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Enabling Delta Life

Water App: a propotype tool for decision-making in Polder 43/2B

Innovation Fund Blue Gold

Acknowledgement

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Disclaimer

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Contents

Appendices

1 Introduction

1.1 Innovation Fund Blue Gold

This project has been funded by the Innovation Fund of the Blue Gold program. Blue Gold is a program aiming to establish and empower communities to improve the management of their water resources, and obtained improved services derived from them. It is a collaboration program between the Government of the Netherlands and the Government of Bangladesh. The implementation is led by Euroconsult Mott MacDonald.

Blue Gold manages an Innovation Fund meant to test different innovations that can contribute to accelerate the development of the water resources management by communities.

The project that we present here was awarded with financial support from the innovation fund due to the innovative aspects of it and the potential contribution to improve water management at polder level.

1.2 Rationale of the project

The use of forecasting tools in water management has increased rapidly over the last 2 decades. Where the first developments typically focussed on Flood Early Warning Systems (FEWS)[1], recent developments have also generated tools, applications and dashboards that help water managers and stakeholders at local level to predict and plan for droughts, ensure safe water abstraction from ground and surface water, anticipate on drainage congestion and optimise water distribution and maintenance. Examples of recent innovations that have been become part of the tactical and day-to-day operational water management at the Dutch Regional Water Authority Brabantse Delta have been presented and discussed with a delegation from the Ministry of Water Resources (MoWR) of Bangladesh and the Bangladesh Water Development Board (BWDB) during a visit to the Netherlands in 2015.

A key advantage of using these tools is the ability to show ‘objective’ information in Geographical Information Systems (GIS). Water managers, be they at catchment or polder level, can visualise key indicators such water levels and depths, extent of drainage congestion, shortages or water quality on a map and discuss these with users, stakeholders and planners. Scenario analysis - asking the ‘what-if’ question - can be carried out by simulating a rainfall event, opening or closing of sluice gates, excavation, and the like. Water managers and stakeholders can use this information to compare the pros and cons of, as example, investments in excavation or sluice gate enlargement, operational rules and maintenance.

In the polder systems of the coastal region of Bangladesh, there is a need for objective and practical knowledge about the behaviour of the water system, understand the impacts and action perspectives of water management options and share this information among stakeholders. Present communication between stakeholders is often scarce, and information on (practical)

[1] The use of these tools and predictive models for flood forecasting has become more mainstream over the last 10 years, with countries like the U.S.A., UK, Bangladesh, Spain and the Netherlands having developed sophisticated National Flood Forecasting Systems.

water management issues is either not readily available or easily shared. With many different stakeholders in one polder, sharing information is a first step towards solving conflicts, planning for Operation & Maintenance (O&M) and anticipating on events such as floods, waterlogging and droughts.

1.3 Short term objective of the project

This projects aims to develop a prototype of an application to plan short and longer term interventions in the water system and to develop scenario based strategies which can be used in daily water management practices. Such an application would be beneficial for all, especially to optimise the economic productivity in the polder areas.

The final application should be a basic, robust and simple to use 'water-app' decision tool that routes water flows through a polder area, and supports water management by informing about the operation of water structures. This 'water-app' will be designed such that it can be used by the BWDB, Water Management Organisations (WMOs), but also by local communities and Non-Government Organisations (NGOs). The application should be operable for all stakeholders, including those with a low literacy level.

1.4 Long term ambition

In the long term, we aim to chart out a fully-fledged development of a *water management decision-making toolbox.*

The ambition is to develop this *water management decision-making toolbox* in close collaboration with IWM and the BWDB in order to ensure its sustainability and embedding in the water management process.

The 'water-app' decision tools, when fully developed, will:
- contribute to improve the livelihoods of the polder communities by reducing their flood vulnerability and optimising water use and distribution, and increase crop yields and fish production;
- promote information sharing and multi-stakeholder involvement;
- improve decision-making ('conflict management - governance') and contributing to the social cohesion within polder communities
- enhance the water management knowledge base, by strengthening BWDB teams, WMOs, and NGO's.

1.5 Structure of the report

This report has been written with the aim of describing the work carried out to develop prototypes of different 'water-apps'. It is a rather theoretical and technical report as it is not intended to act as a guideline for the water-apps application. However, some specific guidelines have been added in the annexes for further explanation of those pre-feasibility water-apps that have been developed during the mission in November 2016.

This report consists of 6 sections. After the introduction just given in this section, the approach for the development of the water-apps is given in section 2. Section 3 describes the activities carried out in Bangladesh such as the field visit and the workshops. These activities led to the choice of the most relevant water-apps which are described in section 4. Section 5 includes a road map and the possible future development of the water-apps. Finally, section 6 summarizes the conclusions of the project.

2 Approach

2.1 Phasing and main activities

First a DEMO of a potential water-app was developed to *show the proof of concept*, including fictitious water flows and hydraulic structure operation schemes.

After initial consultation with the local BWDB engineers and WMOs, we drafted a long list of desired apps and started working on the most popular ones. Through a second consultation, a short list of desired apps was made and three of the apps were developed to the Prototype stage.

The involvement of IWM as knowledge institute increased the sustainability of the application of the water-app(s) decision-tool(s) in the future. By involving IWM from the beginning, future tasks such as developing new applications, upgrading, data management and maintenance are secured.

Basically, two types of 'water-app' prototypes were developed within the project:

- Water-app based on spatially distribution information such as the surface elevation. We call this app the *"Spatial Analyser".* This tool consists of a Digital Elevation Model (DEM), a flow routing algorithm and an application to simulate the impact of the operation of hydraulic structures like gates, pumps and sluices and assess the impact of excavation (changed cross-sections) of khals. The routing information can be used to – as example - : i) develop management strategies to regulate polder and internal khal in- and outflow; ii) discuss scenarios to reduce conflicts / optimise water distribution to maximise crop yields and fish production; iii) anticipate on operational control of gates and water logging and flooding to reduce damages and alternative (gravity-pumping) drainage routes; iv) anticipate on water scarcity and droughts; and, in due course: vi) 'simulate' a whole range of management and maintenance interventions such as dredging, excavation, pumping, modification of hydraulic structures and the like.

- Water-app based on water structure design and operational rules. There were two apps developed: the *"Sluice Designer and Operator"* and the *"Culvert Designer and Maintainer".*

For both types of Apps, a well organised participatory approach to develop the full-fledged tool was important. Stakeholders such as the BWDB, WMOs, Local Governments and others are potential end users of the tool and therefore they were involved from the beginning.
The following activities were carried out to develop the prototypes (these activities are extensively described in Section 3):

2.1.1 Phase 1: Preparation

The first phase included a desk study and technical data preparation in the Netherlands and Bangladesh.
The deliverables were:

- Concise description of the polder 43/2B (Annex A).
- Invitation letter to BWDB and stakeholders in the selected polder.

2.1.2 Phase 2: Field work and Prototype development

The bulk of the work was carried out in the second phase and consisted of an intensive one week design activity, with a 2-day participatory workshop ('pressure cooker' concept) in the middle:

- Start-up meeting at Blue Gold office
- Travel to and from Patuakhali
- Introduction meeting at Blue Gold office
- Field visit
- 1st workshop - consultation with stakeholders at polder level. Identification of main issues in the polder and drafting of the long list of desired water-apps.
- Conceptual demo development, based on the desk work carried out in Phase 1 and the results of the 1st workshop and field visit
- 2nd workshop and conceptual demo testing - stakeholder consultation. Drafting of the short list of water-apps.
- Travel to Dhaka
- Meeting at the Blue Gold Office to show the results of the project
- Meeting with the BWDB to show the results of the project and define potential for up-scaling.

The deliverables were:

- Field work and workshop report (Section 3)
- Draft conceptual demo description (Section 4)
- Suggestions for upscaling to prototype (Section 5)

2.2 Potential gaps and points of attention that were considered

The most important points of attention were:

1. The interest of local stakeholders. Initially, the BWDB and WMO's are considered as the main target group, however other stakeholders need to be involved as well. A practical participatory approach was used during demo development, including design workshops in the office of the BWDB, WMOs and through field visits and focus group work. The involvement of IWM and field level Blue Gold staff was key for the success.
2. The lack and /or insufficient (essential) data was a potential gap. Selecting a polder with sufficient and reliable data (see 'data and information needs') and making a close link with the BWDB, was crucial. IWM played an important role here.
3. The resolution of the DEM should be sufficient to route flows with a certain level of accuracy.

2.3 Data and information used to develop the prototype water-apps

- Digital Elevation Model developed by CEGIS with a resolution of 50 by 50 meters;
- Incidental water level & discharge measurements (rating curves) in adjacent rivers;
- Precipitation data (minimum on daily basis, incl. 'forecasts');
- Dike/embankment/road alignment;
- Overview of cropping pattern distribution in the polder (minimum land-use map);
- Salinity measurements;
- Local/community knowledge and experience on:
  - System behaviour during extreme events;
  - Day-by-day operational activities;
  - Implicit decision criteria.

3 Results

3.1 Preparation phase

The polder report of Blue Gold[2], the DEM and data on precipitation and water levels were the main inputs for the preparation phase. With this information we prepared a concise water system analysis of the polder (Annex 7A) and evaluated the potential of using the DEM for the water-apps.

The DEM of 50 by 50 meters was found to be rather coarse for an area with such small variation in surface elevation (up to 2.5 meters maximum). In such a DEM, the elevations within cells are averaged and therefore detail is lost. The DEM used was not previously filtered (buildings, trees, etc. had not been removed).

In the Polder 43_2B, roads of about 10 meters width lie next to khals that are 25 meters wide. Roads normally lie higher (+2 m.a.s.l.) than the rest of the polder, while khals lie lower (water surface around 0 m.a.s.l.). If these two features are averaged in one cell of 50 by 50 meters, they disappear and the cell obtains an average height representing neither the road nor the khal. This results in a DEM where roads and khals cannot be identified. Besides, given the flat condition of a polder, it is complicated to identify watersheds as water can flow in multiple directions depending on the functioning of structures and drainage khals.

In order to simulate runoff and water levels, the elevation differences within the polder need to be evident; especially the location of the khals. For this reason, we took some steps in processing the DEM to make it more suitable for the purpose of this App (Figure 3.1). It is important to notice that the processed App contains erroneous values, as the processing was done to achieve suitability of the DEM for the App purpose, but no ground truth data was used. The biggest errors are probably related to the bathymetry of the khals, as no information was available, and we derived the depth depending on the order of khal (main or secondary khal), and the flow direction deduced from the draining sluice.

The steps taken to process the DEM are described in Annex 7B. The following figure shows how the DEM changed due to the processing steps:

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[2] http://bluegoldbd.org/wordpress/wp-content/uploads/2016/06/EIA-Report-of-Polder-43_2B.pdf

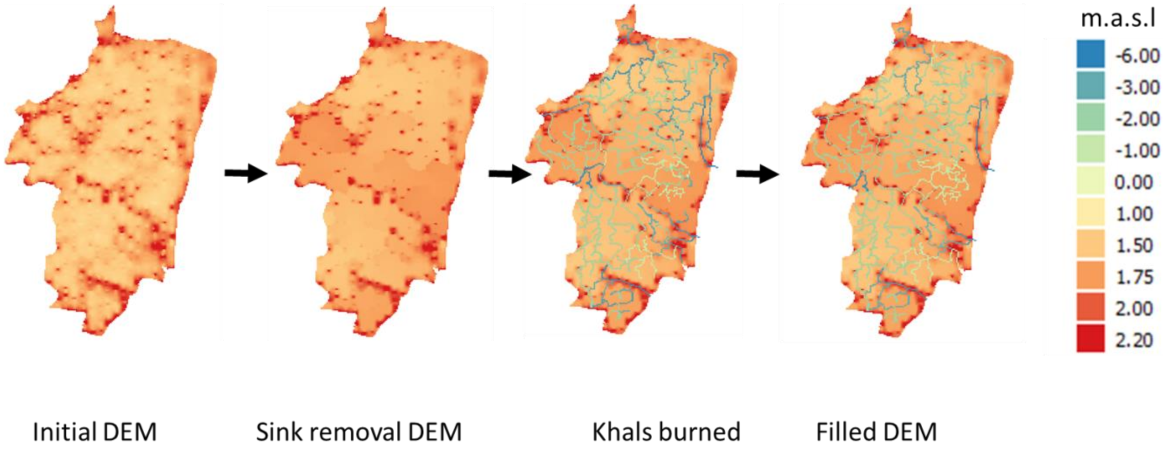

Figure 3.1 Processing of the DEM

3.2 Field Visit Polder 43/2B

On Monday 7 November a field visit in Polder 43-2B was organised to become better acquainted and more familiar with specific water management, and related community issues. The location of the polder can be seen in the following map
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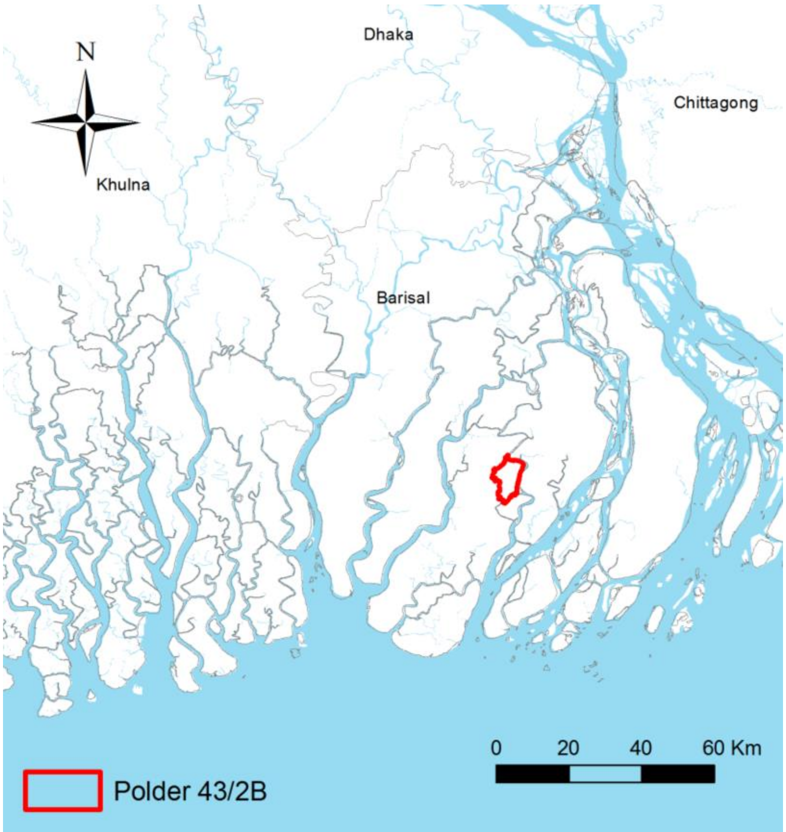


Figure 3.2 Location of the polder 43-2B

The main objectives of the field visit were to:

- Check & verify (ground truth) 'DEM issues' such as high and low areas (filtered data?), vegetation cover (trees), spatial relation between roads and khals, etc.
- Verify 'standard' khal dimensions (large, middle, small – width & depth) and the EIA status description of water courses
- Identify and verify key structures (functioning/non-functioning), actual water conveyance (and silted up) khals and the EIA status description of hydraulic structures (embankments, sluices, inlets, flushing gates, regulators)
- Identify the most important and dominant locations and types of crops and fisheries
- Discuss the (formal and informal) operation rules for water management infrastructure and O&M procedures
- Discuss most important locations and problems (sub-catchment areas) suitable for pilot app
- Prepare for the upcoming workshop(s)

The field visit was organised by the Blue Gold team in Patuakhali. The Blue Gold Field Engineer guided the Deltares/IWM team during the field visit, since they know the operational water management of the polder in detail, and are the most important communication channels with local WMG's and individual farmers.

Pictures 3.1: Joint field visit WMGs, Blue Gold, IWM and Deltares, Polder 43/2B

The locations which were visited are (see Figure 3.1):

1. Badura drainage sluice (lacking maintenance)
2. Mudirhat (road blocking khal)
3. Ramdula/Madda Amkhola area (missing or undersized culverts)
   Amkhola drainage sluice (well-functioning)
4. Masurikati drainage sluice (not functioning, completely demolished flap gates)
5. Bauria drainage sluice (subsidence)
6. Gol Buaria area (high area according to DEM, however road completely covered with trees)
7. Irrigation inlet

Picture 3.2: Bauria drainage sluice

The areas visited are also the most important water logging and drought prone areas (north-west and south).

The Badura drainage sluice is structurally still intact, but is not well-functioning as a result of lacking maintenance (mostly water hyacinth and floating wood/debris) and operation. Water, as is the case with all six drainage sluices, is flowing in and out as a result of diurnal tides on the receiving rivers.

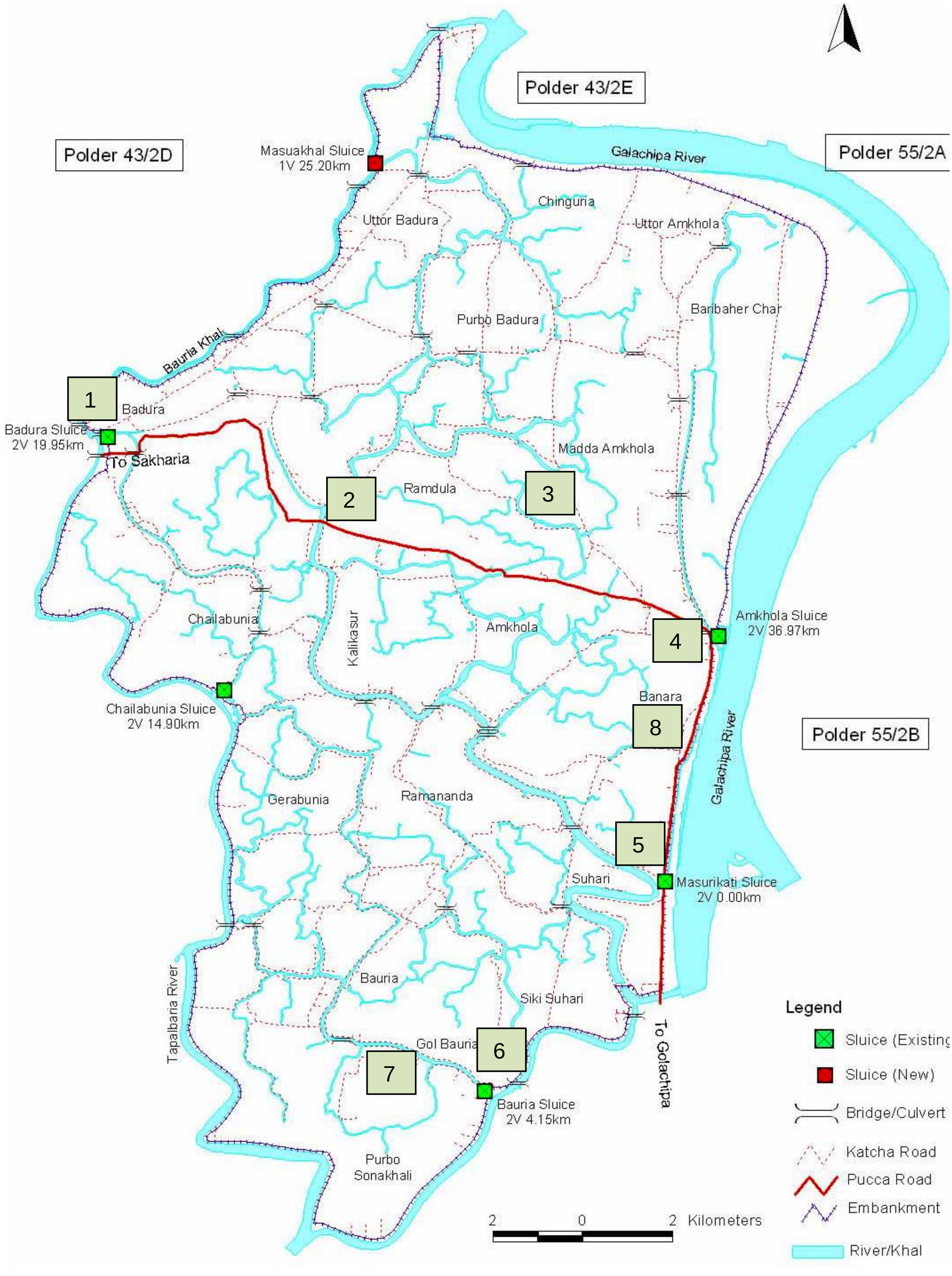


Figure 3.3 Polder 43-2B with locations visited during field trip 7 November 2016 (background map from Polder report).

The Basbinia Main Khal is blocked by the road from Badura to Amkhola at Mudirhat. This results on the one hand in major water logging during the wet season, and water shortage during the drought season. A lack of coordination between the organisations responsible for road design and construction (Local Government Engineering Department - LEGD) and water management leads to these kind of situations. According to the local people, Mudirhat is no exception in Polder 43-2B.

In the area of Ramdula/Madda Amkhola, several examples of missing or undersized culverts in the roads can be seen. Similar to the road blockage at Mudirhat, areas upstream of the road have to temporarily cope with water logging, areas downstream with shortage during the dry season due to a disturbed longitudinal connectivity.

Picture 3.3: Amkhola drainage sluice (Golachipa river side)

The Amkhola drainage sluice is an (the only) example of a well-functioning drainage sluice, although maintenance (mostly water hyacinth and floating wood/debris) could be improved. Local people explicitly stated that they need training to operate the drainage sluice and means to do the necessary maintenance.

The Masurikati drainage sluice is not functioning. The flap gates at the river side are completely demolished, and do not block the tidal flow coming in from the Golachipa river. The sluice gate is not preventing salinity intrusion during the drier periods of the year.

The Bauria drainage sluice in the south of Polder 43-2B is subsiding as a result of an embankment breach adjacent to the hydraulic structure in the past. The extent to which the drainage sluice is subsiding is increasing as a result of progressive seepage under the structure. The drainage capacity of the sluice is not sufficient.

The Gol Buaria area is one of the locations which appear to be elevated in the DEM, however for which no logical explanation could be found beforehand on the basis of e.g. maps and Google Earth images. The altitude of the road next to the khal is approx. 1.5 m above the water level, but the road (and part of the khal) is overlaid by intensive tree coverage.
In this area it was visible that irrigation infrastructure such as secondary channels were not in use anymore. It was also stated that farmers are not willing to relinquish their land for this kind of infrastructure.

All the Water Management Groups have the ability to use inlets for irrigation purposes. These inlets flush water from the rivers into the polder area in the dry season. Most of the (42) irrigation inlets (which sometimes are also used as drainage outlets) are constructed by the BDWB. However, most of the inlets at the western side of the polder (along the Buaria khal and Tapalbaria River) are rather highly elevated, silted up and not often used anymore. Inlets consist of 450 mm pipes with gates. In some cases (groups of) farmers use low lifting pumps to irrigate their fields.

The size of the drainage sluice gates are standardised, the number of vents can differ however. At several drainage sluice locations, local people as well as Blue Gold officials stated that the drainage capacity of drainage sluices needs to be enlarged by adding a minimum of one more vent.

Picture 3.4: Demolished flap gate at Masurikati drainage sluice

The drainage sluices in Polder 43-2B have flap gates on both the land and river side. This is quite exceptional, while normally these kinds of sluice gates have a flap gate at the river side, and a lifting gate at the land side. The former hinders drainage when river stages are high, and the latter facilitates water level management inside the polder.

The diurnal tidal differences in the Galachipa river range within 2 – 3 m.
Water inside the polder is not regulated in any (official) way. The only manner of regulation is based on bund cutting.

Picture 3.5: Elevated road next to khal in Gol Buaria area

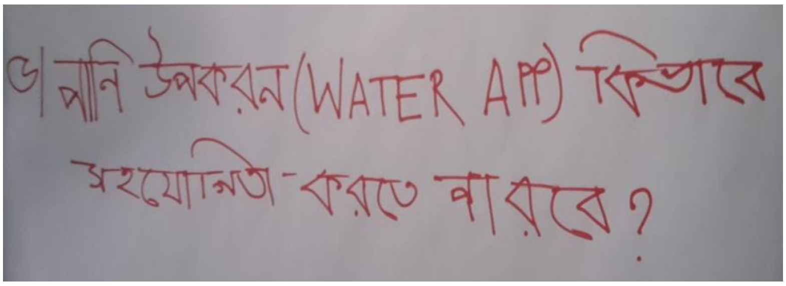
3.2.1 Final impression field visit

- The necessary infrastructure for (large scale) water management in the polder is present but is generally not well functioning. The drainage sluices and irrigation inlets need to be maintained properly, and operation (after repairs) needs to be 'institutionalised' by training and mandating the Water Management Groups (WMG's).
- In quite some cases roads form an important hindrance by blocking the flow of khals. The hydraulic connectivity in the polder needs to be improved to reduce both water logging and scarcity. This implicates the construction of additional culverts, the enlargement of existing culverts and the organisation and execution of maintenance. WMG's could possibly have a role in the latter.
- Many khals are silted up throughout the years, and are nearly fully covered by water hyacinth. This also hinders the flow of water, resulting in both water logging and water scarcity.
- It is evident that the operation and maintenance (O&M) of water management infrastructure in the polder needs to be improved in order to meet the desired levels of service. However, also the 'governance' part of O&M needs to be taken into consideration. This means that local people and WMG's should be more involved in organising and performing O&M, which also means that they should be trained to do so.
- The polder comprises a large variation in areas with drainage congestion and in the same time water shortages. Although some of these water management issues have their origin in the local topography, in many cases lacking O&M and malfunctioning structures are main reason for the water management issues. Reducing water congestion can also be a remedy for diminishing water shortages.
- The available (50 * 50 m) DEM needs additional (survey) data in order to be improved so that it can be used as the basis of apps which function on spatial information. The actual field elevations are not always represented by the DEM. Especially vegetation cover and the spatial and altitude differences between roads and khals needs special attention.

- The potential for the use of water apps to improve tactical and operational water management in the polder is clearly present.

3.3 Workshops

As was planned, two workshops were held as part of prototype development. A collaborative or participatory approach was followed in these workshops, to enhance ownership and client orientation. The first workshop focussed on identification on key information needs in the day-to-day water management practice of Water Management Groups and Associations (WMG/WMAs) and the Bangladesh Water Development Board (BWDB) staff at polder level (basically the Assistant Engineer and to a lesser extent the Sub-Divisional Engineer). After prototype development of two potential apps: the sluice designer and the spatial analyser, elaborated upon later in this report, were further developed between both workshops in Patuakhali by the IWM-Deltares team. The second workshop focussed on prioritising the long-list of potential apps, reviewing the two prototype apps developed and clarifying the next steps proposed by the Innovation Project team.



Picture 3.6: Main question of the First workshop

3.3.1 Workshop 1

The program for the first workshop was as follows.

1 Opening by UP Chairman, BWDB and Agriculture Officer
2 Introduction by Blue Gold
3 Introduction on Water App
4 Presentation Issues and Potential Apps for Polder 43/2BGroup Work. The group distribution for this activity was proposed by the WMG members present.
   – Group Amkhola - Mushurikati
   – Group Bauria
   – Group General
5 Plenary presentation and discussion
6 Next steps and closing

3.3.1.1 Venue

After having met with the Union Parishad chairman the day before after the field visit, and in consultation with the Blue Gold staff, it was decided to hold the workshop in the meeting hall of the Amkhola Parishad Council.

3.3.1.2 List of Participants

The list of participants was agreed upon beforehand with the Blue Gold team. All participants were invited through official letter and direct communication through phone. The list of participants can be found in Annex G.

The three groups each agreed upon a list of key water management issues and information needs. A full description of the outcome of the three groups is described in Annex 7G.

Picture 3.7: Groups working during the First Workshop

An overview of the key water management decisions, information needs and stakeholders, for each of the three groups, are presented here below in Table 3.1.These are considered the main parameters to design the water apps.

Table 3.1 Water management decisions, information needs and stakeholders identified by group 1

WM Decisions	***Information needs***	***Stakeholders***
Waterlogging		
Khal cleaning (water hyacinth)	- How much manpower is needed - Which WMG will help to deliver manpower, since khals go through 2 or 3 WMG's) - Who can help (in terms of money and number of men) -> discuss with Union Parish (Council)	WMG's, WMA, Union Parishad (Council)
Khal embankment repairs	- First discuss ideas, funds and 'scope' (does it fit in year plans) with WMG, them WMA, then BWDB - Amount of soil needed - Which methods to apply	WMG, WMA, BWDB
Small sluice gate repairs & sluice gate operation	- Training on sluice operation needed	WMG, WMA, Blue Gold, BWDB
Cutting of small embankments (bunds)	- Inform Union Parishad (Council) - Advice from the Agricultural Dept.	WMG's, WMA, Union Parishad (Council), Agricultural Dept.
Water shortage		
Optimisation (minimise) of bare land	- Which water sources can be used in which month (availability & planning)	Farmers Agricultural office (advise)
Irrigation by pumping (LLP & plastic pipe)	- Where can a pump be hired - How much water needs to be pumped - How much money is available for irrigation	Farmers Agricultural office (advise), Blue Gold

Table 3.2 Water management decisions, information needs and stakeholders identified by group 2

WM Decisions	**Information needs**	**Stakeholders**
Waterlogging		
Khal cleaning (water hyacinth)	- How much manpower is needed - Which WMG will help to deliver manpower, since khals go through 2 or 3 WMG's) - Who can help (in terms of money and number of men) -> discuss with Union Parish (Council)	WMGs, WMA, Union Parishad (Council)
Khal embankment repairs	- First discuss ideas, funds and 'scope' (does it fit in year plans) with WMG, them WMA, then BWDB - Amount of soil needed - Which methods to apply	WMG, WMA, BWDB
Small sluice gate repairs & sluice gate operation	- Training on sluice operation needed	WMG, WMA, Blue Gold, BWDB
Cutting of small embankments (bunds)	- Inform Union Parishad (Council) - Advice from the Agricultural Dept.	WMGs, WMA, Union Parishad (Council), Agricultural Dept.
Water shortage		
Optimisation (minimise) of bare land	- Which water sources can be used in which month (availability & planning)	Farmers Agricultural office (advice)
Irrigation by pumping (LLP & plastic pipe)	- Where can a pump be hired - How much water needs to be pumped - How much money is available for irrigation	Farmers, Agricultural office (advice), Blue Gold

Table 3.3 Water management decisions, information needs and stakeholders identified by group 3

WM Decisions	**Information Needs**	**Stakeholders**	
		Implementation	Beneficiaries
Secondary khals silted up needs to be re-excavated	Survey work for design data, cross section of khals with water level	BWDB	WMA
Waterlogged area needs one outlet at Nurakhali Khal	Survey work to be done for design data submission	BWDB	WMA
Waterlogged area blocked at Mudirhat blocked by RHD road	Needs survey & design	RHD	WMA
Waterlogged area Re-excavation of khal	Needs survey & design	BWDB	WMA

3.3.2 Workshop 2

After having developed two example prototypes, a long list of waterapps was presented and discussed with the WMG and Blue Gold representatives during the second workshop of the 10th of November. The program of the workshop was as follows:

1 Formal Opening and Introduction
2 Recap Day 1, William Oliemans
3 Presentation Potential Apps for Polder 43/2B, Klaas-jan Douben
4 Group Work
   – Group 1
   – Group 2
5 Plenary presentation
6 Next steps and closing

After presenting the long-list, the workshop, through active discussions and comparing the pros and cons of each waterapp, came to the following prioritisation:

Table 3.4 Prioritisation of WaterApps

Name	Priority	Why?	How?
Khal Excavator (within the Spatial Analyser*)	1	- To mitigate water logging - Increase agriculture production	Inform implementing agency like BWDB, BADC & LGED
Sluice Designer	2	- To remove catchments wise drainage congestion	Inform implementing agency - BWDB
Sluice Operator	1	- To regulate drainage and flushing - To mitigate water logging - Increase agriculture production - Increase longevity of Sluices	It will be operated by WMO
Embankment Designer (within the Spatial Analyser*)	3	- Protection from monsoon flood and storm surge - Protection from climatic disaster	Provide information and suggestion to BWDB & LGED
Flood Risk Mapper	2	- Awareness building for disaster - Taking safety measures - Planning crop pattern	Union Council and WMO will build awareness in the society.
Khal Water Leveller	3	- Choosing appropriate irrigation method - Protection from crop losing - Protect water logging	WMO will implement for water governance
Crop Water Demander	1	- Preparation for quick harvesting and making adjustment with water availability - Increase agriculture production - Proper irrigation for high yield crop production	Consultation with DAE.
Crop Calendar	2	- Right cropping in right time - Gain profit by cultivation high valuable crops	Inform the community after consultation with DAE.
Culvert Designer	3	- Improve transport system - Mitigate water logging - Increase longevity of Roads	Inform Union Council and LGED
Culvert Maintainer	1	- Mitigate water logging - Timely water availability, when required - Increase longevity of culvert	This social activity will formulated by WMGs
Khal Cleaner (within the Spatial Analyser*)	2	- Better water movement - Increase availability of fresh water - Irrigation facility	This social activity will formulated by WMGs. Take necessary support from Union Council, if required.
Embankment Repair (within the Spatial Analyser*)	1	- Protect life and livelihood from flood and surge - Better transport facility - Protect forest resources - Marketing agricultural products	Inform BWDB; WMO will assist in small scale works, if needed.

* The Spatial Analyser would be an App that would include the other apps named in the table)

The priority Codes signify the following:

1. High priority: urgently required and immediately applicable in the day to day practice of WMOs and members.
2. Medium priority: required and applicable for WMOs and members.
3. Low priority: desirable but not viewed as applicable by WMOs and Members.

The next pictures show some impressions of the second workshop:

Picture 3.8: Groups working during the Second Workshop

4 Prototype Apps

As mentioned in section 2.1, three prototype water-apps were developed:
- The Sluice Designer and Operator
- The Culvert Designer and Maintainer
- The Spatial Analyser

The following Fact Sheets, describe the water-apps in short. In Annexes 7D, 7E, and 7F, a full description of the water-apps plus a user-guide per water-app can be found.

Name		
Sluice Designer and Operator		
Short description		
This app can be used to assess the discharge passing through a sluice as a function of the design and operation of a sluice.		
Context		
Sluices are a general feature of all polders in Bangladesh. In the coastal polders, gravity drainage takes place during the low tide situation. Sluice components include: • Sluices gates, generally lifting gates and flap gates. Sluices may be equipped with different gate types on the country (inland) and river (sea) side. • Vents of differing width and height; typically of either 1,5 or 1,8 m opening width • Sill height relative to PWD • Apron (approach) walls • Box culvert for road passage • Bottom and scour protection Key design parameters are: • Outside water levels, resulting from tidal influence and river levels • Drainage requirements, related to runoff from the catchment, and related polder water levels • Ease of Operation, Maintenance and Repair • Availability of materials for construction and maintenance		
App Input requirements		
- Outside river levels; extreme, for different return periods - Average diurnal tidal range - Desired polder water levels - Maximum water level polder side, for different return periods, per season - Vent size options - River side dimensions - Design Standards		
App Outputs – results		
- Drainage requirements, in m^3/s or mm/hour-day, for different return periods - Flow velocities - Optimum # vents of specified size - Opening hours per time unit during varying conditions - Duration (time/%) in exceedance of drainage requirement during varying conditions - Costs		
Hard- and Software requirements		
- Regular PC/laptop with Excel ('prefeasibility' version) and for later versions combined with a QGIS programme		
Ease of development		
Easy	*Moderate*	*Complex*
	Hydraulic design parameters are well known Complex to determine link between water levels in main drain and waterlogging due to inaccuracy of the DEM	
App builder		
Knowledge institute; hydraulic consultant, university		

Hydraulic computations Sluice Operator

Input data	
y1 = upstream water depth (m)	**2**
y3 = tailwater water depth (m)	**1.4**
b = gate opening (m)	**1**
W = width box culvert (m)	1.5
H_bc = height box culvert (m)	1.5
L = length box culvert (m)	8.5
ELC = Entrance loss coefficient (m)	0.2
n = Hydraulic roughness (Manning) ($m^{1/3}/s$)	0.01
B = bottom width outlet water (m)	150
S = slope river bank outlet water (-)	1.5

ONLY APPLICABLE (YET) FOR FREE FLOW

Output	
dy = Box culvert head (max 0,3 m)	0.81
Q = Drainage sluice (2 box culverts) discharge (m3/s)	7.58
v_lg = Flow velocity under liftgate (m/s)	5.05
v_bc = Flow velocity end of box culvert (m/s)	3.61

Warnings	
Hydraulic flow condition:	Free flow
Froude number:	Froude number too high (>1)
Water depth in box culvert:	Partially full flow
Head over box culvert:	Max. head exceeded
Inflow (pot. salinity intrusion):	Outflow

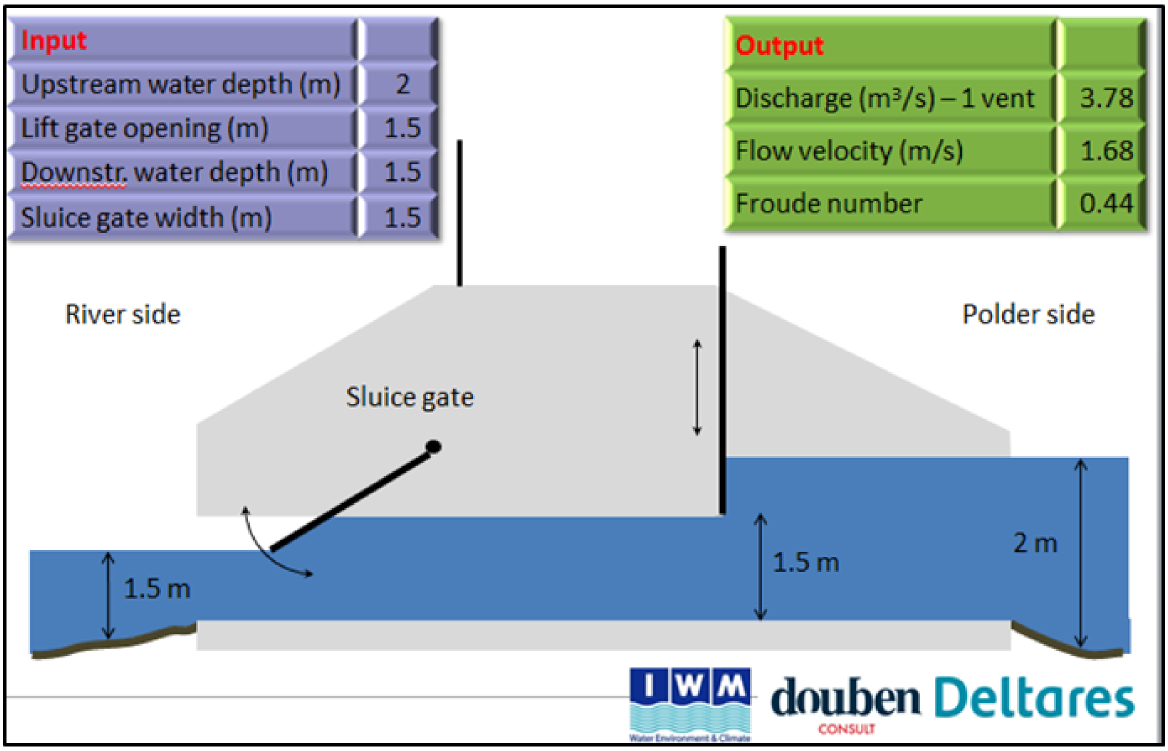


Figure 4.1 Visualization of the Sluice Designer and Operator WaterApp

<table>
<tr><td colspan="3">Name</td></tr>
<tr><td colspan="3">Culvert Designer and Maintainer</td></tr>
<tr><td colspan="3">Short description</td></tr>
<tr><td colspan="3">This app is meant to assess the water level and flow in a culvert as a function of the design of the culvert.</td></tr>
<tr><td colspan="3">Context</td></tr>
<tr><td colspan="3">A culvert is a structure that allows water to flow under a road, railroad, trail, or similar obstruction at natural drainage and stream crossings. It is typically embedded and surrounded by soil, and may be made from cast-in-place or precast concrete (reinforced or non-reinforced), galvanized steel, aluminium, or plastic (high-density polyethylene). Culverts are available in many sizes and shapes including round, elliptical, flat-bottomed, pear-shaped, and box-like constructions. Culvert components (can) include:
• Trash screen
• Barrels
• Sill height and/or bottom plate relative to PWD
• Apron and/or wing (approach) walls (if any) and crown
• Bottom and scour protection

Key design (type and shape) parameters are:
• Requirements for hydraulic performance (pipe size, slope, entrance type, freeboard, inlet/outlet control, flow velocity)
• Prevention of scour holes or slumping of banks adjacent to the culvert structure
• Limitations on upstream water surface elevation and depth
• Roadway embankment height
• Drainage requirements related to size and runoff and related water levels
• Ease of maintenance and repair
• Availability of materials for construction and maintenance</td></tr>
<tr><td colspan="3">App Input requirements</td></tr>
<tr><td colspan="3">- Upstream water surface levels; extreme, for different return periods
- Drainage requirement, in m3/s, for different return periods
- Culvert length and slope
- Culvert size options and material characteristics</td></tr>
<tr><td colspan="3">App Outputs – results</td></tr>
<tr><td colspan="3">- Maximum water level head, for different return periods, per season
- Optimum culvert diameter and/or # pipes
- Flow velocity
- Maintenance criteria related to water level head, per season
- Cost (construction and maintenance)</td></tr>
<tr><td colspan="3">Hard- and Software requirements</td></tr>
<tr><td colspan="3">- Regular PC/laptop with Excel (‘prefeasibility’ version) and for later versions combined with a GIS (?) programme</td></tr>
<tr><td colspan="3">Ease of development</td></tr>
<tr><td>Easy</td><td>Moderate</td><td>Complex</td></tr>
<tr><td></td><td>X
Hydraulic design parameters are well known
Complex to determine link between water levels in main drain and waterlogging due to inaccuracy of the DEM</td><td></td></tr>
<tr><td colspan="3">App builder</td></tr>
<tr><td colspan="3">Knowledge institute; hydraulic consultant, university</td></tr>
</table>

Hydraulic computations Culvert Designer						
Input data	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*
Q = discharge through culvert (m^3/s)	2	2	2	2	2	2
D = culvert height (m) -rectangular	0.8	5	2	0.5	0.5	0.1
b = culvert width (m) - rectangular	1.5	2.5	1.5	1.5	1.5	1.5
H = culvert diameter (m) - circular	-	-	-	-	-	-
h4 = tailwater water depth (m)	0.3	0.3	5	0.3	0.3	0.6
G = difference channel and culvert bottom (m)	0.05	0.05	0.05	0.05	0.05	0.05
L = length culvert (m)	25	25	25	25	25	25
Km_c = Hydraulic roughness culvert (Manning) (-)	100	100	100	100	100	100
EnLC = Entrance loss coefficient (m)	0.5	0.5	0.5	0.5	0.5	0.5
B = width downstream channel (m)	15	15	15	15	15	15
T = Slope road talus (1 :)	1.5	1.5	1.5	1.5	1.5	1.5
So = Bed slope culvert barrel (-)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Output	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*
Z = Culvert head (m)	2.44	0.87	0.04	2.44	2.44	496.48
h1 = Upstream water depth (m)	2.74	1.17	5.04	2.74	2.74	497.08
V = Flow velocity in culvert (range 0.5 - 2 m/s)	4.44	2.67	0.68	4.44	4.44	26.67
dc = Critical water depth (m)	1.81	0.77	3.33	1.81	1.81	328.07
Cd = Discharge coefficient (-)	0.64	0.64	0.77	0.64	0.64	0.27
Aw_c = Wet area culvert barrel (m^2)	0.45	0.75	2.93	0.45	0.45	0.08
A_c = Area culvert barrel (minimum 0.2 m^2)	1.20	12.50	3.00	0.75	0.75	0.15
Warnings & checks						
Froude number:	1.83	1.10	0.11	1.83	1.83	26.92
Control mechanism:	inlet control	inlet control	outlet control	inlet control	inlet control	inlet control
Flow:	super-critical	super-critical	sub-critical	super-critical	super-critical	super-critical
Hydraulic flow condition:	free flow	free flow	submerged fl	free flow	free flow	free flow
Flow type:	type 3	type 5 or 6	type 2	type 3	type 3	type 3
Headwater/culvert depth (HW/D) ratio (max 1.5):	3.05	0.17	0.02	4.88	4.88	4964.78
Culvert barrel flow:	part. full flow	part. full flow	full flow	part. full flow	part. full flow	full flow
Minimum area culvert barrel (0.2 m^2):	ok	ok	ok	ok	ok	too small

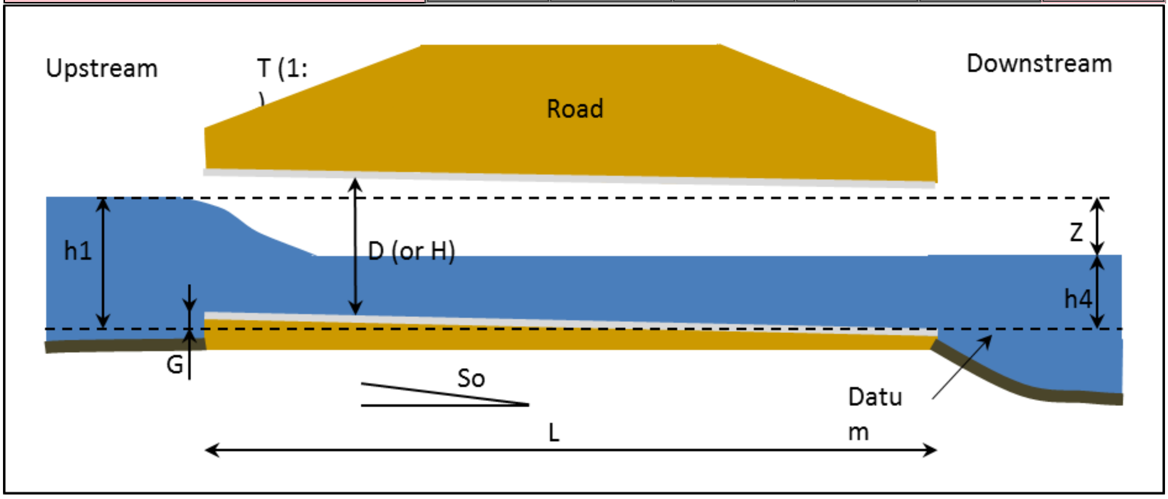


Figure 4.2 Visualization of the Culvert Designer and Maintainer WaterApp

Name

Spatial Analyser

Short description

This app calculates the spatial impact of several interventions on water logging.

Context

In polders, one of the problems during the rainy season is that water accumulates creating water logging areas. Several water structures or simple interventions like dredging or embanking can modify the water flow and change the condition of water logging. The Spatial Analyser allows the user to evaluate the spatial impact of several interventions on water logging, the water levels and on the discharges in the khals and the rest of the area. The interventions that can be simulated with the Spatial Analyser are mainly related to changes in terms of surface elevation, khal dimensions, or roughness of the surface and khal.

Examples of interventions that can be simulated with the Spatial Analyser are:
- Building a new road that blocks a khal, or assess the impact of an existing blockage
- Building, cleaning up a culvert, and re-dimensioning of culverts
- Re-excavation or siltation of a khal
- Sluice not functioning

All the calculations of the Spatial Analyser are based on the Digital Elevation Model (DEM) of the polder. Therefore the DEM, including the khal network, requires most attention.

App Input requirements

The input parameters for the Spatial Analyser are:
- The Digital Elevation Model with the khal network burned
- The Watersheds map
- The Flow Direction map
- A time series of interpolated Precipitation Maps with the time step required for the simulation (in the default case, this is daily)
- The Manning's roughness coefficient

App Outputs – results

The results of the Spatial Analyser are time series of maps for the Polder of:
- Water levels
- Accumulated surface runoff

Hard- and Software requirements

- Regular PC/laptop with:
  - QGIS and plug-in SAGA (version 2.14.8 Essen): https://www.qgis.org/en/site/forusers/download.html
  - WFLOW: WFLOW can be downloaded from here https://github.com/openstreams/wflow/releases . The full documentation of WFLOW can be found here: http://wflow.readthedocs.org/
  - Python 2.7: https://www.python.org/downloads/
    Besides, the most important packages and modules that should also be installed are:
  - PCRaster: http://pcraster.geo.uu.nl/downloads/latest-release/
  - raster_func: module developed by Deltares
  - Numpy: http://www.scipy.org/scipylib/download.html
  - Pandas: https://pypi.python.org/pypi/pandas/0.19.1/#downloads
  - Subprocess: https://pypi.python.org/pypi/pyutilib.subprocess/3.2

Ease of development

Easy	*Moderate*	*Complex*
		The application is a combination of several software packages. There is a need to develop a web-based application that connects the different parts of the app and ensures a seamless process.

App builder

Knowledge institute; hydraulic consultant, university

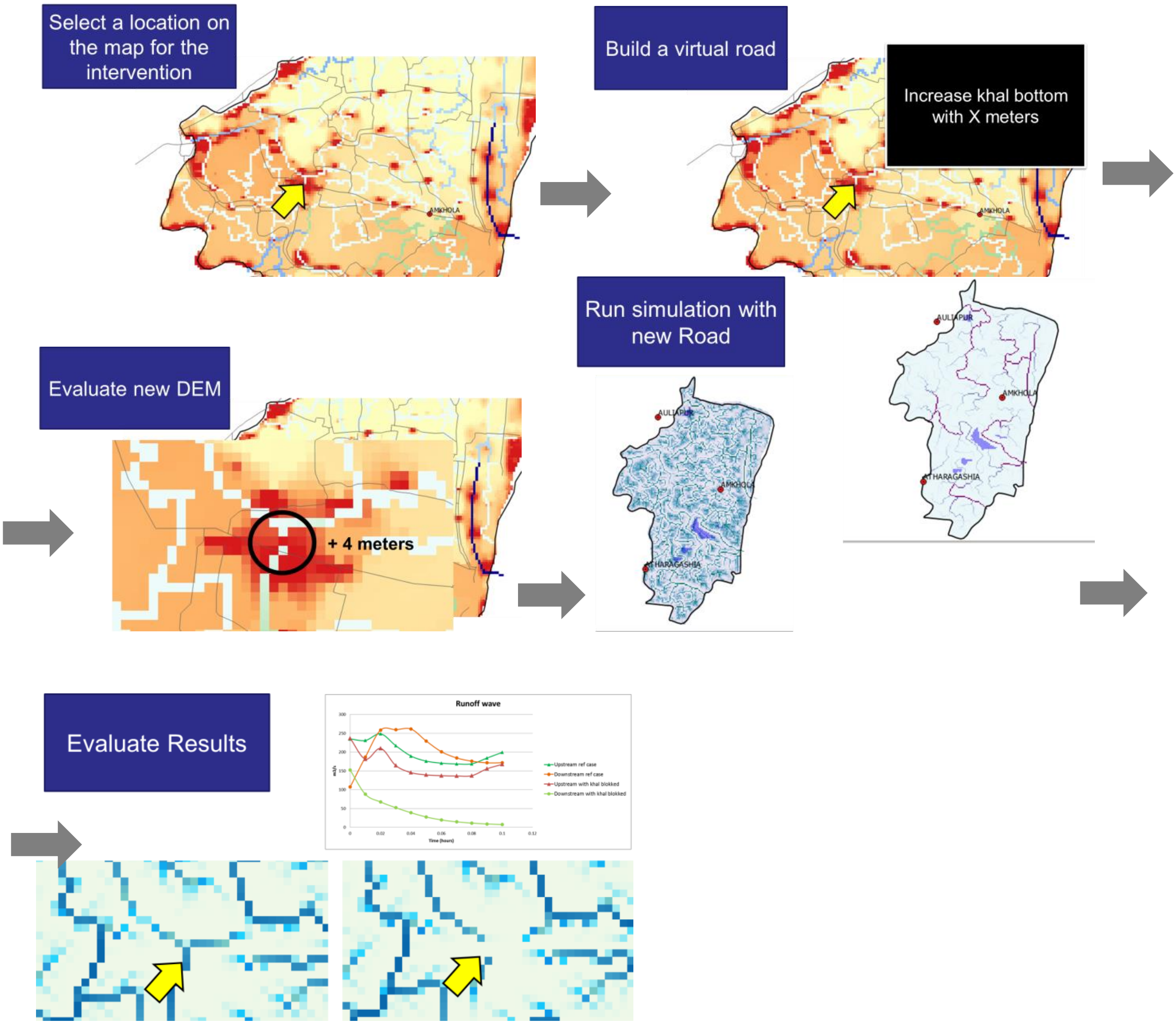


Figure 4.3 Visual example of a Road Block simulation with the Spatial Analyser WaterApp

A further development and integration of the three prototype apps could lead to numerous types of applications. A global distinction can be made between water-apps for operational (daily) use, and apps that can support users in preparing and planning activities or even for tactical/strategical purposes:

- Assess the extent of area being flooded or submerged (low land) and the extent of area suffering from water shortage (high land) depending on the water level in the khals, and/or structural/hydraulic obstacles, and/or malfunctioning hydraulic structures. This application could be used both for operational (e.g. forecasting) as well as tactical/strategical purposes (e.g. risk assessments).
- Evaluate the potential of (operational and/or structural) mitigation measures for water logging.
- Assess the area being affected by water logging or water shortage depending on the season of the year, incl. e.g. cropping patterns and the maintenance status of khals and hydraulic structures.
- Calculate the risk (tactical/strategical - scenario) of surface water salinity intrusion during the dry season.
- Design sluice gates and calculate and visualise discharges, hydraulic jumps, turbulences and scouring up- and downstream of the structure in the country side and riverside canals.
- Operate sluice gates, based on measured EC levels (reduce salinity intrusion) and water levels (country and riverside canals). For this purpose a ‘water level management plan’ needs to be developed, describing the desired water levels in the khals, related to various aspects such as seasonality (drainage-irrigation), water quality (salinity), land-use and crops, infrastructure, etc.
- Evaluate different gate operation scenarios versus varying patterns of rainfall, pictorial views of extent of drainage congestion.
- Evaluate the drainage congestion under different canal cross sections, rainfall patterns, khal depths, river diversion, and time in tidal cycle scenarios.
- Plan culvert maintenance, incl. a spatial risk analysis involving e.g. settlements, infrastructure and cropping patterns.

5 Road Map

In charting the future of waterapps in the Blue God area and the wider coastal zone, we distinguish between the short term actions required to develop the first priority waterapps and the long term development of a suite of waterapps for operational water management and planning (Figure 5.1).

Short term
Key activities in the short term are:
- Improving the DEM in polder 43/2B to support running of the Spatial analyser in connection with apps such as the sluice operator or khal excavator. The improvement is needed to visualize spatial impacts of rainfall and tidal influence on drainage and waterlogging. In the spatial analyser app, a flow routing algorithm is linked to the DEM to simulate rainfall-runoff within the polder command area. The DEM is the basis to show spatial impacts such as flooded areas, duration and depths. The DEM can be improved by limited survey work, making use of already existing survey data of other GoB agencies active in the area, and filtering. A step-by-step guide to carrying out the survey work is included in the Annex H.
- Validate the outcomes and simulations of the Spatial Analyser in the next monsoon season in 2017. Validation will enhance confidence in the results with both the BWDB and WMG/WMA leaders in the polder and pave the way for further app development for a broad range of purposes. Involve young BWDB engineers in development steps of these and other waterapps.
- Develop a desk-top environment in which to download and run the first apps. Developing the first apps for desktop versions is the quickest path to making waterapps applicable. This will limit their use to eg BWDB, Local Government, DoAE and Blue Gold project staff and in some cases: the more educated and well-to-do WMG leaders (those that have access to desktops). Quickly after testing these, by engaging a specialised app-software design company, the first apps can be transformed into apps for tablets and smartphones. Practical guides and tools to facilitate app use need to be developed alongside the first apps.

Medium term
- Develop software environment for tablet and smartphone waterapps, starting with stand alone apps and servers in Bangladesh. Key aspects that need to be addressed include the use of software and IPRs (Deltares has an open-source software policy but this may not apply to all future development partners, moreover, open source application also has specific legal conditions). Reliability, security and speed of downloads and functioning of the app will then become key parameters. It is recommended that, as much as possible, all the data and software is stored on servers in Bangladesh. A server installed with the BWDB or Blue Gold office may be a good short term solution until a long term business model has been developed.
- Continue parallel development of waterapps in line with the priority list as developed during this innovation project. Consideration can also be given to opening up waterapp development to universities and other software-innovation oriented organisations. Competitions, MSc and PhD projects, ia through cooperation between Universities and knowledge organisations in Bangladesh and the Netherlands and other countries, can play a further stimulating role.
- Stimulate involvement of non-water sector agencies and organisations focussed on livelihood improvement and productivity. These include Agriculture, Drinking Water & Health, and Marketing.

- Investigate, by exploring and engaging the Bangladesh water knowledge and software sectors, the development of a sustainable business model for the development and maintenance of such tools. Institutional embedding is a key aspect to develop a sustainable business model. Activities include: operational maintenance, data maintenance, software development and ICT system/ internet connections. The ultimate goal is for app developers and service providers to engage directly with clients such as the BWDB, LGI, DoAE and private entities such as companies, WMG/WMAs and the public at large. Business development opportunities exist for software developer/ companies in Bangladesh, manufacturing, implementing and maintaining/updating additional water-apps.
- As development of the water-apps continues, emerging into more sophisticated (but still easy to use) decision tools, further development/innovation will be needed to operationalize e.g. remote sensing data, optimise flow routing algorithms, and improve the accuracy of the basic tools. International cooperation and competition will foster this development.

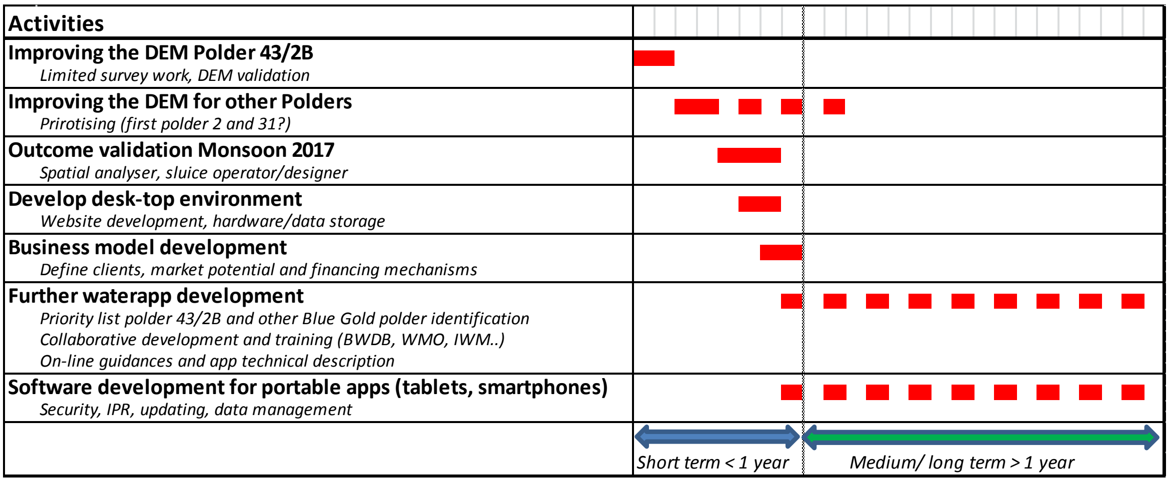


Figure 5.1 Road map scheme

6 Conclusions and recommendations

As a result of the two workshops held and discussions with Blue Gold staff as well as the Blue Gold Project Director, the following conclusions and recommendations were arrived at. The valuable suggestions of the Project Director, Director Planning-III are highly appreciated.

1. *Value of Water Apps enthusiastically embraced*
   WMGs, BWDB and District Agriculture staff, as well as Blue Gold Field Team staff working on the ground, enthusiastically embraced the concept of developing waterapps to facilitate day-to-day water management decisions and more long term planning and simulation of 'what-if' decisions. It was well understood how these apps could further improve cooperation in polder water management between e.g. the BWDB and WMGs and Local Government. In addition, the apps were seen to help making design and investment decisions on the ground by making explicit the hydraulic and hydrological design parameters.
2. *Apps without DEM can be rapidly developed*
   Waterapps that do not depend on DEMs can be rapidly developed and applied in practice. Examples include the design and operation of sluices (regulators), culverts and bridges (rather: bridge openings) as well as irrigation inlets (flushing inlets). Equally, a crop water requirement apps (the 'Crop Water Demander') can also be developed without a detailed DEM.
3. *The DEM needs improvement – detailing for Apps which show spatial impacts such as flooding areas, duration and depths.*
   The DEMs can be enhanced relatively simply by limited survey work + filtering. A step-by-step guide to carrying out the survey work is included in the Annex H.
4. *First focus on desktop applications, then tablet-smartphone; start with stand alone apps and servers in Bangladesh.*
   Developing the first apps for desktop versions is the quickest path to making waterapps applicable. This could limit their initial use to e.g. BWDB, Local Government, DoAE and Blue Gold project staff and in the more educated and well-to-do WMG leaders (those that have access to desktops). Immediately after testing these, by engaging a specialised app-software design company, the first apps can be transformed into apps for tablets and smartphones. Key aspects that need to be addressed include the use of software and Intellectual Property Rights (IPRs)[3]. Reliability, security and speed of downloads and functioning of the app will then become key parameters. It is recommended that, as much as possible, all the data and software is stored on servers in Bangladesh. A server installed with the BWDB or Blue Gold office may be a good short term solution until a long term business model has been developed.
5. *Waterapps work in number of ways: i) improving production & livelihoods; ii) facilitate communication between WMGs & GoB officials; iii) support GoB agencies in optimizing design and maintenance.*
   The main goal of any one application is to improve production or design speed and quality. However, during development of the first prototypes and discussions with the Project Director Blue Gold, it also became apparent that the waterapps can facilitate cooperation and information sharing between WMGs and GoB staff and between GoB

[3] *Deltares has an open-source software policy but this may not apply to all future development partners, moreover, open source application also has specific legal conditions*

implementing agencies. The example of rural road development is illustrative: such infrastructure is highly beneficial for communication, market development and disaster management. However, many rural roads, developed by the RHD and LGED are constructed without adequate drainage provisions, reducing drainage capacity and increasing waterlogging. Simple waterapps can have a great direct impact on design quality if applied.

6. *Practical training is essential, as is quality control and validation.*
   The Project Director Blue Gold (BWDB) reiterated the need for validation of waterapp outcomes, as with any simulation tool or model. Expediting DEM improvement and validation the outcomes of the spatial analyser waterapp is accorded the first priority in follow-up to this innovation project. The spatial analyser waterapp simulates the extent, duration and depth of waterlogging as a result of the design, O&M of hydraulic structures such as regulators and culverts design. The Project Director also stressed the importance of involving the BWDB in such promising innovations at the very early stage of development. Including BWDB experts in app development though hands-on involvement and additional training, which could include study visits to the Netherlands to witness waterapp use and development first-hand, are part of such training.

7 References

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A Concise water system analysis Polder 43-2B

Location, topography and demography

Polder 43-2B is located in the Patuakhali District (Barisal Division), covering the Amkhola union in the Galachipa upazila and the Auliapur union of in the Patuakhali sadar upazila (Map 1). The polder is situated on the Ganges Tidal Floodplain (AEZ-13), in the Ganga-Padma basin, and the Galachipa sub-basin.

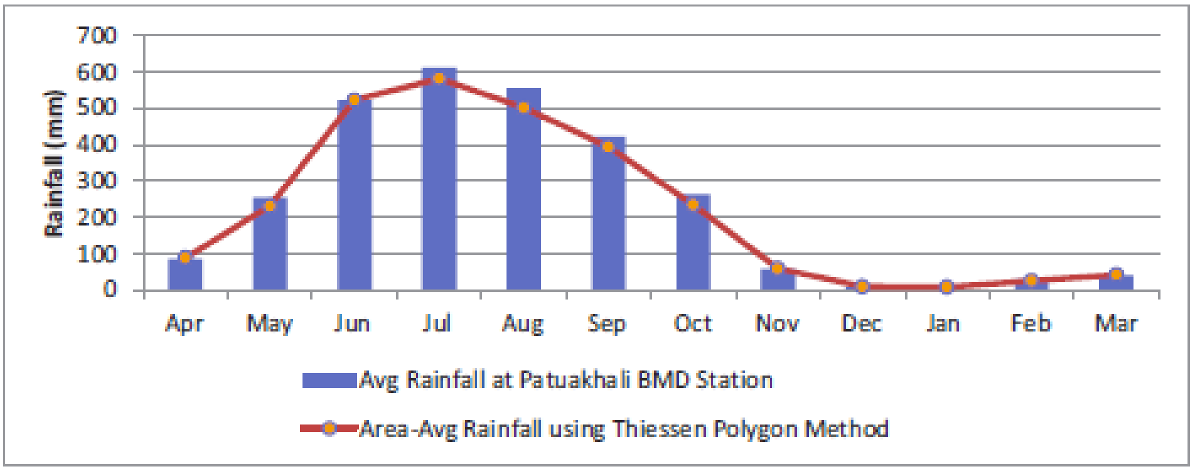
The polder was constructed in 1985-1987, and later rehabilitated under the Integrated Planning for Sustainable Water Management (IPSWAM) project from 2003 to 2011.

The available Digital Elevation Model (DEM; Map 2) shows that the ground elevation levels in the polder are relatively low compared to the mean sea level. The elevation in the polder varies from approx. 0.95 to 2.25 m PWD (0.5 to 1.75 m + MSL), with an average elevation of around 1.60 m PWD (1.15 m + MSL). This is however not exactly matching the DEM which was provided by Blue Gold before the mission in November 2016 ("DEM polder 43_2b"). The average ground level of the polder is higher than the low tidal water levels observed in Mirjaganj (Payra River). The peripheral zone on the edges of the polder are slightly higher than most of the inner areas.

The polder covers an area of 5,700 hectare, and is the home of 36,425 (17,620 male and 17,805 female) people living in 8,070 households. The average population density is 491 persons/km^2. The average size of a household in the polder is 5, and the average literacy rate is 48%.

Climate

The nearest meteorological station of the Bangladesh Meteorological Department (BMD) is located within 5 km from the polder (Patuakhali; see Map 3).

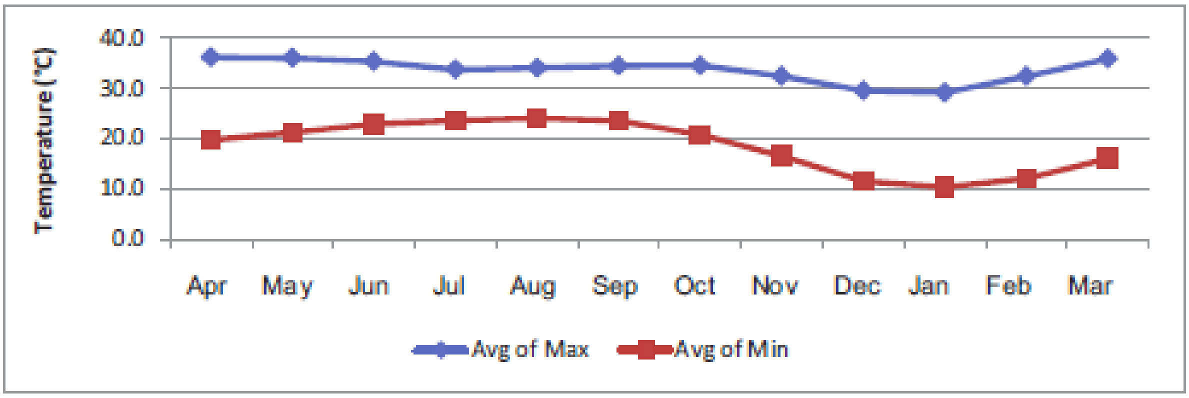


Source: BMD, 2014 and BWD, 2014B

Figure 7.1 Average monthly rainfall at Patuakhali BMD station (1973-2014)

The average monthly rainfall variation at Patuakhali BMD station (1973 to 2014) is illustrated in Figure 1.The average annual rainfall is 2,639 mm. The monsoon starts from May and reaches its peak in July. The maximum monthly rainfall is about 600 mm. The maximum rainfall ever recorded in the area is 610 mm (July), while the lowest rainfall observed is 7.6 mm (December).

The average (1973-2014) maximum temperature at Patuakhali BMD station (Figure 2) varies from 29°C (January) to 36°C (April) and minimum from 10.3°C (January) to 24°C (August).



Source: BMD, 2014

Figure 7.2 Average maximum and minimum temperature at Patuakhali BMD station (1973-2014)

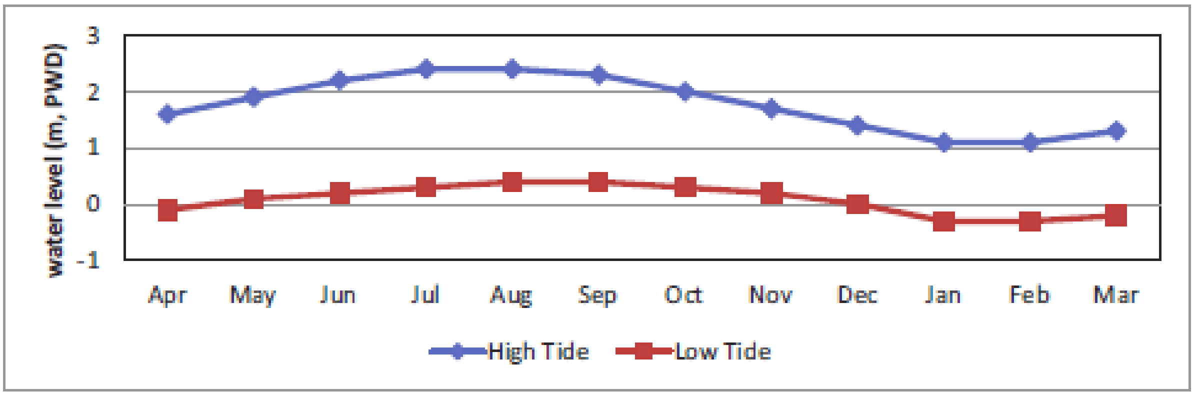
The climatic condition in the kharif-I season (last week of March-May) is characterized by high temperature, low humidity, high evaporation, and high solar radiation. This season is also characterized by uncertain rainfall, resulting in low alternating dry and wet spells. In this season land remains fully fallow due to the high salinity of soil. Scarcity of irrigation water is also another limiting factor. The kharif-II/monsoon cropping season (April-November) is characterized by high rainfalls, lower temperatures, high humidity, and low solar radiation. Rice is the predominant crop grown due to the submergence of soil. Excessive soil moisture and higher temperatures restrict cultivation of other crops in the area. Local transplanted aman (Lt Aman) and very few High Yielding Varieties (HYV) of transplanted aman are also grown during this season.
In the Rabi (winter) cropping season (November-February) crops are favoured with high solar radiation, low humidity and temperature. Due to inadequate soil moisture, the crop yield is low.

River network, hydrology and seasonal flows
The distance between the polder and the coast (Bay of Bengal) is approx. 40 km. The polder is under diurnal tidal influence, mainly via the Galachipa (Lohalia) river in the north and east. The Galachipa originates from an off take of the Payra River, about 18 km north of the polder. The western periphery of the polder is surrounded by the Golkhali khal.
Apart from these rivers, there are approximately 136 km of drainage and irrigation canals within the polder. The Musurikathi, Bauria, Noshaishil, Badura, Mestakhali, and Amkhola khals are perennial. The others are seasonal, only containing water during the wet season. The tidal storage effect in the smaller khals is relatively small during the dry season. The river system of the area is shown in Map 1.

Water from peripheral rivers and khals flows into the polder during high tide, while the opposite occurs during low tide. The sluice gates and outlets surrounding the polder are not operated and maintained properly, which fosters the free circulation of tidal water. A number of distributaries of the Galachipa (Lohalia) River and Golkhali khal (Badura, Athargasia, Bouria, Bhangra, Mushurikata khal, etc.) contribute to the tidal flow into the polder, whereas some other internal khals (Banshbunia, Tafalbaria khal, etc.) ensure the circulation flow within the polder. These khals also drain the surplus of water out of the polder through the peripheral water control structures (sluice gates and outlets).

The entire polder area is classified as medium highland (F1) which is normally continuously flooded between a depth of 0 to 90 cm for more than two weeks to a few months during the monsoon season.

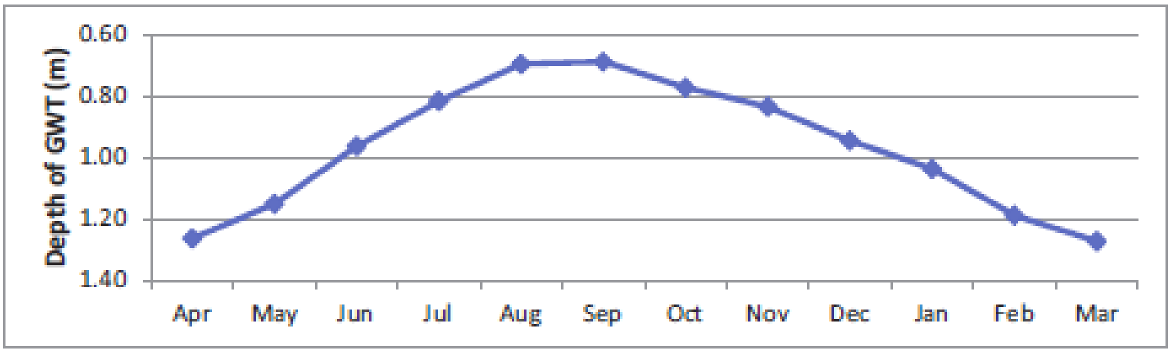
Figure 3 shows the monthly variation of the average water levels (1990-2009) at Amtali (Payra River), 12 km from the south-west corner of the polder (see Map 2). The high tidal water level ranges from 1.1 m to 2.4 m PWD (0.65 to 1.95 m + MSL), whereas low tidal water levels range from -0.3 m to 0.4 m PWD (-0,75 to -0.05 m + MSL).



Source: BWDB, 2014

Figure 7.3 Monthly average surface water levels at Payra river (1990-2009)

Figure 4 illustrates the monthly variations of the groundwater table (GWT) of the BWDB observation well at Galachipa (PAT001 station), see Map 2. The GWT is highest during August-September and drops to its lowest level in March.

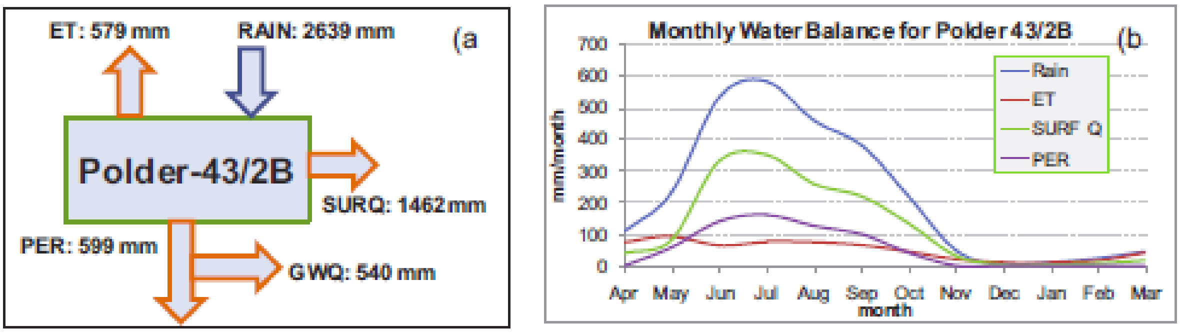


Source: BWDB, 2014

Figure 7.4 Average monthly variations of GWT at Galachipa (1977-2013)

A long-term analysis (1977-2013) indicates a mild decreasing trend of annual GWT variation in the area near the polder.

A water balance has been established using a SWAT model (see Annex C). The model has simulated the period of 1981 to 2012 to estimate the availability of water (Figure 5).



Note: Rain - Rainfall; ET - Evapotranspiration; PER - Percolation; SURQ - Surface Runoff

Figure 7.5 Water balance for Polder 43-2B (1981-2012); (a) average annual, (b) average monthly

The annual evapotranspiration is around 579 mm (22% of the annual rainfall). The maximum evapotranspiration occurs in April and May (about 100 mm/month), the minimum in December and January. About 599 mm/yr percolates (23% of the annual rainfall) into the ground. The percolation rate follows a similar trend like the rainfall, and the maximum rate is 160 mm/month. The remaining portion of water contributes to stream flow as overland flow and lateral (subsurface) flow. Around 55% (1,462 mm) of rainfall contributes to stream flow through surface runoff while the lateral flow is negligible.

Water quality

Five major water quality parameters were measured on site at four different sampling locations in the polder in January 2015 (Table 1).

The pH values at the sample sites were higher than neutral (pH=7), which means that the water in these locations is alkaline in January. Values of DO were mostly found close to the standards set by the DoE for both irrigation (5 to 6 mg/l) and fishing (5 mg/l). Temperature values varied within a typical range for different locations as sample tests were carried out at different times of the day. Furthermore, all samples were found with zero salinity. Local people claimed that no surface water salinity exist in the area in dry season (December to February). March and April are the only two months where the surface water system inside the polder becomes slightly saline. Due to the increased amount of freshwater recharge from the Meghna river system, surface water salinity in the South Central hydrological region is low, and for the local people it is not a major concern.

Table 7.1 Water quality parameters at different locations in Polder 43-2B (January 2015)

Location	Sampling Water Source	GPS readings	pH	TDS (ppm)	Temp. (ºC)	DO (mg/l)	Salinity (ppt)
Bauria Sluice	Tabalbaria river, Outside the polder	22°11'47.0"N 90°22'27.5"E	7.93	164	23.9	5.3	0
Nosaisil sluice	Tabalbaria river, outside the polder	22°14'09.7"N 90°20'49.8"E	7.69	189	27.1	5.7	0
Boloikati, Dari Baherchar	Lohalia river, inside the polder	22°17'38.0"N 90°22'08.1"E	7.51	134	23.2	4.9	0
Amkhola Sluice	Amkhola khal, inside the polder	22°14'33.2"N 90°23'47.8"E	7.92	129	24.8	4.7	0

Source: CEGIS field survey, January 2015

Soils, land-use and vegetation
The greater part of the region has a smooth relief and predominantly saline soils. There is general pattern of grey, slightly calcareous, heavy soils on river banks and grey to dark grey, non-calcareous, heavy silty clays in the extensive basins. The major soil type is non-calcareous grey floodplain soil. Acid sulphate soils also occupy a significant part of the area where it is very strongly acidic during dry season.

The soil salinity is gradually increasing in the polder due to the fact that most of the water control structures are not functioning properly, hence cannot restrict salt intrusion. This is considered to be the major cause of the increasing salinity inside the polder.
The soil and water salinity gradually increases with the dryness from January and reaches a maximum level in March-April and then decreases due to the onset of monsoon rainfall.

Approx. 71% (4,078 ha) of the polder area is net cultivable. Settlement area is 1,240 ha (22%), water bodies (river/khals) 340 ha (6%), and road coverage 42 ha (1%) of the total polder area (see Map 4).

The landownership statistics show that there are 70% smallholders, 23% medium and only 6% large landholders. Arable land is mainly used for crop production. Generally small and medium landholders cultivate a variety of crops. They cannot harvest the full potential from their land due to drainage congestion and siltation of water bodies.

Water management and related infrastructure
<u>Structures and infrastructure</u>
The polder is protected against tidal/storm surges and saline water intrusion by a 39.83 km embankment with a crest width varying from 2 to 4 m, and crest levels of around 3 to 4 m + MSL (see Map 5). There are 6 drainage sluices, 20 closers and 39 flushing inlets in the polder area.

<u>Drainage characteristics</u>
Drainage characteristics from agriculture point of view are divided into six classes, ranging from excessively drained to very poorly drained. The total net cultivable area (NCA) in the polder has a poorly drained condition. A lack of timely drainage in the rainy/monsoon season is the main constraint for growing rabi/dry land crops. The drainage characteristics are illustrated in Map 6.

<u>Water use (domestic)</u>
The average daily domestic water use in Polder 43-2B is around 30 l/capita (field survey). The actual status of drinking water in some of the coastal polders is very poor however; the national standard is considered 50 l/capita. The EIA study found that around 1,275 m^3/day consumed in the polder. Local people prefer Deep Tube Wells (DTWs) as drinking water sources. For other domestic uses, surface water sources are used. Water availability is not a major concern in the polder; local people indicated that they have access to sufficient surface and groundwater sources to meet up their daily need of drinking and domestic purposes.

<u>Water use (irrigation)</u>
Surface water is the only source of irrigation. Khals, and in a few cases ponds, are the source of surface water for a limited period of time. Irrigation is provided mainly in watermelon and groundnut fields. Occasionally, Low Lift Pumps (LLPs) are being used for surface water irrigation. When the khals are re-excavated (Blue Gold project), the watermelon and groundnut cultivation area may double and other Rabi cropped areas will also be increased.

The farmers practice Lt. Aus in Kharif-I (March-June) season, HYV Aman and Lt. Aman in Kharif-II season (July-October) and some other crops (mung bean, sunflower, sesame, khesari, watermelon and groundnut) in Rabi (November-February) season. The rain fed irrigation is sufficient during Kharif-I and Kharif-II seasons for Lt. Aus, HYV Aman, and Lt. Aman crops; whereas surface water irrigation is provided in around 95% of the area for watermelon and groundnut crops during the Rabi season. Irrigation is not required in some areas for groundnut due to a high soil moisture, and for watermelon which are practiced along the banks of the rivers and khals. Water is also required for other rabi season crops (sunflower, sesame, khesari, etc.) but no supplementary irrigation is needed for these crops as sufficient soil moisture is available during the season.

Table 7.2 Irrigation water requirements in Polder 43-2B

Season	Lt. Aus (ha)	Lt. Aman (ha)	HYV Aman (ha)	Sunflower, Sesame, Khesari and Mungbean (ha)	Watermelon and Groundnut	Water requirement (mm/ ha)	Water Used (Mm3)	Type of irrigation
Kharif-I (March - June)	480	-	-	-	-	300	1.44	No supplementary irrigation is required as rain water is sufficient
Kharif-II (July - October)	-	3,798	280	-	-	300	12.23	No supplementary irrigation is required as rain water is sufficient
Rabi (November – February)	-	-	-	2,348	-	200	4.7	No irrigation is provided as existing soil moisture is sufficient
	-	-	-	-	1,730 (*1,050+680*)	200	3.46	Surface water irrigation provided by using LLP and other traditional methods for 1,000 ha watermelon and 650 ha groundnut (95% of the total 1730 ha)

Source: CEGIS Estimation, January,2015

The surface water irrigation coverage is around 40% of the net cultivable area (NCA) in the polder. Around 300 mm of water is usually required for Aus and Aman cultivation (expert opinion). The water demand for groundnut, khesari, watermelon and other rabi season crops is around 200 mm. Using these figures, approximately 1.8 Mm^3 of water would be required during the Rabi season to ensure effective supplementary irrigation.

The low irrigation coverage during the Rabi season is most likely caused by the reduced water conveyance capacity of the khals and poor functioning of water control structures. Irrigation through Low Lift Pumps (LLPs) is very costly (average BDT 5,000 to 5,500 per ha), and therefore cultivation of boro crops, which requires almost 10 times more water than watermelon and groundnut cultivation, is not common.

Fish
The fresh and brackish fish habitat in the polder consists of capture (approx. 340 ha) and culture (approx. 85 ha) fishery. Capture fisheries habitats include the peripheral river (Galachipa), intertidal floodplain and internal khals (Map 7). The tidal regime in the Galachipa river creates a potential habitat for saline and brackish water fish species.
The riverine fish species migrate through regulated khals during the period June to August. The fish migration status is found to be poor due to successive siltation and mal-functioning of water control structures, and inaction of the WMO's for operating sluices and regulators. The improper management of regulators also hinder the migration of fish during the pre-monsoon.
The Musurikathi, Bauria, Noshaishil, Badura, Mestakhali, and Amkhola khals are perennial. The others are seasonal, containing water only during the wet season. The tidal storage effect in the smaller khals during the dry season is not sufficient for fish habitat.

The culture fishery is dominated by fish ponds, and aquaculture practice is increasing; cultured pond (25 ha) and culturable pond (60 ha). The cultured pond fishery is perennial while culturable fish ponds is seasonal where water retains for 6 to 7 months. Almost every household has a pond which is used as fresh water reservoir cum fish culture.
There is no shrimp/prawn gher (pond in rice field with vegetable growing on small surrounding dyke) practice in the polder.
The open water (especially khal) fish habitat is decreasing gradually. About 30% of the perennial internal khals have now become seasonal, where little water is seen in the dry season. Even some of the seasonal khals seem to be used as agriculture land. The main causes are siltation, topsoil erosion, decomposition of excessive duck weed, encroachment of khals for agriculture land and fisheries culture practices.

The fishing season starts in April/May and continues up to December. Most of the fish catch occurs during late June to mid-November. It is to be noted that Ber jal (fish net) and Bendi jal (single pole fish net) are used in the periphery river round the year.

Modelling
In the EIA a semi-distributed hydrological SWAT (Soil and Water Assessment Tools) model was developed to assess the water availability in the polder (Map 8). Delft 3D was used for hydrodynamic modelling. Model calibration data (including topography, soil maps, land use maps, and weather data, river network and cross-sections, water level, discharge and salinity data) were obtained from different sources. The outcome of participatory public consultations has also been used for model validation. The models have also been used to assess the impact of climate change on water availability, salinity intrusion and highest flood level.

Water resources issues and problems
Currently, drainage congestion and water logging, river bank erosion, and tidal flooding are reported as the major water related problems. All these problems are impeding the lives and livelihoods of the inhabitants of the polder.

Structures and infrastructure

Most of the water management structures (sluices, closers and flushing in- and outlets) are not functioning up to the desired level.

The sluice gates cannot prevent salt water intrusion, even when the gates are closed as they are ill-fitted or covered with fishing nets. Among these the sluice gate at Nasaisil was found to have severe damage, as the flap gate underneath cannot be operated mechanically because there are no wheels and shafts. The gate of the sluice needs to be replaced and a new hoisting system has to be installed. The structures at Musurikati, Bauria, Badura, Masuakhali and Amkhola are also functionally damaged, with severe mismanagement issues observed at some locations such as using fishing net, rope, etc. The hoisting system needs reinstallation for most of them. The gate openings at Badura and Musurikati sluices are to be cleaned from debris as well as water hyacinths, which hamper the natural flow through the structures.

Table 7.3 Dimensions drainage end flushing sluices

Sl. No.	Local name of sluice	Number of vent	Vent size (m)	Chainage (km)
1	Musurikati Sluice	2-V	1.5 ×1.8	0+000
2	Bauria Sluice	2-V	1.5 ×1.8	4+150
3	Nasaisil Sluice	2-V	1.5 ×1.8	14+900
4	Badura Sluice	2-V	1.5 ×1.8	19+950
5	Masuakhali Sluice	1-V	1.5 ×1.8	25+200
6	Amkhola Sluice	2-V	1.5 ×1.8	36+970

Source: Blue Gold Program Office, 2015

The drainage outlets cannot drain out water properly during heavy rainfall especially during post monsoon, due to damage of the wheels and shafts to elevate the gates. Similar problems also exist with the flushing inlets of the polder.

Table 7.4 Information irrigation inlets

Sl. No.	Local Name of Inlets	Size (mm)	Location
1	Suhri	300	East side of Noshu Mirdha's house
2	Suhri	600	Beside the House of Mosharraf Hosain
3	Suhri	300	Beside the House of Latif Khan
4	Bouria Chariani	300	Near the House of Jalil Chowkidar
5	Bouria	450	Beside the House of Zakir Hossain
6	Bouria Chariani	600	Beside the House of Rajamia Hawladar
7	Sonakhali	450	Near the House of Abdur Rob Mirdha
8	Purba Sonakhali	600	South side of Sobhan Khan's House
9	Sonakhali	450	West side of Razzaque Mirdha's House
10	Purba Sonakhali	450	Beside the House of Shahjahan para
11	Sonakhali	450	North side of Secondary Molla's House
12	Algi	450	North side of Kadir Hawladar's House
13	Algi	450	East Side of Mofez Member's House
14	Near Munshir Hat	450	North Side of Talukdar's House
15	Gerabunia	450	Beside the House of Badal Molla
16	Soilabunia	600	South Side of Siddique Khan's House
17	Soilabunia	450	South Side of Ismail Talukdar's House
18	Soilabunia	450	South Side of Dholu Gazi's House
19	Soilabunia	450	East side of Delowar Chowkidar's House
20	Soilabunia	600	Beside the House of Salam Hawladar
21	Soilabunia	450	South side of Milon Hawladar's house
22	Soilabunia	450	Beside the House of Bashar Munshi
23	Badura	450	Near the Badura Hat Kaumi Madrasa
24	Badura	450	South side of Selim Hawladar's House
25	Badura	450	Beside the House of Nuru Hawladar
26	Badura	600	North side of Chawkidar's House
27	Badura	450	Beside the House of Jahangir Mirdha
28	Badura	450	Beside the House of Rahman Chowkidar
29	Boloikati	450	South side of Abdul Mannan Maulana
30	Boloikati	450	North side of Belayet Hossain Master's House
31	Boloikati	450	Beside the House of Al Islam
32	Boloikati	450	West side of Rari Bari Masjid
33	Chinguria	600	Beside the Chinguria primary school
34	Chinguria	450	West side of Moslem Biswas House
35	Uttar Amkhola	450	East side of Sohrab Shikdar's House
36	Baherchar	450	North side of Ismail Hawladar's House
37	Dari Baherchar	450	Beside the House of Raja Chowkidar
38	Dari Baherchar	450	South side of Nuruzzaman House
39	Dari Baherchar	450	South of Mozaffar Hawladar's House
40	Dari Baherchar	450	Chinage 35+194 km
41	Dari Baherchar	450	East side of Rashid Biswas's House
42	Dari Baherchar	300	South side of Shah Alam's House
43	Amkhola Bazar	450	Beside the House of Khaled Mia
44	Bhangra	450	Beside the House of Salam Hawladar
45	Mashurikati	600	East Side of Late Hashem Gazi House
46	Mashurikati Sluice	450	East of Late Hazi Afaz Uddin's House

Source: Blue Gold Program Office, 2015

Some of the internal drainage channels are silted up due to top soil erosion from adjacent land, coupled with improper maintenance over the years.

Table 7.5 Information khals

Sl. No.	Name of khals	Approximate length (km)
1	Bauria Khal	4.10
2	Badrar Khal	1.10
3	Bangrar Khal	1.45
4	Karmjatala Khal	1.10
5	Ostakhali Khal	0.70
6	Sobaram Khal	2.00
7	Kalabunia Khal	0.75
8	Badura Khal	3.20
9	Masuakhali Main Khal	5.00
10	Musurikati Khal	2.00
11	Bastalar Khal	1.50
12	Tulabaria Khal	2.00
13	Luhit bari Khal	2.00

Source: Blue Gold Program Office, 2015

The peripheral embankment of the polder is damaged at some locations. There are some discrete damages in Jainkathi (0.5 km) and Bauria (3.0 km). A more severe damage was observed in Dari Baherchar, where the embankment is breached over a length of around 0.5 km.

Water resources management
Poor water resources management is a major issue in the polder, marked by low maintenance and improper use of water management infrastructure (operation of sluice gates, outlets and inlets). Some routine works and practices (establishment of navigation ghats (ramps), construction of shops or houses near the gates, etc.) also harm the structural condition of the gates.
Siltation of khals is another problem, which reduces the water availability for irrigation and causes unfavourable conditions for aquatic biota.

Water shortage
At present, people are suffering from water shortage for irrigation as khals are gradually being silted up. Local people cannot fulfil their irrigation requirements up to the desired level due to reduced surface water sources. If the proposed khals are not re-excavated (Bauria, Bangrar, Kalabunia, Musurikati Khal, etc.) the water scarcity will be more acute in the near future. The EIA study infers that water availability and use may be reduced in future and around 25% people in the polder might be suffering from water scarcity.

Tidal flooding
Almost every day, high tidal waters enter the polder near Dari Baherchar due to a breach in the embankment, causing problems for the local people. The tidal floodplain outside the polder is also flooded during high tides.

Drainage congestion and water logging

Topsoil erosion, and other land filling activities have resulted in a gradual decrease of water courses within the polder over the years. Some of the khals (Bauria, Badrar, Bangrar, Karimjatala, Ostakhali, Sobaram, Kalabunia khal, etc.), which are connected with the external rivers have become very narrow (less than 5 feet wide) at some locations. Siltation especially occurs at the confluence points with the peripheral rivers. The situation is further aggravated due to improper maintenance of sluice gates, which sometimes allows tidal water to remain trapped at the openings of the khals.

The hydrological connectivity is sometimes disrupted, when water from low lying land does not flow into the khals, generating drainage congestion. On average, the water remains stagnated for 2-3 weeks. After heavy rainfall, water needs to be pumped from low lying areas into the adjacent drainage khals.

Navigation

The peripheral rivers and Khals (Galachipa/Lohalia and Golkhali) are used as waterway. Small trawlers carrying passengers and sand navigate through the rivers. However, very little navigation takes place inside the polder as only small fishing boats navigate through the internal khals.

Erosion and accretion

The embankment breaching process of about 0.5 km at the north-east corner along the Lohalia River near Dari Baherchar is lasting already for a couple of years. This breach causes more tidal water to flow into the polder, and eventually may cause severe river erosion in near future. An analysis of Remote Sensing images (1997 and 2014) shows that during the last 17 years the planforms of Galachipa/Lohalia River at Dari Baherchar has been changed due to erosion and a very significant portion of land (20 ha in total) at Boloikati village has been eroded.

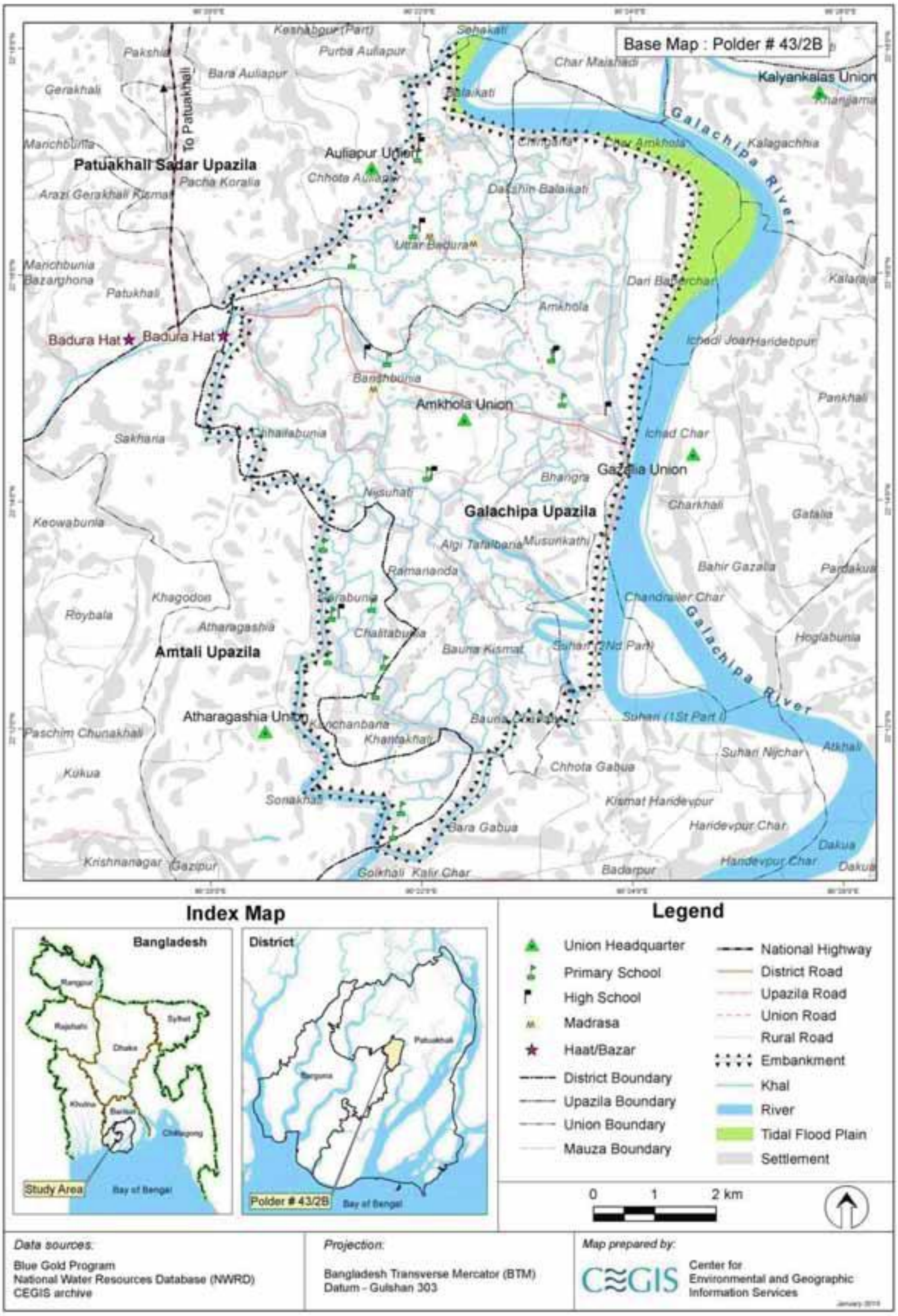


Figure 7.6 Base map of Polder 43-2B

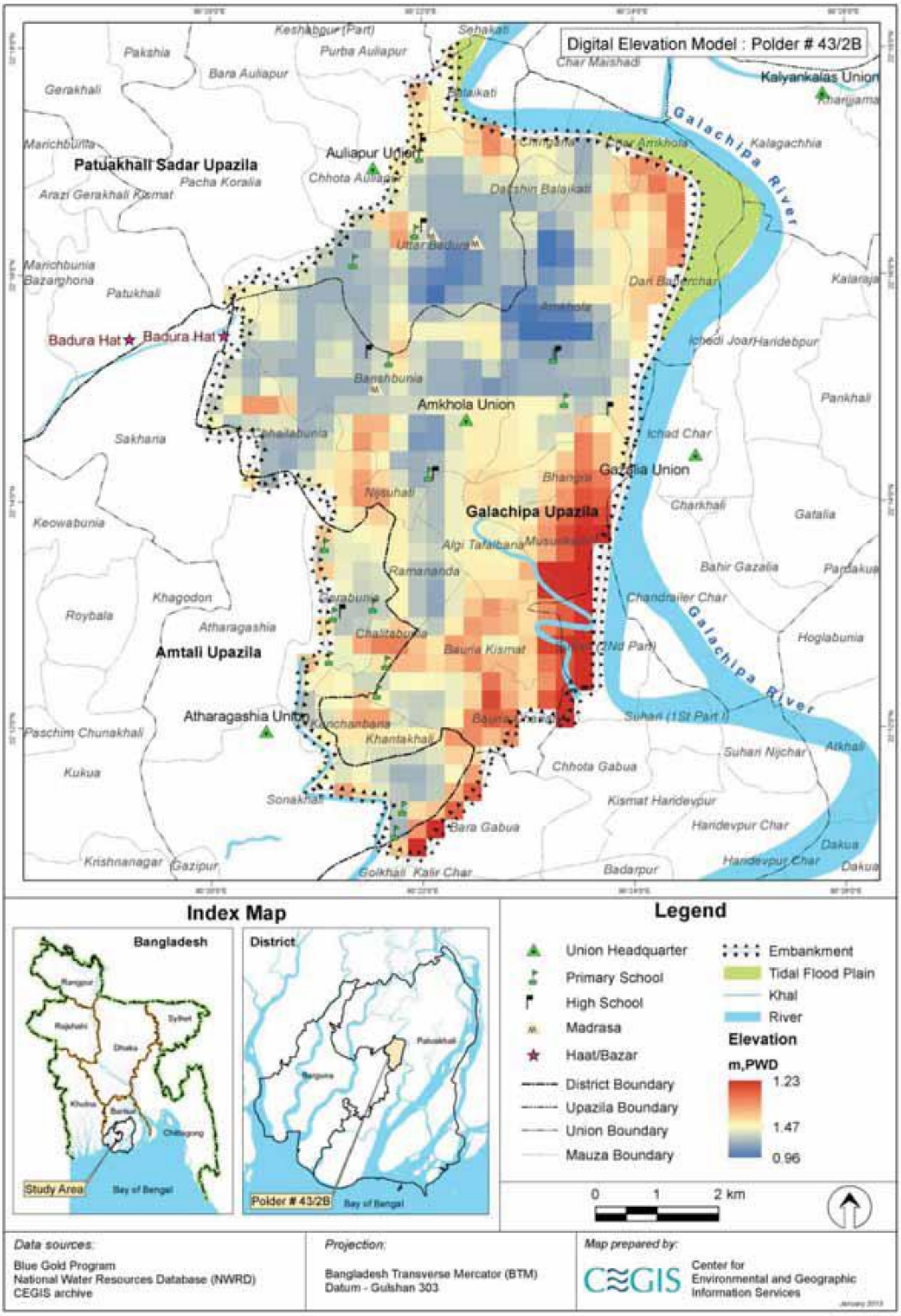


Figure 7.7 Digital Elevation Model (DEM) around Polder 43-2B

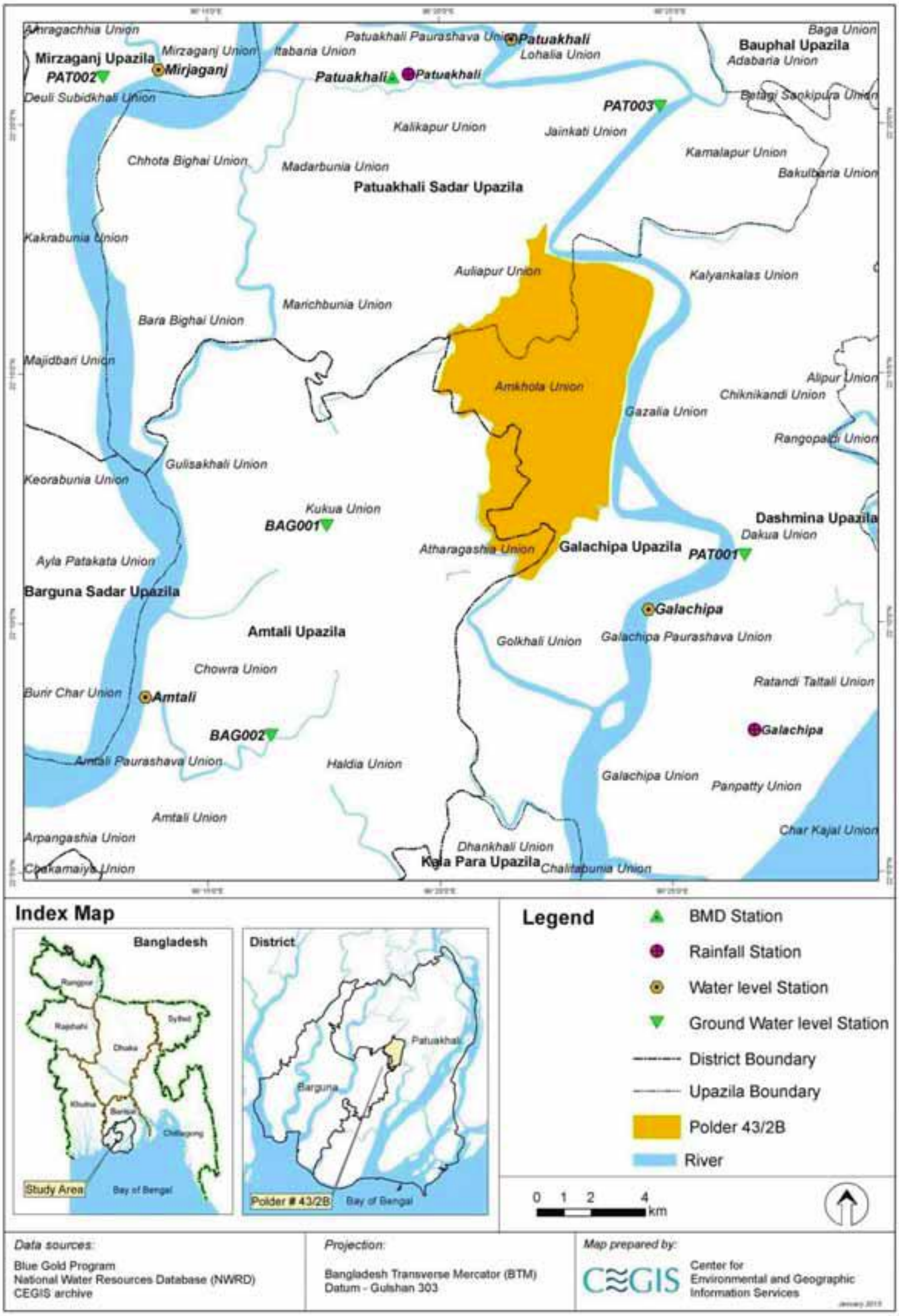


Figure 7.8 BWDB stations of rainfall, water levels and GW observation wells

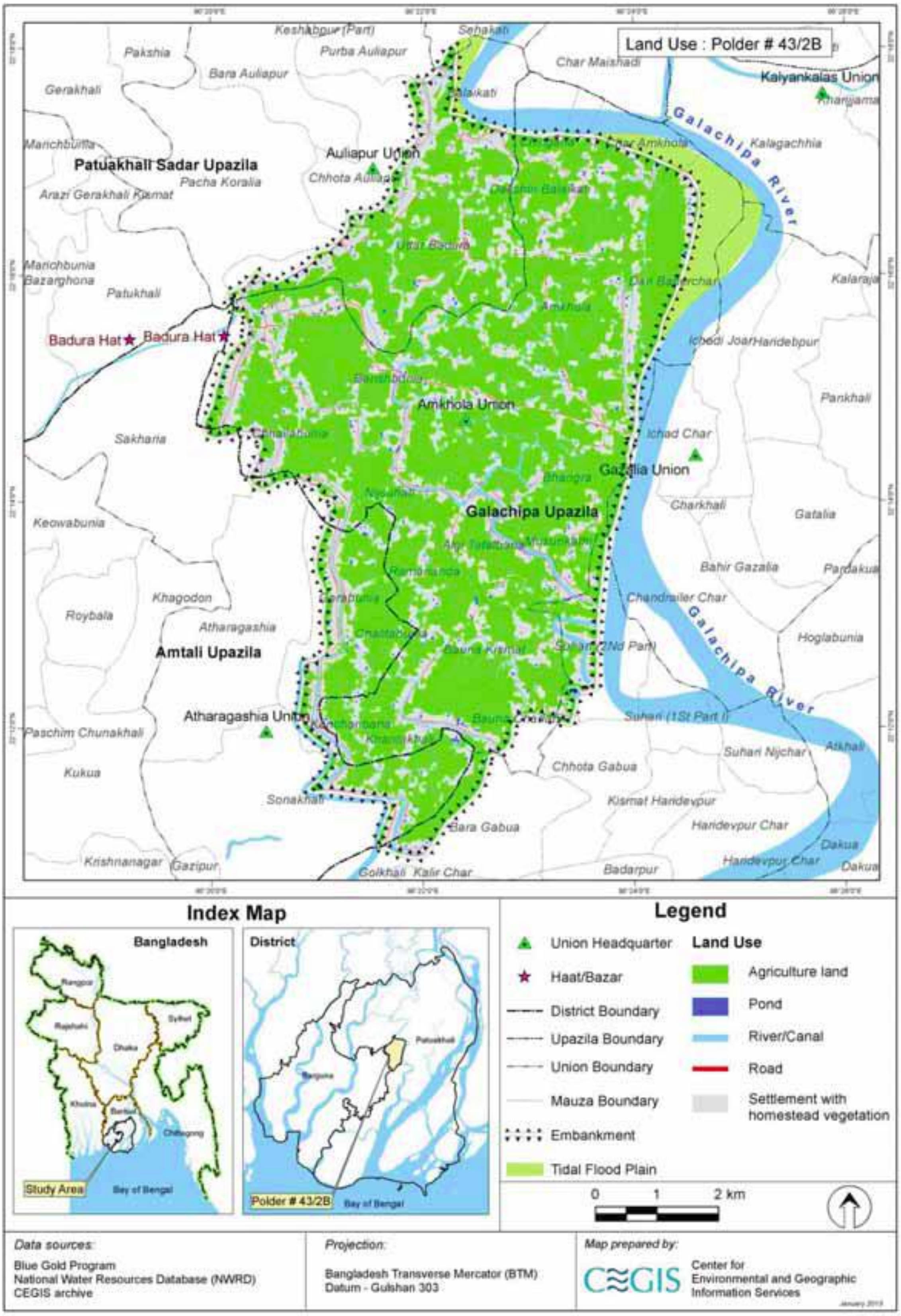


Figure 7.9 Land use in Polder 43-2B

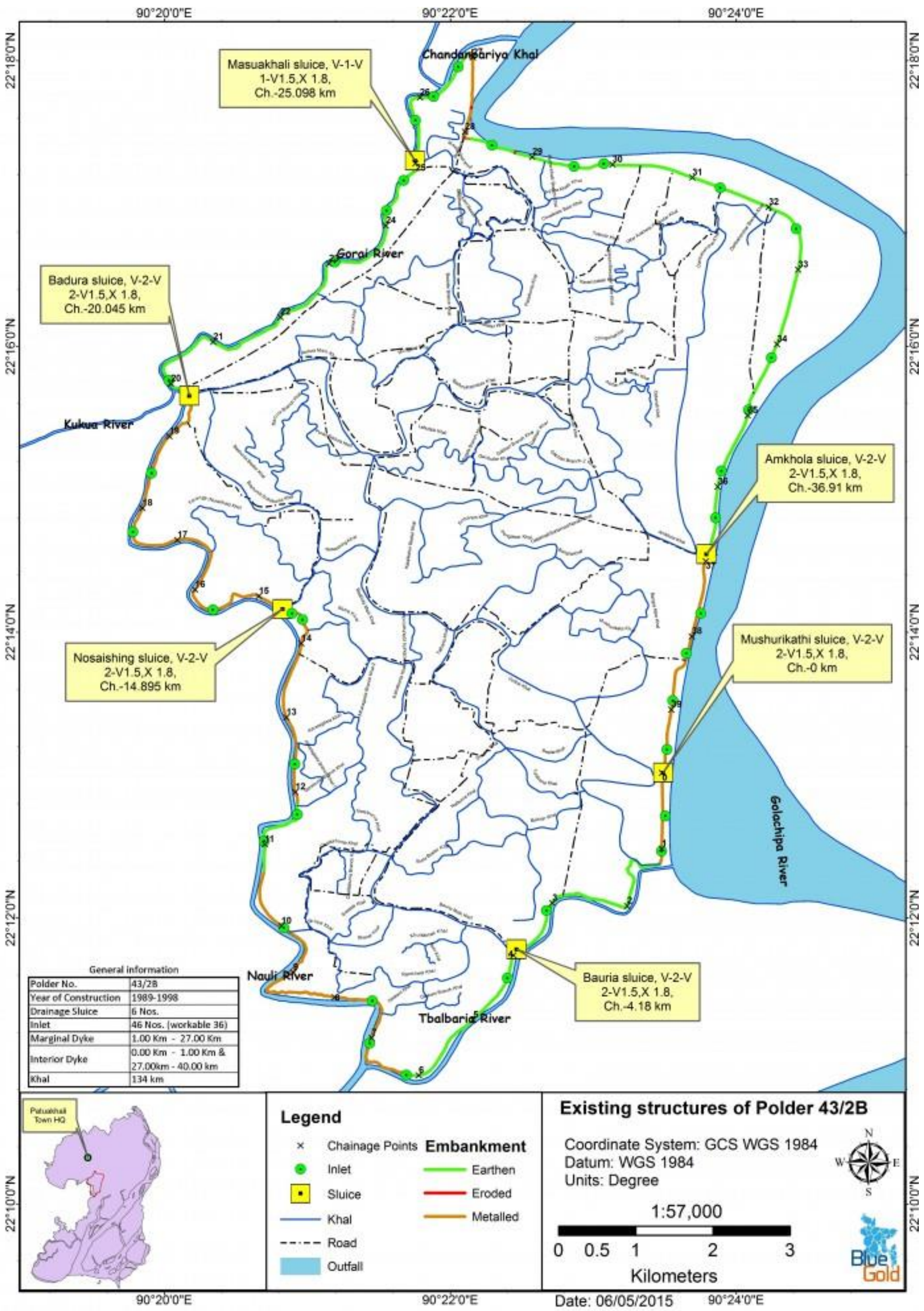


Figure 7.10 Water management infrastructure Polder 43-2B

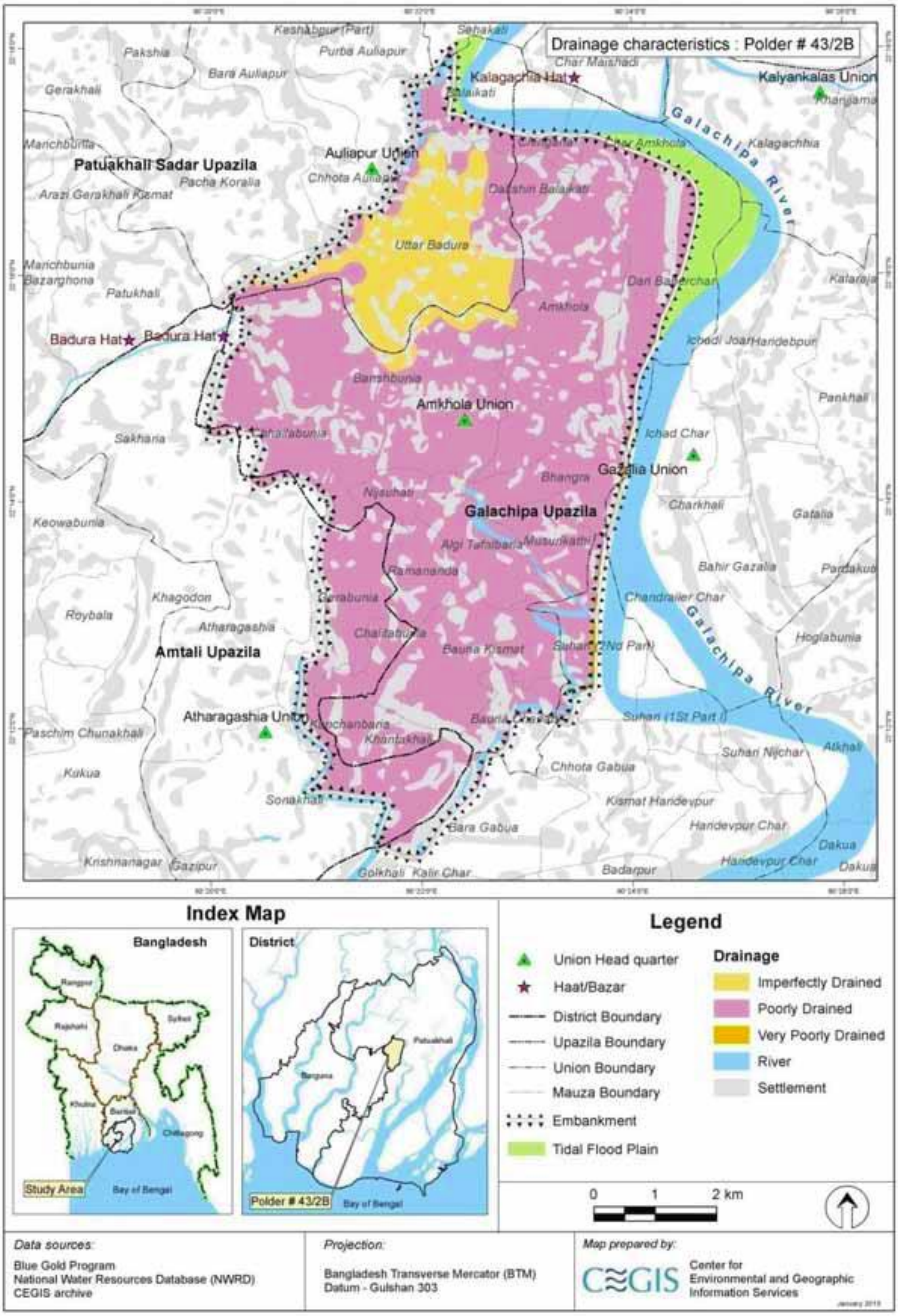


Figure 7.11 Drainage characteristics of the Polder 43-2B

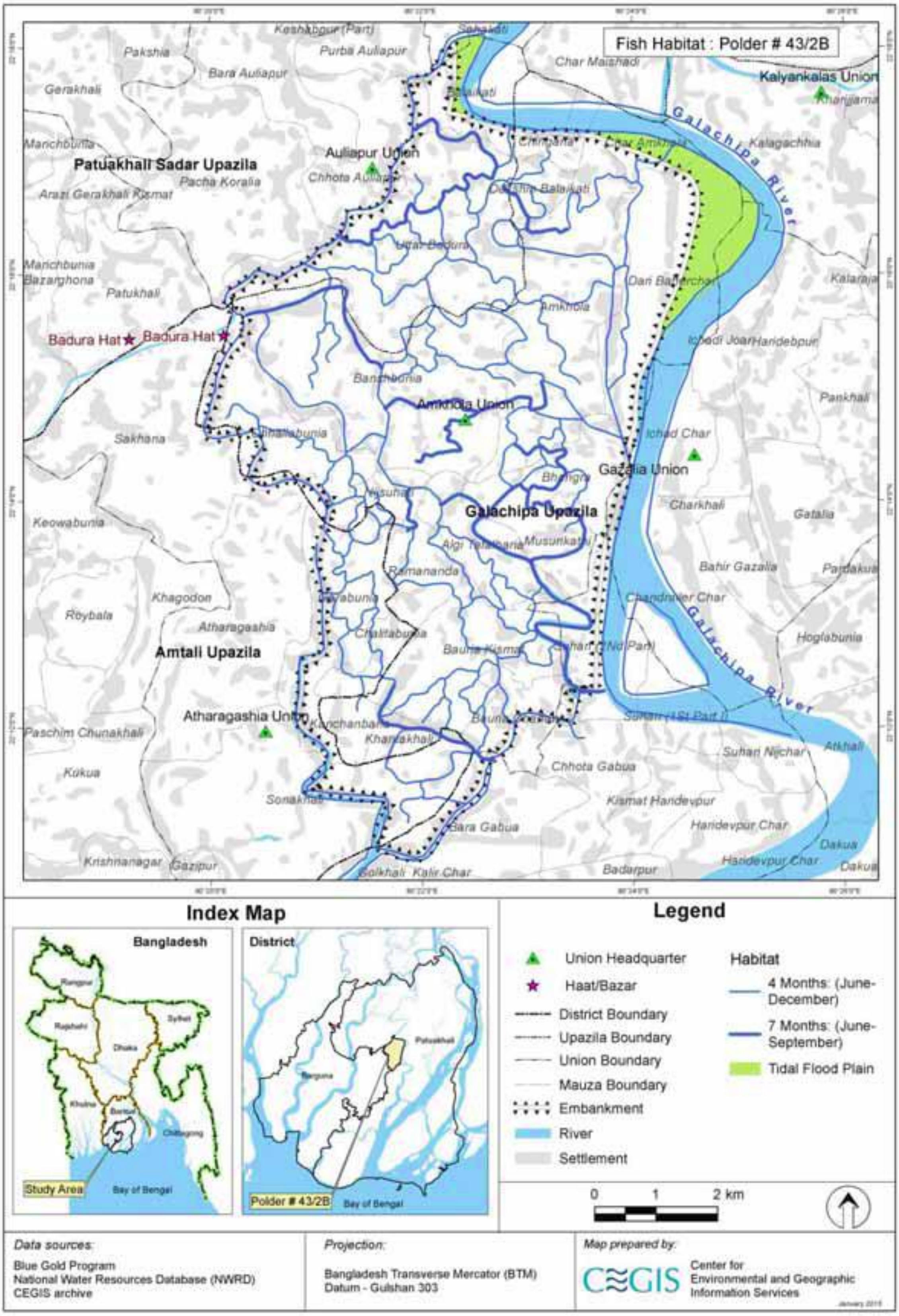


Figure 7.12 Fish habitat in Polder 43-2B

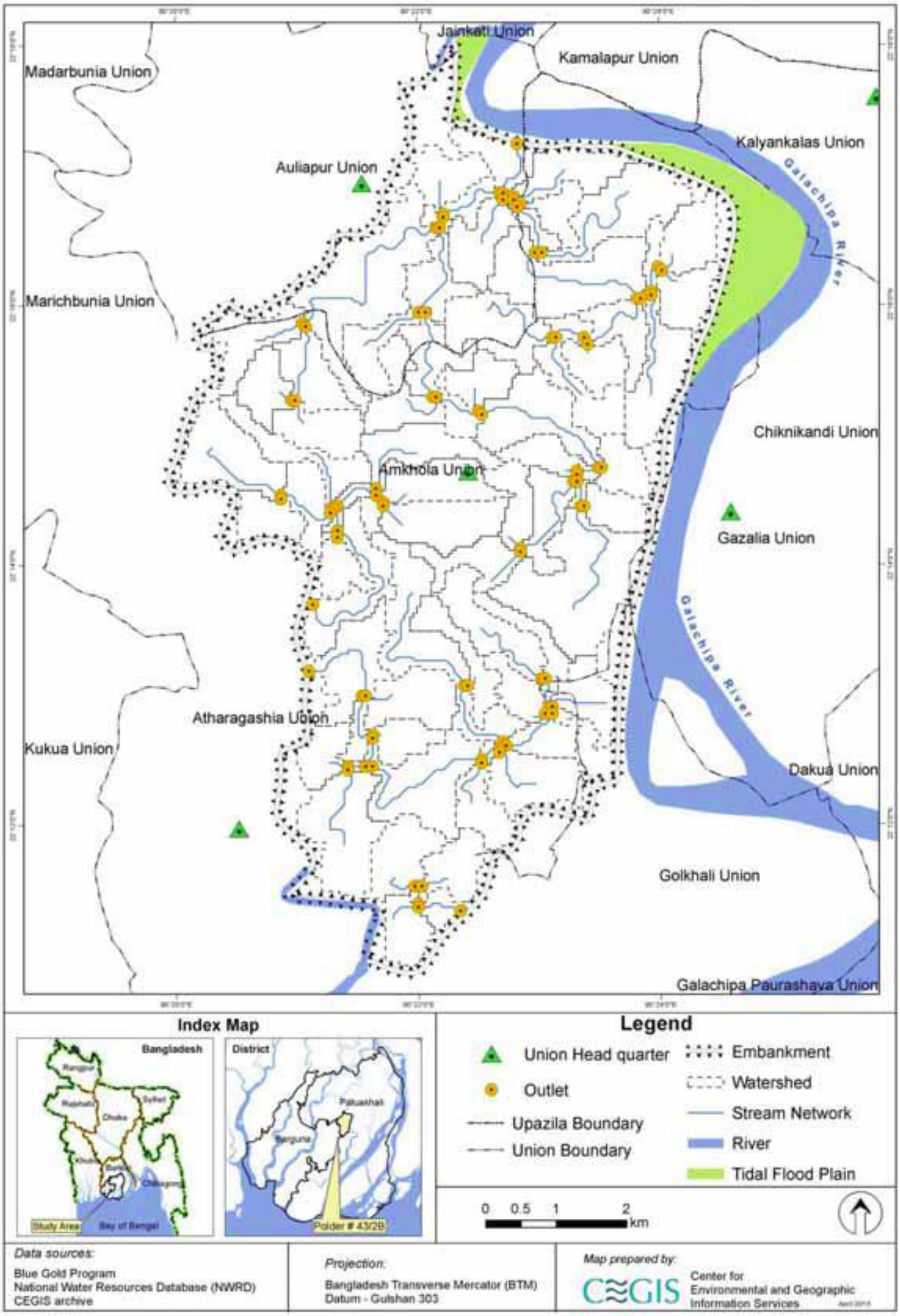


Figure 7.13 Delineated watershed schematization SWAT model for Polder 43-2B

B Processing of the DEM

The steps taken to process the DEM were:

- Remove the sinks
  We used the QGIS SAGA plug-in to remove the sinks of the DEM as generally they are artefacts and not real sinks. We tried different thresholds and finally we used the value 0.5, meaning that any sink with a maximum value of 0.5 will be removed. This is a rather high threshold but it gave the best result in terms of watersheds, otherwise, if lower thresholds were used, there were many small watersheds created.
  Raster: ..\ForBlueGold\GIS\rasters\Processed_DEM_5_CEG_50cm_sink_rem.tif

- Burn the khals
  First we added a new field in the khal shapefile in order to assign the order of the khal. Main khals were given order -6, and progressively orders were given to secondary khals depending on their location and flow direction up to -0.5.
  Shapefile: ..\ForBlueGold\GIS\shapes\Khal_43_2B.dbf

  Then the shapefile was rasterized using the new field and thus the order of the khal also became the depth.
  Raster: ..\ForBlueGold\GIS\rasters\Khals.tif

  After rasterization, the depth of some khals (mostly those draining to Mushurikhati Sluice) was modified to create a slope in the khal.
  Raster: ..\ForBlueGold\GIS\rasters\asc\dem_for_khal_with_depthsasc.asc

  Finally the new khal raster was burned in the processed DEM using the Python Script "Burn_khals.py". Note: When using the script, change the paths of the files and the packages for it to run.
  Raster:
  ..\ForBlueGold\GIS\rasters\Processed_DEM_5_CEG_50cm_sink_rem_cs_khals_depths_1.tif

- Fill the sinks
  As the last step we run the QGIS SAGA plug-in Fill de sinks (Wang & Liu) over the DEM with the khals to create the Watershed and Flow Direction Map. This plug-in still modified the DEM, mostly the depth of the khals, but as the watersheds defined, reasonably matched the Catchments defined by Blue Gold, we decided to use this DEM. The minimum slope preserved to fill in the sinks was 1 degree.

  Rasters:
  - ..\ForBlueGold\GIS\rasters\Filled_DEM_CEG_50cm_1slope_depthkhals.tif
  - ..\ForBlueGold\GIS\rasters\Watersheds_DEM_CEG_50cm_1slope_depthkhals.tif
  - ..\ForBlueGold\GIS\rasters\Flow_directions_DEM_CEG_50cm_1slope_depthkhals.tif

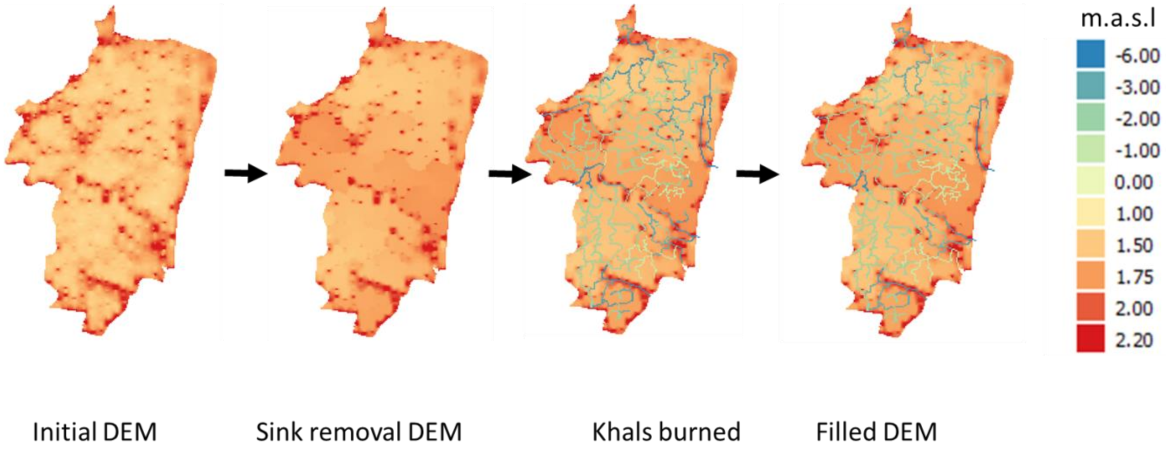
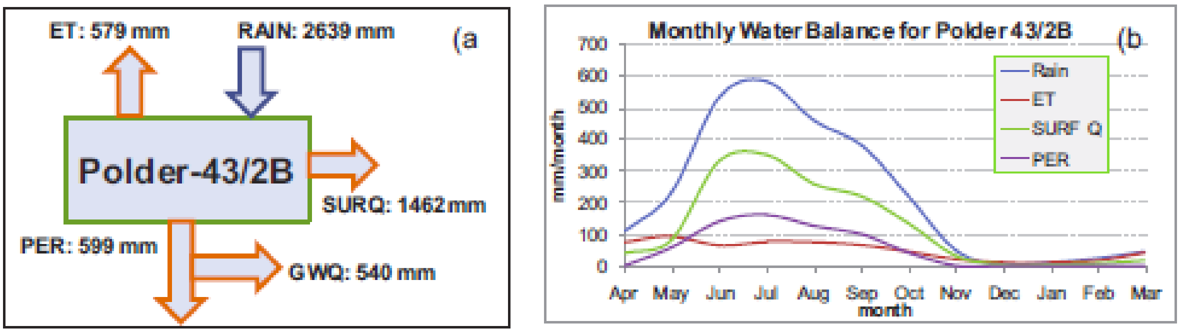


Figure 7.14 Process applied to the DEM for it to be used in the Spatial Analyser

C Water Balance Polder 43-2B

C.1 General description

In the Environmental Impact Assessment on rehabilitation of Polder 43-2B (CEGIS, April 2016) a water balance has been established using a SWAT model. The model has simulated the period of 1981 to 2012 to estimate the availability of water (Figure 1).



Note: Rain - Rainfall; ET - Evapotranspiration; PER - Percolation; SURQ - Surface Runoff

Figure 7.15 Water balance for Polder 43-2B (1981-2012); (a) average annual, (b) average monthly

The annual average evapotranspiration is around 579 mm (22% of the annual rainfall). The maximum evapotranspiration occurs in April and May (about 100 mm/month), the minimum in December and January. About 599 mm/yr percolates (23% of the annual rainfall) into the ground; the maximum rate is 160 mm/month. The remaining portion of water contributes to stream flow as overland flow and lateral (subsurface) flow. Around 55% (1,462 mm) of rainfall contributes to stream flow through surface runoff while the lateral flow is negligible.

C.2 Polder storage vs. cropping seasons

The above illustrated numbers have been used to roughly calculate the storage in the polder (Table 1). The storage is negative (average -20 mm/d) from March till May (Kharif-I season); farmers maintain relative large areas land fallow due to soil salinity and the limited supply of irrigation water. The Kharif-I season is characterized by high temperatures, low humidity, high evaporation, and high solar radiation. The rainfall is uncertain, which means low alternating dry and wet spells.

During the Kharif-II (monsoon) season there is an abundance of storage (average 16 mm/d). The season is characterised by high rainfall, lower temperatures, high humidity, and low solar radiation. Rice is the predominant crop, due to the submergence of soil. Excessive soil moisture and higher temperature restricts cultivation of other crops in the area.

During the Rabi season (November – February), with high solar radiation, low humidity and temperatures there is on average a slight positive storage (0,1 mm/d). Due to inadequate soil moisture, the crop yield (watermelon, sesame, mungbean, groundnut, khesari and sunflower) is low.

Table 7.6 Annual and monthly water balance Polder 43-2B (average 1891-2012)

	P (mm)	***ET (mm)***	***SURQ (mm)***	***PER (mm)***	***GWQ (mm)***	***Storage dS***		***Seasons***		
						(mm)	***(m^3/s***	***Rabi***	***Kharif-I***	***Kharif-II***
Apr	116.6	75.3	38.9	5		-2.6	-0.06		Partly fallow land	
May	146.6	90.3	78.9	50		-72.62	-1.60			
Jun	526.6	65.3	323.9	135		2.38	0.05			
Jul	586.6	70.3	348.9	155		12.38	0.27			Predominantly rice (sub-merged soil -> monsoon)
Aug	481.6	75.3	263.9	120		22.38	0.49			
Sep	391.6	65.3	218.9	85		22.38	0.49			
Oct	231.6	45.3	138.9	40		7.38	0.16			
Nov	51.6	15.3	23.9	1		11.38	0.25	Sesame, mungbeans, watermelon, chilli, khasari, sunflower		
Dec	16.6	10.3	3.9	2		0.38	0.01			
Jan	16.6	10.3	3.9	2		0.38	0.01			
Feb	26.6	15.3	3.9	2		5.38	0.12			
Mar	46.6	40.3	13.9	2		-9.62	-0.21			
Annual	2.639	579	1.462	599	0	-0.44	-0.01			

D Sluice Designer and Operator App

D.1 Introduction

In principle, the Sluice Operator App is a 'water level regulator'. The drainage sluices in Polder 43-2B regulate the upstream water level and discharge with gates (see Figure 1). Hydraulic structures under upstream control maintain the upstream water level at a target water level, implying that the upstream water level is constant (between up- and down thresholds) for each discharge. However, the sluices of Polder 43-2B all drain in an outlet with a diurnal tide, hindering the control and maintenance of the upstream water level in the polder.

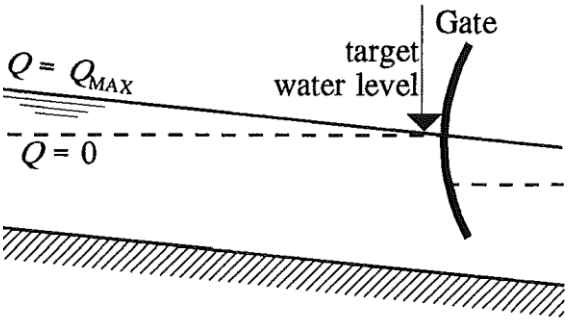


Figure 7.16 Principle of upstream control (Ankum, 2002).

The drainage sluices in Polder 43-2B (Figure 2) basically consist of a culvert with flap gates on both the polder as well as the (tidal) river side. The use of lift gates would be more appropriate to regulate the water levels in de polder. When the drainage sluice gates are to be repaired, it would be advised to install lift gates. In the Sluice Operator App the discharge is regulated by a lift gate.

Picture 7.1 Drainage sluice Polder 43-2B with flap gates.

D.2 Types of flow

The flow through a gated drainage sluice is quite complex. Basically, there are five different flow types (Figure 3):

- Free overflow. The water level does not touch the gate, and the tailwater level is sufficient low to allow for a free overflow (like a broad-crested weir).
- Conveyance flow. The water level does not touch the gate, and the tailwater level is so high that the flow is submerged (like a bridge).

- Free underflow. The flow under the gate is not influenced by the tailwater level. The outflowing jet is open to the atmosphere because the hydraulic jump is formed at some distance from the gate.
- Partially-submerged underflow. The flow under the gate is super-critical (Fr > 1). However, the flow is influenced by the tailwater level as the jet is overlaid by the hydraulic jump.
- Fully-submerged underflow. The flow under the gate is sub-critical (Fr < 1), and as such, is influenced by the tailwater level.

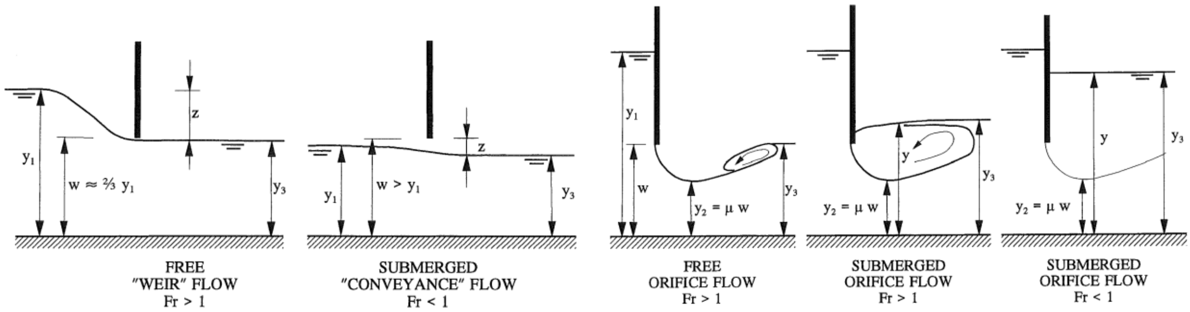


Figure 7.17 . Flow types through a gated drainage sluice (Ankum, 2002)

The flow conditions in the culvert barrel can be:
- Open canal flow, with a free water surface.
- Pipe flow, with the culvert barrel completely filled.
- Free flow or inlet control for large head losses.
- Submerged flow or tailwater control.

D.3 Conditions of use for Sluice Operator App

The Sluice Operator App can be applied for all culvert flow conditions, but is currently only applicable for free flow types regarding the lift gate. Furthermore, calculations only account for steady, uniform flow. Submerged, as well as unsteady non-uniform flow, situations still need to be developed.
Backwater curves and diurnal tides should be incorporated at a later stage. For now, a stepwise approach (calculating with time steps of e.g. 0.5 hours), could be sufficient.

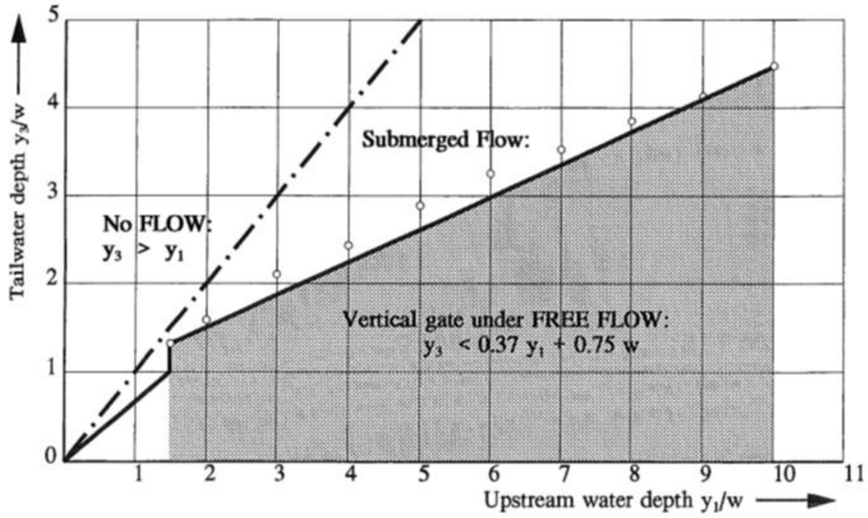


Figure 7.18 Conditions for the vertical gate under free flow

The lift gates rest on the bottom of the box culvert, there is no crest present.
The box culvert is considered clean, no soil or debris is present. The influence of the maintenance status on the flow conditions could be included in future versions.

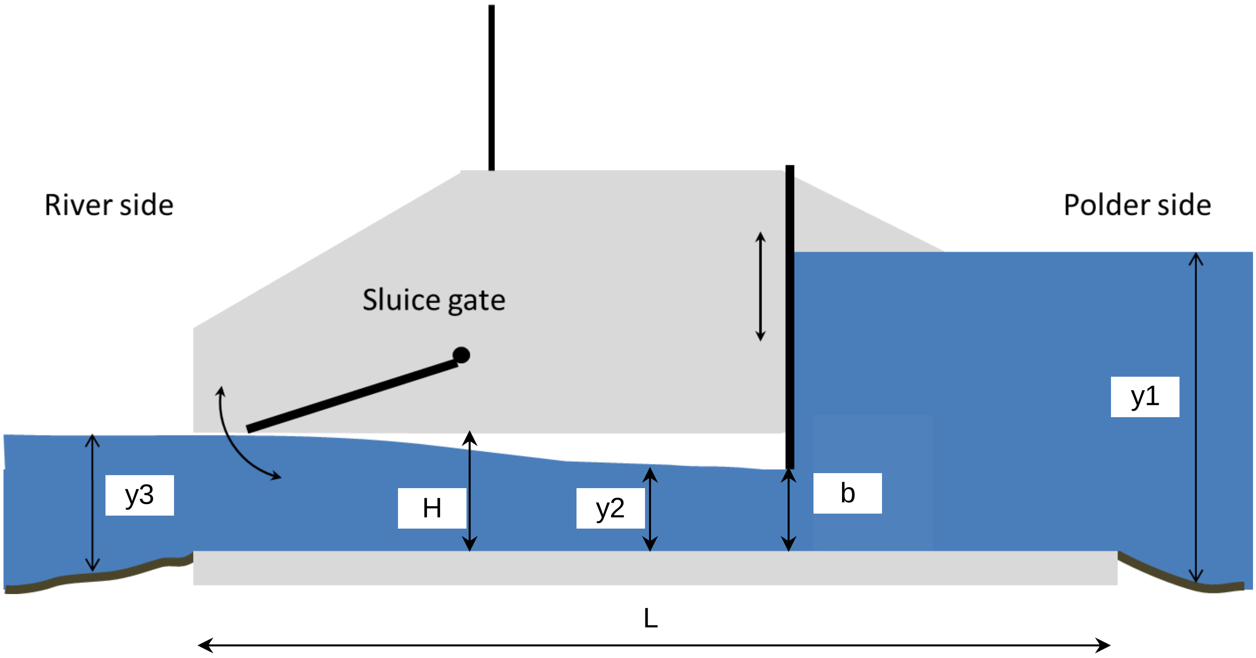


Figure 7.19 Drainage sluice gate parameters

D.4 Parameters

Besides the up (y1)- and downstream (y3) water depth, and gate opening (b), several other input parameters need to be specified for calculating the discharge, head and flow.
The dimensions of the box culvert: width (B), height (H), and length (L). The entrance loss coefficient is specified for three situations (square cut end walls, wingwalls, or a rounded

entrance). Furthermore, Manning's hydraulic roughness (n), the bottom width (B) and slope (S) of the outlet water need to be specified.

Input:
y1 = upstream water depth (m)
y3 = tailwater water depth (m)
b = gate opening (m)
W = width box culvert (m)
H = height box culvert (m)
L = length box culvert (m)
ELC = Entrance loss coefficient (m)
n = Hydraulic roughness (Manning) ($m^{1/3}/s$)
B = bottom width outlet water (m)
S = slope river bank outlet water (-)

Intermittent computations:
Cd = discharge coefficient (-)
q = discharge per unit width of channel (m^2/s)
Q = discharge (m^3/s)
y2 = flow section depth (m)
v_lg = flow velocity under liftgate (m/s)
FL = friction loss (-)
µ = Drag coefficient (-)
A_tot_bc = total area box culvert (m^2)
A_a_bc = air area box culvert (m^2)
Fr = Froude number (-)
y_bc = water depth in box culvert (m)
a_bc = air in box culvert (m)
Aw_oa = wet area outlet water (m^2)
ELBC = Box culvert exit loss (-)
Aw_bc = wet area box culvert (m^2)
O = wetted perimeter (m)
R = hydraulic radius (m)
C = Chezy coefficient ($m^{1/2}/s$)

Output:
dy = Box culvert head (max 0,3 m)
Q = Box culvert (sluice) discharge (m^3/s)
v_lg = Flow velocity under liftgate (m/s)
v_bc = Flow velocity end box culvert (m/s)

D.5 Calculations Sluice Operator App

The Sluice Operator App calculates the effect of lift gate operation on discharge, head, and flow velocities (under the lift gate and at the outlet of the box culvert), given an up (y1)- and downstream (y3) water depth, and gate opening (b). The sluice consists of a lifting gate, a box culvert and an apron wall.

The hydraulic flow condition is assessed with:

Free flow $$y_1 \geq 0.81 y_3 \left(\frac{y_3}{b}\right)^{0.72}$$

Submerged flow $$y_3 < y_1 < 0.81 y_3 \left(\frac{y_3}{b}\right)^{0.72}$$

For free flow, the discharge coefficient (Cd) is calculated with: $C_d = 0.44457\left(\frac{y_1}{b}\right)^{0.1219}$

The specific discharge is calculated, based on Bernoulli's equation for free flow, which can be written for a sluice gate with hydraulic jump flow, as:

$$q = C_d b\sqrt{2g(y_1 - C_c b)}$$

The sluice gate has two culverts besides each other, therefore the total discharge is calculated as: Q = 2 * q * W

The vena contraction flow section depth is calculated as y2 = Cc * b, the flow velocity under the lift gate as v_lg = Q / (b * B), and the Froude number as $Fr = v / (g * b)^2$

The box culvert flow is calculated with the Chezy formula: $C = 1/n * R^{1/6}$, which is used to estimate the drag coefficient (μ = 1/(sqrt(ELC+ELBC+FL)) on the basis of the entrance loss coefficient, the exit loss of the box culvert ($ELBC = 1 – (Aw\_oa/Aw\_bc)^2$) and the friction loss ($FL = (2*g*Cc)/(C^2*R)$)

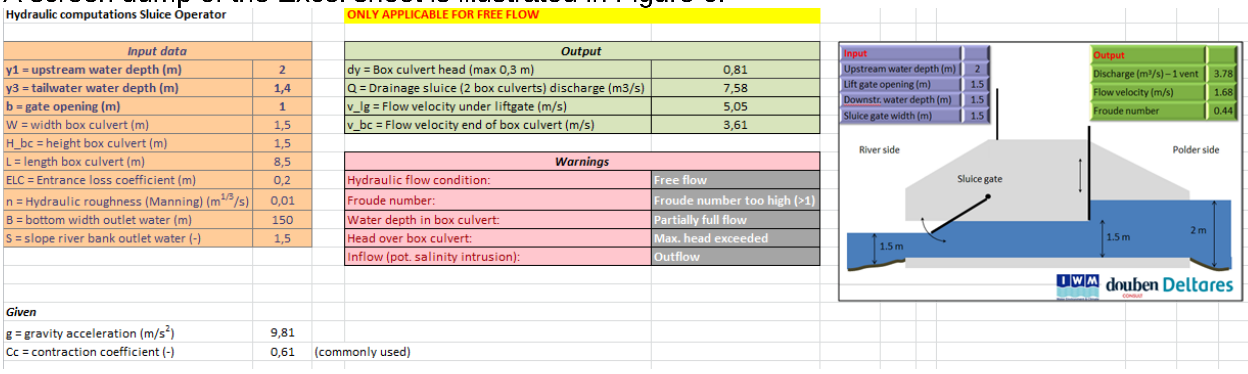
Finally the box culvert (sluice gate) head, which should not exceed 0.3 m, is calculated by $dy = Q^2 / (\mu^2 * Aw\_bc^2 * 2 * g)$, and the flow velocity at the end of the box culvert by $v\_bc = \mu * (2g * dy)^{1/2}$

D.6 Warnings

The app gives several warnings for:

- The hydraulic flow condition: free flow or submerged flow. In case of submerged flow, the concomitant discharge coefficient (Cd) needs to be adjusted manually at the moment.
- Froude number: <1 or >1. Froude numbers > 1 indicates super critical flow, which might be problematic for the sluice construction and its downstream components.
- Water depth in box culvert: partially full flow or full flow. The full flow situation has not been incorporated in the spreadsheet yet.
- Head over box culvert: < or > 0.3. The head of the sluices (in Polder 43-2B) may not exceed 0.3 m.
- Inflow (pot. salinity intrusion): in- or outflow, indication of the flow direction.

A screen dump of the Excel sheet is illustrated in Figure 6.



Hydraulic computations Sluice Operator — ONLY APPLICABLE FOR FREE FLOW

Input data	
y1 = upstream water depth (m)	2
y3 = tailwater water depth (m)	1,4
b = gate opening (m)	1
W = width box culvert (m)	1,5
H_bc = height box culvert (m)	1,5
L = length box culvert (m)	8,5
ELC = Entrance loss coefficient (m)	0,2
n = Hydraulic roughness (Manning) ($m^{1/3}/s$)	0,01
B = bottom width outlet water (m)	150
S = slope river bank outlet water (-)	1,5

Output	
dy = Box culvert head (max 0,3 m)	0,81
Q = Drainage sluice (2 box culverts) discharge (m3/s)	7,58
v_lg = Flow velocity under liftgate (m/s)	5,05
v_bc = Flow velocity end of box culvert (m/s)	3,61

Warnings	
Hydraulic flow condition:	Free flow
Froude number:	Froude number too high (>1)
Water depth in box culvert:	Partially full flow
Head over box culvert:	Max. head exceeded
Inflow (pot. salinity intrusion):	Outflow

Given		
g = gravity acceleration (m/s^2)	9,81	
Cc = contraction coefficient (-)	0,61	(commonly used)

Figure 7.20 Screen dump Sluice Operation App (Excel)

E Culvert Designer and Maintainer App

E.1 Introduction

A culvert is considered a so-called ‘non-regulating conveyance structure’, and is required at crossings of natural, drainage and/or irrigation channels with (rail) roads, trails or embankments. Culverts are specifically designed for low head losses at all discharge levels (Ankum, 2002).

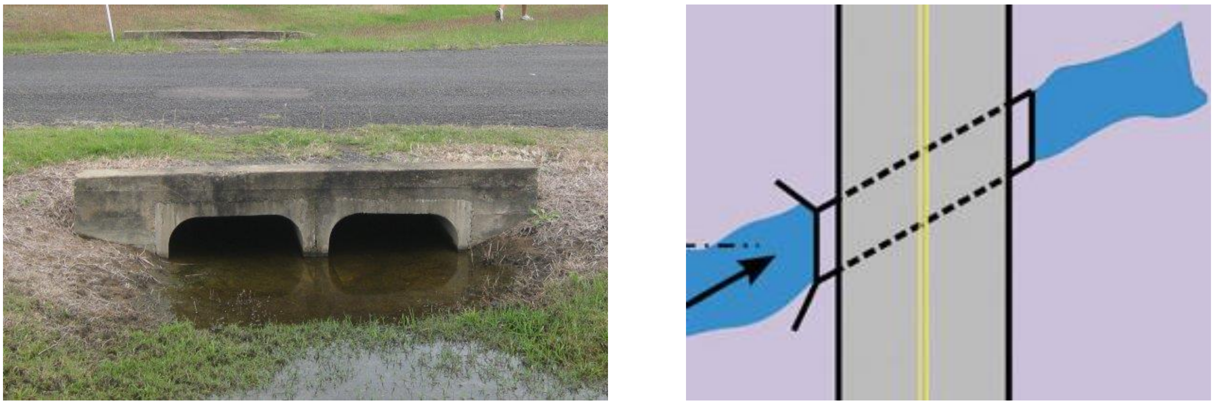


Figure 7.21 Culvert crossing a road

The Culvert Designer App is a tool to analyse and design the possibility to allow water to flow under a road or embankment at (natural) drainage and stream crossings. In quite some cases in Polder 43-2B the lack of culverts or their undersized dimension is causing water logging at the upstream side of a road. The Culvert Designer App can be used to prepare and/or quickly verify design studies of new culverts, or to analyse possibilities to enlarge existing culverts.

Generally a culvert consists of the following main components (Figure 2):

- Barrel(s), or a pipe, for the water to flow under a road;
- A crown to connect the barrel(s) with the soil and the road talus surrounding the culvert;
- (flared) Wingwalls to protect the road talus from erosion and to guide the flow into the barrel(s).

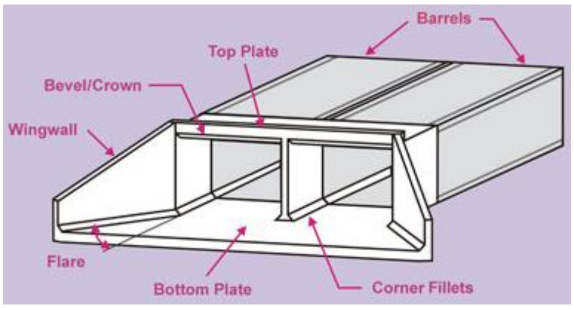


Figure 7.22 Culvert components

Hydraulic design considerations and flow conditions

The hydraulic design of a culvert basically consists of an (iterative) analysis to convey a required flow from one side of the road (or embankment) to the other.

Formally, a design flood flow frequency should be selected, followed by an estimate of the design discharge for that frequency, and an allowable headwater elevation should be set. These criteria are typically dictated by local requirements.

Normally, the culvert size and type can be selected after the (design) discharge, design headwater, slope, tailwater depth, and allowable outlet velocity have been determined. In the Culvert Designer App the headwater and flow velocity will be calculated, based on a given discharge and tailwater depth.

The hydraulic design of a culvert basically includes the determination of the following (Schall et al., 2010):

- Impacts of various culvert sizes and dimensions on up- and downstream water levels (and flood risks), including potential road or embankment overtopping. For this aspect, the outcomes of the Culvert Designer App need to be combined with iterative computations of the Spatial Analyser App.
- Alignment, slope, length, size, headwater, and outlet velocity of the culvert;
- In addition, the following aspects also need to be taken into consideration for the design of a culvert:
  - ➢ Amount and type of cover on top of the culvert;
  - ➢ Barrel or pipe material and type of coating (if required);
  - ➢ Need for fish passage measures, in specialized cases;
  - ➢ Need for protective measures against abrasion and corrosion;
  - ➢ Need for specially designed inlets or outlets;
  - ➢ Structural and geotechnical considerations.

Flow conditions
There are several flow conditions through a culvert, depending on the discharge, the cross section, length, and the downstream flow conditions (see Figure 3). The flow conditions in the culvert barrel can be considered as follows:

- Open channel flow, with a free water surface in the barrel;
- Pipe flow, with the barrel completely filled.

Furthermore, the water in the culvert may flow as:

- Free (super-critical) flow with large head losses (flow types 1 and 5), which is basically contradictious to the requirement of a conveyance structure (i.e. low head loss). These situations are known as ‘inlet control’.
- Submerged flow or ‘tailwater control’ (flow types 2, 3, 4 and 6).

The types of flow are classified for the convenience of computing culvert flow (Carter, 1957), based on the location of the control section and the relative heights of the head- and tailwater surfaces (see Table 1).

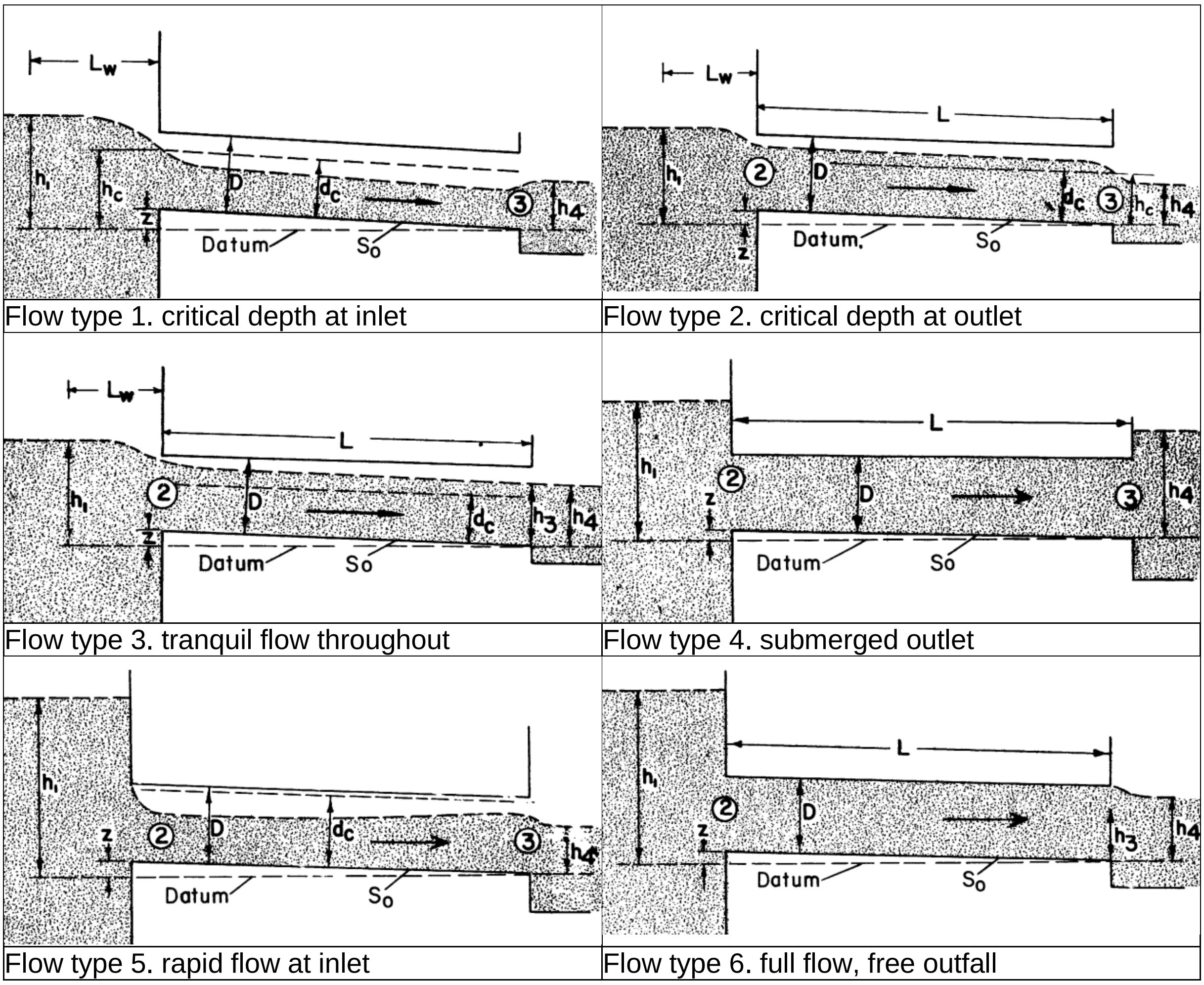
Table 7.7 Culvert flow classification

Flow type	***Culvert barrel flow***	***Control section location***	***Control type***	***Culvert slope***	$\frac{h1-z}{D}$	$\frac{h4}{hc}$	$\frac{h4}{D}$
1. critical depth at inlet	Part full	Inlet	Critical depth	Steep	< 1.5	< 1	≤ 1
2. critical depth at outlet	Part full	Outlet	Critical depth	Mild	< 1.5	< 1	≤ 1
3. tranquil flow throughout	Part full	Outlet	Tailwater	Mild	< 1.5	> 1	≤ 1
4. submerged outlet	Full	Outlet	Tailwater	Any	> 1	-	> 1
5. rapid flow at inlet	Part full	Inlet	Entrance geometry	Any	≥ 1.5	-	≤ 1
6. full flow, free outfall	Full	Outlet	Entrance and barrel geometry	Any	≥ 1.5	-	≤ 1

Based on the ratio’s $\frac{h1-z}{D}$, $\frac{h4}{hc}$ and $\frac{h4}{D}$ the flow types may be narrowed to 1 of 3 groups.

Inlet Control

If water flows through and out of the culvert faster than it can enter, the culvert is under inlet control. The flow capacity is controlled at the entrance by the headwater depth, cross-sectional area (barrel shape) and type of inlet edge. Culverts under inlet control (flow type 1 and 5) are always partially full with (high velocity) super-critical flow (Froude number > 1). Any downstream water level disturbance will not propagate upstream, since the flow velocity of the water is too high. The barrel (friction) roughness, length and outlet conditions do not determine the conveyance capacity. Flow is therefore controlled upstream and is limited to the amount that can enter the culvert. Culverts with inlet control usually have a drawdown at the inlet and a hydraulic jump at the outlet.



Flow type 1. critical depth at inlet

Flow type 2. critical depth at outlet

Flow type 3. tranquil flow throughout

Flow type 4. submerged outlet

Flow type 5. rapid flow at inlet

Flow type 6. full flow, free outfall

Figure 7.23 Culvert flow types

Outlet Control

Water is under outlet control if it flows faster into the culvert than it can flow through and out. Culverts under outlet control can flow either partially full or full. The water in the culvert is relatively deep and flows slow, which is known as sub-critical flow (Froude number < 1). A downstream disturbance propagates upstream; i.e. the water level upstream of the culvert changes if the water level downstream is changed. Therefore flow is controlled downstream and limited to what the barrel can carry. In this case friction and barrel roughness significantly determine the flow through the culvert, and the difference in head- and tailwater depth represents the energy which conveys flow through the culvert.

Inlet and outlet control are set by the slope of the stream, and is principally not a designed feature. Generally, when culverts are designed, initial calculations are made assuming both inlet and outlet control and comparing the headwater depth under various conditions. Designs for low headwater depths reduce the pipe diameter and fill material, however risk overtopping and often result in undersized culverts. Conversely, designs for higher headwater depths are more conservative.

Table 7.8 Factors affecting in- and outlet control

Outlet Control (Fr < 1)	***Inlet Control (Fr > 1)***
Headwater depth	Headwater depth
Tailwater depth	-
Inlet edge	Inlet edge
Cross-sectional area	Cross-sectional area
Barrel shape	Barrel shape
Fall	-
Length	-
Barrel roughness	-

Culvert design procedure

The design of culverts is essentially based on the head loss calculation, thus for tailwater control (flow types 2, 3, 4 and 6). Generally the design velocity may range from 0.5 to 2.0 m/s, which also determines the headloss Z over the structure. However, inlet control (flow types 1 and 5) with a large head loss with super-critical flow in the barrel can also be analysed with the Culvert Designer App.

The choice of a single or multi-barrel culvert (hence, the maximum size of one barrel) depends on the bed width of the channel, the water depth of the channel invert, the available head loss for the culvert and the minimum sand/clay package on top of the culvert.

Below, the various steps for culvert design and analysis are described, and reference is made to features of the Culvert Designer App. Generally, the design of a culvert is characterised as an iterative approach, for which various parameter values need to be assumed and tested later on during the calculation procedure. For this reason the App allows the user to compare up to six different scenarios in one overview.

Step 1. Determine initial assumptions for input parameters

Initial assumptions need to be made for several input parameters, such as:

- The maximum discharge (Q) that needs to flow through the culvert. This design parameter is usually estimated on the basis of a preselected storm recurrence interval (design discharge). However, this kind of information can also be derived as an output of e.g. the Spatial Analyser, but can also be based on hand calculations (drainage coefficients in mm/day or l/s/ha and drainage area).
- Culvert dimensions (height (D) and width (b) for rectangular culverts and diameter (H) for circular culverts);
- The required tailwater depth (h4) in the downstream channel measured from the invert at the culvert outlet. This can be an important factor in hydraulic culvert design because a submerged outlet may cause the culvert to flow full rather than partially full. A field inspection of the downstream channel should be made to determine whether there are obstructions that will influence the tailwater depth. The tailwater depth may be controlled by the water level in a contributing stream, headwater from structures downstream of the culvert, reservoir water surface elevations, or other downstream features.

- The difference between the channel and culvert bottom (G). Often the bottom of a culvert is constructed approx. 5 to 10 cm under the channel bottom to reduce the head loss due to entrance flow.
- The length of the culvert (L);
- The hydraulic roughness (Manning) (Km_c) of the culvert (values of 75, 90 or 100 can be selected);
- The Entrance loss coefficient (EnLC) of the culvert, depending on the specific situation (with or without wingwalls);
- The width of the downstream channel (B), the slope of the road talus T (1 :), and the bed slope of the culvert barrel (So) to calculate the Exit Loss Coefficient (ExLC) of the culvert.

The above mentioned parameter values all need to be entered into the Culvert Designer App. Beware that a choice is made for either a rectangular or a circular culvert; the App will give faulty results if parameter values are filled in for both.

Step 2. Calculation of the wet area culvert (Aw_c)

The wet area of the culvert is calculated by: $Aw\_c = h4 * b$ for partly filled situations. For full culverts it is calculated by: $Aw\_c = b * (D - G)$

Step 3. Calculation of the wetted perimeter (O)

The wetted perimeter is calculated by: $O = 2 * h4 * b$ for partly filled culverts, and for situations with full culverts by: $\mathrm{O} = (2 * \mathrm{b}) * (2 * (\mathrm{D} - \mathrm{G}))$

Step 4. Calculation of hydraulic radius (R)

The hydraulic radius is calculated by: $\mathrm{R} = \frac{Aw\_c}{O}$

Step 5. Calculation of the discharge coefficient (Cd)

The discharge coefficient is made up of various loss coefficients. The Culvert Designer App takes the entrance (EnLC) and exit (ExLC) loss coefficients, and the barrel (friction) roughness (Br) of the culvert into account by: $Cd = \frac{1}{\sqrt{(EnLc+ExLc+Br)}}$

The entrance loss coefficient is determined by the user, selecting 0.5 for a square cut end, 0.4 for wingwalls (30 – 75 degrees), or 0.2 for a rounded entrance.
The exit loss coefficient is calculated by using the wet area of the culvert (Aw_c) and the area of the downstream receiving channel (Aw_ds chan): $ExLC = 1 - \left(\frac{Aw\_c}{Aw\_\ ds\ chan}\right)^2$
The barrel roughness of the culvert is calculated by: $Br = \frac{2gL}{Km\_av^2} * R^{\frac{4}{3}}$
The average hydraulic roughness (Km_av) parameter of the culvert is compiled by using roughness values for the wetted area of the culvert and the wetted area of the soil in the culvert (if present): $Km_{av} = \frac{(Km_c*a)+\ (Km_s*e)}{a+e}$

The value of a depends on the following situations:

- $a = 2 * h4$ for a partially full culvert;
- $a = b + 2 * (D - G)$ for full flow situations with soil;
- $a = 2 * (b + D)$ for full flow situations without any soil in the culvert.

The value of e equals b with soil and 0 without any soil in the culvert.

Step 6. Calculate head loss (Z) over the culvert and headwater depth (h1)
Culverts generally constrict the natural stream flow, causing a rise of the upstream surface water level. The elevation of this upstream water surface is called headwater elevation, or head loss. In selecting the design head loss elevation, one should basically consider the following:

- Anticipated up- and downstream flood risks, for a range of return frequency events;
- The Headwater/Culvert Depth (HW/D) ratio. Often a max. ratio of 1.5 * diameter (or height) of the culvert barrel is assumed. If the HW/D ratio is too high, generally extremely high velocities will occur, which causes super-critical flow conditions, potential hydraulic jumps, excessive erosion, etc. Another reason to avoid excessively high head losses is that a large hydraulic gradient between the outlet and inlet side of the culvert increases the risk of piping (erosion by flow paths along the outside of the culvert barrel).
  The Culver Designer App includes a warning for the HW/D ratio. It is advised to either reduce the loss coefficients or to adjust the dimensions of the culvert to reduce the head loss.
- Location of the lowest point in the road or embankment alignment. If this location is near to the location of the culvert, overtopping of the road or embankment could occur;
- Road or embankment elevation above the culvert. The likelihood of overtopping, leading to damages of the road or embankment, will increase when the head loss is high compared to the ground elevation above the culvert.
- Elevation at which water will flow to the next cross drainage, pipe, culvert or bridge.

It should also be verified that the watershed divides near the culvert location are higher than the design headwater elevations. In flat terrain, drainage divides are often undefined or non-existent, hence culverts should be located and designed for the least disruption of the existing flow distribution.

The head loss (Z) over the culvert is calculated by: $Z = \left(\frac{Q}{Cd * Aw\_c}\right)^2 * \frac{1}{2g}$
The headwater (upstream) depth (h1) is calculated by: $h1 = h4 + Z$

Step 7. Calculate the flow velocity (V) in the culvert
The outlet velocity of a culvert is usually higher than the natural stream velocity. This higher velocity can cause streambed scour and bank erosion downstream of the culvert outlet. Permissible velocities at the outlet will depend on e.g. streambed type, bottom and bank protection, and the kind of energy dissipation (outlet protection) that is provided.
If the outlet velocity of a culvert is too high, it may be reduced by changing the barrel roughness (Br). If this does not give a satisfactory reduction, it may be necessary to use some type of outlet protection or energy dissipation device.
Variations in shape and size of a culvert seldom have a significant effect on the outlet velocity. Slope and roughness of the culvert barrel are the principal factors affecting the outlet velocity.

The flow velocity (V) in the culvert is calculated by: $V = Cd\sqrt{2gZ}$

Step 8. Checks on Froude number, flow conditions and flow type
The Culvert Designer App includes various ‘designer warnings and checks’.

To analyse the flow conditions (sub- or super-critical flow and respectively outlet or inlet control) the Froude number is calculated in by: $Fr = \frac{V}{\sqrt{g\left(\frac{Aw\_c}{b}\right)}}$
High velocity super-critical flow (inlet control) occurs when Fr > 1, sub-critical slow velocity flow (outlet control) when Fr < 1.

The critical water depth (dc) in the culvert, which represents the threshold between super-critical (below) and sub-critical (above) flow, is calculated by: $dc = 0.66 * \left(h1 - \frac{So}{L}\right)$

Other flow conditions (free or submerged flow) are analysed, based on the relation between the head loss (Z) and the upstream water depth (h1). A free flow situation occurs when $Z > \frac{1}{3}h1$, submerged flow when $Z < \frac{1}{3}h1$.

The flow type is verified by applying the equations depicted in the last three columns of Table 1. The culvert barrel flow is verified by comparing h1 and h4 with D. Full flow occurs when h1 ≥ h4 ≥ D; partially full flow when h1 or h4 is smaller than D.

Finally, a warning is displayed, whether the criterion of the minimum required area of the culvert barrel (0.2 m^2) is met.

Step 9. Design optimisation
Step 9a. Invert elevations
After determining the allowable headwater elevation, the tailwater elevation, and the approximate length, invert elevations must be assumed. Scour is not likely when the culvert has the same slope as the natural channel. To reduce the probability of scour failure, invert elevations corresponding to the natural slope should be used as a first trial. For natural channels, the flow conditions in the channel upstream from the culvert should be investigated to determine if scour will occur.

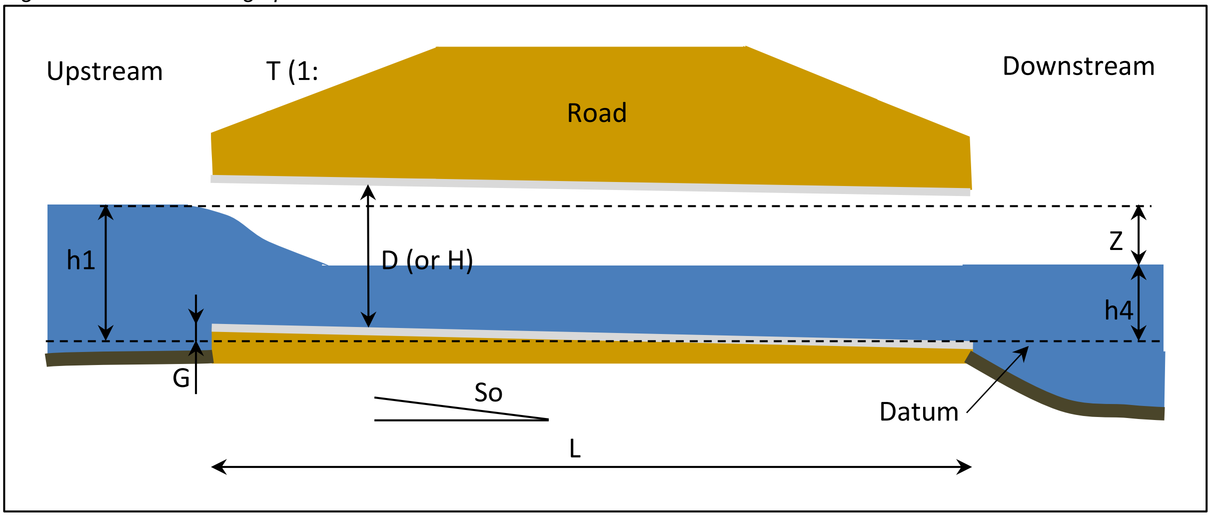
Step 9b. Culvert dimensions
After the invert elevations have been assumed, the culvert dimensions that will meet the headwater requirements should be determined. Since small diameter pipes are often plugged by sediment and debris, it is recommended that pipes < 0.5 m (or with a minimum area of 0.2 m^2) are not used.

Step 9c. Limited headwater
If there is insufficient headwater elevation to convey the required discharge, it is necessary to oversize the culvert barrel, lower the inlet invert, use an irregular cross section, or use any combination of these. If the inlet invert is lowered, special consideration must be given to scour. The use of gabions or concrete drop structures, riprap, and headwalls with apron and toe walls should be investigated and compared to obtain the proper design.

Step 9d. Culvert outlet
The outlet velocity must be checked to determine if significant scour will occur downstream during high discharges and flow velocities. Short-changing outlet protection is no place to economize during design and construction because downstream channel degradation can be significant and the culvert outlet may be undermined.

<u>*Step 9e. Minimum slope*</u>
To minimize sediment deposition in the culvert, the culvert slope must be equal to or greater than the slope required maintaining a minimum velocity, which is approx. 0.5 m/s. The slope should be checked for each design, and if the proper minimum velocity is not obtained, the pipe or barrel dimensions may be decreased, the slope steepened, a smoother barrel roughness used, or a combination of these may be used.

Figure 7.24 Culvert design parameters



Parameters
Initially, the maximum (design) discharge (Q), culvert dimensions (height (D) and width (b) for rectangular culverts and diameter (H) for circular culverts) and the required tailwater water depth (h4) in the downstream channel need to be specified as input.
The difference between the channel and culvert bottom (G), the length (L), hydraulic roughness (Manning), and Entrance loss coefficient (EnLC) of the culvert need to be specified as well.

The width of the downstream channel (B), slope of the road talus T (1 :), and the bed slope of the culvert barrel (So) need to be specified to calculate the Exit Loss Coefficient (ExLC) of the culvert.

Input:
Q = discharge through culvert (m^3/s)
D = culvert height (m)
b = culvert width (m)
H = culvert diameter (m)
h4 = tailwater depth (m)
G = difference channel and culvert bottom (m)
L = length culvert (m)
Km_c = Hydraulic roughness culvert (Manning) (-)
EnLC = Entrance loss coefficient (m)
B = width downstream channel (m)
T = Slope road talus (1 :)
So = Bed slope culvert barrel (-)

Intermittent computations:
O = wetted perimeter (m)
R = hydraulic radius (m)
Fr = Froude number (-)
ExLC = Exit Loss Coefficient culvert (-)
Aw_c = wet area culvert (m^2)
Br = Barrel (friction) roughness (-)
Aw_ds chann = area downstream channel (m^2)
Km_s = hydraulic roughness soil in the culvert (Manning) (-)
Km_av = average hydraulic roughness culvert (Manning) (-)
Sc = critical bed slope culvert (-)

Output:
Z = Culvert head (m)
h1 = Upstream water depth (m)
V = Flow velocity in culvert (range 0.5 - 2 m/s)
dc = Critical water depth (m)
Cd = discharge coefficient (-)
Aw_c = Wet area culvert barrel (m^2)
A_c = Area culvert barrel (minimum 0.2 m^2)

F Spatial Analyser App

Currently, the Spatial Analyser consists of several tools and GIS steps that need to be taken sequentially to first produce the input maps and then run the simulation to calculate the water levels (and water logging areas) and discharges. This allows the user to understand every step of the process, but on the other hand, it makes this “App” at the moment rather user unfriendly. The objective for the eventual next phase of the project is to integrate all steps into one single tool, so that Spatial Analyser becomes a user friendly App.

The structure of the folders that form the Spatial Analyser is:
- GIS
- Simulation
- Scripts
- Python_packages

GIS folder: here some of the most relevant maps and shapes for the spatial analyser are found.

Simulation: The core of the Spatial Analyser is a module of the WFLOW model. The module is called wflow_routing.py. WFLOW is an open source hydrological model that can be freely downloaded (see end of the section for more information). In this folder, the inputs and the code for the simulation, and the outputs of the simulation are found.
Scripts: all python scripts that need to be used for the Spatial Analyser are here.

Python_packages: two relevant packages are found in this folder. The other packages need to be downloaded and installed from the web. See end of the section for details.
In the following paragraphs, the steps that need to be taken to create the inputs for the Spatial Analyser and to obtain results are described.

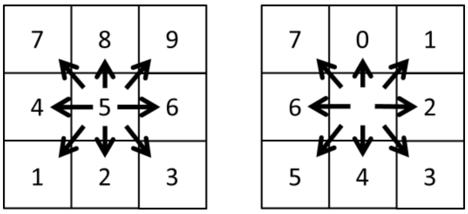
The input parameters for the Spatial Analyser are:
- The Digital Elevation Model with the khal network burned
- The Watersheds map
- The Flow Direction map
- A time series of Precipitation Maps
- The Manning’s roughness coefficient

F.1 Processing of the DEM
The steps needed to process the DEM are described in Annex B.

F.2 Transformation of “Tif” files to PCRaster files and creation of new Flow Direction Map
The simulation of the runoff and water levels is done with the module wflow_routing.py from the WFLOW model. This model is written in PCRaster integrated in Python. Therefore, all input maps for the model need to be transformed to PCRaster.

This is done using the script “Transform_to_PCRaster.py”. Note: When using the script, change the paths of the files and the packages for it to run.

For the Flow Direction Map, an extra transformation is needed, because the flow direction system used by Wang and Liu is different than the one of PCRaster. Below both systems are shown:



Left side: flow direction system of PCRaster, right side: flow direction system of Wang &Liu

The transformation of flow direction systems is also done in the same script “Transform_to_PCRaster.py”. In the same script, other maps needed for the flow simulation are created. Note: When using the script, change the paths of the files and the packages for it to run.

F.3 Prepare Precipitation Maps

The precipitation used in the Spatial Analyser is a time series of maps created interpolating the precipitation of the nearest station to the Polder, in this case, the station with ID 12103. This station has data since 1973. All available values have been used, and if there is no data, a value of 0 is given for that day.

The time series of maps are made with the script “Make_precip_maps.py”. Note: When using the script, change the paths of the files and the packages for it to run.

F.4 Prepare simulation to calculate runoff and water levels

As mentioned, the code used for the simulation is the “wflow_routing.py”. In order to simplify the work and avoid having to install too many python packages, the entire WFLOW code is provided, and wflow_routing is given as an executable (..\ForBlueGold\Simulation\Wflow1.0.2016.03-64-wflow_kernel_deltashell\Wflow1.0.2016.03-64-wflow_kernel_deltashell\wflow_routing.exe). This code uses a so-called “.ini” file to indicate the input for the simulation (..\ForBlueGold\Simulation\model\wflow_routing.ini). Then a batch file can be used to run the simulation (..\ForBlueGold\Simulation_run_wflow_routing_test.bat).

The wflow_routing.ini file includes information on the input files that need to be used for the simulation. The files that need to be replaced in case the simulation needs to be run with another DEM are:

- Processed DEM with the khals burned in it
- Catchment area
- Flow direction
- River file

The process to make these files has been described before.

The results of the simulation are runoff and water level maps for each time step, these can be found in this folder: ..\ForBlueGold\Simulation\model\run_routing_test_ref\outmaps\

The maps created are called:

- “ _levch00.*” for the water level in the channels (* being the number of the time step)
- “_run0000.*’’ for the runoff (* being the number of the time step)

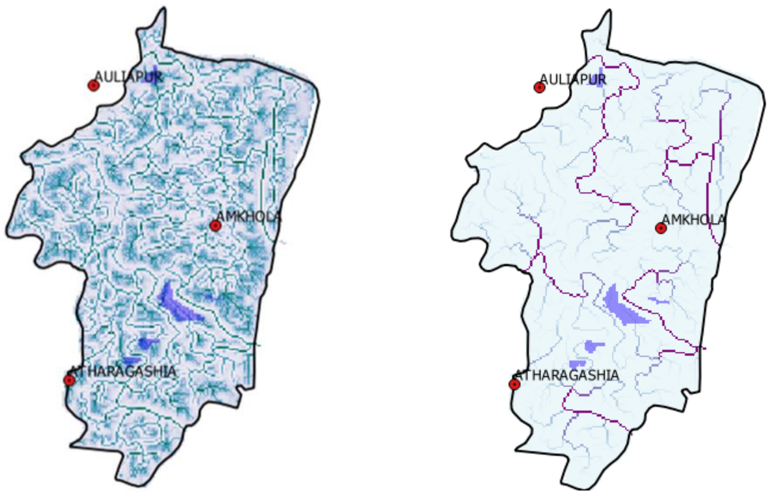


Figure 7.25 Output examples. Left: water levels. Right: surface runoff

F.5 Define an intervention and compare results

In order to evaluate the impact of an intervention, the results of the reference case, should be compared with the results of the intervention.

To simulate an intervention, several steps are needed:

1) A new DEM file needs to be created. An example of an intervention can be the construction a road. To simulate this, we would change the elevation of the cells where the road is found. This can be done using the code “Modify_DEM.py”. In this program, the coordinates of the cells for which we want to modify the DEM and the new DEM value can be introduced. The program generates a new DEM. Note: When using the script, change the paths of the files and the packages for it to run.
2) Run the QGIS SAGA plug-in Wang and Liu to generate the Catchment and the Flow Direction Maps.
3) Run the “Transform_to_PCRaster.py” code to generate the PCRaster files. Note: When using the script, change the paths of the files and the packages for it to run.
4) Modify the wflow_routing.ini file substituting the old DEM, Catchment Area and Flow Direction Maps by the new created ones
5) Run WFLOW with the batch file. Note: change the name of the ini file if you have renamed it.
6) Load all results in QGIS and using the Raster Calculator, subtract the results of the reference case from the results of the intervention using the “Raster Calculator”

G Overview of key water management problems identified in the workshops

G.1 Attendants list workshop 1

#	Name of Participant	Position and Organization
1	Md. Mozammel Haque	A F O, Golachipa, Department of Forest
2	Md. Mokbul Hossain	President, WMA
3	Md. Delowar Sharif	Member, WMA
4	Md. Sikandar Ali	Secretary (farmer), WMA
5	Md. Harunor Rashid	Chairman, WMG
6	Kuddus Munshi	Farmer, WMG
7	Khadeza Parvin	C.H.P.D.M
8	Abul Madber	Fisherman, WMG, Badura
9	Md. Shahalam	Secretary, WMA
10	Zakir Matbor	Fisherman, WMG
11	Jahangir Akon	Member of WMG
12	Md. Shafiullah	BDC, Blue Gold Program
13	Md. Matiur Rahman	SSE, Blue Gold Program
14	Md. Shamim Ahed Yousuf	Team Coordinator, Blue Gold Program
15	Md. Delowar Hossain	Civil Engineer, Blue Gold Program
16	Husnera Begum	Member, Amkhola Union Parishad
17	Abul Hossain	Member, Amkhola Union Parishad
18	A. K. M. Abul Bashar	Sub-Divisional Engineer, BWDB, Patuakhali
19	Md. Kamruzzaman Manir	Chairman Amkhola Union Parishad
20	Md. Jabed Iqbal	Assistant Engineer, BWDB, Patuakhali
21	Abdul Mannan	Upazila Agricultural Officer, DAE
22	Minarah Begum	Seretary, WMA-Badura
23	Md. Nurul Haque	SAAO, Amkhola Union Parishod
24	Md. Safiqul Islam	Community Organizer, 43/2B Polder
25	K. J. Fardouse	AEO, DAE-Golachipa
26	Narottam Biswas	SAAO, DAE-Golachipa

G.2 Attendants list workshop 2

SL	Name of Participant	Position and Organization
1.	Md. Mokbul Hossain	President, WMA
2.	Md. Delowar Sharif	Member, WMA
3.	Md. Sikandar Ali	Secretary (farmer), WMA
4.	Md. Harunor Rashid	Chairman, WMG
5.	Kuddus Munshi	Farmer, WMG
6.	Abul Madber	Fisherman, WMG, Badura
7.	Md. Shahalam	Secretary, WMA
8.	Zakir Mridha	Fisherman, WMG
9.	Jahangir Akon	Member of WMG
10.	Md. Matiur Rahman	SSE, Blue Gold Program
11.	Md. Shamim Ahed Yousuf	Team Coordinator, Blue Gold Program
12.	Md. Delowar Hossain	Civil Engineer, Blue Gold Program
13.	Husnera Begum	Member, Amkhola Union Parishad
14.	Abul Hossain	Member, Amkhola Union Parishad
15.	Md. Kamruzzaman Manir	Chairman Amkhola Union Parishad
16.	Minarah Begum	Seretary, WMA-Badura
17.	Md. Safiqul Islam	Community Organizer, 43/2B Polder
18.	Bashir Hawlader	Secretary, WMG
19.	Md. Nurul Haque	SAAO, Amkhola Union Parishod
20.	Khadeza Parvin	C.H.P.D.M

G.3 Group Report Group 1: Amkhola and Mushurikati

G.3.1 Overview of key water management problems

#	Problem description
1	Waterlogging in area A due to road blockage and limited drainage capacity of culverts
2	Waterlogging in area B due to silting up of khals
3	Water shortage in area A, B and C due to limited khal conveyance and storage capacity due to hyacinth growth and siltation
4	Water shortage in area D due to a general lack of khals, those that are present are silted up
5	Lack of functioning irrigation - farmers don't want to give up their land for irrigation infrastructure and – canals. Note: the area has three different elevations. When water is supplied via the khals, low areas have sufficient water, the middle elevation areas sometimes have a shortage, the higher areas don't receive any water.

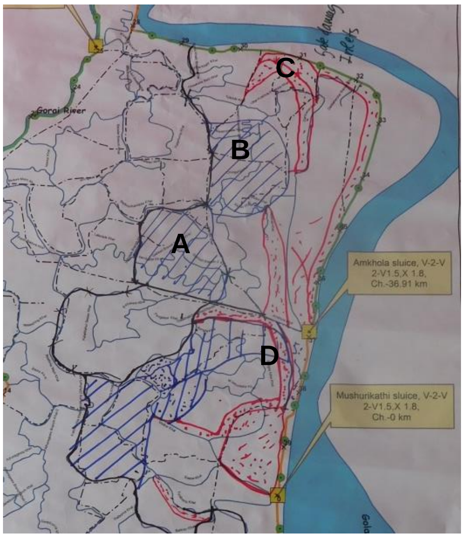


Figure 7.26: Map showing problem areas Amkhola

Overview of WM Decisions, Information Needs and Stakeholders

WM Decisions	***Information needs***	***Stakeholders***
Waterlogging		
Khal cleaning (water hyacinth)	- How much manpower is needed - Which WMG will help to deliver manpower, since khals go through 2 or 3 WMG's) - Who can help (in terms of money and number of men) -> discuss with Union Parish (Council)	WMG's, WMA, Union Parishad (Council)
Khal embankment repairs	- First discuss ideas, funds and 'scope' (does it fit in year plans) with WMG, them WMA, then BWDB - Amount of soil needed - Which methods to apply	WMG, WMA, BWDB
Small sluice gate repairs & sluice gate operation	- Training on sluice operation needed	WMG, WMA, Blue Gold, BWDB
Cutting of small embankments (bunds)	- Inform Union Parishad (Council) - Advice from the Agricultural Dept.	WMG's, WMA, Union Parishad (Council), Agricultural Dept.
Water shortage		
Optimisation (minimise) of bare land	- Which water sources can be used in which month (availability & planning)	Farmers Agricultural office (advise)
Irrigation by pumping (LLP & plastic pipe)	- Where can a pump be hired - How much water needs to be pumped - How much money is available for irrigation	Farmers Agricultural office (advise), Blue Gold

G.3.2 Priority Changes in the Polder

- *Structural interventions:*
  - Khal re-excavation (1st and 2nd order)
  - Sluice gate repairs
  - Culvert enlargement
  - Alleviate road blockages
  - Repair damaged irrigation inlets
- *Management:*
  - Proper sluice gate operation
  - Training WMG's for sluice operation; should be provided by WMA, Blue Gold, Agricultural Dept, Fisheries Dept, BWDB

G.3.3 Proposed Water apps

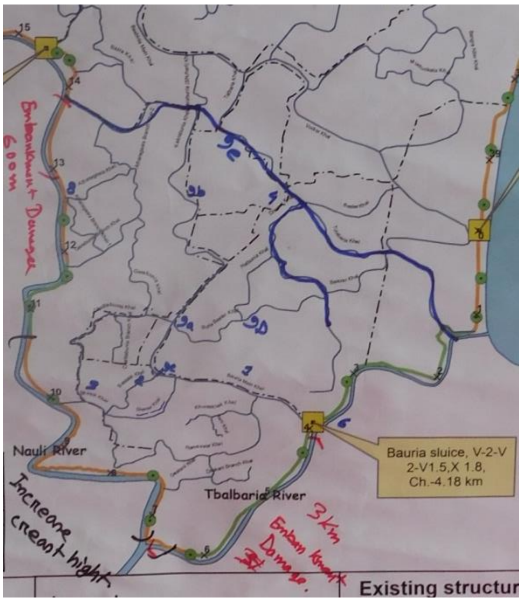
Apps can contribute to the operational water management (sluice gate operation), management/maintenance, as well as discussing and planning of interventions (impacts)

- BWDB is responsible for the maintenance of sluice gates.
- LGED and the Union Council (Parish) are responsible for cleaning the culverts.

G.4 Group Report Group 2: Bauria Khal

G.4.1 Overview of key water management problems

#	Problem description
1	Bauria sluice main khal silted
2	Bashtola khal silted
3	Shinnir khal silted
4	Dhopar khal silted
5	Increased water hyacinths all khals
6	Bauria sluice fully damaged
7	Outlet needed at Munshirhat
8	Embankment damaged on south-east side (3 km) and west side (600m). Crest level too low in the south-west side, overtopping during storm surge and high tide



G.4.2 Proposed solutions

#	Solution proposed
8	Large outlet in Munshirhat needed – improve connectivity
9	Road culverts needed on a) Bauria khal, b) Doshjositar khal, c) Bashtolar khal, d) Bauria branch khal, and e) Ramanondo khal
10	Activation of inlets
11	Repair damaged parts of the embankment

G.4.3 Overview of WM Decisions, Information Needs and Stakeholders

WM Decisions	***Information needs***	***Stakeholders***
Waterlogging		
Khal cleaning (water hyacinth)	- How much manpower is needed - Which WMG will help to deliver manpower, since khals go through 2 or 3 WMG's) - Who can help (in terms of money and number of men) -> discuss with Union Parish (Council)	WMGs, WMA, Union Parishad (Council)
Khal embankment repairs	- First discuss ideas, funds and 'scope' (does it fit in year plans) with WMG, them WMA, then BWDB - Amount of soil needed - Which methods to apply	WMG, WMA, BWDB
Small sluice gate repairs & sluice gate operation	- Training on sluice operation needed	WMG, WMA, Blue Gold, BWDB
Cutting of small embankments (bunds)	- Inform Union Parishad (Council) - Advice from the Agricultural Dept.	WMGs, WMA, Union Parishad (Council), Agricultural Dept.
Water shortage		
Optimisation (minimise) of bare land	- Which water sources can be used in which month (availability & planning)	Farmers Agricultural office (advice)
Irrigation by pumping (LLP & plastic pipe)	- Where can a pump be hired - How much water needs to be pumped - How much money is available for irrigation	Farmers, Agricultural office (advice), Blue Gold

G.4.4 Priority Changes in the Polder

- *Structural interventions:*
  - Khal re-excavation (1st and 2nd order)
  - Sluice gate repairs
  - Culvert enlargement
  - Alleviate road blockages
  - Repair damaged irrigation inlets

- *Management:*
  - Proper sluice gate operation
  - Training WMG's for sluice operation; should be provided by WMA, Blue Gold, Agricultural Dept, Fisheries Dept, BWDB

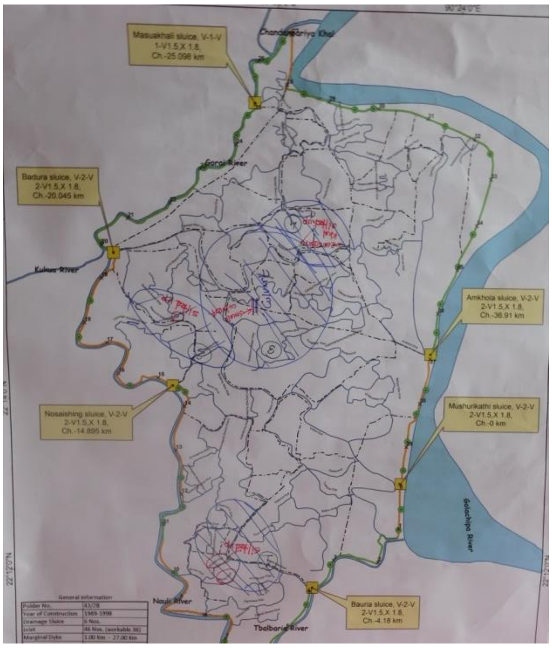
G.4.5 Proposed Water apps

Apps can contribute to the operational water management (sluice gate operation), management/maintenance, as well as discussing and planning of interventions (impacts)

- BWDB is responsible for the maintenance of sluice gates.
- LGED and the Union Council (Parish) are responsible for cleaning the culverts.

G.5 Group report Group 3: General polder 43/2B

Group 3 consisted of the representative Government officials working in the Polder. These included the Sub-Divisional Engineer and Assistant Engineer BWDB; Forestry Officer; Civil Engineer Blue Gold; and the Assistant Agriculture Officer



G.5.1 Overview of key water management problems

Group 1 identified waterlogging in three areas as key problem in the polder, as drawn on the polder map.

#	Problem description
1	Waterlogging at Nurakhali khal due to road construction without adequate drainage provision
2	Waterlogging at Mudirhat due to Road construction without adequate drainage
3	Siltation of primary and secondary khals

G.5.2 Overview of WM Decisions, Information Needs and Stakeholders

Water Management Decision	Type of Information Needed	Stakeholders	
		Implementation	Beneficiaries
Secondary khals silted up needs to be re-excavated	Survey work for design data, cross section of khals with water level	BWDB	WMA
Waterlogged area needs one outlet at Nurakhali Khal	Survey work to be done for design data submission	BWDB	WMA
Waterlogged area blocked at Mudirhat blocked by RHD road	Needs survey & design	RHD	WMA
Waterlogged area Re-excavation of khal	Needs survey & design	BWDB	WMA

G.5.3 Proposed Water apps

Based on the problems identified before, three (3) potential Water Apps have been identified.

G.5.3.1 Sluice Designer

Sluices are a general feature of all polders in Bangladesh. In the coastal polders, gravity drainage takes place during the low tide situation. Design variables include:

- Sluices gates, generally lifting gates and flap gates. Sluices may be equipped with different gate types on the country (inland) and river (sea) side.
- Vent width and height; typically of either 1,5 or 1,8 m opening width
- Sill height relative to PWD

Key parameters in the design include:
- Outside water levels, due to tidal influence and river levels
- Drainage requirements, related to runoff from the catchment, and related water levels
- Ease of Operation, Maintenance and Repair
- Availability of materials for construction and maintenance

The sluice design app would assist the BWDB staff to design sluice structures consisting of multiple vents in relation to the drainage requirements. If the app could also optimise sluice design taking into account benefits – benefitted area resulting from improved drainage, that would allow for optimisation of sluice design. A DEM + rainfall-runoff model would be needed for that purpose.

G.5.3.2 Khal Excavator

Khal excavation is a recurring activity in polder 43/2B, many coastal and inland polders as well as in unprotected areas where natural erosion processes no longer ensure adequate conveyance capacity. BWDB, LGED and City Corporations need to regularly estimate the volume of earthworks to be excavated, the depth of required cut and khal sections along which excavation should take place.
Design parameters include:
- Drainage requirements in m3/s
- Design cross section at slope sections
- Cost

This app would help design – survey engineers to calculate the quantity of work to be carried out, if the desired cross section and the actual situation are given. If the app could also optimise excavation taking into account benefits – benefitted area resulting from improved drainage, that would allow for a better optimisation of khal excavation. A DEM + rainfall-runoff model would be needed for that purpose.

G.5.3.3 Crop Water Demander

In polder 43/2B and coastal polders in general, a variety of crops are grown. Crops in the dry Rabi season display the largest variation in crop water and irrigation requirements. In Polder 43/2B, according to Blue Gold data, the following crops are grown:
- Chili
- Cowpea
- Mung bean
- Peanut
- Sesame
- Sunflower
- Sweet Potato
- Vegetables
- Water Melon

For extension workers (DOA) and farmers, this information helps to decide which crops to grow. Other factors include soil conditions, market demand, and labour requirements.

H Proposed plan to improve the DEM

H.1 Introduction

The field visit and workshops during the November 2016 Water App Blue Gold mission revealed that the available Digital Elevation Model (DEM) of Polder 43-2B is not sufficiently accurate to directly serve as a basis for e.g. a ‘Spatial Analyser App’.

The DEM resolution of 50 meters is, given the limited surface elevation variations (up to 2.5 meters), too low in some parts of the polder to represent the changes in elevation. The elevations within cells are averaged and therefore too much detail is lost.
In Polder 43-2B roads of about 10 meters width lie next to khals that are 25 meters wide. Roads are normally elevated (approx. 2 m a.s.l.) above the rest of the polder, while khals lie lower (water surface around 0 m a.s.l.). If these two features are averaged in one cell of 50 by 50 meters, they disappear and the cell obtains an average height representing neither the road nor the khal. This results in a DEM where roads and khals cannot be identified as such.

H.2 DEM improvement

The DEM needs to be improved locally, in order to facilitate spatial computations, simulations and analyses for several designer and operational water apps that still need to be developed.
It is suggested to locally improve the Polder 43-2B DEM for two sub catchments; Amkhola and Mushurikati. These to catchments can then be used as pilot areas for the development and validation of water apps.

Stepwise approach
The following stepwise approach is suggested to improve the DEM, and to prepare grid data for further use:

1 Selection of pilot areas (Amkhola and Musurikati sub-catchments)

2 Analyse the existing DEM and select specific areas and elements that need further detailing. The selection needs to be based on the situation and alignment of roads, khals, low lying (water logging) areas, areas with blockage of flow due to roads, hydraulic structures such as culverts and siphons, areas with drought problems, etc. These areas and structures are relevant for the rainfall-runoff flow and routing of water. The DEM should be able to facilitate simulation features of the present situation, and impacts/effects of structural and/or operation interventions/ measures.

3 Search for additional elevation data of e.g. roads and hydraulic structures at the Local Government Engineering Department (LGD; Patuakhali district). These could also be derived from design drawings.

4 Set up a survey plan which describes the areas and features that need to be surveyed, and the methods that will be used. The survey should be planned during the dry season (November – February) to be able to locate and measure low lying areas. The survey ‘density’ should at least be less than 50 m (minimum of one measuring point in 50 m) to locally improve the DEM. Relative abrupt differences in elevation (road and

embankment toes and banks) should also be surveyed. Basically three methods could be applied in the case of Polder43-2B:

– Measuring elevations by height differences between various points. The most common way is levelling, which is often performed digitally nowadays to achieve a relative high degree of accuracy. Levelling should preferably be performed by measuring cross-sections near locations with relative large elevation differences, including low lying land, khals and roads.
– In addition, trigonometric height measurements can be carried out by using the horizontal spacing in the field and a vertical angle. A widely used tool for this type of height measurement is a tachymeter. This method generally is a little less accurate compared to levelling, however can be carried out by one person and is quicker.
– A third altitude measuring method is to use GPS instruments. These measurements are characterized by simplicity and speed, however are less accurate compared to levelling and trigonometric height measurements. GPS measurements can be performed by one person, and are relatively fast (e.g. a motor bike driving on roads).

Besides surveying the surface elevations, pictures should be made of all measuring locations, including their surroundings. This is also the case for (large scale) elevation differences in the landscape, e.g. water logging areas.

5 The planned survey activities need to be organised and performed.

6 Survey data needs to be handled, which refers to the collection and processing techniques or methodologies and technologies used for the capture, processing and lodgement land surveying data. The specifications of data handling methodologies, incl. quality control, used by the survey contractor should be analysed and discussed before going into the field.

7 Survey data should be delivered in the correct format to adjust the DEM as quickly and easy as possible, and to use the grid for water app purposes.