Technical Feasibility for Pursat Drainage and Embankment[1]

[1] Prepared by the projection preparation technical assistance (TA 7986-CAM) consultant team.

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A. Introduction

1. This report provides the detailed analysis and technical justification for the flood protection and mitigation works in Pursat.

2. It provides a description of the existing situation and the impact of inundation in the town. Section C forms the options and strategies for flood mitigation, while Section D develops the design and provides a detailed description of the project. Costs are developed in Section E. Benefits and risks are described in Section F and arrangements for implementation and procurement are at Section G. Project sustainability through improved operation and maintenance is covered in the next and final Section.

3. This report aims to provide the technical feasibility for the proposed project, it only alludes to environmental or resettlement issues under risks as these aspects are comprehensively covered in their own sections of the report. Similarly while risks are assessed, the cost-benefit analyses are also covered in their own sections of the report.

4. An overview of Pursat is provided in Section Four of the main report. As such this appendix deals only with the proposed drainage and embankment protection interventions in Pursat.

B. Background to Flooding Issues

1. Existing Situation

5. Pursat is situated 175 kilometers northwest of Phnom Penh on the main highway (NH5) to Battambang and the Thai border at Poipet. It lies on the Pursat River which flows into the Tonle Sap about 20 kilometers west of the town. It is the administrative center of Pursat Province and has a population of around 64,000, of which around 40,000 reside in the urban area. By 2020, Pursat's population is expected to rise to between 60,000 to 65,000[2]. The town center area lies just to the north of NH5 and to the west of the Pursat River and covers approximately 1.5 square kilometers. There is a dense market and commercial area in the southeast section with a few narrow roads, while the rest of the town center comprises low density administration buildings, educational and health care establishments, and residential properties with relatively wide roads and rights of ways. The population of this area is currently around 18,000, although during the day this increases with workers, students, and shoppers.

6. Rising in the Cardomom Mountains to the west of the town, the Pursat River provides mainly amenity value for the town, as well as its main source of drinking water, and is also an important source of irrigation for the surrounding agricultural areas. Although lying between the mountains and the Tonle Sap, Pursat' s town center is relatively flat and varies between 12 to 16 meters above mean sea level (MSL). Figure B.1 shows the layout of Pursat and the river.

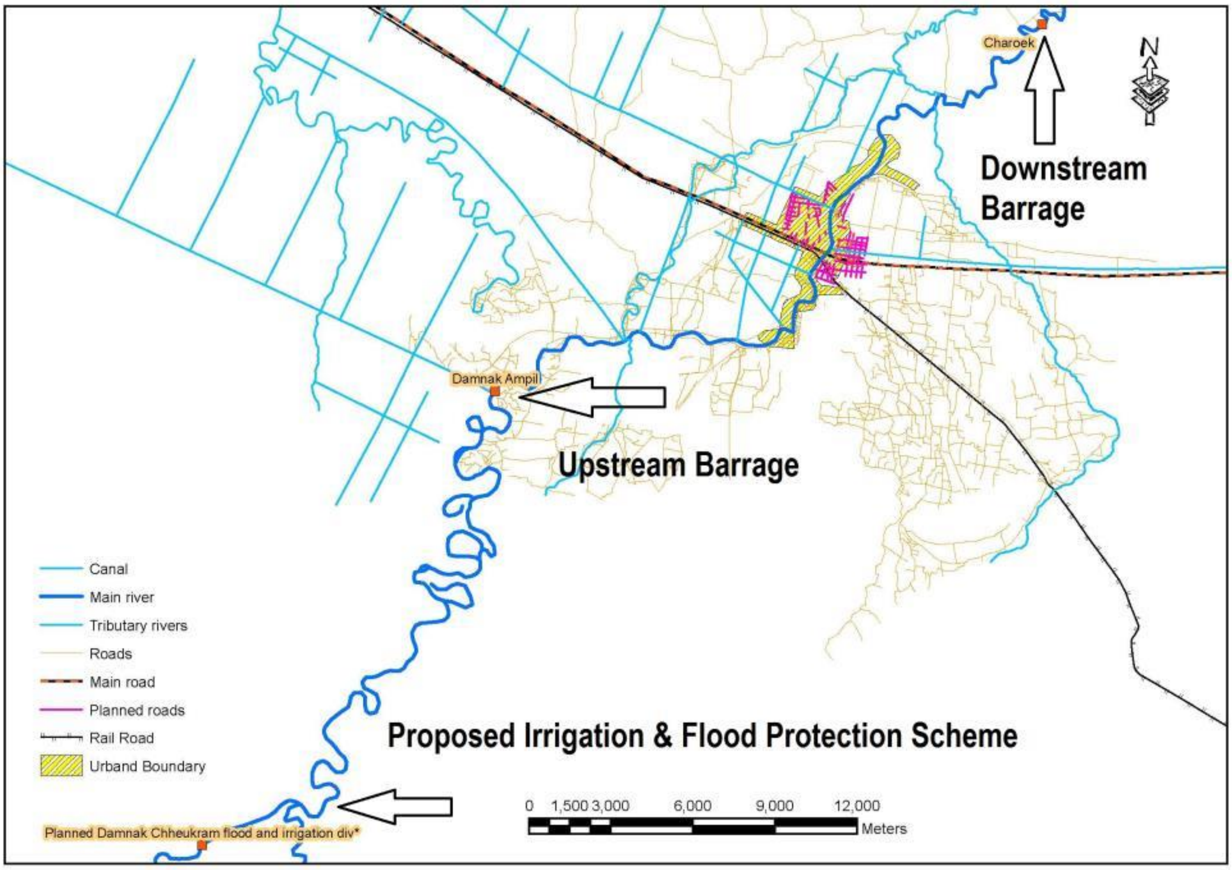
1 7. A major issue in Pursat is flooding. The town center lies in a depression and the natural slope of the town is away from the river. This was possibly created by the training of the Pursat River and raising of embankments that have distorted the river's natural flow. Although there are channels to the northwest of the town where the river could have previously run. There are issues with drainage and high water levels that cause annual flooding from both the Pursat River and rainfall. Flooding can last up to a few weeks. The worst affected area is the town center and along the river banks as the existing

[2] PPTA 7986-CAM consultants estimate based on census data.

embankments are not high enough to protect the town and sandbags are required to protect roads and property. They are placed by both the province and municipality. The river level was reported as being particularly high during the last two years and damaged embankments. The high water levels of the Pursat River between 1996 and 2012 are shown in

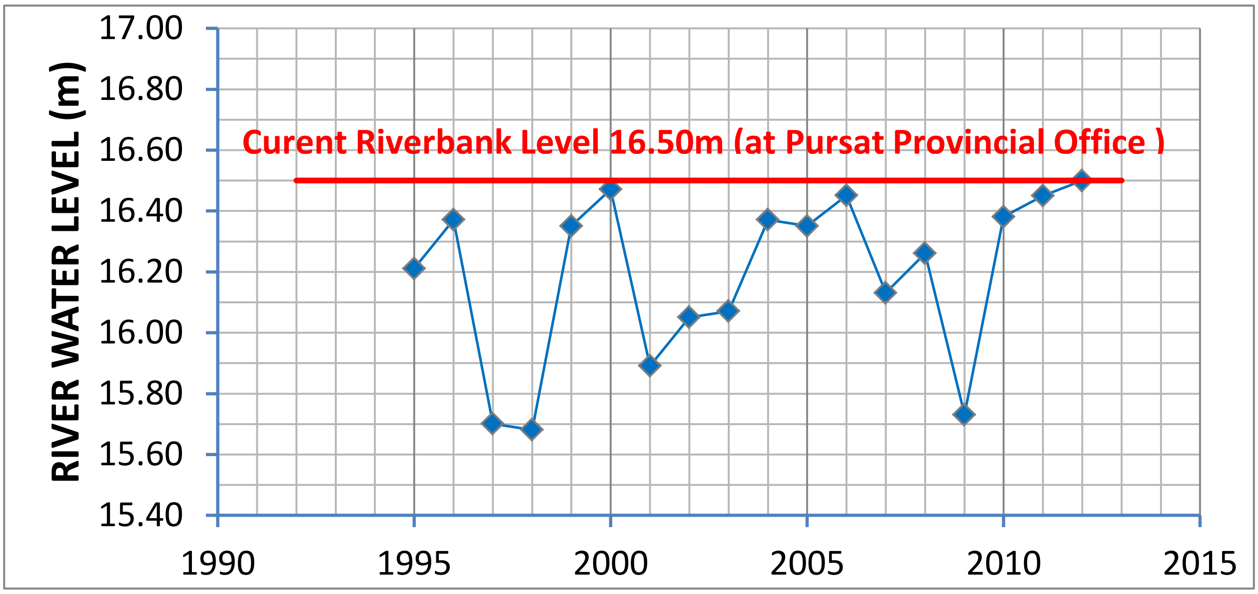
Figure B.2.

Figure B.1 Map of Pursat and Pursat River



Source: TA7986-CAM Consultants

Figure B.2 Annual Flood Levels of the Pursat River in Pursat



Source: TA7986-CAM Consultants

2. Current Issues

8. The town center is the area that is most frequently inundated, although the settlements along the river banks clearly suffer when the riverside embankments are overtopped. Pursat's topography does not lend itself to drainage and many of the natural drainage channels have been blocked as the town has developed. Old, small retention ponds have also been filled in for development thus reducing attenuation of storm flows. There is no properly planned drainage system, although drains have been built to alleviate some flooding, but they tend to just move the issue from one place to another. Only around 20% of the town's roads have drains with NH5 and other main roads lacking side drains.

9. The causes of flooding in Pursat are complex and have possibly been exacerbated by other development interventions. The river used to flood upstream of NH5 bridge and the town, but as it flooded agricultural land, the embankments along this part of the river were raised. This may be the cause of flooding further downstream at the town. The Municipality estimates that 12 kms of embankment on the town side and 10 kms on the other side of the river need improvement.

10. Various barrages have been built across the river both upstream and downstream of the town. Some of these barrages have fallen into disuse or, or in one case, completely bypassed by the river changing course, two barrages remain operational. These are shown in Figure B.1. Both these barrages were constructed as part of irrigation programs in the 1990s and use automatic flap gates to cope with flood flows. During peak flows, when the automatic flood gates on the upstream barrage open, a large plug flow is released into the river which then backs up from the downstream barrage until these gates automatically open. During the time when there the upper barrage is open and lower one still shut, the river levels are artificially high and can overtop the embankments. With no manual means to regulate the flow of water in the river through the town during floods, these barrages could be an additional cause of flooding. Figure B.3 below shows the barrage and a detail of the automatic flood gates.

11. The design and operation of the barrages and the raising of the riverbanks, demonstrates the need to consider both rural and urban development in the design of river and flood control structures as they can impact on both areas.

Figure B.3 Upstream Barrage on Pursat River with Flapgate Detail

Source: TA7986-CAM Consultants

12. Maintenance of the embankments is divided between the provincial government and the municipality as the municipality does not include all of the town center area.

13. River levels are measured by the Provincial Department of Water Resources and Meteorology (PDWRAM) which has a gauge at an old disused barrage just downstream of the town center. The embankment level is 4.90 m above datum[3] and the flood level reached 5.35 in 2011. PDWRAM state that most years it usually reaches around 5.1 or 5.2 m, so flood levels still overtop parts of the embankment.

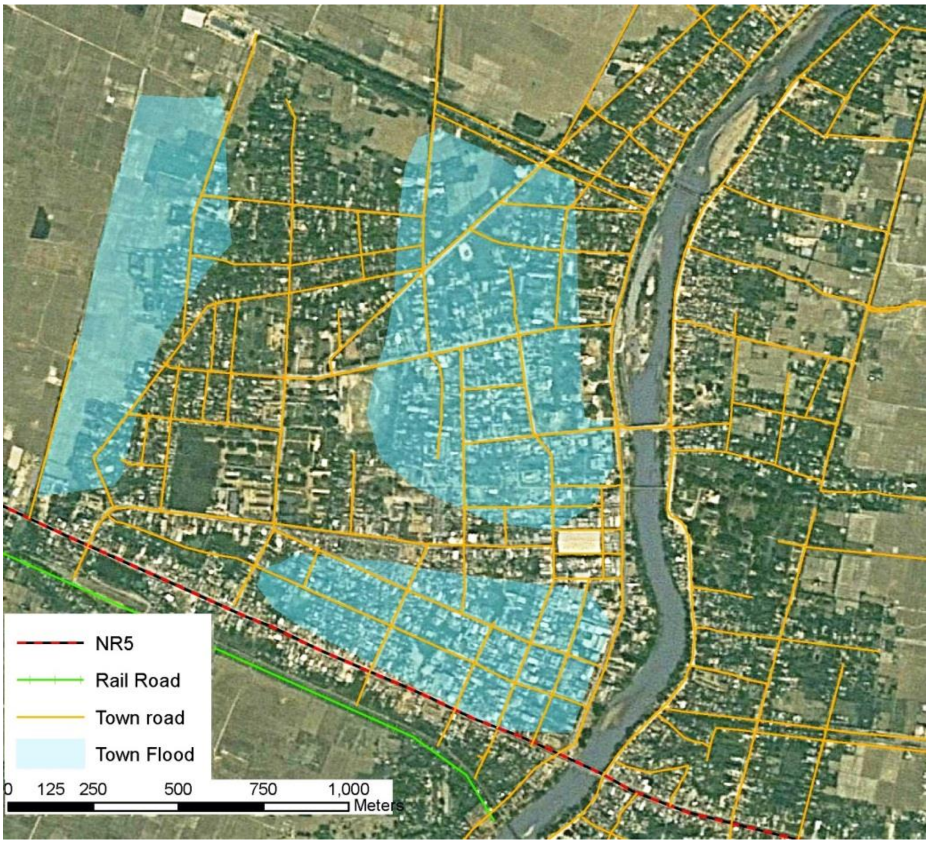
3. Impacts

14. There are two types of impacts from flooding in Pursat: i) flooding in the town center from heavy rainfall; and, ii) the far less frequent flooding from the river. The flooding in the town center affects around 80 per cent of the roads in this area which is shown in Figure B.4. It should be noted that it is mainly the roads and commercial properties that are flooded. Houses are usually raised, either on stilts for traditional housing, or for brick and cement-built structures, the plinth level is raised.

15. All of the town center lies in Phteah Prey Sangkat which comprises six villages. The total population of this area is around 18,000 of which around 14,000 say they are affected by flooding (See Table B-1). This is around 2,700 households plus the many non-residential properties in this area.

[3] This datum is used by PDWRAM based on a gauge on an old Khmer Rouge barrage in the town. The top of the barrage is 15.555 meters above mean sea level (MSL).

Figure B.4 Flooding Extent from Rainfall in Pursat Town Center



Source: TA 7986-CAM consultants, developed from data provided by Pursat PDPWT and Municipality

16. The impact of the riverbank overtopping can be more consequential, but occurs much less frequently. In addition, action can be taken to minimize this impact by placing sandbags along the riverbank edges. Impacts of this flooding are shown in Figure B.5.

Table B-1 Flooding Impact in Pursat Town Center

Flooded Villages	Flooded Population
Chamkar Chek Cheung	2,516
Chamkar Chek Tboung	1,158
Peal Nghek 1	6,313
Peal Nghek 2	2,838
Ra	845
Kbal Hong	647
Total	**14,317**
Total Population	**17,852**
Per cent Flooded	**80%**

Source: TA7986-CAM Consultants

Figure B.5 Flooding in 2012 from High River Levels

Source: TA7986-CAM Consultants

4. Existing and Ongoing Interventions

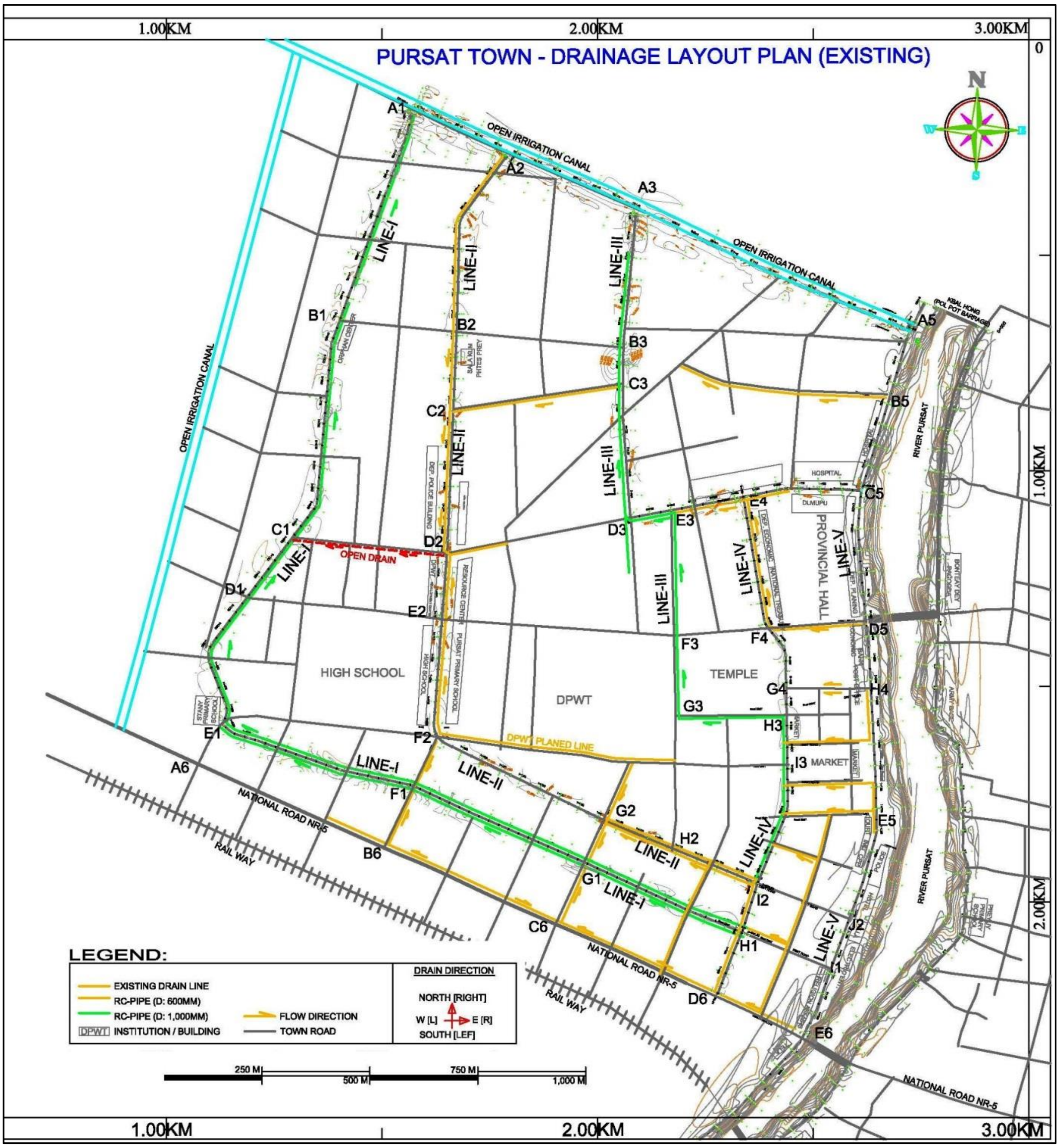
17. There is an existing drainage system that covers the central area and drains to northwest of the town away from the river. A pump station to discharge effluent to irrigation ditches at this point was planned, but not built. An existing treatment facility was built in 2001. It was designed by the Ministry of Water Resources and Meteorology (MOWRAM) and built by provincial department of water resources and meteorology (PDWRAM). The original aim was to build two parallel treatment facilities, but due to budget constraints only one was built. The facility aims to only treat dry weather flow[4] (DWF). The design of this facility is not available and it is difficult to assess accurately by inspection how the plant was intended to function. Possibly, just as a large septic tank as there do not seem to be any mechanical or aeration devices. However, the treatment facility is not functioning due to blocked and broken inlets that divert all the flow into a nearby disused irrigation drain. All flow is by gravity with no pumping.

18. The provincial government has been incrementally constructing drains as funds become available. By the end of September 2013 a total of 5.64 kms have been constructed. These drains are made of reinforced concrete of either 600 mm or 1,000 mm diameter. The drains seem to be placed around 2.5 meters deep with the soffit[5] levels at 1.5 meters depth. Large manholes, sized more as inspection chambers, are also installed at around 20 meter intervals. A plan of the existing drainage system is shown at Figure B.6.

[4] This is the flow in the sewer when there is no rainfall or stormwater. It comprises sullage and wastewater from households and other non-domestic properties plus any groundwater infiltration if there is any.

[5] Highest point of the inside of a pipe.

Figure B.6 Existing Drainage System



Source: TA 7986-CAM consultants

19. There are a number of issues with this system:

- There is an overall plan for the drainage system, but it lacks any information on ground or pipe invert or soffit levels to guide the contractor as to how deep the drains should be. The area covered is relatively small, but its topography does not lend itself to simple or obvious drainage solutions. A detailed topographical survey is needed to allow the design of an effective, and subsequently, cost-effective, drainage system;

- Although designed to deal with stormwater, many of the manholes have household connections and receive wastewater.[6] Thus, the system functions as a combined sewerage system. These connections are made at manholes, probably explaining why the manholes are built so close together. Connections are not made by skilled masons and have no screens or traps.
- The drains are large diameter and with very shallow gradients which decreases the velocity of flow. During dry weather, most of the flow comprises only household wastewater and the low velocity means that solids settle out in the drains and can begin to build up as blockages. Pools of wastewater also can collect in any recesses that may have developed as drains settle or may have even been laid that way. In fact, the drains themselves can begin to act as *mini treatment plants* which can cause gas emissions, particularly hydrogen sulfide, which when mixed with water becomes acidic and can corrode the cement in the drains and cause them to fail. This can be avoided by using sulphate resistant cement, but this does not seem to be used.
- The inlets are often not placed to best collect run-off. Part of this issue is that the edges of many of the wide roads in the town center are gravel which allows the gravel to be washed into the drains and can block them. Some examples are shown in Figure B.7.
- The manholes are not benched to maintain the velocity of the dry weather flow, but have flat bases that again decrease the velocity of water passing through them and allow settlement of any solids.
- Overall construction quality seems poor. The reinforcement used in the concrete pipes is spaced at around 300 mm. For this size of pipe, this should be only 150 mm with smaller mesh also used to prevent surface cracks. The placing and jointing of the pipes could also be sub-standard, although this was not confirmed. The pipes are spigot and socket but there is no rubber ring used. Hence the rigid joints can settle and crack when flowing full and pollute groundwater.

Figure B.7 Recently Constructed Drain Inlets

Source: TA 7986-CAM Consultants

20. In August 2013, this drainage work was still ongoing. At a meeting with HE the Provincial Governor of Pursat, PDPWT, the drainage contractor and the PPTA consultants, the

[6] These terms are often used interchangeably, but for this report, wastewater is used as a general term for all household liquid waste. It comprises sullage and sewage. Sullage is waste from kitchens and bathrooms, but not toilets. Sewage is faecally contaminated liquid waste from toilets. Wastewater can also contain industrial liquid waste.

Governor stated that the contractor would complete the remaining 600 meters of one line under construction and then carry out no more work.

2 21. The PDPWT also plan to build one line and as it has already cast the 600 mm diameter pipe sections, these will also be laid in the near future. Both these drains are included in the existing drainage lengths quoted in paragraph 0 and

Table D-2.

22. The provincial government is also currently improving the embankment outside the Provincial Governor's office by strengthening and raising the sides with a concrete frame. The figure below shows the type of embankment strengthening being provided by the Provincial Government to the Pursat River. The level of the top of this embankment is 16.90 meters above MSL. This provides a freeboard[7] of around 400 millimeters from the previous highest flood level.

Figure B.8 Ongoing Embankment Protection Works in Pursat

Source: TA7986-CAM Consultants.

23. The Greater Mekong Subregion (GMS) Flood and Drought Risk Management and Mitigation Project (REG 40190) proposes to divert some flow from the Pursat River for irrigation and is setting up a PIU for its Pursat River interventions in the Pursat PDWRAM office. This project aims to upgrade water management infrastructure by supporting the Dhamnak Chheukrom Irrigation System Rehabilitation for improved drought management and increased flood protection of Pursat township. The subproject which is situated about 40 kms upstream of Pursat town includes[8]:

(i) a supply managed irrigation scheme to provide wet season supplementary irrigation for 16,100 hectares and full irrigation to a smaller command area during the dry season;

(ii) a new head works structure to withdraw water from the Pursat River for the command area and facilitate peak flood diversion using the scheme's main canal, comprising of: (a) a new barrage located on the Pursat River that is **designed to safely convey the 50-year flood under anticipated climate change conditions**; and (b) an intake structure that can control river withdrawals for both command and flood diversion flows;

(iii) a 30km main canal that will convey the peak flood diversion discharge of 40m^3/s from the Pursat River to the Svay Donkeo River, which includes the rehabilitation

7 Freeboard is the area above the highest water level and the top of the embankment.

8 Information from Report and Recommendation of the President to the Board of Directors; Project Number 40190; Proposed Loan and Administration of Loan and Grant; Kingdom of Cambodia - Greater Mekong Subregion Flood and Drought Risk Management and Mitigation Project; November 2012

of a 14km reach of an old non-functioning canal constructed during the Khmer Rouge era; plus further construction of 16km of a new main canal;

(iv) four new main canal regulator structures to control flows and water levels within the main canal for diversion of command flows into the secondary canals while allowing conveyance of the peak flood discharge of $40m^3/s$;

(v) a new outlet structure near the Svay Donkeo River;

(vi) four new secondary canals with a total length of 51.5km, including check structures and outlets to the tertiary system;

(vii) new tertiary and distribution canals, and new drainage systems;

(viii) canal cross-drainage and overflow structures along the main canal; and,

(ix) new road bridges along the main and secondary canals.

24. It is envisaged that this project will be commissioned by March 2019.

C. Stormwater Drainage and Flood Mitigation Strategy

1. Objectives and Guiding Principles

25. While the Pursat River can cause major flooding, the proposed Dhamnak Chheukrom Irrigation System Rehabilitation Project, described in the section above, should alleviate this flooding. However, flooding from rainfall will still inundate the town center. Thus, the main objective of the flood prevention interventions in Pursat is to alleviate the town center flooding.

26. To develop the drainage strategy, some guiding principles have been developed. The objective of Pursat's flood prevention strategy should be:

- Drains should not be built in an ad hoc manner, this tends to just move the problem elsewhere – a plan for the drainage system with prioritized routes and levels, is required;
- Aim to reduce not just the frequency of flooding, but also the length of time that any floods occur;
- Recognize that greater urbanization will increase run-off, and introduce actions to accommodate this – planning should importantly avoid reducing drain sizes or filling in retention areas either intentionally or by allowing them to be encroached upon;
- Develop a hierarchy of flood damage based upon minimizing the cost of damage – details on this are provided in paragraph 0 below;
- Aim to use topography as much as possible to minimize costs and any pumping;
- Aim to use any existing drainage system and any flood protection works as much as possible;
- Design the drainage system to accommodate both storm flows and wastewater coming from houses – if a combined system is used, then grades must allow for minimum velocities for wastewater to avoid solids settling in the drains and blocking them.
- Accommodate climate change scenarios by translating the variables and options into practical, tangible, and importantly, cost effective, figures that can be built into the design.

27. The aim of any flood prevention strategy should be to avoid floods and the damage they cause. However, this can be very expensive to achieve and in reality a “hierarchy of potential damage” is usually developed. This aims to ensure that the costs and impacts of any flooding damage are limited and only gradually move up the scale with more severe conditions. The hierarchy can be described as guiding any flooding to first impact on:

- Main drains and retention areas; then
- Open land – recreation areas and fields; after which
- Roads; and then,
- Non-structural property such as gardens.
- The aim is to completely avoid any flooding inside or structural damage to buildings, and most importantly, any human casualties.

2. Options

a. Stormwater Drainage

28. In Pursat, there are not many options regarding the drainage design. The major option could have been whether to have a separate or combined drainage system. However, as previously discussed in Section 4 a *de facto* combined system has already been constructed in parts of the town center. Technically, it is possible to separate a combined system, but it is expensive and either requires moving connections from the combined drain to the new wastewater sewer, or constructing the new wastewater sewers lower than the existing storm drains and linking them with small diameter sewers at regular intervals.

29. This latter option can be simpler to construct and allows the wastewater to flow into the wastewater sewer. When the storm drain fills with rainwater, some rainwater flows into the wastewater sewer (which can help to flush the wastewater sewer), but the bulk of the stormwater flows down the storm drain. This might be the best option Pursat. However, as discussed in paragraph 0 above there are doubts about the effectiveness of the drains that have been already constructed in Pursat. There might be issues with their construction quality and strength, but the main issue is that the grades are very flat and their effective functioning is questionable.

30. As such, building a parallel, yet linked separate drainage system, might not alleviate flooding. This issue, plus the existing institutional and financial framework that currently has no user charges, or proposals for user charges, means that there is little option but to continue with the construction of the combined system.

31. If a charge can be introduced that allows the effective operation of the system and wastewater treatment and more connections can be made, a separate sewerage system can still be constructed.

32. Thus the strategy for the drainage system in Pursat is to:

- Keep the system combined to receive both rainwater and household wastewater;
- Design and build drains that will work effectively with both these flows;
- Ensure that dry weather flows, which will be wastewater with possibly a little groundwater infiltration, do not allow settlement in the drains by designing drains to maintain a minimum velocity. This will mean deeper drains and pumping to the final effluent receiving area. However, to avoid pumping stormwater overflow structures

will be built to divert storm flows into a local disused irrigation drain that drains to the Pursat River;

- Construct new drains to alleviate the existing flooding and transfer the stormwater to streams and channels outside the town center;
- Use as much of the existing system as possible, but recognizing its limitations, ensure that the new system is able to cope even if this system fails to function;
- Encourage connections into the system – no charge, but permission required;
- Provide treatment to the wastewater, but not the stormwater;
- In the longer term, aim to ensure the sustainability and expansion of the system by introducing payments for using the wastewater system which will allow upgrading of the system and wastewater treatment.

b. Riverbank Protection

33. The ADB supported GMS Flood and Drought Risk Management and Mitigation Project which provides support to the Dhamnak Chheukrom Irrigation System (DCIS) Rehabilitation described in paragraph 0 above should prevent flooding in Pursat. However, the main technical study for this project[9] proposes that the main canal is designed to divert peak flood flows from the Pursat River to the Svay Donkeo River to help Pursat Town maintain its current standard of flood protection. It goes on to state that the corresponding standard of protection for Pursat Town under both current and anticipated climate change conditions will reduce flooding as shown in the table below.

Table C-1 Standard of Protection for Pursat Town

	Return Period (years)	
	Current Climate	**Projected Climate Change**
Without DCIS Diversion	3 to 4	< Annual
With DCIS Diversion	4 to 5	~ Annual
Reduction in Flood Occurrence (%)	~25	~50

Source: ADB TA 6456-REG: Preparing the Greater Mekong Subregion Flood and Drought Risk Management and Mitigation Project; Irrigation Engineer's Report (May 2012).

34. This table seems to suggest that annual flooding will still occur but only every four to five years, but that with climate change, it could still be annual. This report also goes onto state that "the combined flooding from the Tonle Sap is generally restricted to areas downstream of National Highway No.5. The flooding that occurs upstream of the highway is mainly caused by extreme flow within the Pursat River. To what extent the Tonle Sap water levels influence the Pursat River water levels should be considered in a later study that focuses on flood management.

35. The automatic flap gate barrage downstream on the Tonle Sap river that can impede the dissipation of extreme flows in the Pursat River, probably means that Pursat town could be vulnerable to floods from both up and down stream. To address the flooding issues, a much greater understanding of the effect on the river's hydrology from these barrages is required. However, the report is correct in that further study is required. A study to assess the impact of the hydraulic structures on the flow regime of the river and determine what should be done to reduce the shock flows from the automatic gates opening would need to be carried out. However, this study would have more value if it is carried out after the DCIS scheme is commissioned and more river level data is obtained.

9 ADB TA 6456-REG: Preparing The Greater Mekong Subregion Flood And Drought Risk Management And Mitigation Project - Irrigation Engineer's Report (May 2012)

36. Hence, at this period it would not be advisable to raise the embankment levels on the Pursat River as the impact of both the DCIS scheme and climate change need to be better understood. Raising the embankment levels would have significant impact upon the many houses and businesses that are built along the riverbank. The Municipality states that many of these properties are illegal and that all land 25 meters from top of the riverbank is public land. However, many of these encroachments are well established, while access to parts of the river bank would require temporary relocation of many legal properties. Such large scale relocation should only be undertaken once a design embankment level has been fixed by a detailed hydrological study.

37. The Pursat river follows a sinuous course both upstream and downstream of Pursat and there are sections of the embankment, particularly at the outside of bends that are at risk of erosion when the river is in spate. These sections have been protected by wooden groynes that have rotted and allowed more erosion to occur. As the embankment has local access roads along its crest, there is a need to protect these sections from further damage. In addition, if the embankment failed, it could cause flooding, in particular inundating properties near the river.

38. Thus, the main aim of the riverbank protection is to protect the embankment in these vulnerable sections. As these sections are at risk from collapse, no settlements have been constructed near them, thus access is simple.

D. Project Design and Description

1. Climate Change Considerations

39. Climate change could also have an impact on the flood levels of the Tonle Sap. An overview of the expected consequences of climate change between 2020 and 2050 has been carried out by the Mekong River Commission (MRC)[10]. The main predictions relating to flood levels and river flows in Cambodia are the following:

- The mean annual rainfall in Cambodia will be unchanged or even decrease by up to eight per cent. The largest increase is expected in the wet season, but will also occur in the dry season in Upper Mekong
- The Mekong's flow is expected to increase by four to 13 per cent in the wet season and by 10 to 30 per cent in the dry season. The largest increases will appear from the Chinese border to Kratie in Cambodia.
- The snow melt contribution from the Upper Mekong is expected to increase and to start earlier due to increased temperatures.
- The increased flow in the Mekong will improve water availability in the dry season, but also increase the risk of flooding in the wet season. The low-lying areas downstream of Kratie including the Tonle Sap area are expected to be particularly at risk. The areas affected by flooding due to rainfall and upstream flow from Mekong are estimated to increase by nine per cent, not including effects of a possible sea level rise. Areas with flooding depths higher than two meters are estimated to increase by almost 40 per cent.
- The storage capacity of hydropower installations may potentially reduce impacts of flooding in some areas. The Lower Mekong Basin 20-year development plan alone estimates a decrease of the wet season river flow by 7 to 17 per cent, while the climate change scenarios for this season estimate a flow increase of between two to

[10] Impacts of climate change and development on Mekong flow regimes. First assessment – 2009, Mekong River Commission Technical Paper No. 29, June 2010

11 per cent. The combined effect is expected to vary between a decrease of 13 per cent to an increase of three per cent.

40. Importantly, the report states that there is a high degree of uncertainty related to both the climate change scenarios and the different development plans in the basin.

41. However, another 2010 study "Modeling climate change impacts on the flood pulse in the Lower Mekong floodplains"[11] indicates that by 2050 the average water levels in the Tonle Sap may increase by 0.2m and peak water levels may increase by up to 0.3m. This study estimated flood durations to be nine per cent longer under anticipated climate change conditions and therefore the probability of coincidence with river floods is likely to increase. However, the 2010 study also considers the development of water infrastructure along the Mekong River and its impact on reducing downstream flood impact under climate change conditions. It concludes that while the two phenomena may balance each other, further detailed studies are required.

42. In Pursat, the GMS supported GMS Flood and Drought Risk Management and Mitigation Project for the DCIS rehabilitation has included climate change in its design and this is one key factor in not currently proposing any work to raise the embankment levels of the Pursat River in the town. However, climate change still needs to be considered for the stormwater drainage system. Increased and more intensive rainfall will create larger storm flows which in turn will require larger drains.

2. Drainage System

a. Design Purpose

43. The drainage system's pipes have been able to perform two main tasks. First they have to be of adequate size to accommodate the maximum flood flows and secondly they have to be able to transfer the wastewater along the drains without depositing solids on the drain bed. It is normal to specify a minimum velocity which should be achieved in a drain at least once per day in order to re-suspend any solids which may settle out during periods of low sewage flow. This is termed the *self-cleansing velocity*. In order to prevent severe siltation when drains are first brought into use, it is necessary to ensure that these velocities are achieved throughout the drainage system even when flows are relatively low in the early stages of development.

44. The existing drain, and embankment, levels were surveyed through a topographical survey subcontract issued by the PPTA consultants. This limited survey aimed to establish the alignment and levels of the existing drains and embankments and identify any properties and establish rights of way. Levels were fixed using an existing national benchmarks which has been fixed by the MOWRAM at the now disused Khmer Rouge barrage just downstream on the Pursat River from the Provincial Governor's office.

45. **Materials.** The design life of the drainage system has been taken as 25 years. However, some of the concrete pipes already built by the Provincial Government will most likely need to be replaced before this time. The usual material for larger diameter drains in Cambodia is reinforced concrete. The same material will be used for the drains in Pursat, but the drains' design will be improved and fabrication better supervised.

46. Technical standards for drains will be upgraded to ensure more effective operation of the drainage network. This includes using reinforced concrete pipe designed to European or US standards. Flexible spigot and socket rubber jointed concrete drains are preferred, if available. These require 150 millimeter sand or gravel cushion base.

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[11] Vastila et al, 2010, Modeling climate change impacts on the flood pulse in the Lower Mekong floodplains, Journal of Water and Climate Change.

47. Sulphate resistant cement will also be used for the pipes to ensure their longevity. Sulphate resistant cement is available in Cambodia and is only ten per cent more expensive than standard ordinary portland cement.

b. Average Return Period for Drainage Design

48. To determine the size of the drains an assumption has to be made as to the design return period to be used. Drainage design is usually based upon a statistical analysis of historical rainfall or discharge. From this design, *return periods* are developed to estimate the likely recurrence interval between rainfall events and levels of flooding. Return periods are statistical measurements denoting the average recurrence interval over an extended period of time. For drainage and flood control the return period is given in years, such that a drainage system might be designed for a 20 year flood return period. This implies that there is a probability of the drainage system's capacity not being able to deal with floods every 20 years. However, it is a purely statistical calculation and it is possible that the stormwater system's capacity could be overcome during storms in two consecutive years, or even twice in the same year. Conversely, the drainage system could cope for 50 years or longer.

49. The greater the return period, implies a larger and more expensive drainage system. For Pursat, the greater the return period considered, the larger the drain sizes need to be. Return periods are usually based on historic data so there is also a need to consider climate change which through more intensive rainfall will increase flows over the design life of the drains.

50. Table D-1 shows typical design return periods for various land use types. Rainfall data for Pursat is available from 1981 and the total annual rainfall is shown in Figure D.1.

Table D-1 Typical Annual Return Period Values for Flooding

Land Use	Range - (Years)
Town Center and Commercial Area	20 – 100
Industrial Areas	10 - 50
Urban Residential High Density >20 dwellings/ha	20 - 50
Urban Residential Low Density >5<20 dwellings/ha	10 - 20
Rural Villages	2 – 10
Agricultural Land	1 – 10
Recreation areas	1 - 5

Source: PPTA 7986-CAM Consultants amended from Andhra Pradesh Urban Services for the Poor, Infrastructure Planning and Design Guidelines for Municipal Engineers, GHK International Consortium, March 2003

51. The town center catchment area includes the town center and existing medium density residential areas as well as lower density institutional areas. However it is expected that these areas will rapidly develop over the design period of the project. Therefore, a return period of 20 years has been adopted for the drainage design.

c. The Rational Method

52. The Rational Method is a widely used method for predicting peak stormwater flows. It predicts the peak runoff according to the formula:

$$Q\ (m^3/s) = CiA/360$$

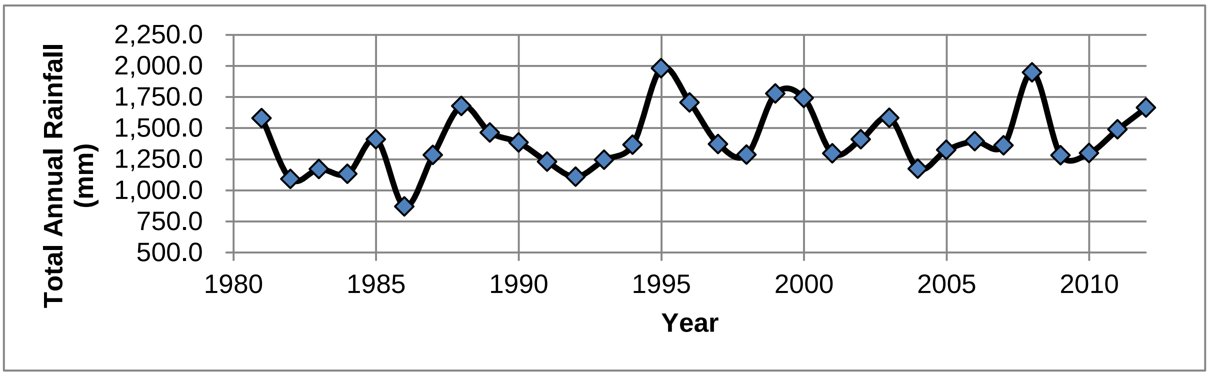
where: Q = peak design flow; i = design rainfall intensity in millimeters per hour; A = catchment area in hectares; and C = a runoff coefficient that is based upon land use – eg flat grassland would be 0.1, while a completely paved area would be 0.95 or even 1.0.

For Pursat; C is assumed across the whole area as 0.6. Currently in parts of the town center it is much less than this, but as the area is expected to develop over time, run-off will increase as more areas are paved over through urbanization.

A more accurate assessment will be made during detailed engineering design

53. Detailed rainfall data for Pursat is available from 1981 and Figure D.1 shows the variation in total annual rainfall over this period. However, this data is insufficient to prepare the intensity-frequency-duration (IFD) curves that would allow an accurate estimation of the time of concentration and thus the intensity. The MPWT uses IFD curves as contained in the Cambodia Road Design Manual for the design of storm water canals, pipes and culverts. These are available for Battambang which, at only 100 kilometers Northwest of Pursat with a very similar climate and rainfall pattern, can be used as an indicative guideline for Pursat. These are shown in Figure D.2.

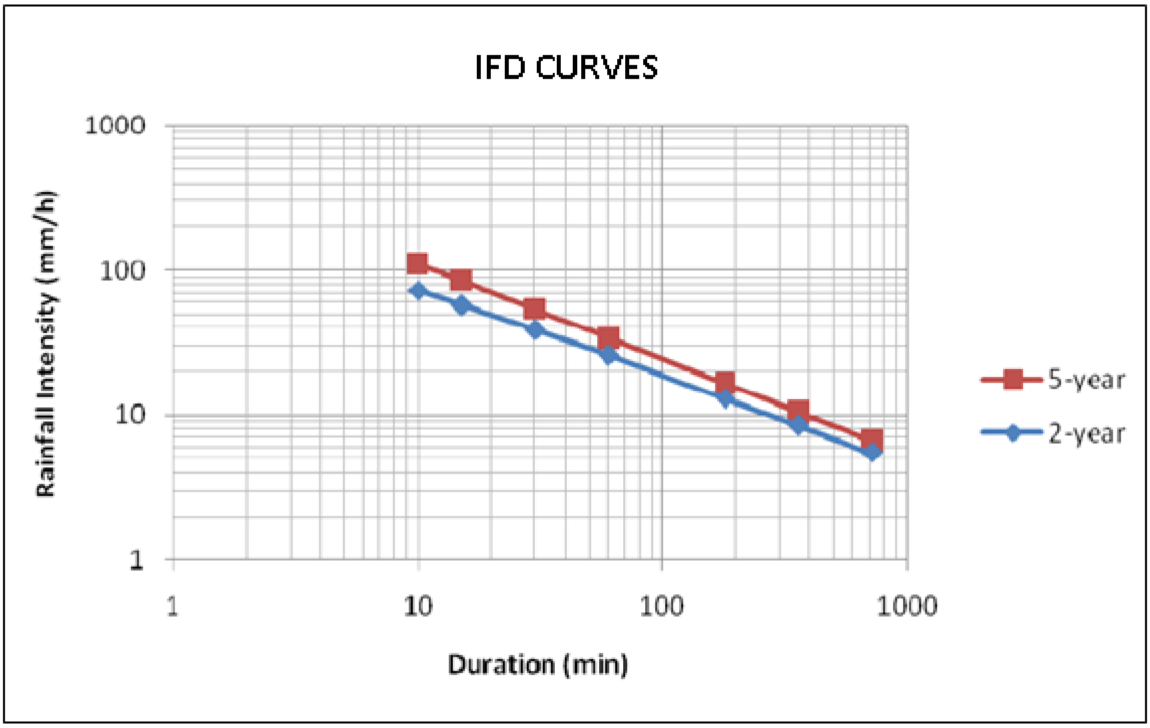
Figure D.1 Total Annual Rainfall in Pursat



Source: PDWRAM, Pursat

54. The rain intensity was taken as 30 mm per hour which is similar that used elsewhere in the region. However, this has been increased to 40mm per hour to accommodate the more intense rainfall expected from climate change and used for the drain design. While a more accurate assessment of the runoff coefficient will be made during detailed engineering design, given the somewhat conflicting and intangible information on climate change, it is still difficult to estimate future rainfall intensities. However, using 40 mm/hr provides a factor of safety to cover greater changes in rainfall intensity.

Figure D.2 IFD Curves for Battambang as a Proxy for Pursat



Source: Royal Government of Cambodia. 2010 Road Design Manual

55. Proper use of the Rational Method requires that the correct critical duration and its corresponding rainfall intensity be used at each point of study. For each element of the drainage system proposed, the storm duration that produces the highest peak flow in that element is used for the design of that element. It is normal to start at the head of a catchment, and as progressive downstream sections of the catchment are analyzed, the critical duration generally increases and its determination becomes more complex. The area for each pipe's catchment obviously varies. These were plotted on a main plan of the town center. Clearly as the drains further down in the system need to be able to accommodate both the flow coming from upstream pipe as well as the storm water entering the pipe from its own catchment area.

56. Applying the rational method, the size of the drains was thus developed to accommodate stormwater. This involved both checking the existing drains for size as well as designing the new drains to ensure they can accommodate the flows.

4 57. This is shown in

Table D-2, which shows the existing and proposed drain sizes. The letters given to the nodes refer to the points as shown in the plan of the proposed drainage system in Table D-4.

Table D-2 Drain Size for Stormflows

Line	Node		Drain								
			Existing			**Proposed**					
			Length(m)			**Left**		**Right**		**Total(m)**	**Manhole**
	>	**<**	***Left***	***Right***	***Diameter***	**L(m)**	**Diameter**	**L(m)**	**Diameter**		**(nos)**
I	E1	C1	-	*510*	*1,000*	510	1,500	-	-	510	10
	C1	B1	-	*515*	*1,000*	515	1,750	-	-	515	10
	B1	A1	-	*525*	*1,000*	525	1,750	-	-	525	11
	I1	H1	-	-		220	600	110	600	330	7
	F5	J3	-	-		110	600	220	600	330	7
II	D2	B2	*510*	-	*600*	510	1,750	-	-	510	10
	B2	A2	*455*	-	*600*	455	1,750	-	-	455	9
	F2	D2	-	*410*	*600*	420	1,500	-	-	420	8
	G2	F2	-	-		480	1,500	-	-	480	10
III	D3	B3	*300*	-	*1,000*	-	-	385	1,750	385	8
	B3	A3	*320*	-	*1,000*	-	-	320	1,750	320	6
	E4	D3	*110*	-	*1,000*	-	-	270	1,500	270	5
IV	H3	E4	-	*310*	*600*	-	-	540	1,500	540	11
-	B3	B1	-	-		770	1,000	-	-	770	15
-	D2	C1	*340*	-	*Open*	340	1,000	-	-	340	8
	H1	H3	*390*	-	*1,000*	-	-	510	1,000	510	12
-	C5	E4	*100*	-	*600*	-	-	260	1,000	260	5
V	E6	A5	*240*	-	*600*	1460	600	-	-	1,460	29
-	H4	G4	-	-		180	600	180	600	360	12
-	A3	A1	-	*600*	*Canal*	600	600	-	-	600	12
TOTAL			***2,765***	***2,870***		**7,095**	**-**	**2,795**	**-**	**9,890**	**206**

Source: TA 7986-CAM Consultants.

58. Some of these drains would seem to be oversized, but a factor of safety has been included to ensure that if the already existing drains fail, then the Project drains will be able to carry the stormwater. As the Project drains will be lower than the existing ones (see section below) cross connections will be able to convey stormwater to the new drains. Thus the total length of drains to be constructed is 9.89 kilometers as shown in the table below.

Table D-3 Summary of Drain Lengths

Drain	**Total Length (meters)**	
Dia.(mm)	**Existing**	**Proposed**
1,750	-	2,710
1,500	-	2,220
1,000	2,025	1,880
600	2.670	3,080
TOTAL	**5,635**	**9,890**

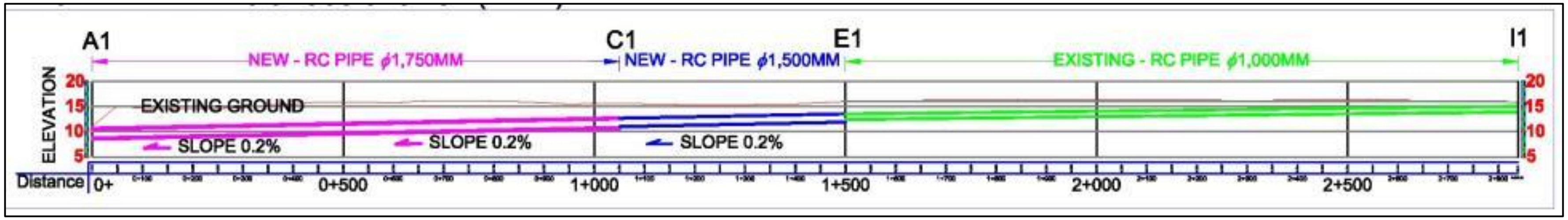
Source: TA 7986-CAM Consultants

Table D-4 Drain Sizes for Proposed Drains

Pipe										Upstream Node					Downstream Node				
Section	From	Ground Level	Invert Level	Depth to invert (m)	To	Ground Level	Invert Level	Length (m)	Grade	Area (km^2)	Max Storm Flow (m^3/s)	Pipe Diameter (mm)		Flow Capacity (m^3/s)	Area (km^2)	Max Storm Flow (m^3/s)	Pipe Diameter (mm)		Flow Capacity (m^3/s)
												Left	Right				Left	Right	
Ia	H1	15.669	13.169	2.500	E1	16.177	10.485	1,342	0.0020 or 1 in 500	0.0368	0.245	1,000	1,000	2.304	0.4025	2.684	1,500	1,000	4.528
Ib	E1	16.177	10.485	5.692	C1	15.595	9.465	510		0.4025	2.684	1,500	1,000	4.528	0.5745	3.830	1,500	1,000	4.528
Ic	C1	15.595	9.465	6.130	B1	15.903	8.435	515		0.5745	3.830	1,750	1,000	6.030	0.6533	4.355	1,750	1,000	6.030
Id	B1	15.903	8.435	7.468	A1	11.048	7.385	525		0.6533	4.355	1,750	1,000	6.030	0.7533	5.022	1,750	1,000	6.030
IIa	I2	15.954	13.454	2.500	G2	16.037	12.694	380		0.0000	0.000	600	600	0.589	0.0576	0.384	1,500	none	8.254
IIb	G2	16.037	12.694	3.343	F2	16.807	11.734	480		0.0576	0.384	none	1,500	8.254	0.0883	0.588	1,500	600	3.671
IIc	F2	16.807	11.734	5.073	D2	16.567	10.914	410		0.0883	0.588	600	1,500	3.671	0.5346	3.564	1,500	none	8.254
IId	D2	16.567	10.914	5.653	B2	16.772	9.894	510		0.5346	3.564	none	1,750	9.756	0.7056	4.704	1,750	none	9.756
IIe	B2	16.772	9.894	6.878	A2	14.987	8.984	455		0.7056	4.704	none	1,750	9.756	0.8163	5.442	1,750	none	9.756
IVa	I2	15.954	13.454	2.500	H3	16.050	12.644	405		0.1048	0.699	1,000	1,000	2.304	0.2557	1.704	1,000	1,500	4.528
IVb	H3	16.050	12.644	3.406	E4	14.844	12.024	310		0.2557	1.704	1,000	1,500	4.528	0.4777	3.185	600	1,500	3.671
IVc	E4	14.844	12.024	2.820	D3	14.763	11.804	110		0.4777	3.185	600	1,500	3.671	0.5488	3.659	1,000	1,500	4.528
IIIa	D3	14.763	11.804	2.959	B3	14.876	11.204	300		0.5488	3.659	1,000	1,500	4.528	0.6130	4.087	1,000	1,750	6.030
IIIb	B3	14.876	11.204	3.672	A3	14.487	10.564	320		0.6130	4.087	1,000	1,750	6.030	0.8195	5.463	1,000	1,750	6.030
V	A3	14.487	10.564	3.923	A1	11.048	7.385	550				600							0.549

Source: TA 7986-CAM Consultants.

Figure D.3 Typical Long Section of Drain Extension



Source: TA 7986-CAM consultants

d. Wastewater Flows

59. As mentioned in Section 4, the drainage system receives wastewater from households in the area. This comprises most of the dry weather flow. This wastewater currently drains untreated from the drainage system into the disused irrigation ditch. This wastewater should be treated and it is proposed to rebuild a disused WWTP located at the end of the drainage system at point A1 as shown on Table D-4. The disused plant is described in paragraph 0. The effluent from the WWTP will discharge to the same drain that receives the stormwater discharge and the currently untreated wastewater.

60. The main issue with the wastewater is maintaining adequate slopes to ensure self-cleansing velocities are reached. This is actually a greater issue at present and should improve as more household connections are made to the water supply and the overall use of water increases. This will increase base flows and ensure self-cleansing velocity is achieved.

61. PDIME state that around 80 per cent of the town center has water supply connections, however flows are not known and there are many government offices, educational establishments and a large hospital, plus a market and many businesses, including hotels and restaurants. If the town center has 100 per cent connections in the future with usage at say 120 liters per capita per day, plus, say an equal consumption for non-domestic use, the total daily flow would be around 3,500 m^3 per day[12]. Assuming a peak factor of three this would give a flow of 0.2 m^3 per second. This is three per cent of the drain capacity at the end of the system and demonstrates the very low wastewater to stormwater flow ratio. The current wastewater flow is probably around 20 per cent of this flow. The exact quantity is difficult to assess as the number of connections is not known, neither is the per capita daily usage, while the non-domestic demand is also difficult to assess. However, assuming 75 per cent connections, a usage of 60 liters per person per day and adding 25 per cent for non-domestic flow gives a daily flow of 1,100 m^3 in 2025. These figures are shown in the table below and the design year will be 2025.

Table D-5 Wastewater (dry weather flow) Estimation

Item	Unit	Year					
		2015		2025		2035	
Population			18,000		22,000		30,000
Per cent connected	%		60%		75%		90%
Water use per capita	liters/day		50		75		100
Sewage Flow (80% of water use)	liters/day	80%	40	80%	60	80%	80
Total domestic sewage flow	m3/day		432		990		2,160
Non-domestic flow as % of domestic flow	m3/day	20%	86	25%	248	35%	756
Total flow	m3/day		467		1,114		2,624
Flow per second	m3/sec		0.01		0.01		0.03
Dry weather flow (dwf)	m3/day		**467**		**1,110**		**2,624**

Source: TA 7986-CAM consultants

62. To ensure self-cleaning velocities, a gradient of one in five hundred (1:500) had to be adopted for the drains. This means that over the 2.5 kilometers length of the longest drain, the depth will be up to 8 meters at some points, but at the outfalls the maximum depth will be 6 meters and 4 meters at the wastewater treatment plant. Thus the wastewater will need to be

12 The water treatment plant currently only produces 4,500 m^3/day with an installed capacity of 5,700 m^3/day.

pumped from this point. However, to minimize pumping, three stormwater overflow structures will be constructed where the main storm drains meet an existing irrigation channel to divert excess stormwater.

63. Basic treatment will be provided to the wastewater. The simplest form of wastewater treatment is to use waste stabilization ponds. These are especially suitable for Cambodia as they require minimum maintenance and function better in hot climates. Many of the properties that are connected to the drainage system already have septic tanks which provide some pollutant load reduction before the wastewater enters the sewers. Waste stabilization ponds are also effective in treating this type of wastewater. Thus the site of the existing disused wastewater treatment facility (structure) will be developed and improved using waste stabilization ponds that will provide improved treatment and increased capacity within the same location as the existing facility.

64. The ponds will be preceded by preliminary treatment to screen the wastewater and remove large solids. Two types of ponds are proposed: anaerobic ponds and facultative ponds. Two days' retention will be provided in the anaerobic pond and 20 days for the facultative ponds. With the depth of the anaerobic ponds taken as 4.00 meters and the facultative ponds as 1.5 meters, this will require about 1.5 hectares as shown in

Table D-6.

Table D-6 Estimation of Pond Sizes

2025	Retention days	Volume	Depth (m)	Area (m^2)	Area (Ha)
Anaerobic	2	2,220	4.00	555	0.06
Facultative	20	22,200	1.50	14,800	1.48
				Total	1.54
Pond Sizes	**Number**	**Area of each Pond (m^2)**	**Breadth**	**Length**	**Total Area (m^2)**
Anaerobic	3 ponds	185	8	23	555
Facultative	4 ponds	3,700	30	123	14,800

Source: TA 7986-CAM Consultants.

65. The existing site is 2.2 hectares in size, it is proposed to develop ponds for the whole site to accommodate future increases in wastewater flows and loading and ensure compliance with the discharge standards. The WWTP location is shown in

6 66.

Figure D.4 where the total area comes to 1.82 hectares. The pond sizes and length to breadth ratios are constrained by the site width, hence the rather long ponds.

8 67. These sizes were then checked to ensure that they would be adequate to ensure a final effluent that would comply with national standards as shown in

Table D-7 below. Preliminary calculations are shown in Table D-8, which shows that the final BOD_5 is less than 80 mg/l which is the national standard. This will be checked and refined, as needed, during detailed design.

68. Treatment is to an extent constrained by the size of the existing site, and sometime after 2025, the site will area need to be expanded or mechanical treatment provided. Another advantage of using ponds is that it relatively simple and inexpensive to expand them. The anaerobic ponds can also be used to treat septage that is collected by tankers when emptying septic tanks.

Table D-7 Effluent Standards for Discharging Wastewater to Public Water or Sewers[13]

Number in Standards	Parameter	Unit	Discharge to Public Water Area & Sewers
3	BOD_5 (5 days at 200 C)	mg/l	< 80
5	Total Suspended Solids	mg/l	< 80
6	Total Dissolved Solids	mg/l	< 2000
10	Nitrate (NO_3)	mg/l	< 20
15	Phosphate (PO_4)	mg/l	< 6.0
34	Ammonia (NH_3)	mg/l	< 7.0
35	Dissolved Oxygen	mg/l	>1.0

Source: TA 7986-CAM Consultants

Table D-8 Check on Pond Sizes and Load Removal

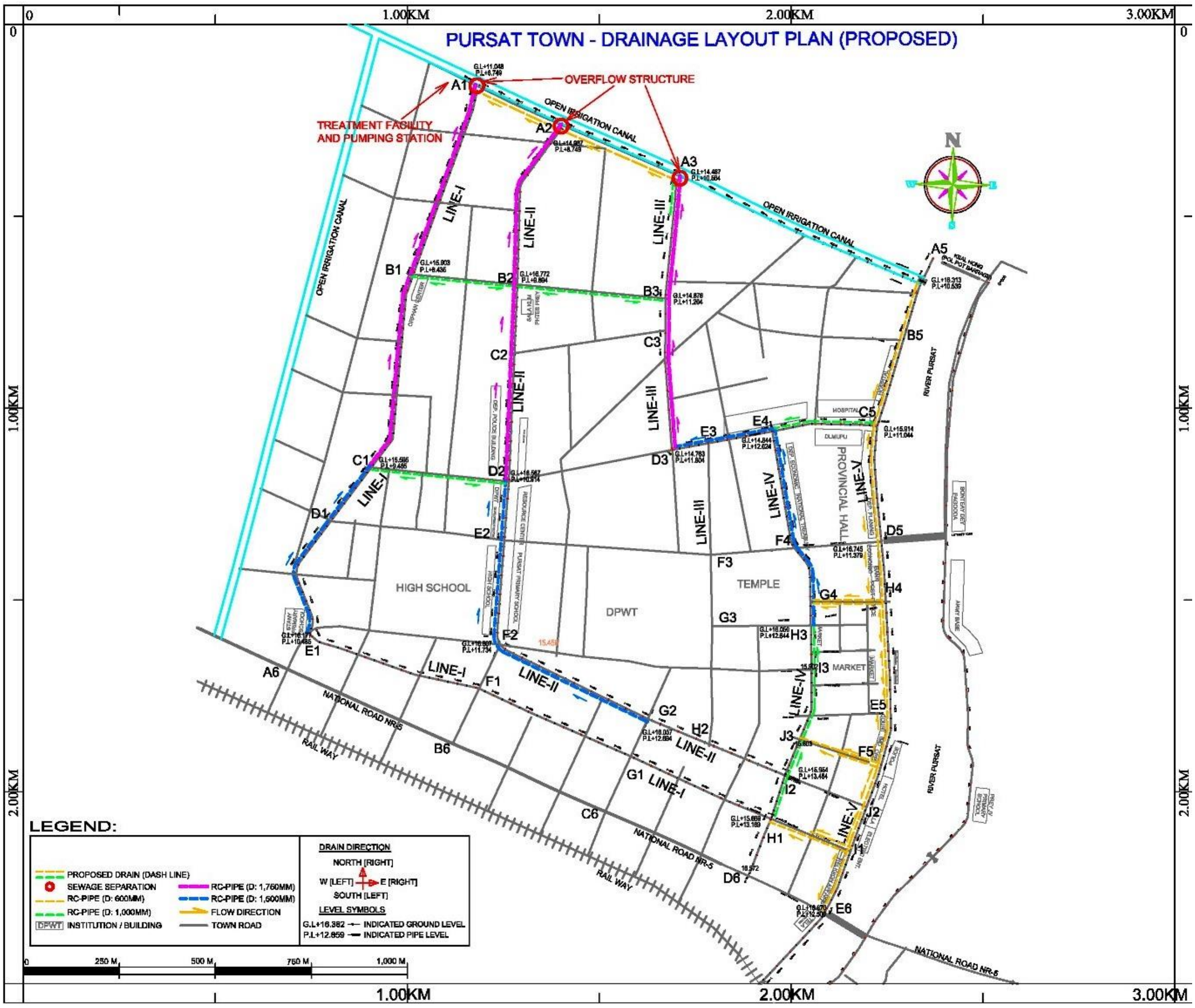
Item	Description	Unit	Quantity	Comments
1	**INFLUENT FLOW & CHARACTERISTICS**			
1.1	**Design Flow - Wastewater**	**m^3/d**	**1,110**	
	Wastewater Contribution per capita	l/cap.d	65	
	Equivalent Population	No.	17,077	
	BOD Contribution per capita	g/cap.d	45	
	Total Organic Load	kg/d	768	
	Reduction in BOD for existing septic tanks	%	30	
	Adjusted Total Organic Load	kg/d	538	
	Influent BOD Concentration	mg/l	485	
1.2	**Design Flow - Septage**	**m^3/d**	**5**	
	Influent BOD Concentration	mg/l	5,000	
	Organic Load	kg/d	25	
1.3	**Influent Bacterial Concentration (Typical)**	million./100 ml	**100**	
	Reduction in fecal coliforms from Septic Tanks used in Sewer System	%	50	
	Adjusted fecal coliform concentration	million./100 ml	50	
1.4	**Minimum Temperature**	**degrees C**	**25**	
2	**ANAEROBIC PONDS' CHECK**			
2.1	**Anaerobic Pond Loading and Design Hydraulic Retention Time**			
	Design Organic Loading (WW+septage)	kg/d	563	
	BOD Concentration of Influent	mg/l	505	
	Maximum Volumetric Loading to avoid odor problems	g/m^3.d	400	
	Design Volumetric Loading	g/m^3.d	300	
	Minimum Required Volume	m^3	1,876	
	Check Hydraulic Residence Time (HRT)	d	2	**Minimum is 1.25**
	Volume of aerobic ponds	m^3	2,220	**Thus OK**
2.2	**Estimated BOD Removal in Anaerobic Ponds**			
	Estimated BOD removal in anaerobic Ponds	%	60	Range 50 - 70%

[13] Annex 2, Sub Decree On Water Pollution Control, Royal Government of Cambodia, 2009.

Item	Description	Unit	Quantity	Comments
	Selected Value for BOD Removal	mg/l	202	
3	**FACULTATIVE PONDS' CHECK**			
3.1	**Pond Loading and Required Surface Area**			
	Surface BOD Loading - Primary	kg/ha.d	380	
	Surface BOD Loading - Secondary	kg/ha.d	440	
	Selected Surface Loading	kg/ha.d	350	
	Influent BOD to Facultative ponds	mg/l	202	
	Minimum total surface area required	m^2	6,405	
3.2	**Pond Sizing**			
	Design Depth	m	2	
	Number of ponds	No.	4	
	Minimum surface area of each pond	m^2	1,601	
	Surface area of proposed ponds	m^2	3,125	**Thus OK**
3.3	**Estimated BOD Concentration in Effluent**			
	Estimated BOD Removal in Facultative Ponds	%	70	
	Effluent BOD	mg/L	61	**Less than 80 thus OK**

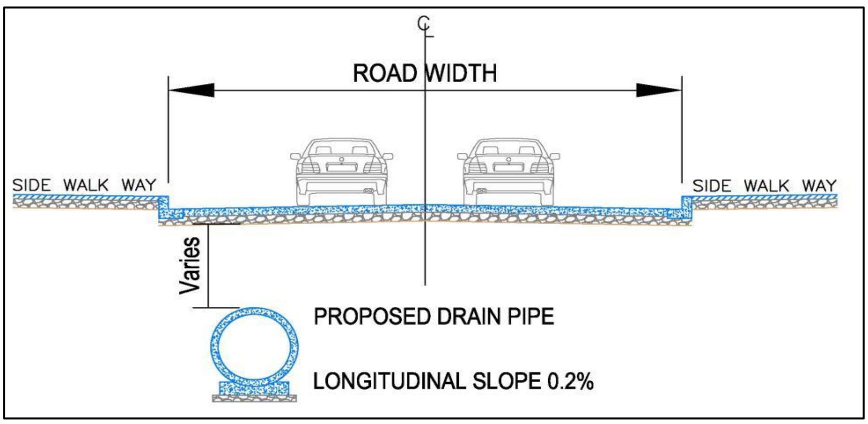
Source: TA 7986-CAM Consultants

Figure D.4 Plan of Proposed Drainage System in Pursat Town Center



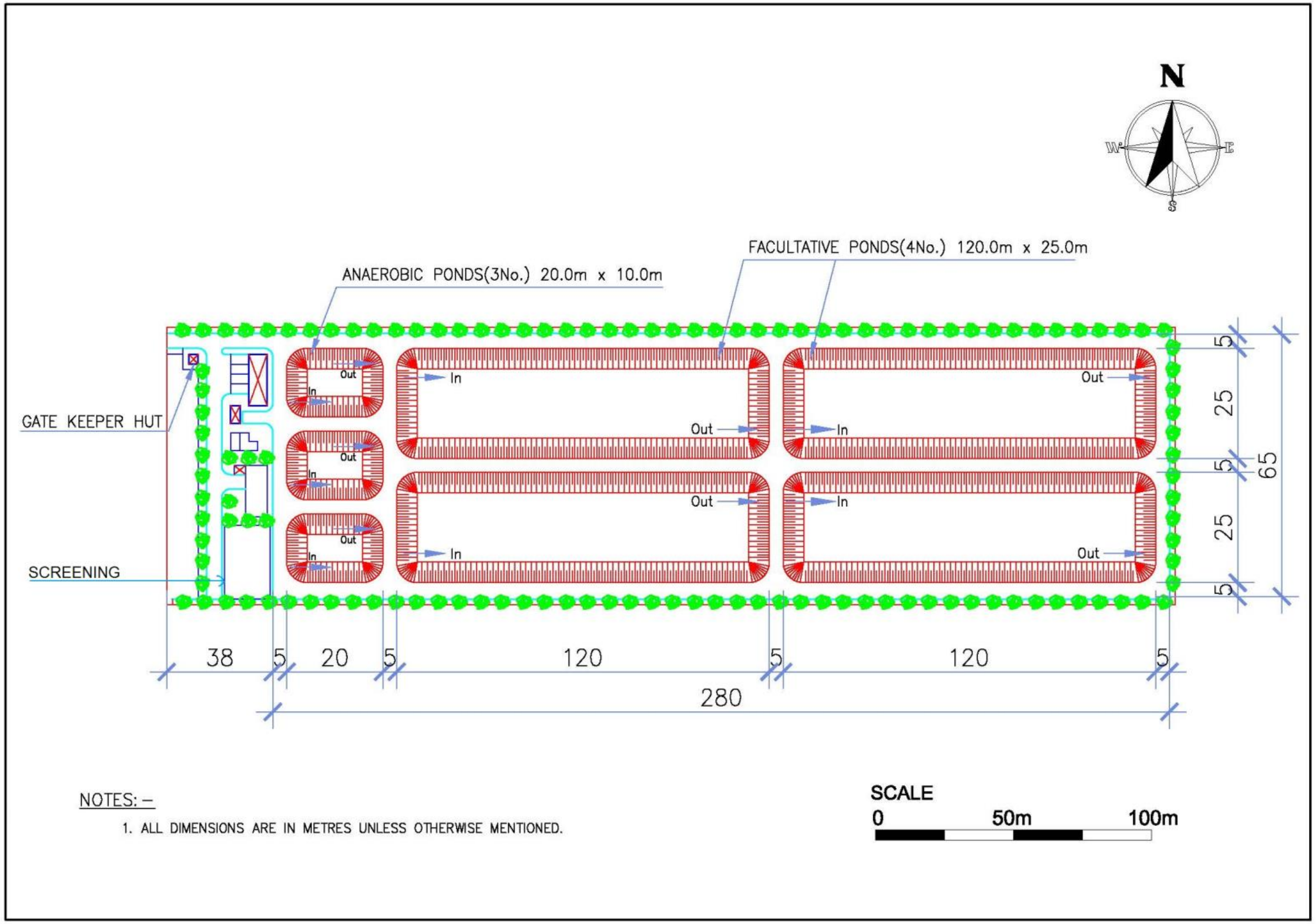
Source: TA 7986-CAM Consultants

Figure D.5 Typical Cross Section of Drain



Source: TA 7986-CAM Consultants

Figure D.6 Layout of Waste Stabilization Ponds



Source: TA 7986-CAM Consultants

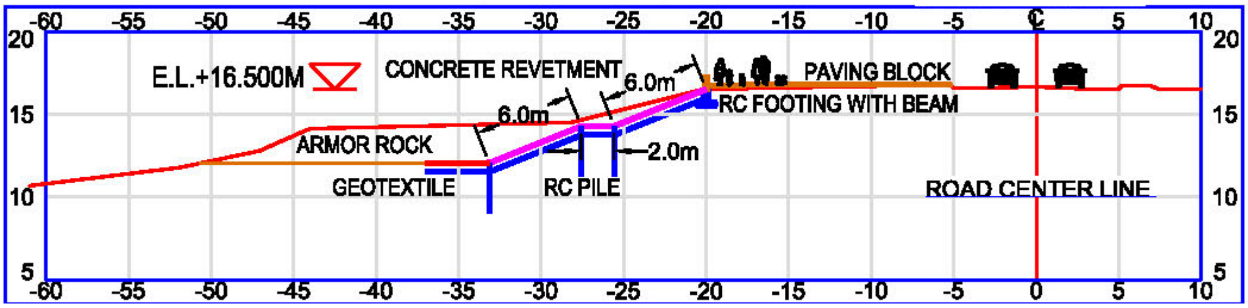
3. Riverbank Protection

9 69. The riverbank protection work has two components. One is to complement the ongoing work at the Provincial Governor's office and improve the embankment at this location (Source: TA 7986-CAM Consultants

Figure D.8). The other is to stabilize the embankment in two locations on the South bank upstream of the railway bridge (Figure D.9).

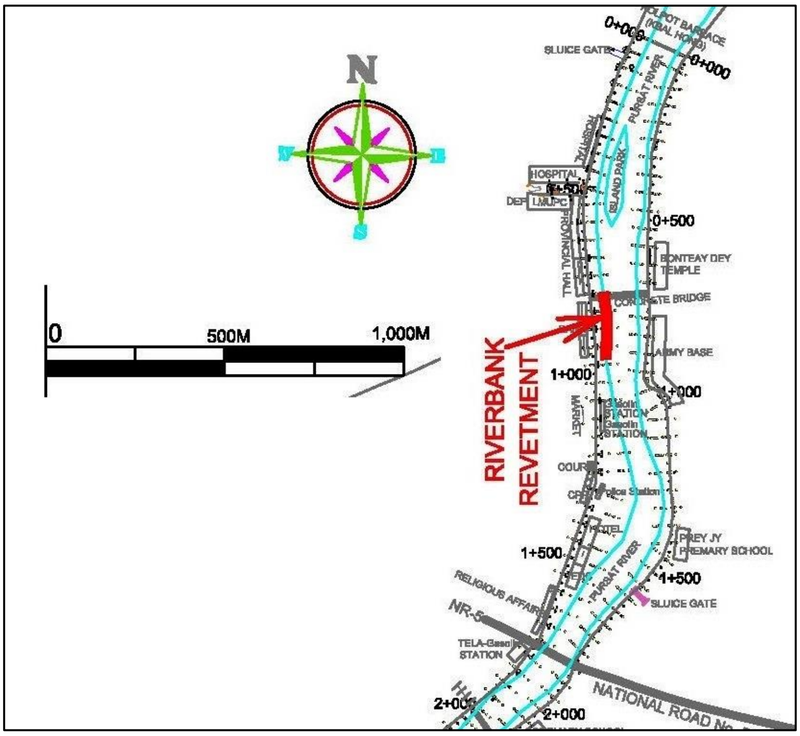
70. The work at the Provincial Governor's office also aims to demonstrate improved embankment protection that can then be used as a model for future work. The 200 meter section of embankment will be made of concrete, similar to the ongoing work described in paragraph 0. However, the embankment work will also include reinforced concrete (RC) piles and geotextiles, with armor rock protection at the tow of the embankment as shown in Figure D.7.

Figure D.7 Typical Cross-section of Embankment Protection Work



Source: TA 7986-CAM Consultants

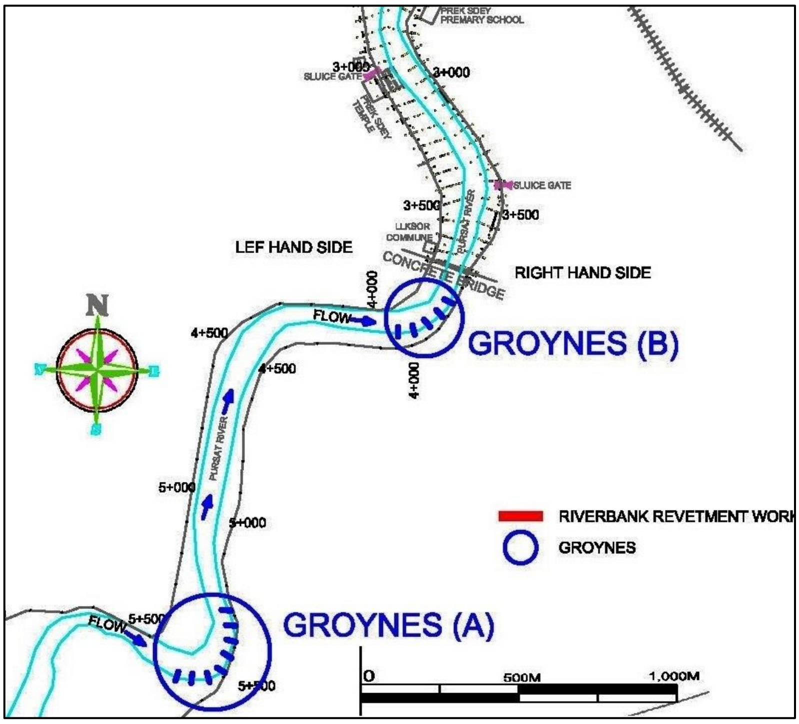
Figure D.8 Location of Embankment Strengthening Work



Source: TA 7986-CAM Consultants

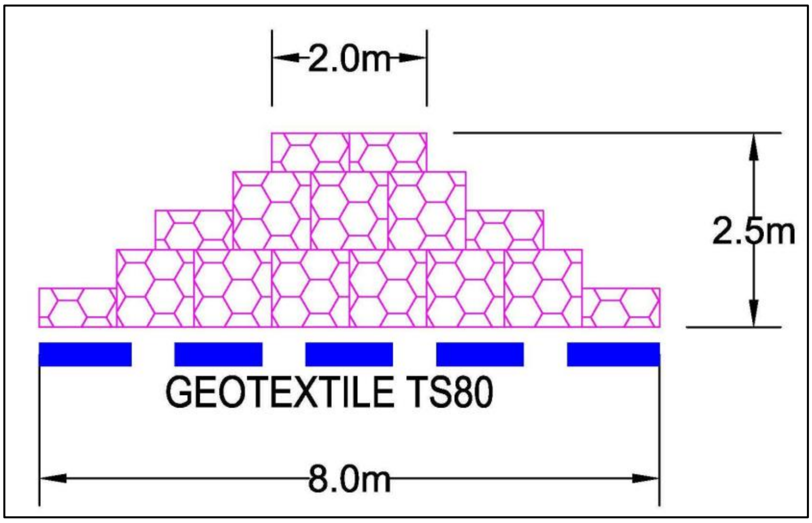
71. Two areas upstream that are in danger of collapsing due to erosion will be protected by the construction of groynes. These areas have previously been protected by wooden groynes which have been washed away. Thus the project will place gabion groynes at 30 meter intervals into the river at each of these two locations. Point A as shown in Figure D.9, will have five groynes, while point B requires eight groynes due to its longer length.

Figure D.9 Location of Groynes for Embankment Protection



Source: TA 7986-CAM Consultants

Figure D.10 Typical Groyne Cross Section



Source: TA 7986-CAM Consultants

72. The quantity estimate for the embankment protection work is contained in Table E-5.

E. Cost Estimates

1. Sources and Development of costs

73. Costs were obtained from the PDPWT in Pursat in July 2013 for various ongoing works. Costs not available in Pursat, were obtained from Phnom Penh. Costs have been reviewed and modified to reflect costs in Pursat in September 2013 as shown in Table E-1 below.

Table E-1 Unit Costs

Item	Names and Description	Unit	Unit Price (USD)
I.	EARTH WORKS		
1.1.	Excavation	m^3	0.60
1.2.	Compaction	m^2	0.60
1.3.	Normal Soil	m^3	4.20
1.4.	Laterite Soil	m^3	8.19
1.5.	Sand for backfilling	m^3	7.50
II.	STONE, ROCK, AGGREGATE WORKS		
2.1.	Mixed Aggregate - M30/M40	m^3	18.45
2.2.	Compaction	m^2	0.60
2.3.	Stone 15cmx25cm	m^3	17.22
2.4.	Stone 4cmx6cm	m^3	15.90
III.	CONCRETE WORKS / REBAR WORKS		
3.1.	Concrete Cylinder 30Mpa	m^3	114.00
3.2.	Mortar	m^3	90.00
3.3.	Cement (Sulphate Resistant-Cement)	ton	138.00
3.4.	Reinforcement Steel Bar (V steel, SD390)	ton	900.00
3.5.	Plywood Formwork	m^3	614.64
3.6.	Brick (Solid/Hollow)	pcs	0.07
IV.	PAVEMENT		
4.1.	Laterite Soil (Thick 200 mm)	m^2	2.71
4.2.	Mixed Aggregate, M30 (Thick 200 mm)	m^2	3.95
4.3.	RC concrete, DB12@175 (Thick 175 mm)	m^2	40.28
4.4.	Bituminous Pavement,	m^2	14.36
4.5.	Paving Block / Tile	m^2	8.96
4.6.	Concrete curb (Standard H350mm)	l.m.	7.00
4.7.	Surface drain (V-drain)	l.m.	16.99
4.8.	Grass and Plating	m^2	1.50
4.9.	Galvanized Wire Mesh for capping the stone	m^2	3.00
V.	GEOSYNTHETIC		
6.1.	Geotextile, Polyfelt TS30	m^2	1.22
6.2.	Geotextile, Polyfelt TS50	m^2	1.98
6.3.	Geotextile, Polyfelt TS80	m^2	3.18
6.4.	Galvanized Gabion Box 2.0mx1.0mx1.0m	pcs	54.00
6.5.	Galvanized Gabion Box 2.0mx1.0mx0.5m	pcs	44.40

Item	Names and Description	Unit	Unit Price (USD)
6.6.	Galvanized Mattress Box 6.0mx2.0mx0.3m	pcs	144.00
C	Unskilled Labor (1man/day)	man	4.38
	Skilled Labor (1man/day)	man	7.30

Source: TA 7986-CAM Consultants

2. Capital Costs

74. The total capital cost for the work in Pursat is **USD 8.79 million** of which 92 per cent is for the drainage system.

75. Costs were then developed for each drain section per meter length. That is for diameters 600 millimeters; 1,000 millimeters; 1,500 millimeters, 1,750 millimeters and a 3.0 meter box culvert. These are shown in the table below.

Table E-2 Unit Costs for Drain Installation

Item	Description	Quantity	Unit	Price (USD)	Amount (USD)
I.	**Preliminary Work**				
1.1.	Remove existing road surface	11.00	m^2	0.50	5.50
1.2.	Other infrastructure facilities	3.00	m^2	1.00	3.00
	Sub Total (I)				**8.50**
II.	**Excavation**				
2.1.	Open cut down to required depth	5.50	m^3	0.60	3.30
2.2.	Export soil out (pipe hole)	0.45	m^3	1.00	0.45
2.3.	Compacting the foundation	2.00	m^2	0.60	1.20
	Sub Total (II)				**4.95**
III.	**Pipe Installation (less pipe cost)**				
3.1.	Bedding work (Crusher, Thk150mm)	0.23	m^3	21.45	4.84
3.2.	Concrete Support	1.00	linear meter	5.00	5.00
3.4.	Installation Labor Cost	1.00	linear meter	5.00	5.00
	Sub Total (III)				**14.84**
IV.	**Backfilling**				
4.1.	Selected soil material (Assume 50%)	2.41	m^3	8.19	19.74
4.2.	Compaction	4.82	m^3	3.00	14.46
	Sub Total (IV)				**34.20**
	Total (I+II+III+IV+V)				**63.00**
	600 millimeter diameter pipe	1.00	linear meter	39.45	39.45
	Total Cost 600 millimeter pipe				**102.45**
	1,000 millimeter diameter pipe	1.00	linear meter	128.86	128.86
	Total Cost 1,000 millimeter pipe				**191.86**
	1,500 millimeter diameter pipe	1.00	linear	272.37	272.37

Item	Description	Quantity	Unit	Price (USD)	Amount (USD)
			meter		
	Total Cost 1,500 millimeter pipe				**335.37**
	1,750 millimeter diameter pipe	1.00	linear meter	334.55	334.55
	Total Cost 1,750 millimeter pipe				**397.55**
	Box Culvert 3.0 meters by 3.0 meters				**828.87**

Source: TA 7986-CAM Consultants

76. Table E-3 provides a summary of each drain section cost and the total cost of the drainage system which is USD 8.147 million base cost, not including physical or price contingencies.

3. Climate Change

77. Paragraph 0 shows that the time of concentration applied to accommodate envisaged climate change through more intensive rainfall is 40 mm / hr. Less intensive rainfall could use a concentration time of 35 mm/hr which, in the past has been more common for drain designs. Concrete road surfacing has also been used as it is more robust and less liable to damage through storms, rather than the more usual double bituminous surface treatment (DBST) which is more common in Cambodia. Using this time of concentration and DBST road surfacing the drains were redesigned which resulted in a cost of USD 5.428 million as shown in Table E-4.

78. Thus the incremental cost of climate change adaption for the drainage system is USD 2.719 million.

Table E-3 Cost of Drainage System

All costs in Thousand USD

Line	Node		Drain										Pavement			Reinstatement Cost				Cost per Section
			Length		Left side		Right side		Total	Man-holes (nos)	Cost	Type		Cost	Side-walk	Water Pipe	Fiber Optic Cable	Electric Poles	
	>	<	Left	Right	L(m)	Dia (mm	L(m)	DIA.				Exist	New						
I	E1	C1	-	510	510	1,500	-	-	510	10	229.9	Earth	RC-P	168.7	18.3	20.4	13.2	7.1	457.5
I	C1	B1	-	515	515	1,750	-	-	515	10	301.0	Earth	RC-P	170.4	18.4	20.6	13.2	7.1	530.7
I	B1	A1	-	525	525	1,750	-	-	525	11	306.8	Earth	RC-P	173.7	18.8	21.0	13.2	7.3	540.8
II	D2	B2	510	-	510	1,750	-	-	510	10	298.0	Earth	RC-P	168.7	18.3	20.4	-	7.1	512.5
II	B2	A2	455	-	455	1,750	-	-	455	9	265.9	Earth	RC-P	150.5	16.3	18.2	-	6.3	457.2
II	F2	D2	-	410	420	1,500	-	-	420	8	189.3	DBST	RC-P	138.9	15.0	16.8	16.8	5.8	382.7
II	G2	F2	-	-	480	1,500	-	-	480	10	216.4	DBST	RC-P	158.8	17.2	19.2	-	6.7	418.2
III	D3	B3	305	-	-	-	385	1,750	385	8	225.0	Earth	RC-P	127.4	13.8	15.4	-	5.3	386.9
III	B3	A3	320	-	-	-	320	1,750	320	6	187.0	Earth	RC-P	105.9	11.5	12.8	-	4.4	321.6
III	E4	D3	110	-	-	-	270	1,500	270	5	123.5	DBST	RC-P	89.3	9.7	10.8	-	3.7	237.0
IV	H3	E4	-	310	-	-	540	1,500	540	11	247.0	DBST	RC-P	178.6	19.3	21.6	-	7.5	474.0
IV	B3	B1	-	-	770	1,000	-	-	770	15	189.7	Earth	RC-P	254.7	27.6	-	-	10.7	482.7
IV	D2	C1	340	-	340	1,000	-	-	340	8	84.5	Earth	RC-P	112.5	12.2	-	-	4.7	213.9
IV	H1	H3	390	-	-	-	510	1,000	510	12	138.8	DBST	RC-P	168.7	18.3	20.4	-	7.1	353.2
IV	C5	E4	100	-	-	-	260	1,000	260	5	69.3	DBST	RC-P	86.0	9.3	10.4	-	3.6	178.6
V	E6	A5	240	-	1460	600	-	-	1,460	29	156.4	DBST	RC-P	483.0	52.3	58.4	44.0	20.2	814.3
-	H4	G4	-	-	180	600	180	600	360	12	39.8	DBST	RC-P	119.1	12.9	-	-	5.0	176.8
-	A3	A1	-	600	600	600	-	-	600	12	64.3	Earth	DBST	112.3	21.5	-	-	8.3	206.3
I	I1	H1	-	-	220	600	110	600	330	7	35.4	DBST	RC-P	109.2	11.8	-	-	4.6	160.9
-	F5	J3	-	-	110	600	220	600	330	7	35.4	DBST	RC-P	109.2	11.8	-	-	4.6	160.9
Total Drains			**2,770**	**2,870**	**7,095**	**-**	**2,795**	**-**	**9,890**	**206**	**3,403**	**-**	**-**	**3,185**	**354**	**286**	**100**	**137**	**7,467**
Overflow Structures												3	Nos	60					180.0
Preliminary Treatment												1	Nos	500					500.0
TOTAL																			**8,147**

Source: TA 7986-CAM Consultants

Table E-4 Cost of Drainage System without Climate Change Measures

Line	Node		Drainpipe									Pavement			Reinstatement cost				Total COST PER SECTION
			EXISTING		NEW PROPOSED														
			LENGTH(m)		LEFT		RIGHT		TOTAL L(m)	MH	COST	TYPE		COST	SIDE WALK	WATER PIPE	OPTIC CABLE	ELECTRIC POLES	
	>	<	LEFT	RIGHT	L(m)	DIA.	L(m)	DIA.		(nos)	(USD)	EXIST	PROPOSE	(USD)					
I	E1	C1	-	510	510	1,200	-	-	510	10	229.9	EARTH	DBST	95.4	13.7	10.2	6.6	7.1	362.9
I	C1	B1	-	515	515	1,200	-	-	515	10	232.1	EARTH	DBST	96.3	13.8	10.3	6.6	7.1	366.4
I	B1	A1	-	525	525	1,500	-	-	525	11	236.7	EARTH	DBST	98.2	14.1	10.5	6.6	7.3	373.4
II	D2	B2	510	-	510	1,500	-	-	510	10	229.9	EARTH	DBST	95.4	13.7	10.2	-	7.1	356.3
II	B2	A2	455	-	455	1,750	-	-	455	9	265.9	EARTH	DBST	85.1	12.2	9.1	-	6.3	378.7
II	F2	D2	-	410	420	1,000	-	-	420	8	103.5	DBST	DBST	78.6	11.3	8.4	8.4	5.8	216.0
II	G2	F2	-	-	480	1,000	-	-	480	10	118.3	DBST	DBST	89.8	12.9	9.6	-	6.7	237.2
III	D3	B3	305	-	-	-	385	1,500	385	8	176.1	EARTH	DBST	72.0	10.4	7.7	-	5.3	271.5
III	B3	A3	320	-	-	-	320	1,750	320	6	187.0	EARTH	DBST	59.9	8.6	6.4	-	4.4	266.3
III	E4	D3	110	-	-	-	270	1,500	270	5	123.5	DBST	DBST	50.5	7.3	5.4	-	3.7	190.4
IV	H3	E4	-	310	-	-	540	1,200	540	11	247.0	DBST	DBST	101.0	14.5	10.8	-	7.5	380.8
-	B3	B1	-	-	770	1,000	-	-	770	15	189.7	EARTH	DBST	144.1	20.7	-	-	10.7	365.2
-	D2	C1	340	-	340	1,000	-	-	340	8	84.5	EARTH	DBST	63.6	9.1	-	-	4.7	162.0
IV	H1	H3	390	-	-	-	510	1,000	510	12	138.8	DBST	DBST	95.4	13.7	10.2	-	7.1	265.2
-	C5	E4	100	-	-	-	260	1,000	260	5	69.3	DBST	DBST	48.6	7.0	5.2	-	3.6	133.7
V	E6	A5	240	-	1460	600	-	-	1,460	29	156.4	DBST	DBST	273.1	39.3	29.2	22.0	20.2	540.3
-	H4	G4	-	-	180	600	180	600	360	12	39.8	DBST	DBST	67.3	9.7	-	-	5.0	121.8
-	A3	A1	-	600	600	600	-	-	600	12	64.3	EARTH	DBST	112.2	16.1	-	-	8.3	201.0
I	I1	H1	-	-	220	600	110	600	330	7	35.4	DBST	DBST	61.7	17.7	-	-	4.6	119.4
-	F5	J3	-	-	110	600	220	600	330	7	35.4	DBST	DBST	61.7	17.7	-	-	4.6	119.4
TOTAL			2,770	2,870	7,095	-	2,795	-	9,890	206	2,963	-	-	1,850	284	143	50	137	**5,428**

Source: TA 7986-CAM Consultants

79. For the Embankment Protection the costs are shown below.

Table E-5 Cost and Quantity Estimate for the Embankment Protection

	Quantity	Unit	Rate	Cost
Revetment Work - Length 200m				
I. Foundation Works				
Soil Removal	2,550	m^3	1.50	3,825
Soil Reclamation	200	m^3	4.80	960
Concrete Piles	120	piles	100.00	12,000
Footings	40	footings	189.00	7,560
II. Slope Works				
Slope Length	14.0	m		
Geotextile	2,800	m^2	2.57	7,207
Stone Bedding	420	m^3	22.39	9,402
Beams	1,360	m	21.84	29,702
Lean Concrete	140	m^3	148.20	20,748
Concrete Slab	2,800	m^2	35.00	98,000
III. Apron Works				
Apron Length	4.0	m		
Geotextile	900	m^2	2.57	2,317
Armor Rock	240	m^3	22.39	5,373
IV. Wall				
Masonry Wall	200	m	3.15	630
V. Sidewalk				
Paving Block	3,000	m^2	8.96	26,888
Total Revetment Work Cost				**224,611**
Groynes (2 Locations - 5 Groynes at each location				
Total of Groynes used:	13	groynes	(A)=8; (B)=5 pieces	
Gabion 2.mX1.mX1.m	3,250	pcs	81.00	263,250
Stone	6,500	m^3	22.39	145,509
Geotextile	3,120	m^2	4.13	12,898
Total Groyne Work (USD)				**421,657**
Total Embankment Protection Costs (USD)				**646,269**
			Rounded off -	**650,000**

Source: TA 7986-CAM Consultants.

Table E-6 Drainage Maintenance Equipment

Item	Unit	Quantity	Rate	Amount (USD)
Sewer Maintenance				
Extendable rod and brush sets to 30 meters	Number	10	3,000	30,000
Safety clothing	Sets	50	250	12,500
Total				**42,500**

Source: TA 7986-CAM Consultants

4. Recurrent Costs

80. The recurrent costs for the embankment works will be minimal. However, the drainage will require substantial costs for operation and maintenance. The annual recurrent costs are estimated at USD 500,000. The operation and maintenance arrangements are described in Section H.

F. Benefits and Risks

1. Direct Indirect Benefits

81. These are fully described in sections 12 and 13 of the main reports and the appendices containing the financial and economic analyses.

2. Risks

82. A risk assessment was completed. The risk matrix is given in the table below, with mitigation measures.

Table F-1 Risk Matrix

Risk	Probability	Impact	Mitigation Measures
Drainage system not maintained	Very High	High	Design – aims to minimize maintenance Implementation – proper supervision to ensure drains are built correctly – PDPWT identifies and train staff to operate the pumps and preliminary treatment facility. Operation – ensure funds are available for operation. Budget – include operation and maintenance sots in annual budgets.
Existing drains do not function	Low to Medium	Low	Design – new drains able to accommodate stormflows
Wastewater pollutes fields	Low	Medium	Design – stormwater flows to channels, wastewater treated with preliminary treatment.
Embankments are damaged	Low	High	Implementation – ensure proper supervision

Source: TA 7986-CAM Consultants

a. Potential Negative Impacts of the Projects

83. The main potential negative impacts of the drainage system will be balancing treatment with connections. A payment system will need to be introduced to ensure that funds are available for operation and maintenance. This will be explored through the pilot demonstration establishments of urban service units.

G. Implementation

1. Existing Responsibilities and Issues

84. Currently PDPWT is responsible for the operation and maintenance of the drains in Pursat. At present the department is not always fully involved in the planning and implementation of the drainage system. This can mean that they are responsible for maintaining an asset that they haven't been able to review its effectiveness. This is a constraint given the issues with the existing drainage system discussed in paragraph 0.

85. Currently PDPWT employ manual labor on an as-needed contract basis to carry out maintenance of the existing drains. They have about 20 laborers working under this method.

86. The Provincial Department of Water Resources and Meteorology (PDWRAM) is currently responsible for looking after most of the existing embankment.

2. Implementation Arrangements

a. Implementation Program

87. In Pursat the management of the embankment construction will be by the Provincial Department of Works and Transport (DPWT) with oversight provided by the Municipality as PDPWT has greater capacity for managing this type of work.

88. The PDWRAM will also need to be involved, as it will be responsible for some of the embankment protection. This will be done through the local steering committee. A detailed description of the full project implementation arrangements is contained at Section 14 of the main report and in various appendices.

89. The embankment protection work will need to be carried out during the dry season. The scale of the work is such that it should all be able to be completed within one dry season, , but 15 months have been allowed in the schedule. The main issue will be ensuring that the detailed surveys can be carried out before the next wet season. The drainage work construction can be carried out all year.

Table G-1 Indicative Implementation Schedule

Item	2015	2016	2017	2018	2019	2020	2021	2022
2.1 Improved Town Centre Drainage								
Conduct topographical and soil surveys	□□□□	□□□□	■□□□	□□□□	□□□□	□□□□	□□□□	□□□□
Update feasibility study and prepare appraisal report for ADB and government approval (2 sets: one for drainage [ICB]).	□□□□	□□□□	■■■□	□□□□	□□□□	□□□□	□□□□	□□□□
Issue ICB bids, evaluate bids and submit to ADB for no objection (drainage)	□□□□	□□□□	□□□■	■■□□	□□□□	□□□□	□□□□	□□□□
Submit external resettlement M&E report to ADB (continuous, as per agreed RPs)	□□□□	□□□□	■■■■	■■■■	■■■■	□□□□	□□□□	□□□□
Award contract for drainage works	□□□□	□□□□	□□□□	□□■□	□□□□	□□□□	□□□□	□□□□
Transfer of O&M responsibilities for drainage to USU	□□□□	□□□□	□□□□	□□■□	□□□□	□□□□	□□□□	□□□□
Construct drainage system starting at foot of system, construct pumping stations and WWTP with road rehabilitation as required.	□□□□	□□□□	□□□□	□□□■	■■■■	■■□□	□□□□	□□□□
Supervise start-up and commissioning of WWTP	□□□□	□□□□	□□□□	□□□□	□□□□	□□■■	□□□□	□□□□
Final handover of works	□□□□	□□□□	□□□□	□□□□	□□□□	□□□□	■□□□	□□□□
Internal monitoring of safeguards, including RPs and EMPs (continuous, as per agreed safeguard documents)	□□□□	□□□□	■■■■	■■■■	■■■■	■■■■	■■■■	■■■□
Defects liability period	□□□□	□□□□	□□□□	□□□□	□□□□	□□□□	□■■■	■□□□
2.2 Riverbank Erosion Protection								
Conduct topographical and soil surveys	□□□□	□□□□	■□□□	□□□□	□□□□	□□□□	□□□□	□□□□
Update feasibility study and prepare appraisal report for ADB and government approval (one set for riverbank protection [NCB]).	□□□□	□□□□	■■■□	□□□□	□□□□	□□□□	□□□□	□□□□
Issue ICB bids, evaluate bids and submit to ADB for no objection (drainage)	□□□□	□□□□	□□□■	■■□□	□□□□	□□□□	□□□□	□□□□
Submit external resettlement M&E report to ADB (continuous, as per agreed RPs)	□□□□	□□□□	■■■■	■■■■	■■■■	□□□□	□□□□	□□□□
Award contract for riverbank erosion protection	□□□□	□□□□	□□□□	□■■□	□□□□	□□□□	□□□□	□□□□
Construction of riverbank protection	□□□□	□□□□	□□□□	□□■■	■■□□	□□□□	□□□□	□□□□
Final handover of works	□□□□	□□□□	□□□□	□□□□	□□■□	□□□□	□□□□	□□□□
Internal monitoring of safeguards, including RPs and EMPs (continuous, as per agreed safeguard documents)	□□□□	□□□□	■■■■	■■■■	■■■■	■■■■	■■■■	■■■□
Defects liability period	□□□□	□□□□	□□□□	□□□□	□□□■	■■■□	□□□□	□□□□

Source: TA 7986-CAM Consultants.

b. Implementation Support

90. The PDPWT in Pursat has limited capacity and has not carried out design or construction management of such a large scale project and also lacks the capacity to procure contractors for such works. Assistance will be required in project design, procurement and supervision. In particular this will require the following expertise:

- Surveying;
- Soil mechanics;
- Drainage engineering;
- Roads' engineering;
- Cost engineering and estimation;
- Procurement;
- Construction management including supervision.

91. This expertise overlaps with the type of expertise required for the other infrastructure interventions under the Project and clearly there are efficiencies in combining inputs. Thus much of the design and procurement work will be carried out in the PMU. However, supervision will need to be done locally and will require extensive field-based work. While a major

secondary objective of providing implementation support should be to develop local level capacities.

3. Procurement

92. All procurement to be made using the ADB loan proceeds will be carried out in accordance with ADB's Procurement Guidelines (2007, as amended from time to time). Full details of procurement are contained in Section 14 of the Main Report and in relevant supporting annexes.

93. The work will mainly be all civil work, although there is an option to procure the pipes separately. However, it is much simpler to include the pipes within the civil works' contract. This not only simplifies management, but also ensures that only one contractor is responsible for the whole drainage system. There will be very little equipment procurement. Hence only civil works contracts will be procured.

94. It is proposed to use one contractor for the embankment protection works and another for the drainage works. As the cost of the drainage works is less than USD one million, national competitive bidding can be used. For the drainage works, International competitive bidding (ICB) will be applied.

H. Operation & Maintenance

1. Responsibilities

95. PDPWT will be responsible for the operation and maintenance of the drainage system. The embankment protection would be under the jurisdiction of the PDWRAM.

96. All the work has been designed to minimize any maintenance. However, the drains will require continual operation to ensure that wastewater is pumped to the preliminary treatment facility. Even the embankment protection will require routine and periodic maintenance.

97. The drainage system will require both human and financial resources for operation and maintenance. Power will be required for the pumps which could be a substantial cost, although the overflow structures are designed to minimize pumping of stormwater. At least four staff will need to be employed by either the municipality to operate the pump station and treatment facility. However, the PDWT currently has a pool of around 12 day-laborers that it uses. This could be expanded and even formalized. The drainage system will require cleaning very three years, with annual checks to clear any blockages. At least 20 staff will be required. The large diameter of the drains (600 millimeters to 1,750 millimeters), means that access should be relatively easy and mechanical equipment is not proposed for cleaning the drains. Rods and brushes can be used to clear any debris and blockages for diameters less than 900 millimeters.

98. Maintenance costs for large static civil works structures, such as roads and embankments, tend to be variable over time. For example, bitumen roads need resurfacing every four or five years, while concrete walls should be plastered every ten years. However, annual operation and maintenance budgets usually do not cover these items. The cost of these larger maintenance items is best covered by including them in the annual capital budgets. As such the table below only includes the annual costs for maintenance. It also does not include any incremental administration costs by government.

2. Costs

99. Table H-1 below provides a description of the annual operation and maintenance costs. As this is a very broad estimate, the quantities and amounts have been rounded.

Table H-1 Annual Operation and Maintenance Costs

Description	Unit	Quantity	Rate (USD)	Amount (USD)
Drainage				
Operation				
Power Supply	kWh	7,500	2.8	21,000
Staffing Pump Station	Person Months	48	120	6,000
Other costs	Lump Sum			15,000
Total Operation Costs				**42,000**
Maintenance				
Drain Cleaning (3% of capital)				240,000
Total Drain Costs				**250,000**
Embankment (1% of cost)	Lump Sum			6,000
Total				**496,000**
Rounded-off				**500,000**

Source: TA 7986-CAM Consultants.

100. To assist with maintenance, a budget of USD 80,000 will be provided to purchase sewer/pipe cleaning equipment. This will include rods and brushes as well as protection equipment for laborers.