliers), the following values were calculated for different combinations of duration and return period:

Location	Duration	2 years return period	5 years return period	10 years return period	25 years return period
Sittwe	1 day	240 mm	342 mm	432 mm	579 mm
	2 days	343 mm	483 mm	608 mm	809 mm
	3 days	441 mm	623 mm	774 mm	1,005 mm
	4 days	520 mm	716 mm	865 mm	1,079 mm
	5 days	592 mm	809 mm	971 mm	1,197 mm
	6 days	657 mm	869 mm	1,026 mm	1,243 mm
Kyaukpyu	1 day	220 mm	276 mm	318 mm	379 mm
	2 days	328 mm	410 mm	466 mm	539 mm
	3 days	415 mm	509 mm	573 mm	655 mm
	4 days	488 mm	589 mm	653 mm	730 mm
	5 days	552 mm	643 mm	699 mm	767 mm
	6 days	619 mm	720 mm	777 mm	842 mm

As can be seen, the calculated peak rainfall in Sittwe is much higher than in Kyaukpyu. Precisely what causes this is not clear. In Sittwe two incidences of one-day rainfall around 600 mm were recorded in the past 17 years (631 mm on 14 August 1997[4] and 563 mm on 8 September 2002[5]), while Kyaukpyu the highest measured one-day rainfall was 411 mm. It is thus likely that the estimates for Sittwe are too high, while those for Kyaukpyu are too low. Therefore it is suggested to use the average of the two locations as a quick and dirty estimate for the design rainfall:

Duration	2 years return period	5 years return period	10 years return period	25 years return period
1 day	230 mm	309 mm	375 mm	479 mm
2 days	335 mm	446 mm	537 mm	674 mm
3 days	428 mm	566 mm	673 mm	830 mm
4 days	504 mm	652 mm	759 mm	905 mm
5 days	572 mm	726 mm	835 mm	982 mm
6 days	638 mm	795 mm	902 mm	1,043 mm

3.2 DRAINAGE VOLUMES AND ACRES PER SLUICE

Because there are large tidal variations within the program area (see section 2.1.1), the area that one sluice can serve varies.

In Myanmar, the standard practice for calculating the capacity of drainage systems for paddy areas is that the total amount of rain that falls in six days must be drained in these six days. Using a return period of 10 years, this means that for the Tat Lan program area, the drainage systems (and sluices) must be capable of draining 902 mm in 6 days. Paddy can survive six days of being under water without much damage to the crop, but not much more.
The design rainfall value can be corrected for evaporation, infiltration and evapotranspiration (which are losses out of the system), but not for whatever is buffered in the catchment area. The reason for this is that filling up buffer storage reduces the amount of buffering capacity should another event of heavy rainfall occur.

Because the soil in the polders is heavy clay, and because the most heavy rainfall tends to occur several weeks into the rainy season, it is to be expected that the soil is pretty much saturated when heavy rainfall occurs, and infiltration losses are minimal. A somewhat conservative estimate for losses out of the system is about 5 mm/day, which means that the corrected design value for six-day rainfall is 902 – 6 x 5 = 872 mm. This is the same as 16.8 l/s/ha for the entire six-day period.

[4] This may have been a typing error. On the days before and after 14 August, very little rainfall was recorded in Sittwe. In Kyaukpyu, rainfall was around 20 mm/day in this period.
[5] It looks like this was a correct reading. On 9 and 10 September 2002 heavy rainfall was also recorded in Sittwe. There are no rainfall data available for Kyaukpyu for this month.

Because no water flows through the sluices during high tide, the design capacity of the sluices must be double the average drainage modulus[6]. However, because rainfall is not evenly spread over the six days, this is only possible if there is sufficient buffer capacity in the catchment to store water that falls during the peak of the rainfall period, for release during the days with less rainfall. For the Tat Lan area, the required design buffer capacity is about 2,700 m^3/ha.

Some of this buffer capacity can be found in the creeks, but most of the buffering happens by allowing the paddy fields to get flooded for a few days. In a catchment area with 100% polders, buffering 2,700 m2/ha means that the paddy fields will come under up to 27 cm of water (almost 1 foot). In catchment areas with hills however, the flooding levels in the paddy fields will be higher, because all the buffering must be done in the part of the catchment area that is covered by paddy fields and creeks. If the percentage of hills in the catchment area is too high, the water level in the polder will go above the design maximum of 1.5 times the height of the sluice (measured from the sill of the sluice), and may even go beyond the maximum spring high tide level. That will lead to overtopping of and damage to the embankments.

In order to avoid excessive flooding inside such polders and damage to the embankments, it is necessary to increase the number of sluices such that the maximum water level in the polder stays below 1.5 times the sluice height or below maximum spring high tide level, whichever is lowest.
Increasing the drainage capacity and reducing the buffer capacity is only feasible up a point. The minimum required buffer capacity is the amount that must be stored during high tide on the day with the highest rainfall (and the sluices must have the capacity to drain this water during the subsequent low tide).

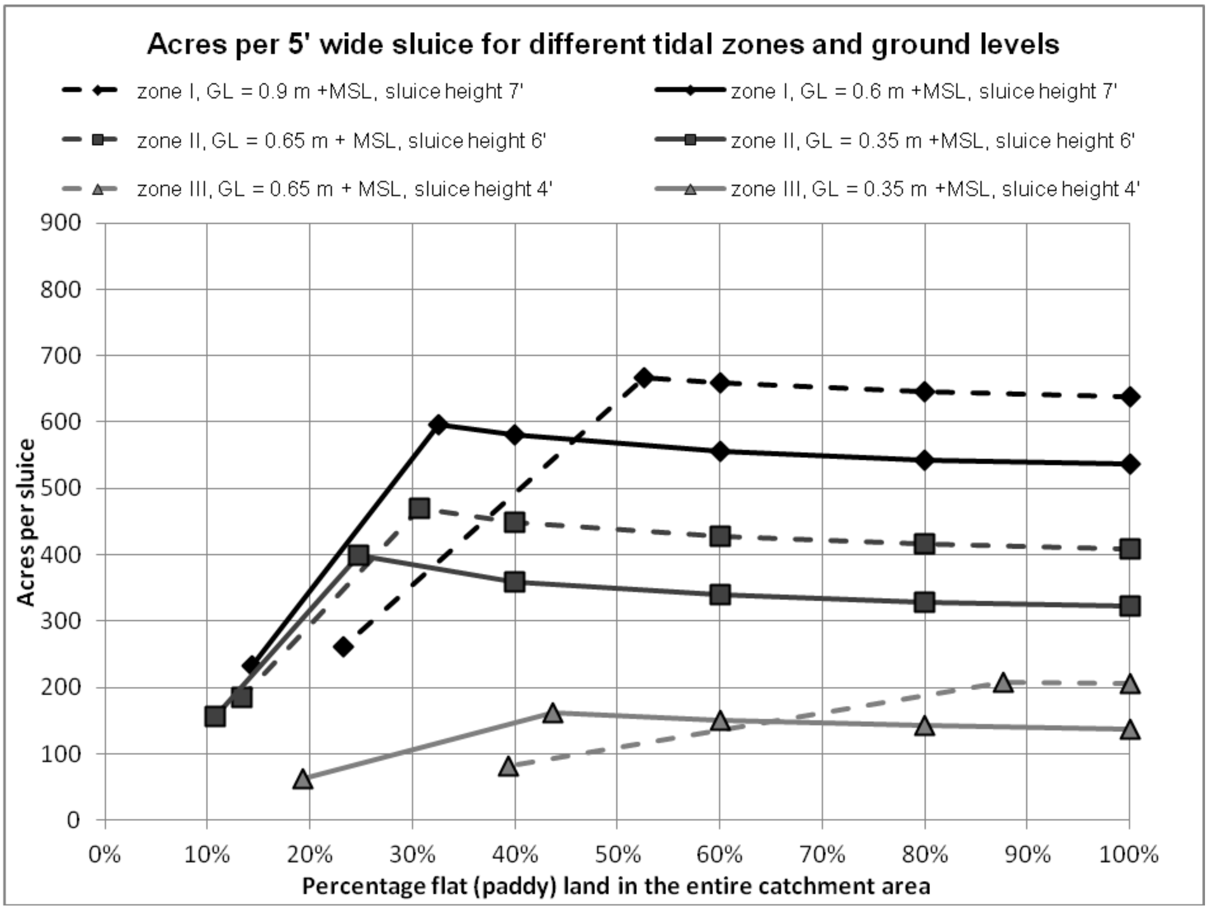
For the three different tidal zones, the maximum area per sluice was calculated for different percentages of polder and hills in the catchment area. This is presented in the graph below. For zone I, the sill level was put at 0.3 m above lowest low tide level (1.75 m –MSL). For zones II and III, the sill level was put at the lowest low tide level (1.3 m –MSL and 0.55 m –MSL, respectively).
Because not all polders have the same level compared to MSL, the two most common options were calculated for each zone. For zone I, the options are 0.6 m +MSL and 0.9 m +MSL , and for zones II and III, the options are 0.35 m +MSL and 0.65 m +MSL. These values are for the average ground level on the land side of the embankments – it is assumed that average polder level is about 0.15 m (6”) higher than that.

All lines in the graph show a slight increase with reducing percentage of polder in the catchment area. This is because as the buffer area is smaller, the buffer height increases – and if the water level goes up, so does the discharge through the sluice.

The point where the acreage per sluice drops sharply is the point where the buffer capacity is so small that the maximum allowable water level is reached. If the percentage of polders reduces further, the buffer volume needs to reduce and the design outflow from the catchment must increase.

The point where the line stops is the point where the buffer capacity in the catchment area is less than necessary for storing the inflow during high tide. If a catchment area has a higher percentage of hills than this point, it is not possible to find a safe and affordable combination of sluices and embankments, and polders are not feasible unless embankments are raised and sluices are made higher.

[6] There will be flow through the sluices for about 13-14 hours per day, of which only about 10 hours are critical flow and the remainder is subcritical flow during the transitions between high and low tides. The total flow is about the same as 12 hours of critical flow, which is half of the time. To drain the full amount in half the time, the average flow through the sluice must be double the drainage modulus.



To give an example: Suppose there is a polder of 400 acres that is bordered by 100 acres of hills that drain into the polder (and not into a separate creek) in the middle of Myebon (Zone II), and that has an average ground level at the embankment of 0.35 m +MSL. In this tidal zone, that means that the highest spring high tide is about 1.35 m (4'6") above ground level.
The catchment consists of 80% polder and 20% hills, which gives a design capacity per sluice of about 320 acres. For a total catchment area of 500 acres, two sluices are needed.

If the same polder was located in interior Minbya (zone III), we need to work with a design capacity of about 140 acres per sluice, which means that four sluices are needed. Because the tidal variation is lower, an average ground level of 0.35 m +MSL is 0.6 m (2') below highest spring high tide.

If the same polder in Minbya would have 20% of polder land and 80% of hills, the design capacity would be around 85 acres per sluice. This means that six sluices are needed.

3.3 SLUICE DESIGN CONSIDERATIONS

3.3.1 TECHNICAL CONSIDERATIONS

There are three options for the design of sluice gates: stop logs, sliding gates or flap gates.
Most traditional sluices are fitted with stop logs. These logs are placed in the sluice at the end of the rainy season, and stay in place until the start of the next rainy season. If there is unseasonal rainfall, it is difficult to remove the stoplogs, and flooding may occur.
Some gates in the Tat Lan target area are fitted with sliding gates, which can be opened or closed by mechanical means. Such gates are easier to adjust than stop logs, but require more frequent adjustments. Because the water flows underneath the gate, the gate needs to be closed as soon as the outside water level is higher than the water level in the polder; otherwise saltwater will flow into the polder. Besides, sliding gates suffer from the same disadvantage as stop logs: if it starts raining,

the sluice needs to be opened, but the sluice is not always easily accessible then (especially during the night).
Flap gates are fixed to the sluice with a hinge. They open automatically when the water level inside the polder is higher than the outside water level, and close automatically when the outside water level exceeds the inside water level. They will prevent both flooding and saltwater intrusion without requiring any direct operation. Because of this, flap gates should be the standard design used for sluices constructed under the Tat Lan program.

The Irrigation Department in Rakhine State works with a standard size for sluices fitted with flap gates of 6' high and 5' wide. It is possible to adjust the height of the flap gates if the sluice is higher or lower, but it is recommended to stick to a width of 5', as wider gates are heavier and harder to maintain.

Steel flap gates are available with the Irrigation Department in Yangon. While these gates are stronger than wooden gates, repairs and especially replacement will be prohibitively expensive for the farmers who will be responsible for them. Therefore, it is recommended to use wooden flap gates. To avoid leakage, proper rubber seals must be fitted.

The sill level of the sluices should be at or slightly below the average low tide level. This ensures maximum outflow through the sluices, while inspection is possible during low tide. If the sill level is above average low tide level, the flow through the sluice will be less, and there is a risk of undermining on the downstream side that can only be addressed by constructing substantial (and expensive!) stilling basins. In tidal zone I, the sill level should be 1' above the lowest low tide level. In tidal zones II and III, the sill level should be at the lowest low tide level.

The height of the sluices must be 7' in zone I, 6' in zone II, and 4' in zone III. This will minimise construction cost while still ensuring optimum capacity of the sluices. This means that the top of the sluice may be below the high tide level. As long as the water level inside the polder remains below about 1.5 times the height of the sluice, the sluice will operate as an overflow weir and not as a submerged culvert. Submerged culverts have a comparatively lower capacity, and may act as a bottleneck if the inflow increases. Because of that, sluices must be designed such that they will always function as overflow weirs.

Sluices must be constructed on a rock foundation wherever possible. If no rock foundation is available, piling is needed – which adds substantially to the cost of the structure.

3.3.2 COST CONSIDERATIONS

The estimated cost of a single 5' x 8' sluice (made of stone masonry, including wooden flap gate and pile foundation) is around MMK 20 million (about USD 25,000). A double sluice costs around MMK 37.5 million (about USD 46,875). Sluices with lower openings cost marginally less, as the bulk of the costs is in the foundation and the concrete slabs underneath and on top of the sluice.
If the sluice is built on a rock foundation, the unit cost is roughly estimated around MMK 12-15 million (USD 15,000-19,000) for a single sluice, and MMK 25-30 million (USD 31,000-37,500) for a double sluice.
The embankment study estimated the unit cost of a sluice to be between USD 4,000 and USD 7,500, depending on the height of the sluice. That is much less than estimated by this study, most probably because pile foundations and flap gates have not been incorporated. Besides, a first very rough estimate of the number of sluices needed indicates that for the polders listed in the embankment study, about 50 more sluices must be constructed than foreseen in the embankment study. Only constructing these sluices will cost USD 5-6 million, almost the entire amount estimated for infrastructure in the embankment study.