Bangladesh Metamodel

Waterbalance Module

v1.0

- Draft -

1. Summary

In order to estimate socio-economic impacts of flooding and droughts, a vertical waterbalance is developed for Bangladesh to simulate water levels at field level, in the rootzone and sub-soil. These water levels are used for estimating agricultural production (separate module), damages and losses due several types of floods (e.g. riverine, tidal and rainwater flooding – separate module), as well as agricultural drought.

The waterbalance is setup for each landtype within an upazila in Bangladesh and calculates waterlevels and volumes for a decadal (10-day) timestep. Within an upazila, the area is further divided in existing FCDI-project area and non-project area in order to simulate flood control, drainage and irrigation.

The waterbalance ingests BMD timeseries (1985 - 2017) of decadal rainfall from 34 meteorological stations, communicates with the water demand module to retrieve estimated evapotranspiration per land type. It calculates how much water infiltrates into the rootzone and percolates to the sub-soil. The waterbalance is connected to the network module in order to exchange water between land and the river. Each upazila (544) is connected to the nearest river network calculation node. Over these connections, water can be drained from land to river network and vice versa, from river to land (inlet of water and riverine/tidal flooding).

This note describes the concepts of the waterbalance module, its configuration and verification of the results.

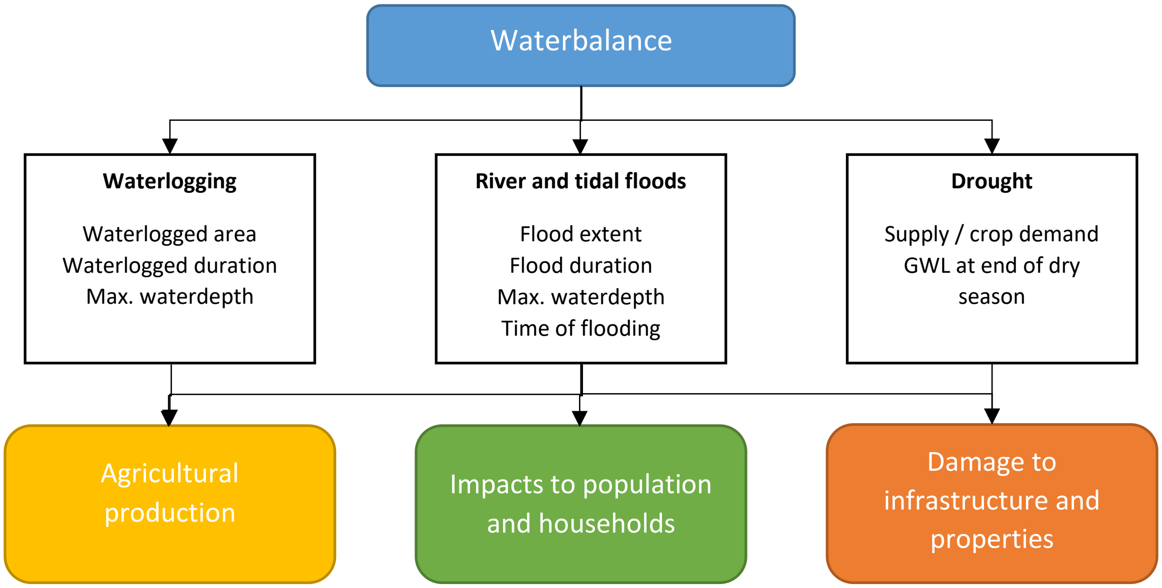
2. Purpose/Objective of the Module

The main objective of the Waterbalance Module is:

> "To simulate flooding and droughts at field level for each landtype per upazila"

Specific objectives are:

- Calculate temporal and spatial distribution of waterlevels at field level, in rootzone and sub-soil;
- Distinguish between FCDI-project and non-project area;
- Creating input for agricultural production and flood impact module.



3. Extent of Waterbalance Module

The waterbalance module is developed for each (BWDB)-project and non-project area per upazila (544) on decadal (10-day) time step. It discerns between 10 landtypes within an upazila: 1. Permanent waterbodies (khals, ponds etc.), 2. Shrimp areas, 3. F4 land (Very lowland – land which is normally inundated more than 300 cm deep), 4. F3 land (Lowland – land which is normally inundated in the range of 180-300 cm deep), 5. F2 land (Medium lowland – land which is normally inundated in the range of 90 – 180 cm deep), 6. F1 land (Medium highland – land which is normally inundated in the range of 30 – 90 cm deep), 7. F0 land (Highland – land which is normally above normal inundation level or less than 30 cm deep), 8. Forest area, 9. Settlement area and 10. River area. Each of the land types is considered a separate vertical water balance.

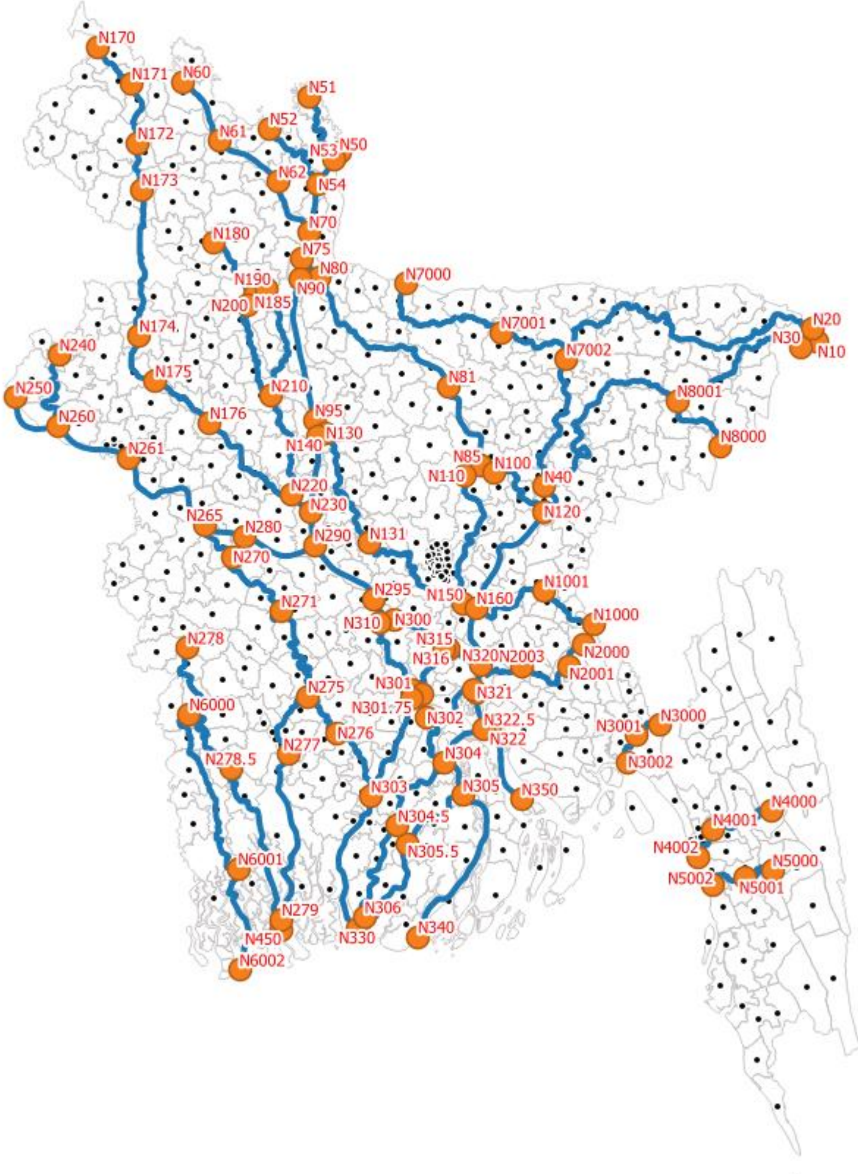


Figure 3.1 Waterbalance per upazila is connected with nearest river network nodes

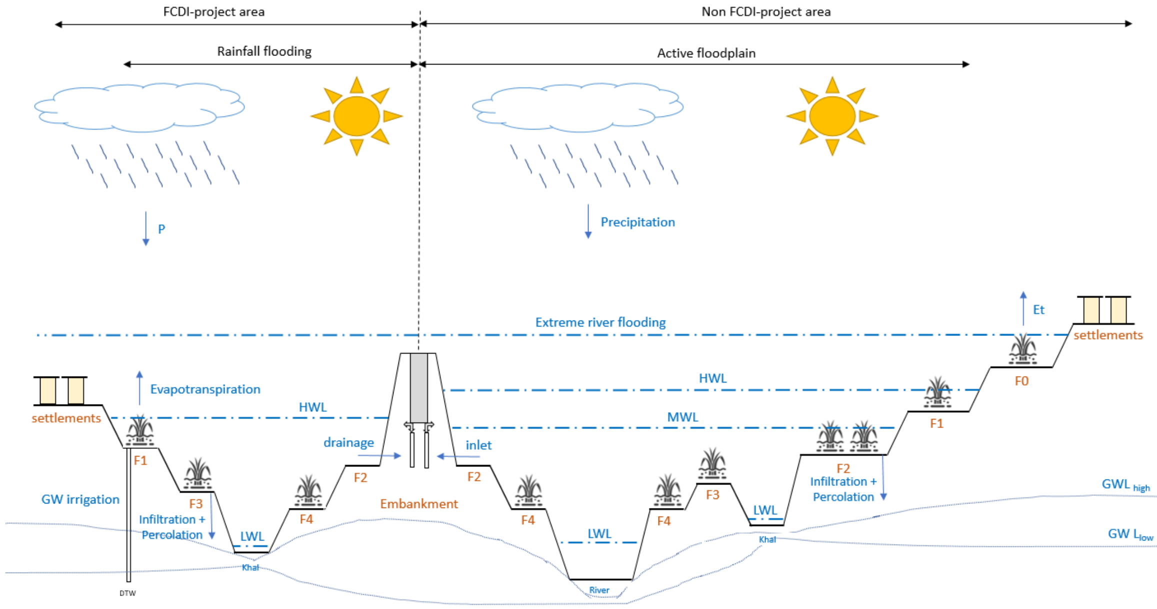


Figure 3.2 Conceptual diagram of waterbalance(s) per upazila (not on scale)

Figure 3.2 provides a representative cross section of an upazila with a delinated FCDI and non FCDI-projectr area. The delineation is based on an overlay between:

1. a GIS-layer with upazila boundaries (from WARPO and BBS (2011));

2. a GIS-layer with FCDI-project boundaries (BWDB, 2018);

2. the detailed agricultural land type map (BARC, 1999); and supplemented with

4. general land use map with forest, settlements, rivers and waterbodies (WARPO/CEGIS, 2010).

For each of the 10 waterbalance landtypes a dominant soil category with infiltration parameters is assigned; based on the generalized 20-classes topsoil texture map. For each landtype an *average* land height (mPWD) is derived from Bangladesh Digital Elevation Model (WARPO).

The *average* height of embankment per upazila is assumed to be 50cm higher than the nearest highest river level occurred in the period 1985-2018. Initial groundwater levels are derived from a national map with average groundwater levels from BADC.

A timeseries of precipitation and reference evaporation is created from BMD daily data available for 34 meteorological stations. Precipitation and reference evaporation per upazila is created based on the nearest meteorological station. Reference evaporation is used in the water demand module to determine evapotranspiration.

4. Approach and Methodology

4.1 Approach

The waterbalance module carries out for each land type in a project and non-project area of an upazila[1] three steps in each timestep:

1. solving the vertical distribution of water; from rainfall to infiltration;

2. solving the horizontal distribution of water; exchange with network module;

3. determining shortage / excess of water at field level.

In the vertical distribution process, the effective decadal rainfall is calculated by subtracting evapotranspiration from the rainfall, including available soil moisture in the rootzone. The potential evapotranspiration is calculated per timestep by a separate module, the water demand module. Actual infiltration to the rootzone is derived as a function of volume of water at field level (excess), a maximum soil infiltration rate and available storage capacity in the rootzone layer. In case the effective rainfall becomes negative (potential evapotranspiration is larger than rainfall) and no water is left on the field, the rootzone buffer can still deliver water to the crops. If water is available in the rootzone, water is further percolated to the deeper sub-soil, bounded by the rootzone water content, a constant percolation rate and a maximum percolation volume[2].

After the vertical water transport calculation within a timestep is finished, the remaining absolute field water level is then used to calculate the head difference with the perennial river network (through nearest node). When the river water level is higher than the water level at the field for a certain landtype, water flows from river on to the field. When the river water level is lower than the water level at the field for a certain landtype, water flows from field into the river. For FCDI-projects, the operational status (open/close) and dimensions of a regulator determines whether water actually is actually exchanged between the water balance and network.

Before water can be exchanged, the network module requires the irrigation demand per node (m3/dec) in order to calculate, whether water is available (and whether the head is positive) in that timestep in the related network stretch. After the network module has determined the fraction of water that can be transferred from river to field, the waterbalance finalizes the timestep by first calculating the impact of the river water to field water level[3] and then GW irrigation demand and supply (in case still too little water is available). If finally, even after GW irrigation, at the end of the timestep too little water has been available for evapotranspiration (from field and rootzone), crop production is hampered. This is calculated in the agricultural production module.

If there is excess of water at field, potential drainage per timestep is determined per land type. The actual drainage is mainly dependent on the drainage efficiency (level of resistance to drain) per land type and upazila, a maximum drainage rate, which is limited by regulators for FCDI-project area and head difference between field water level per land type and river water level. It is ensured that no more water can be drained than the difference between field water level and river water level.

[1] The waterbalance entails 10 landtypes x 2 areas x 544 upazila = 10880 calculation units

[2] Baseflow of the river could be modelled by using this variable

[3] For now it is assumed that water inlet is 100% efficient; in other words, surface water let in is completely distributed over the area within a timestep

River and tidal flooding is included in the waterbalance after field water level is determined after vertical water transport. When river water level is higher than field water level, field water level is river water level. FCDI-projects area is only flooded when the average embankment height is exceeded by the river water level (for each node). Due to use of derived Q-h relations in the network module, theoretically, a volume-dependent exchange is modelled.

4.2 Methodology

Five main input files are used in the waterbalance:

1. Precipitation timeseries (decadal) for each upazila (1985 – 2017) and for different future scenarios (BDP2100).

2. Upazila to nodes connection file, which describes which upazila is connected to which river network node; this relation is determined based on nearest distance and sub-catchment maps (from detailed model).

3. Potential evapotranspiration for each upazila per timestep; dynamically calculated by the water demand module.

4. Initialization waterbalance values file, in which for each project and non-project area within an upazila input parameter values can be set.

5. Landtype drainage efficiency rate, in which for each landtype in project or non-project area, urban or rural area[4] a specific drainage efficiency rate can be set. This value is multiplied by the drainage efficiency rate per upazila set in the initialization waterbalance values file.

4.2.1 Initialization waterbalance values file

For each non-project and project area per upazila a record is available (544 x 2 = 1088 units) which describes a unique code, division name, district name, upazila name, total upazila area and calculation area (% project and % non-project area). Each record further includes:

- an *average* embankment height (mmPWD)
- areas per landtype (ha)
- initial field water level per land type (mm)
- initial rootzone waterlevel (mm)
- initial sub-soil waterlevel (mm)
- max. rootzone storage volume (mm)
- max. sub-soil storage volume (mm)

[4] Not yet in use; but is a placeholder for modelling sewer drainage in urban areas

The following modelling parameters per record can be set:

- max. percolation loss (mm / day)
- max. infiltration rate (mm / day)
- max. percolation rate (mm / day)
- drainage efficiency (% / day)
- max. drainage rate (m3 / s)
- regulator open (decade)
- regulator close (decade)
- max. drainage pump drainage capacity (m3 / s)
- drainage pump status on (decade)
- drainage pump status off (decade)
- max. SW irrigation pump capacity (m3 / s)
- SW irrigation pump status on (decade)
- SW irrigation pump status off (decade)
- SW irrigation efficiency (%)
- GW irrigation status on (0 or 1)
- GW irrigation efficiency (%)
- Max. GW irrigation pump capacity (mm / day)

4.2.2 Landtype drainage efficiency rate

Landtype	Area	Cat	DRrate
Permanent waterbodies	Project	Urban	0.01
Permanent waterbodies	Non-project	Urban	0.01
Permanent waterbodies	Project	Rural	0.01
Permanent waterbodies	Non-project	Rural	0.01
Shrimp areas	Project	Urban	0.01
Shrimp areas	Non-project	Urban	0.01
Shrimp areas	Project	Rural	0.01
Shrimp areas	Non-project	Rural	0.01
F4 land	Project	Urban	0.025
F4 land	Non-project	Urban	0.025
F4 land	Project	Rural	0.025
F4 land	Non-project	Rural	0.025
F3 land	Project	Urban	0.05
F3 land	Non-project	Urban	0.05
F3 land	Project	Rural	0.05
F3 land	Non-project	Rural	0.05
F2 land	Project	Urban	0.075
F2 land	Non-project	Urban	0.075
F2 land	Project	Rural	0.075
F2 land	Non-project	Rural	0.075
F1 land	Project	Urban	0.1
F1 land	Non-project	Urban	0.1
F1 land	Project	Rural	0.1
F1 land	Non-project	Rural	0.1
F0 land	Project	Urban	0.15
F0 land	Non-project	Urban	0.15
F0 land	Project	Rural	0.15
F0 land	Non-project	Rural	0.15
Forest land	Project	Urban	0.4
Forest land	Non-project	Urban	0.4
Forest land	Project	Rural	0.4
Forest land	Non-project	Rural	0.4
Settlement area	Project	Urban	0.4
Settlement area	Non-project	Urban	0.4
Settlement area	Project	Rural	0.4
Settlement area	Non-project	Rural	0.4
River area	Project	Urban	1
River area	Non-project	Urban	1
River area	Project	Rural	1
River area	Non-project	Rural	1

5. Verification

Work in progress.

Fit-for-purpose verification will be done at district, division or hydrological region level.

The following metrics are explored:

1. River and tidal flooding

- largest flooded areas compared to detailed model results and if available off-the-shelf remote sensing images (for ‘extreme’ and ‘normal’ years) – difficulty: model neglects embankment breaches

2. Rainwater flooding -> waterlogging

- area logged due to impeded drainage at unwanted locations and times compared to landtype F0 to F4 by definition (e.g. normal flooding depth up to 90cm for max. 4 months); deeper and longer gives problems

3. Drought

- Groundwaterlevel at end of dry season compared to measured trends from BWDB stations

- Supply / crop demand; trends of dry/wet years impacting agricultural production.

6. Follow-up activities

1. Verification and calibration activities take place.

2. BDP2100 scenarios and measures related to water system functioning are reflected in the waterbalance module; as such the following list of measures can be included:

a) new or extending FCDI projects
b) embankment height
c) increase water storage
d) improve land management practices: increase soil infiltration rate / soil storage capacity
e) increase / decrease drainage efficiency (culverts, bridges, encroachment)
f) improve regulator dimensions / efficiency / optimize operation
g) pumped drainage
h) SW irrigation schemes
i) SW irrigation efficiency
j) GW irrigation schemes
k) GW irrigation efficiency

3. Including salinity level in river, as an additional condition to let water in or not by regulator; as such salinity damage will be reflected as drought damage.

References

- Hugh Brammer books / FAO
- BARC, land types and soil maps
- CEGIS land use maps
- BWDB, FCDI-projects map
- BBS, administrative data
- BMD, meteorological data (1985 – 2017)
- IWM detail regional models
- WARPO, digital elevation model Bangladesh