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The BTOP Model with Supplementary Tools

User Manual

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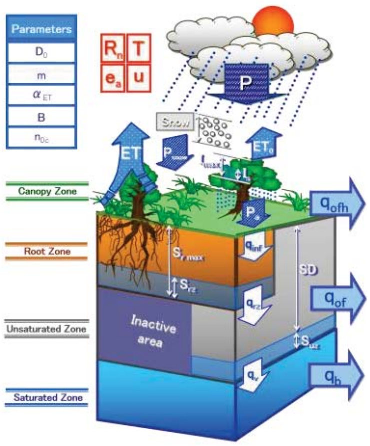

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The BTOP Model with Supplementary Tools

User Manual

(Version 1.1)

by

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Synopsis：

This user manual (“the manual”) summarizes theoretical concepts of the BTOP model and the procedure to use it with necessary supplementary tools. The explanation of the procedure takes the Fujikawa River basin, Japan, as an example. The BTOP model is a distributed hydrological model developed to simulate the basin scale rainfall-runoff processes including snowmelt, overland flow, soil moisture in the root and unsaturated zones, subsurface flow, river flow routing, and dam operation. The supplementary tools allow the user to prepare input files for the BTOP model project setup and to visualize BTOP model results.

Key Words：Distributed Hydrological Model, Rainfall-Runoff Process, Flow Routing, Flood control dam operation

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- and many others who contributed, but are not listed here.

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1. Introduction

1.1. Purpose of the user Manual

The purpose of this user Manual ("the manual") is to demonstrate the necessary procedure of using the Block-wise TOPMODEL (BTOP) [1, 2, 3] model as a part of the Yamanashi Hydrological Model (YHyM) [4, 5] system for river basin simulation. The manual provides main BTOP equations and parameters, installation of software, preparation of BTOP input files, BTOP simulation and post-processing of BTOP results. The manual demonstrates an example application of the BTOP model using the Fujikawa River basin, Japan, and has the following components:

- Executable file "**BTOP*.exe**", which is the latest version of the BTOP model;
- Supplementary pre- and post-processing tools starting with "**y_**" and having "**y_*.exe**" and bash "**y_*.sh**" extensions (highlighted in bold in the manual);
- Complete BTOP simulation example, which is called fujikawa project (in blue color in the manual), including 1) provided data of the Fujikawa River basin to make a new fujikawa project, 2) the so-called project files of fujikawa project, 3) the dam infrastructure files and 4) readme file describing the fujikawa folders and files.

Following this section, we give a brief history of BTOP development and application as well as model structure (Chapter 1) and provide the main theoretical concepts of the BTOP model and the BTOP model processes (Chapter 2). Chapter 3 describes the installation of the BTOP model with supplementary files in the user's Operating System (OS). Here it is suggested that the user make a test run of the BTOP model executable file to check the correct settings of the user's computer. In Chapter 4, we provide a detailed description of preparatory steps taken by the user using the fujikawa project as an example. A summary of these steps is provided in a sample script (**sample_run.sh**) and the user is suggested to run the sample scripts to see the fujikawa project preparation and the BTOP model run of the fujikawa project. In Chapter 5, we demonstrate the BTOP model run using the BTOP executable file with the fujikawa project and outputted files. We also provide steps of the BTOP calibration procedure using BTOP model parameters for the Fujikawa River basin and discuss the parameter sensitivity. As one of many BTOP applications, we demonstrate a simulation of operating flood control dams, which are located in the Fujikawa River basin (Chapter 6). In addition, the manual provides a list of all BTOP project files shown in blue color in the alphabetical order in Appendix 1, useful Linux commands in Appendix 2, description of globally available datasets in Appendix 3, and a list of supplementary tools highlighted in bold in Appendix 4.

1.2. Short history of model development and applications

In 2006, the newly established International Centre for Water Hazard and Risk Management (ICHARM) under the auspices of UNESCO, located at Public Works Research Institute (PWRI), Tsukuba, Japan, employed the BTOP model as one of hydrological simulation tools to quantify water-related hazards, especially floods and droughts. The development of distributed hydrological model BTOP started in 1999 in Prof. Kuniyoshi Takeuchi's research laboratory located at University of Yamanashi (UY), Kofu, Japan [1]. The idea was to establish a simple and robust hydrological model to simulate basin scale hydrology on the basis of well-known TOPMODEL [6].

Since then, research and development of the BTOP model has been on-going by the joint team of ICHARM and UY researchers under leadership of Kuniyoshi Takeuchi, who served as the Founding Director of ICHARM from 2006 to 2014. These research activities resulted in a revised concept of the BTOP model (Version 1.4) that was tested in the Mekong River basin [3, 5, 7]. The supplementary tools were also developed and utilized to prepare input files required for the BTOP model project and process BTOP model outputs [8]. As a result, the BTOP model has been used as a core hydrological model of the YHyM system (e.g. [4, 5]), and been applied for Integrated Water Resource Management (IWRM) studies in many river basins around the world. In addition, the BTOP results have been utilized with various modules such as sediment transport of the Yellow River by [9] and nutrient transport of the Mekong River basin by [10]. The recent developments are focused on improving the elementary hydrological processes [11], incorporating water infrastructure such as multi-purpose dams [12].

In ICHARM, the BTOP model simulations have been applied in a variety of Integrated Water Resource Management (IWRM) studies for global and river basin projects. For the global extent, BTOP projects the have been developed on 600-arcsec (about 20-km) grid for about 2300 river basins around the world and are run using the BTOP model [8]. This system is called the Global BTOP and has used for flood assessment in the "Innovative Program of Climate Change Projection for the 21st Century (KAKUSHIN Program)" funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japanese Government from 2006 to 2011 [13] and for flood and drought risk assessment at both global and local scales in a joint UY/ICHARM project conducted under the SOUSEI Program, which continued the KAKUSHIN program from 2012 to 2017 [8]. In addition, BTOP training is conducted at ICHARM for graduate students and visiting researchers and their applications of selected river basin indicate that the 600-arcsec BTOP model is a useful tool in many river basins including Rhine, Ganges-Brahmaputra-

Meghna, Upper North Ngiro, and Magdalena [14-19]. For local scale applications, IWRM studies have been conducted with the BTOP model applied at grid resolutions between 0.08-km and 1-km squared in several river basins: Rhine (the EU), Malwathoa (Sri Lanka), Ba (Fiji), Pampanga (the Philippines), Chao Phraya (Thailand), Solo (Indonesia), Indus (Pakistan), and Tone (Japan) [20-23]. These global and local application results indicate that the BTOP model is a useful tool in many river basins for a variety of IWRM applications (see also [5] and the reference list of this manual for further details on a variety of BTOP applications at numerous places around the world).

1.3. Structure of the BTOP model

The structure of the BTOP model with supplementary preprocessing tools is demonstrated in Figure 1.3.1 (the abbreviations of model output data are provided in Appendix 1 as well as in the following Chapters). In order to run the BTOP model with the **BTOP*.exe** file, precipitation (orange) and meteorological (light yellow) input data are required and topographical (dark yellow) data is supplied for the preprocessing tools. As a result of the successful run, the BTOP model outputs internal variables in the time-series and spatially distributed formats.

In Figure 1.3.1, the BTOP model includes the core components (grey) and optional modules (dark green) utilized depending on simulated processes. The core components such as topographic index, runoff generation, parameterization, and flow routing are integrated in the **BTOP*.exe** file. The optional modules, which could be excluded from the model simulation, are fully integrated ("on-line") modules. The off-line module (light green) can be run either as an external tool providing boundary condition data for the BTOP model or as an integrated tool in the BTOP model requiring input data files.

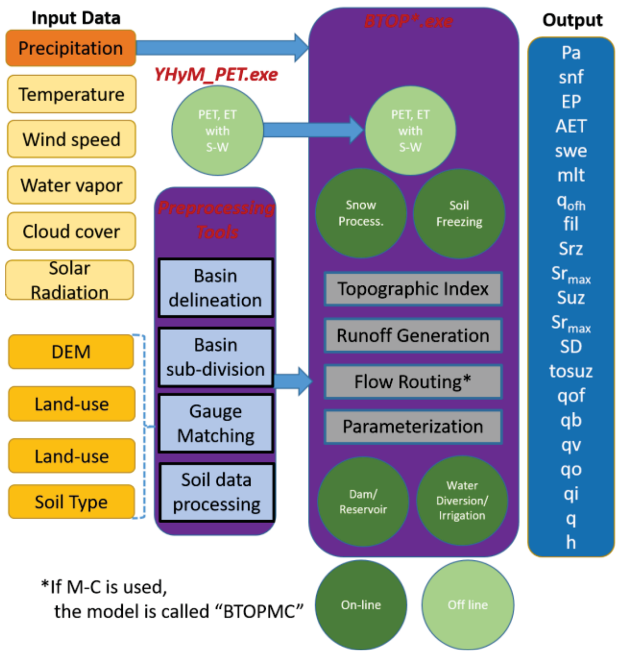


Figure 1.3.1 Structure of the BTOP model.

2. Theoretical background

2.1. Main concepts of the BTOP model

The BTOP model, a distributed hydrologic model, is designed to perform simple and robust simulations of rainfall-runoff, soil moisture, groundwater and river discharge processes in watersheds (Figure 2.2.1). This is achieved by utilizing a block-wise concept introduced by [1] to enhance the TOPMODEL formulation [6] for river basin simulations [2]. Following TOPMODEL, the BTOP model utilizes a topographic index concept and re-defines the topographic index, γ_i[-], of the grid *i* as:

$$\gamma_i = \ln\left(\frac{a_i f(a_i)}{a_{0i}} / \tan\beta_i\right) \tag{1}$$

where a_i[m^2] is the total area upstream of the grid *i*, $f(a_i)$[-] is the fraction of effective contributing area to the grid *i*, a_{oi}[m^2] is the area of the grid *i*, and $\tan\beta_i$[-] is the terrain slope of the grid *i*. The topographic index concept adopts an assumption that the subsurface water table follows by the terrain variations [24], which has been demonstrated as reasonable in humid climate watersheds with permeable subsurface materials [25]. The fraction of effective contributing area at any grid *i* is defined as:

$$f(a_i) = \sum_j a_{oj} g(x_{j\to i}) dx_i / a_i \tag{2}$$

where the summation is with respect to all grids (denoted by *j*) that contribute to the grid *i*, $g(x)$[1/m] is the probability density, $x_{i\to j}$[m] is the flow distance from the grid *j* to downstream grid cell *i*, dx_i[m] is the stream length of grid *i*, and $g(x_{i\to j})dx_i$ is the contributing fraction of grid *j* to grid *i*. In the current BTOP version, the probability density function, $g(x)$ is assumed to be exponential type:

$$g(x) = (1/b)\, e^{-x/b} \tag{3}$$

where *b*[m] is the mean travel distance of groundwater. This simple representation of groundwater movement improves groundwater dynamics of TOPMODEL [26, 27] and can be validated with groundwater mean transit estimated with tritium-tracer [28] .

The BTOP utilizes the saturation deficit of cell *i*, SD_i, which has the advantage of being independent of the subsurface thickness [3], in relation to the block-wise parameters:

$$SD_i = \overline{SD} + m\,(\bar{\gamma} - \gamma_i - \ln\bar{D} + \ln D_i) \tag{4}$$

where $\overline{SD}$ [m] is the block-average saturation deficit, $\bar{\gamma}$ [-] is the block-average topographic index, D_i [m/hr] is the groundwater dischargebility, and $\bar{D}$ [m/hr] is the block-average value of groundwater dischargebility. The groundwater dischargebility, D_i, describes subsurface property, which controls the capacity of groundwater discharge to the surface (stream), and is computed as:

$$D_i = U_{sand} D_{0sand} + U_{silt} D_{0silt} + U_{clay} D_{0clay} \tag{5}$$

where U_{sand}, U_{silt}, and U_{clay}[%] is the proportion of sand, silt and clay in the grid, respectively, and D_{0sand}, D_{0silt} and D_{0clay}[m/hr] are the groundwater dischargebility of the sand, silt and clay, respectively. The dischargebility, D_i, may be assumed to be aquifer transmissivity, T_i[m^2/hr], divided by the aquifer saturated thickness if it is known.

2.2. Core BTOP processes

Rainfall-runoff

The BTOP model conducts rainfall-runoff calculation at each BTOP grid dividing the rainfall-runoff process into four zones: vegetation, root, unsaturated and subsurface (Figure 2.2.1). The inactive area indicates the volume filled by subsurface materials that cannot contain water and are excluded from the calculations. For each BTOP grid, the net rainfall, P_a[mm/Δt], is applied in the vegetation zone and is reduced by the canopy interception water storage, I_s [mm], and actual interception evaporation, ET_o[mm/Δt], of the canopy [3]:

$$P_a(t) = P(t) - (I_s(t)/\Delta t - I_s(t-1)/\Delta t + ET_o) \tag{6}$$

where $P(t)$[mm/Δt] is the rainfall at time t per simulation time step Δt, which is selected as 24 hr for daily simulations. In this version of BTOP, the interception vegetation storage, I_s, is calculated as a product of the interception coefficient, c_{int}[mm], of 0.2 and the leaf area index (LAI), which is a ration of leaf and ground area [28]. The actual interception evaporation, ET_o[mm/Δt], is calculated as:

$$ET_o(t)\Delta t = min(I_s(t), PET_o(t)\Delta t) \tag{7}$$

where PET_o[mm/Δt] is the potential interception evaporation. This calculated net rainfall, P_a [mm/Δt], is considered to be the actual rainfall that falls on top of the land surface and is used to calculate water percolation in the root zone and Hortonian overland flow.

When the actual precipitation, P_a, is larger than the maximum infiltration capacity, Inf_{max}, of soil, Hortonian overland flow, q_{ofh}[m/s], occurs:

$$q_{ofh} = P_a - k_u a_{acic} \qquad P_a > Inf_{max} \tag{8a}$$

$$q_{ofh} = 0 \qquad P_a \leq Inf_{max} \tag{8b}$$

where k_o[m/hr] is a root zone hydraulic conductivity and a_{acic}[-] is an infiltration coefficient. The infiltration coefficient, a_{acic}[-], was introduced by [11] to account for the Hortonian flow processes in the semi-arid and arid regions.

From the vegetation zone, the root zone storage, $S_{rz}(t)$[m], at time t is calculated using water balance:

$$S_{rz}(t) = S_{rz}(t-1) + \Delta t\big(P_a(t) - q_{ofh}(t) - ET(t) - q_{rz}(t)\big) \qquad (9)$$

where $S_{rz}(t-1)$[m] is the root zone storage at time step *t-1*, $ET(t)$[m/Δt] is the actual evapotranspiration at time *t* and q_{rz}[m/Δt] is the storage excess of the root zone that drains into the unsaturated zone. The actual evapotranspiration, ET [mm/Δt], is considered to occur from the root zone and estimated as:

$$ET(t)\Delta t = min(S_{rz}(t) + S_{rz}(t-1), G_{rz}PET(t)\Delta t) \qquad (10)$$

where G_{rz}[-] is the drying function related to soil surface wetness in the root zone and equals to G_{rz}=1 when $S_{rz}(t) \geq S_{rzmax}$ or is computed as:

$$G_{rz}(t) = (1 - e^{-\alpha S_{rz}(t)/S_{rmax}})/(1 - e^{-\alpha}) \quad S_{rz}(t) < S_{rmax} \qquad (11)$$

where α[-] is the block-wise drying parameter and S_{rmax}[m] the maximum water storage capacity of the root zone is obtained from:

$$S_{rmax} = d_{rz}\big(\theta_{fc} - \theta_{rs}\big) \qquad (12)$$

where d_{rz}[m] is the root depth obtained from the land cover classes (see Appendix 3), θ_{fc}[-] is the soil field capacity, and θ_{rs}[-] is the residual moisture content obtained from the U.S. Department of Agriculture (USDA) soils [28]. When the root zone water storage exceeds the maximum water storage capacity of the root zone ($S_{rz}(t) \geq S_{rzmax}$), the gravity drainage, q_{rz}[m/Δt], occurs from the root to the unsaturated zone.

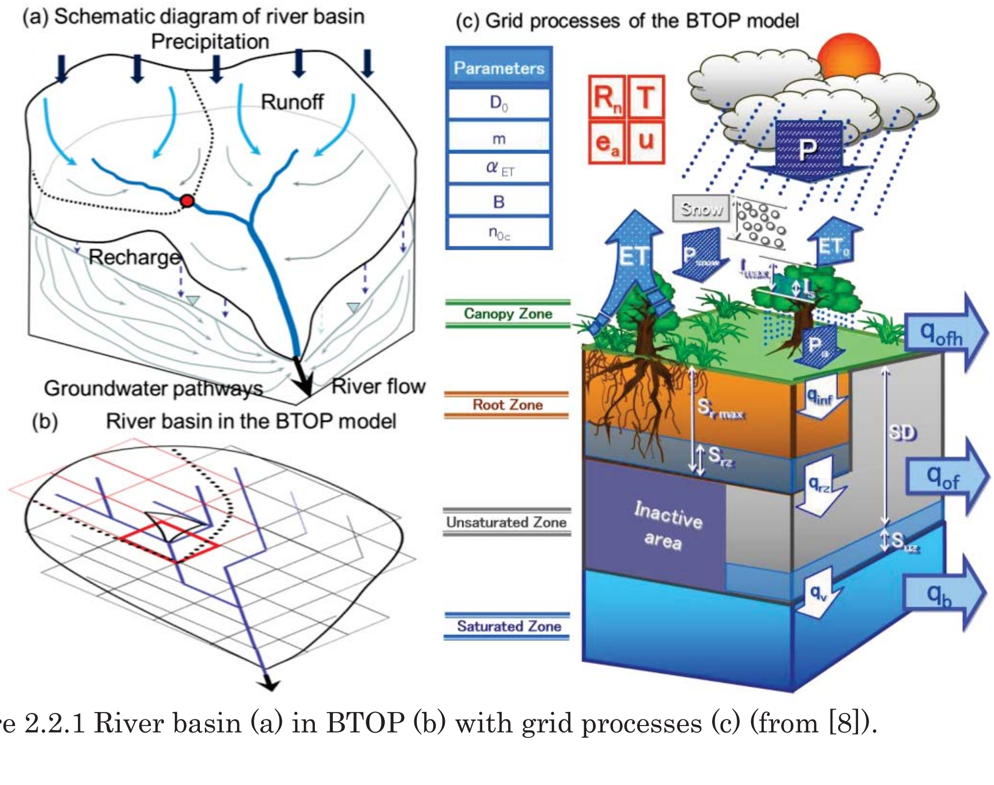


Figure 2.2.1 River basin (a) in BTOP (b) with grid processes (c) (from [8]).

In the unsaturated zone, the unsaturated zone water storage, S_{uz} [m], receives water from the root zone and reduces the soil moisture deficit, *SD* [m], in the unsaturated zone. From the unsaturated zone, the unsaturated zone water storage, S_{uz} [m], recharges deeper subsurface aquifer by the groundwater recharge flux, q_v[m/Δt], as:

$$q_v = k_u e^{-SD/m} \qquad SD>0 \qquad (13a)$$

$$q_v = k_u \qquad SD\leq 0 \qquad (13b)$$

where k_u [m/Δt] is the unsaturated hydraulic conductivity. From [3], the groundwater flux, q_b[m/Δt], at each cell is calculated:

$$q_b = D \tan\beta \, e^{-SD/m} \qquad SD>0 \qquad (14a)$$

$$q_b = maximum\ (D \tan\beta\ ,\ q_v\ ) \qquad SD\leq 0 \qquad (14b)$$

The saturation deficit of cell *i*, SD_i, at time, *t*, becomes:

$$SD_i(t) = SD_i(t-1) - (q_{rz} + q_v - q_b\ )\Delta t \qquad (15)$$

where $SD_i(t-1)$[m] is the saturation deficit at time *t-1* and Δt[hr] is the time step of the BTOP model. When the unsaturated zone is fully saturated, the soil moisture deficit, *SD*, equals to zero, the saturation excess runoff flux, q_{of}[m/Δt], occurs from the unsaturated zone. From each BTOP grid, the total flux, q_{oft}[m/s], is generated by the rainfall-runoff process and is the sum of simulated q_{ofh}[m/s], q_{of}[m/s] and q_b[m/s] fluxes. From these fluxes, the inflow into a stream is obtained by multiplying the total flux, q_{oft}, and the area of BTOP grid. This completes the BTOP grid calculation and the river flow routing is started.

Flow routing

Though several methods for flow routing can be used, the modified Muskingum-Cunge (MC) method is the default flow routing (see Figure 1.3.1). When BTOP is applied with MC routing the model is referred to as BTOPMC (e.g. [2-4]). The modified MC method was described by [30] and indicated a better performance compared to the original MC method implemented in earlier applications of BTOP (e.g. [2, 31]). The modified MC method calculates outflow at each BTOP grid as:

$$q_o(t) = C_1 q_i(t) + C_2 q_i(t-1) + C_3 q_o(t-1) \qquad (16)$$

where q_o[m^3/s] is the outflow from BTOP grid at time *t* and *t-1*, q_i[m^3/s] is the inflow into the BTOP cell at time *t* and *t-1*, and C_1[-], C_2[-] and C_3[-] are the weights of the M-C routing. These weights are calculated as:

$$C_1 = (\Delta t - 2kx)\ /(2k(1-x) + \Delta t) \qquad (17a)$$

$$C_2 = (\Delta t + 2kx)\ /(2k(1-x) + \Delta t) \qquad (17b)$$

$$C_3 = (2k(1-x) - \Delta t)\ /(2k(1-x) + \Delta t) \qquad (17c)$$

where Δt[s] is the time step, and k[s] and x[-] are the M-C routing parameters with:

$$k = \Delta L / \omega \tag{18a}$$
$$x = 0.5 - 0.5\, \mu \quad /(\Delta L \omega) \tag{18b}$$

where ΔL[m] is the length of routing reach, ω[-] is the celerity of the water wave and μ[-] is the kinematic water velocity. The celerity, ω[m/s], is defined as:

$$\omega = 1.67 q^{0.4} i^{0.3} n^{-0.6} \tag{19}$$

where q[m/s] is the river discharge per channel width, i[-] is the river bed slope, and n[-] is the Manning coefficient. The kinematic water velocity, μ[m^2/s], is calculated as:

$$\mu = h^{1.67} \quad /(2 n i^{0.5}) \tag{20}$$

where h[m] is the river stage and is calculated from:

$$h = q^{0.6} i^{-0.3} n^{0.6} \tag{21}$$

The Manning coefficient, n[s/$m^{1/3}$], is used for a channel at each BTOP grid from:

$$n = n0c\ (\tan \beta_i \quad / \beta_{coeff})^{0.333} \tag{22}$$

where n0c[s/$m^{1/3}$] is the block-average Manning coefficient, tan β_i[-] is the river channel slope of the cell i, and β_{coeff}[-] is the scaling factor. The default β_{coeff} value equals to the cell slope of the block outlet or can be specified by the user, see Sections 3.3 and 5.1.

Potential evaporation and evapotranspiration

The BTOP model requires an input of the meteorological forcing data such as potential evaporation from canopy (PET_o) and potential evapotranspiration from soil (PET) to estimate actual evaporation (ET_0) and actual evapotranspiration (ET), see Section 2.2. In the current version of the BTOP model, PET_o and PET values are computed using the Shuttleworth-Wallace (S-W) equation [32], which is extended the P-M combination equation to dual sources, the vegetation canopy and the substrate soil, and considered their interaction through a resistance network into a model for latent and sensible heat fluxes in a heterogeneous plant stand [28]. These PET_o and PET values may also be computed from other equations such as Penman-Monteith (P-M) and utilized as the boundary condition files. In the S-W equation, the ET (mm/d), is obtained as:

$$ET = (C_c ET_c + C_s ET_s)/\lambda \tag{23}$$

where λ[MJ/kg] is the latent heat of water vaporization, C_c and C_s are weighting coefficients as functions of resistances, and ET_c and ET_s are terms similar to the transpiration and the evaporation by applying the P-M equation to closed canopy and bare substrate, respectively. The ET_c and ET_s terms are defined as follows:

$$ET_c = \{\Delta(R_n - G) + [86400 \rho c_p (e_s - e_a) - \Delta r_a^c (R_n^s - G)]/(r_a^a + r_a^c)\}/\{\Delta + \gamma \left[1 + \frac{r_s^c}{r_a^a + r_a^c}\right]\} \tag{24a}$$
$$ET_s = \{\Delta(R_n - G) + [86400 \rho c_p (e_s - e_a) - \Delta r_a^s \left(R_n - R_n^s\right)]/(r_a^a + r_a^c)\}/\{\Delta + \gamma \left[1 + \frac{r_s^s}{r_a^a + r_a^c}\right]\} \tag{24b}$$

where Δ[kPa/°C] is the slope of saturation vapour pressure curve, R_{n}[MJ/(m^{2}day)] is the net radiation at the reference height, R_n^s[MJ/(m^{2}day)] is the net radiation flux at the substrate soil surface, G[MJ/(m^{2}day)] is the substrate soil heat flux, ρ[kg/ m^3] is the mean air density at constant pressure, c_p[MJ kg^{-1} °C^{-1}] is the specific heat of moist air at constant pressure, e_s[kPa] and e_a[kPa] are the saturation and actual vapour pressures respectively, γ[kPa/°C] is the psychrometric constant, r_a^c[s/m] is the bulk boundary layer resistance of the canopy, r_s^c [s/m] is the bulk stomatal resistance of the canopy, r_a^a [s/m] is the aerodynamic resistance between the canopy and the reference height, r_a^s [s/m] is the aerodynamic resistance between the soil and the mean canopy height, r_s^s [s/m] is the surface resistance of the soil, and the coefficients are:

$$C_c = 1/\left[1 + \frac{R_c R_a}{(R_s R_c + R_s R_a)}\right] \tag{25a}$$

$$C_s = 1/\left[1 + \frac{R_s R_a}{(R_s R_c + R_c R_a)}\right] \tag{25b}$$

$$R_s = (\Delta + \gamma) r_a^s + \gamma r_s^s \tag{25c}$$

$$R_c = (\Delta + \gamma) r_a^c + \gamma r_s^c \tag{25d}$$

$$R_a = (\Delta + \gamma) r_a^a \tag{25e}$$

Evaporation from the water surface can be estimated using the equation proposed by Shuttleworth, who substituted the aerodynamic resistance equation of Penman wind speed function and $r_s = 0$ into the P-M equation [28]:

$$ET = (0.408\Delta\left(R_n - G\right) + 2.624(1 + 0.536u_2)\gamma)/(\Delta + \gamma) \tag{26}$$

where u_2[m/s]is the wind speed measured at 2 m height. For the PET estimation, minimal stomatal resistance under local environmental conditions is used as 500 s m^{-1} but unlimited soil moisture is used for the canopy and the soil surface resistance. While for the PET_o, both resistances are set to zero. The parameterization of the S-W model was given in detail by [32].

2.3. Optional BTOP modular processes

Snowfall and snowmelt module

The BTOP model includes a snowfall and snowmelt processes based on degree-day method as an optional BTOP module [33]. The module is optional and only included in the BTOP simulation when it is activated by the user. The snowfall, P_s[mm/Δt], is simulated as the fraction of precipitation, P[mm/Δt], at each active BTOP grid [33]:

$$P_s = 0 \qquad T > T_r \tag{27a}$$

$$P_s = P\,[1 - (T - T_b)\,/(T_r - T_b)] \qquad T_b < T < T_r \tag{27b}$$

$$P_s = P \qquad T_b < T \tag{27c}$$

where T[°C] is the average daily air temperature, T_r [°C] is the threshold air temperature at which some precipitation begins to fall as snow, and T_b[°C] is the threshold air temperature at which 100% of precipitations falls as snow. The simulated snowfall, P_s, is summed up at each grid and the accumulated snow is recorded as the snow water equivalent, SWE[m], which is defined as the equivalent depth of water of a snow cover [28]. When the average daily air temperature, T, rises above the is the threshold temperature of snowmelt, T_{base}[°C], the snowmelt occurs from the snowpack. Georgievsky et al. [33] reported T_r = 2.0 °C, T_b =-2.0 °C, and T_{base} = 1.0 °C for the Yellow River basin. These threshold temperatures are used as default values in the module and adjusted during calibration by the user. The snowmelt rate, M[mm/Δt], is computed as:

$$M = M_f\,(T - T_{base}) \qquad T_{base} < T \quad (28a)$$

$$M = 0 \qquad T < T_{base} \quad (28b)$$

where M_f[mm/Δt/°C] is the degree-day factor and is calculated for the Yellow River basin elevation zones: 4.8 (DEM < 1000 m above sea level (masl)), 4.0 (1000 ≤ DEM < 2000 masl), 1.3 (2000 ≤ DEM < 3000 masl), 0.7 (3000 ≤ DEM < 4000 masl) and 0.18 (4000 ≤ DEM < 5236 masl) [33]. For the snowpack processes, the meltwater outflow, R_w[mm/Δt], is calculated as:

$$R_w = M/(1-\varphi) + P_r \qquad \Sigma(M+P_r) > \varphi * SWE \quad (29a)$$

$$R_w = 0 \qquad \Sigma(M+P_r) \le \varphi * SWE \quad (29b)$$

where φ[-] is the maximum liquid holding capacity of a single layer snowpack, and P_r[m] is the rain component of the precipitation. The refreezing of the meltwater may also occur when the temperature drops below the threshold snowmelt temperature, T_{base}, and is calculated using the rate of refreezing, S[mm/hr]:

$$S = C_{fr} M \qquad T_{base} < T \quad (30)$$

where C_{fr}[-] is the refreezing coefficient, which has the default value of 0.05 [33].

Soil freezing module

The soil freezing is included in the BTOP model as an optional soil freezing module. In the soil freezing module, the soil freezing process is implemented in the root and unsaturated zones using the average daily air temperature with a threshold temperature of soil freezing. The soil freezing occurs only when the average daily air temperature is below the threshold temperature of soil freezing. Once the threshold temperature is reached, the root and unsaturated zones are considered frozen in the module. As a result, any precipitation that falls on the frozen soil does not infiltrate into soils and is a treated as runoff from the frozen surface.

Dam/reservoir operation module

The dam/reservoir module of the BTOP model calculates the water balance at each time step t for the dam site to obtain reservoir water storage, $V(t)[10^6\ m^3]$:

$$V(t) = V(t-1) + \Delta t[Q_{in}(t) + \big(P(t) - E(t)\big)A(t) + Q_{out}(t)] \qquad (31)$$

where $V(t-1)[10^6\ m^3]$ is the reservoir storage at time step $t-1$, $\Delta t[s]$ is the time step of the BTOP model, $Q_{in}(t)[m^3/s]$ is the reservoir inflow at time step t, $P(t)[m/\Delta t]$ is the precipitation on the reservoir open water area, $E(t)[m/\Delta t]$ is the evaporation from the reservoir, $A(t)[km^2]$ is the area of reservoir water surface, and $Q_{out}(t)[m^3/s]$ is the outflow discharge from the dam. This outflow discharge is specified by the dam operation rule.

Figure 2.3.1 illustrates a schematic diagram of inflows and outflows for the dam with reservoir water volume. The colored lines indicate four gates at the dam site for different discharge operation and five reservoir water levels and volumes. In Figure 2.3.1, the minimum reservoir water volume utilized for the irrigation water release is shown by the blue line and for the electricity generation by the green line. The volume below the lowest gate (blue line) cannot be released from the dam. For the flood control operation, the volume between orange and black lines is the flood control capacity of the reservoir and is used to store flood peak inflows. The black line indicates the position of flood control gates and an additional reservoir volume that can be used for the flood control. When the water volume of the reservoir reaches the flood gates (black line), the controlled release of the spillway gates is stared with constant or variable dam discharge (Figure 2.3.1). In case of high flood peak inflows, the ungated spillway release from the dam is conducted, see the red line at the dam site. In exceptional flood peak inflows, the reservoir volume may reach the cress of the dam and cause the dam overflow discharge. This overflow jeopardizes the dam structure and is usually avoided by dam operators.

In the current version of dam/reservoir module, we have implemented several types of dam and reservoir discharge operation: 1) constant discharge (dam with constant flood discharge, dam without a gate (dry dam), and flood retention pond), 2) constant discharge generation with variable flood discharge (electricity generation with flood control), 3) irrigation water supply from the dam and from the reservoir (irrigation, industry and municipal water diversions). A brief description of each type is provided in Section 6.

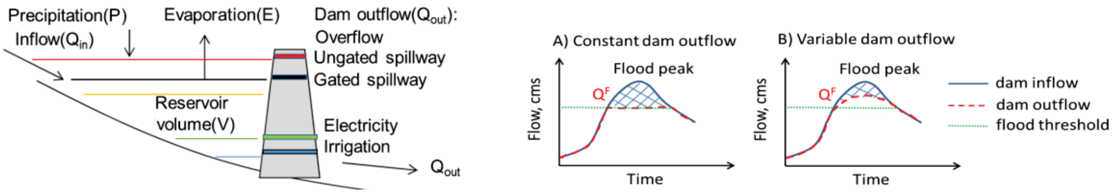


Figure 2.3.1 Schematic diagram of the multi-purpose dam operation in the BTOP model. Flood control operation with constant (a) and variable (b) dam outflows.

3. Setup of model files

To use the BTOP model and supplementary tools, the user must 1) install the BTOP tools, 2) set up a correct path to the BTOP directory and 3) use an appropriate computer to run the preprocessing tools and the BTOP model. In addition, usage of ready to use "BTOP virtual machine" setup is also described.

3.1. Overview of supplementary files

Latest BTOP tools are maintained as Character user Interface (CUI) tools and executable with Unix-line environment available Bourne shell (sh) or Bourne Again Shell (bash) in most common Operating Systems (OS) on both 32- and 64-bit computer architectures. The default is the 64-bit architecture due to memory and files handling memory for the BTOP modeling projects with a large number of grids and simulation time steps.

Directory/File structures and File types

BTOP executable tools are stored in "opt/YHyM/bin" folder. The "data" directory contains supplementary required input files using in some tools and "utl" directory is used to store sample utility scripts, see figure below.

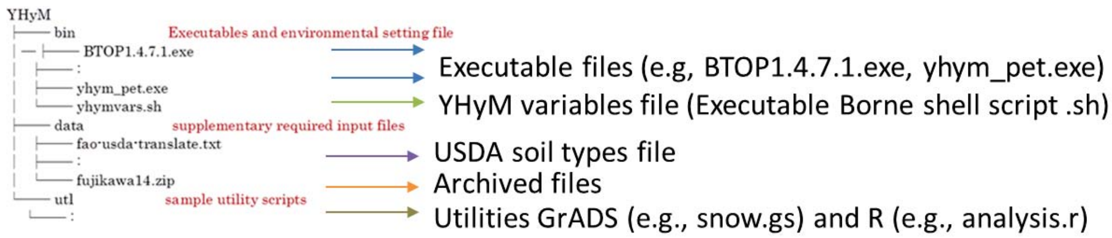


Figure 3.1.1 Directories and files of the supplementary tools of YHyM package.

Required Environment

The BTOP supplementary tools are executable on Bourne shell (sh) or Bourne Again Shell (bash) requires Unix-line environment, which should be prepared if you use Windows OS. The Unix, Linux and MacOS have sh/bash environment, so there is no need to install additional third party software.

3.2. General steps of model setup

For the current version, we provide a standard installation procedure (recommended as it results in optimal performance) as well as an alternative/optional installation procedure for 32-bit PCs without access to a Unix or Linus environment for advanced users.

Standard Procedure

1) Download BTOP files from the ICHARM or UY-VA web-site.
2) Extract and Set to installed directory.
3) Set a shell environmental variable (PATH).
4) Test

Alternative/Optional Procedure (for advanced users with ready-to-use Virtual Machine)

1) Download Virtual Machine (VM) from the UY-VA web-site.
2) Unzip folders and files.
3) Run a BTOP on VM.
4) Test.

Standard Setup

This manual describes three options of the standard setup below:

1) Mac OS

The BTOP related files must be copied to the "/opt/YHyM/bin" directory on the C drive. To run BTOP and supplementary files, the user must set a correct PATH variable by specifying "PATH=$PATH:$HOME/bin:/opt/YHyM/bin" in the user's profile ".bash_profile". The fujikawa project files may be copied at any directory and can be run on with the use of default terminal emulator.

2) Windows OS

Firstly, the BTOP model and supplementary files are copied to the "/opt/YHyM/bin" directory on the C drive. Secondly, a freeware terminal emulator such as MobaXterm must be installed on Windows OS. Next, the user must specify the location of the BTOP directory in the "value" field of the "PATH" environment variable of the Windows OS. The steps of creating new "PATH" variable are demonstrated in Figure 3.2.1. Finally, the user must append Windows environment variables to the MobaXterm terminal by selecting the box of the MobaXterm configuration menu as demonstrated by Step 5 and 6 in Figure 3.2.1. After that, the fujikawa project files may be copied at any directory and run with executable file of the BTOP model as described in Section 3.3.

3) Windows OS with Unix-like OS

In one PC, the user may have both Windows and Unix-like OS. This setting is so-called dual-boot and allows the user to interchangeably use OS. For the Unix-like OS, a 64-bit free-ware Ubuntu or Centos OS can be selected and used to boot up the PC. After that, the BTOP model and supplementary files are copied to the "/opt/YHyM/bin" directory and the correct path must be specified by the user. Note that Ubuntu OS requires to set the correct path in *.profile file.

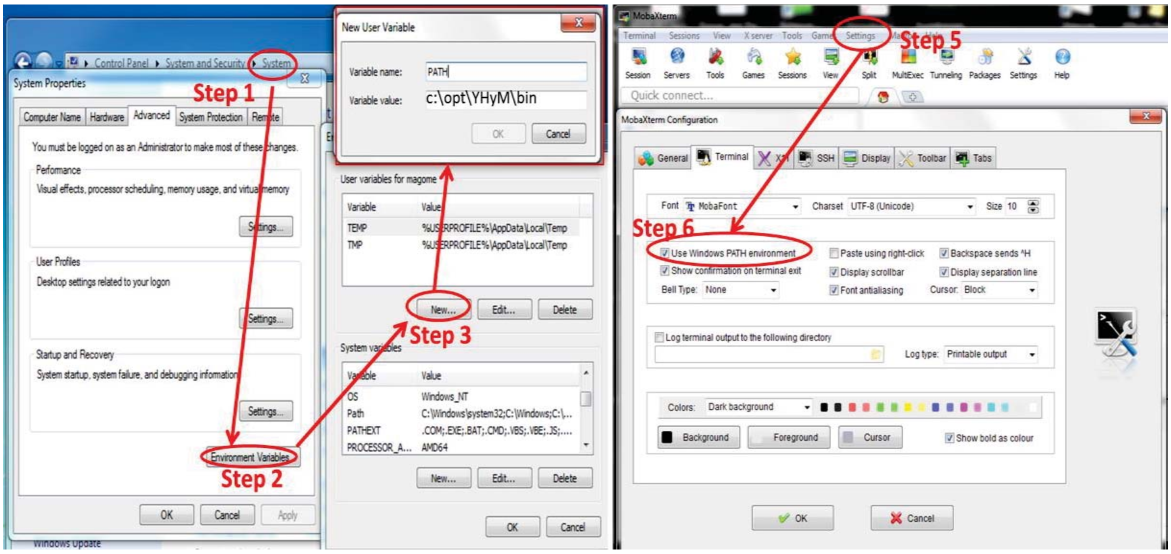


Figure 3.2.1 Steps of creating a new environment variable “PATH” in Windows OS (left) and appending the PATH variable to the MobaXterm version 8.1 (right).

Using remote server installed BTOP files via network.

In some cases, the user can access a remote server, which stores the installed BTOP tools and allows the user to run BTOP tools via network or internet with ssh and xdmcp. For the Windows OS, a terminal emulator such as MobaXterm must be installed to access the files located on the server and sftp software such as FileZilla or CoreFTP need to be installed for the file transfer between the server and Windows PC. On the server, the BTOP model and supplementary tools’ files must be stored at “/opt/YHyM/bin” directory while the BTOP project files may be stored on a remote hard drive. To run these files, the user must set a correct PATH variable by specifying “PATH=$PATH:$HOME/bin:/opt/YHyM/bin” in the user’s profile “.bash_profile”.

Alternative/optional procedure

The alternative/optional procedure offers ready-to-use “BTOP Virtual Machine”. In this option, the user installs Virtual Machine (VM) software on the Windows OS and runs Linux and Windows OSs in parallel. The UY-ICRE team has prepared an archived file of the VM Player for 32- and 64-bit Windows OS and a special executable “**linuxmint-16-xfce_x64.exe**” file, which contains with Linux Mint OS, the BTOP model and supplementary files, and the fujikawa project. To use the VM, we recommend these minimum specifications of a PC: processor with more than 2GHz, 2GB RAM and about 8GB of free hard disk space. The default VM settings are 1GB memory with 3GB swap memory and can be adjusted by the user. For the Linux Mint OS, GNU gcc and gfortran compiler are installed with several useful tools such as eog, r-base, gdal, GrADS, GMT, qgis, gnuplot, etc. To obtain the archived file, please visit the UY-VA web-site or contact the authors by e-mail.

After the installation of VMware Player software, the start of VM is demonstrated in Figure 3.2.2. In Step 1, the user starts the VMware Player and selects to Linux Mint VM in Step 2. In Step 3, the user selects to "play" and must enter the "btopmc" to get access to the Linux Mint OS desktop. In the Linux Mint OS, the user starts the terminal emulator as shown by Step 1 and 2 in Figure 3.2.3. Once the terminal emulator is open, the user should execute a list of sample commands provided in the "**YHyM_setup_sample.sh**" script to illustrate the usage of BTOP model with supplementary files (Figure 3.2.3).

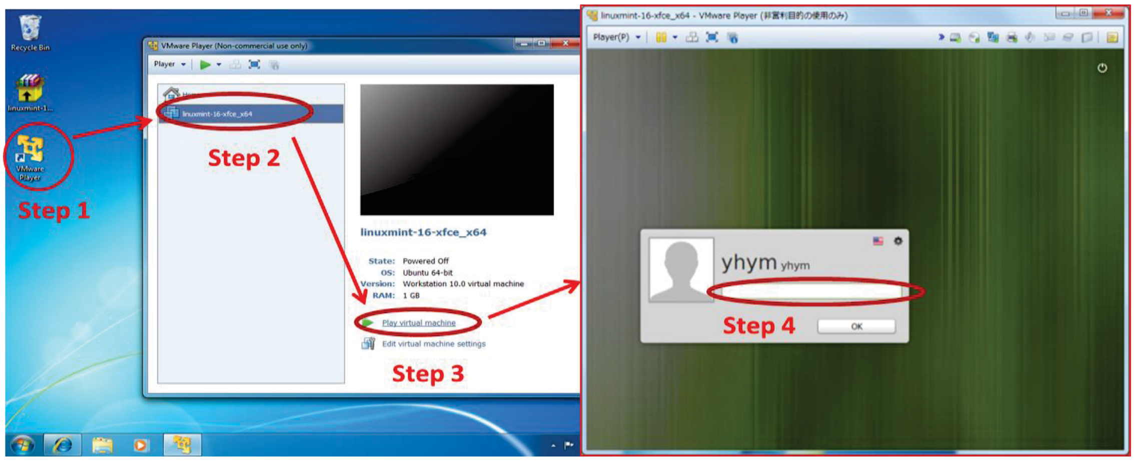


Figure 3.2.2 Starting the Virtual Machine (VM) with the VM Player.

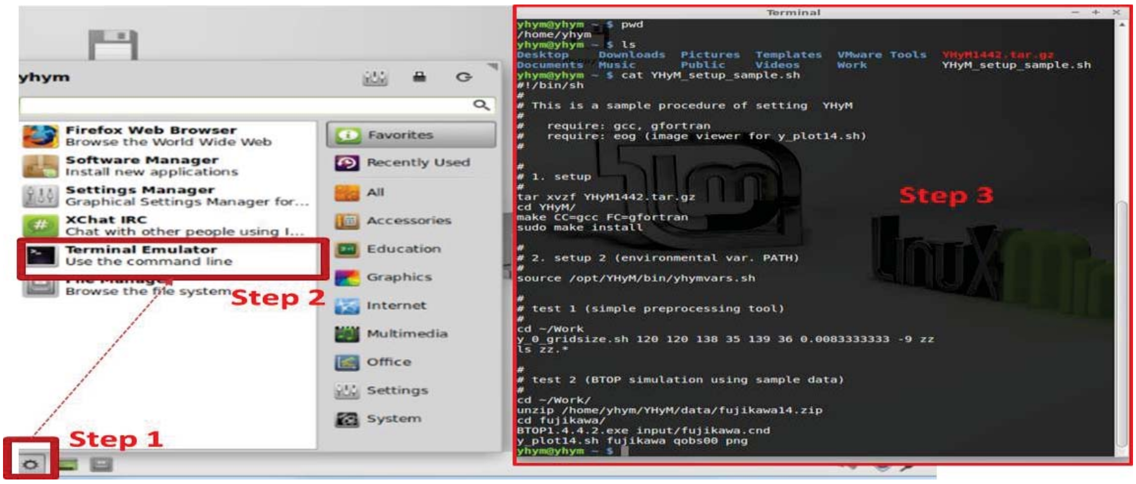


Figure 3.2.3 Terminal on the Linux Mint OS (left) and a summary of commands to be run by the user (right).

3.3. Testing the BTOP setup

To check the correct setup, the user should conduct a test run of the BTOP model executable file and obtain a screen output message such as that shown in Figure 3.3.1. Any error message indicates an incorrect setup of environmental settings and the use should go back and repeat the steps outlined above. In addition, the user should conduct a test run of the fujikawa project using commands described in Chapter 4 to get better understanding of the BTOP model output messages and files.

<u>Important Check</u>: If the environment is set up correctly, you should be able to access the BTOP related files automatically while typing "**y_**" in your terminal window.

```
File  Edit  Setup  Control  Window  Help
-bash-3.2$ BTOP1.4.7.1r.exe

 ************************************************************************
 **   Runoff/Discharge Simulation tool (YHyM/BTOP(MC) - Ver. 1.4.7.1)   **
 **                                                                     **
 **      All Rights Reserved                                            **
 **         - University of Yamanashi, Hydrology and WaterResources Lab.**
 **         - All members of YHyM/BTOP(MC) Development Team             **
 **      Maintained by                                                  **
 **         - J.Magome (UY) : magome@yamanashi.ac.jp                    **
 ************************************************************************

 usage : BTOP1.4.7.1.exe  project_name.cnd  [OPTIONS..]

  ex) : BTOP1.4.7.1.exe  input/fujikawa.cnd
  ex) : BTOP1.4.7.1.exe  input/fujikawa.cnd  -a
  ex) : BTOP1.4.7.1.exe  input/fujikawa.cnd  -n
  ex) : BTOP1.4.7.1.exe  input/fujikawa.cnd  -a -n

 OPTIONS
  -a --autoplot : autoplot : simple drawing by autoplot.sh
  -n1    -1    --newn1 -n -14 : n calc 1(ref. slope 1/1)
  -n1000 -1000 --newn2        : n calc 2(ref. slope 1/1000)
      (none)                  : n calc 0(ref. slope outlet) old way)
  -gl VAL: lower boundary value for Topographic Index (ganma)
  -gu VAL: upper boundary value for Topographic Index (ganma)

-bash-3.2$ █
```

Figure 3.3.1 Running the BTOP model executable file in the terminal.

4. Starting a new BTOP project

4.1. Summary of preparatory steps

The preparatory steps of a BTOP project, which are summarized in the **sample_run.sh** file in Section 3 and to be run by the user, can be grouped into four steps (Figure 4.1.1):

- *Data collection (Step 1).*
  The user collects required BTOP input data of the study river basin from local and global datasets. These data include digital elevation model (DEM), soil types of Food and Agriculture Organization (FAO), land cover classes of the International Geosphere-Biosphere Programme (IGBP), observed precipitation and river discharge, and climatic variables such as temperature, wind speed, solar radiation, cloud cover, vapor pressure, daily sunshine duration and normalized difference vegetation index (NDVI) to estimate leaf area index (LAI). For these climatic variables, the user may also chose to obtain estimated climatic forcing input of canopy evaporation (EP) and potential evapotranspiration (PET), and LAI from other sources.

- *Topography and soil files preparation (Step 2).*
  The user creates a new BTOP project with one block (Step 2.1), copies prepared input files into the relevant project folders (Step 2.2), and conducts DEM (Step 2.3) and soil (Step 2.4) processing steps.

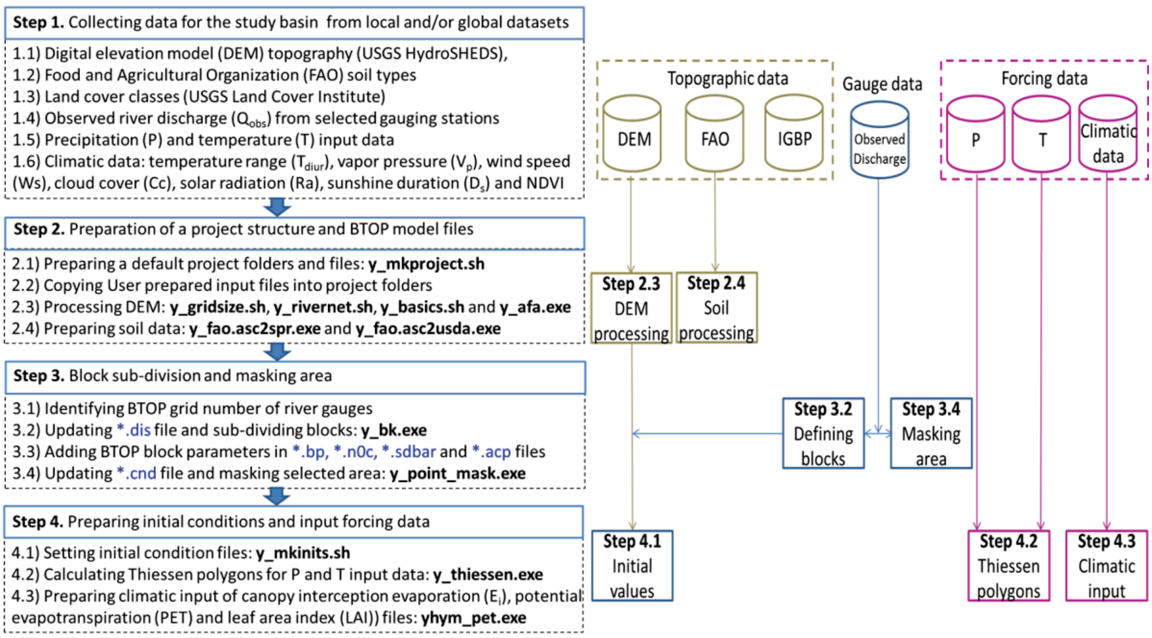


Figure 4.1.1 Preparation steps of the BTOP project.

- *Identifying blocks and masking area (Step 3)*
  The user utilizes river discharge of the selected gauges (Step 3.1) for the block sub-division (Step 3.2), specifies block parameters in the relevant files (Step 3.3) and masks area for outputting results of the BTOP model simulation (Step 3.4). Note that sub-divided blocks and masked area are treated independently in the BTOP model simulation and outputs. For example, the user can have a BTOP model with one block and four masked areas for outputting model results. However, increasing number of blocks may provide better representation of river basin in the BTOP model and improve statistical performance of the BTOP model.

- *Preparing initial and climatic input files (Step 4)*
  Preliminary initial condition files are calculated prior BTOP simulation (Step 4.1) and should be replaced with BTOP model results at the selected time step by the user. For the climatic input files, the user can produce Thiessen polygons files for the precipitation gauges and temperature gauges with the supplementary tool (Step 4.2) or prepare Thiessen files using different software such as ArcGIS. In Step 4.3, the user computes EP, PET and LAI forcing files from collected climatic input data. Instead of doing Step 4.2 and 4.3, the user can obtain the precipitation and temperature input as well as climatic forcing data directly from global datasets. In that case, the user should make sure that the formatting of these files is consistent with the BTOP model options listed in the *.cnd file.

4.2. User prepared input data

River basin files (*.dem, *.fao, *.igbp)

To start a BTOP project of the study river basin, the user needs to prepare DEM, FAO soil types, and IGBP land cover classes with desired grid size dimensions, which need to be determined by the user. The BTOP grid dimensions are selected by the user based on the aims of the study, the river basin area and simulation period. For the Fujikawa River basin, the drainage area is about 3,900 km^2 and the expected length of BTOP model simulation is only 365 days. Therefore, the cell size of 1 km is selected for this model project.
Once the desired cell size is selected, the x- and y- coordinates of the lower left corner are identified to compute number of rows and columns in the BTOP model grid. This information is required to establish river basin files in ASCII format. For the Fujikawa River basin, the x- and y- coordinates are 138.0 and 35.0, respectively. The selected cell size is 0.00833333, which is about 1 km in degree format.

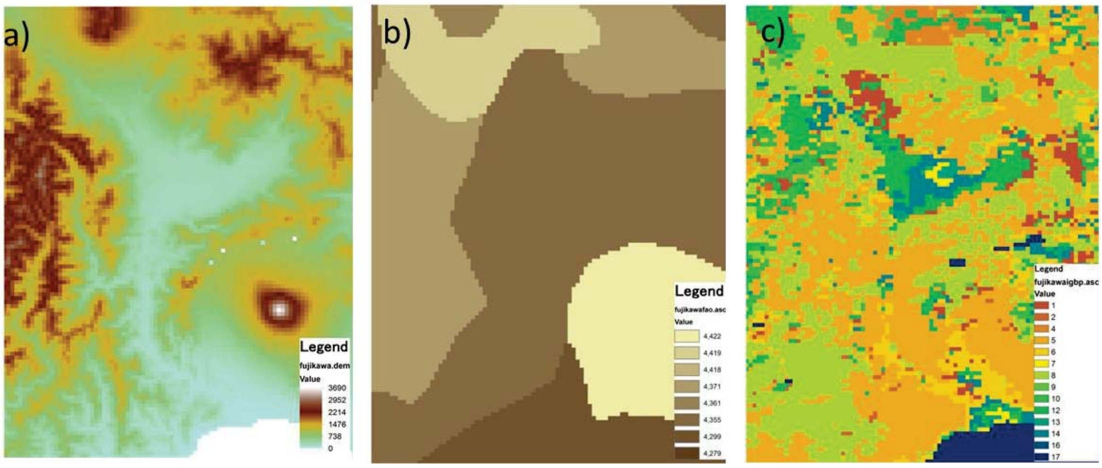


Figure 4.2.1 DEM fujikawa.dem a), FAO soil types fujikawa.fao b), and IGBP land cover classes - fujikawa.igbp c) files of fujikawa project.

Observed river discharge files (*.obs)

The user manually prepares river discharge data at selected river gauging stations with extension *.obs. Four river gauging stations of the fujikawa project are shown in Figure 4.2.2. The *.obs files must have a two column format with the total number of BTOP model steps: the date of observation in YYYYMMDD format (Column 1) and the observed discharge value in m^3/s (Column 2). These file must have the exactly the same name as listed in *.cnd file and be stored in "output/station" sub-folder.

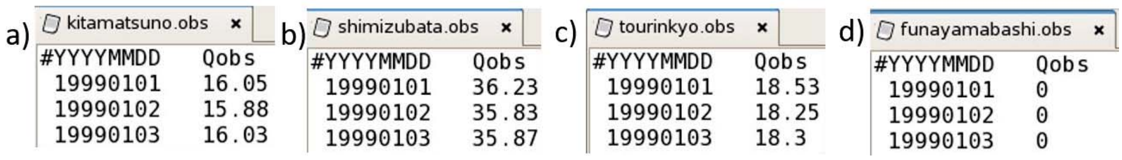


Figure 4.2.2 River discharge from selected stations: kitamatsuno.obs a), shimizubata.obs b), tourinkyo.obs c), and funayamabashi.obs d).

4.3. Starting a new BTOP project

The tool **y_mkproject.sh** allows the user to make a BTOP model project and requires the input of the project name with additional options for the tool' generated fujkawa.cnd file, see Box 1. The user specifies a name of the project, which is called "fujikawa" in the first example. In the second example, the fujkawa.cnd file has user specified "0" option for the precipitation (-p), temperature (-t) and EP/PET/LAI (-e) input files. The user also specifies the BTOP model spatial and temporal dimensions: 120 rows (-r 120), 120 columns (-c 120), 24 hour time step (-d 24) and 365 time steps (-s 365) of the BTOP simulation.

Box 1. Making a BTOP project with the y_mkproject.sh tool.

```
Usage: y_mkproject.sh [options] project_name

Example 1: -$y_mkproject.sh fujikawa
Example 2: -$y_mkproject.sh –t 0 –p 0 –e 0 –r 120 –c 120 –d 24 –s
365 fujikawa
```

After a successful use, the tool creates "input" and "output" folders with 17 sub-folders as well as 8 project files (Figure 4.3.1). The BTOP simulation results are stored in sub-directories of the "output" folder: "station" for the specified location and "final" for the each grid.

In the "input" folder, fujikawa.cnd file is main control file used to start BTOP simulations. The other files are located in "common", "initial", and "parameter" sub-folders. The "common" sub-folder contains files obtained elsewhere such as igbp.rtdpt and usda.theta0 files (Figure 4.3.1). The igbp.rtdpt file is the root depth by IGBP land cover type in the GLCC dataset (17 classes) (Appendix 3) and usda.theta0 represents field capacity and wilting point by United States Department of Agriculture (USDA) classification (10 classes) using the residual water content instead of moisture content at wilting point.

a)
```
- fujikawa
|-- input
|   |-- channel
|   |-- climate
|   |-- common
|   |   |-- igbp.rtdpt
|   |   `-- usda.theta0
|   |-- fujikawa.cnd
|   |-- initial
|   |   |-- fujikawa.dis
|   |   `-- fujikawa.sdbar
|   |-- misc
|   |-- parameter
|   |   |-- fujikawa.bp
|   |   |-- fujikawa.ddp
|   |   |-- fujikawa.n0c
|   |   |-- fujikawa.stc
|   |   `-- fujikawa.thd
|   |-- sce_ua
|   |   `-- fujikawa.acp
|   |-- soil
|   |-- station
|   |-- topo
|   `-- vegetation
`-- output
    |-- autoplot
    |-- final
    `-- station
```

b)

igbp_cover(no)	root_depth(m)
1	2.5
2	2.5
3	2.5
4	2.5
5	2.0
6	1.0
7	1.0
8	1.0
9	1.0
10	0.5
11	1.0
12	0.7
13	0.001
14	1.0
15	1.3
16	1.0
17	0.001

c)

soil	theta0	theta_fc	theta_r
1	0.395	0.091	0.020
2	0.410	0.125	0.035
3	0.435	0.207	0.041
4	0.451	0.270	0.027
5	0.485	0.330	0.015
6	0.420	0.255	0.068
7	0.476	0.318	0.075
8	0.477	0.366	0.040
9	0.426	0.339	0.109
10	0.492	0.387	0.056
11	0.482	0.396	0.090

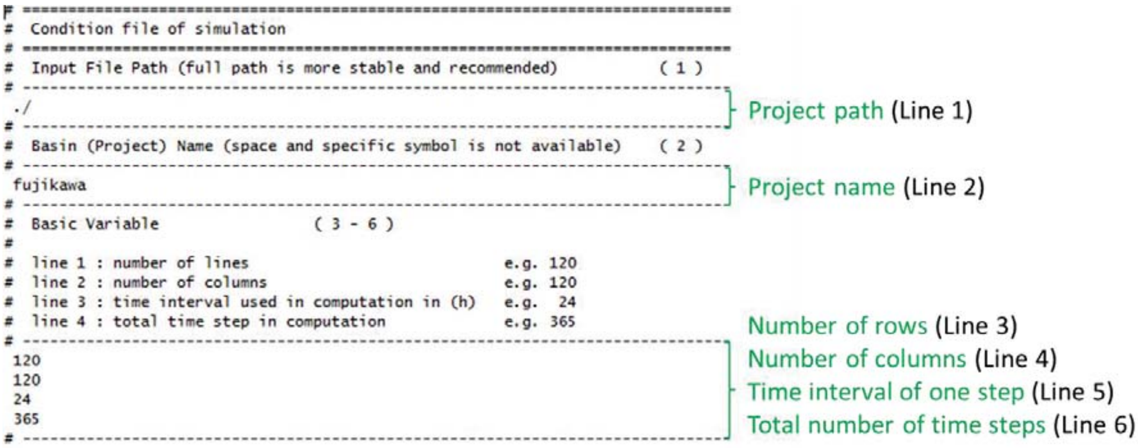
Figure 4.3.1 Folders and files of fujikawa project a), and igbp.rtdpt b) as well as usda.theta0 c) files.

Condition file (*.cnd) of fujikawa project

In Box 1, the fujikawa.cnd file was created with default (Example 1) or specified (Example 2) settings of the fujikawa BTOP project. A condition file (*.cnd) is required to start a BTOP model simulation and contains necessary information about the BTOP project. For example, the BTOP model simulation may include optional modules, which can be included or excluded in the *.cnd file. Therefore, the understanding of the *.cnd file settings is important for the BTOP model simulation.

The settings of the fujikawa.cnd file describe project details and dimensions in Lines 1-6 (Figure 4.3.2), simulation settings in Lines 7-14 (Figure 4.3.3), and specified output of the BTOP simulations in Lines 15-54 (Figure 4.3.4). The character "# indicates commented lines that are not used in the BTOP simulation and included for brief explanation of the settings.

In Figure 4.3.2, Line 1 is the path to BTOP project files and Line 2 indicates the project name, which is used for all created BTOP project files. The BTOP model dimensions are specified by number of rows (Line 3), number of columns (Line 4), time interval of the simulation (Line 5), and the total number of time steps in the BTOP simulation (Line 6). The BTOP model uses hourly time step and the 24 hours should be selected for the daily simulations in Line 5. The BTOP model simulation starts from 0 time step to the total number of time steps specified in Line 6. Note that the leap years need to be account explicitly in the total number of time steps. For example, if the simulation period is from 1995 to 2000, the total number of time steps for daily simulation equals to 365*6+2=2192, where 2 days are added for two leap years between 1996 and 2000.



```
# ============================================================================
#  Condition file of simulation
# ============================================================================
#  Input File Path (full path is more stable and recommended)          ( 1 )
# ----------------------------------------------------------------------------
 ./
# ----------------------------------------------------------------------------
#  Basin (Project) Name (space and specific symbol is not available)    ( 2 )
# ----------------------------------------------------------------------------
 fujikawa
# ----------------------------------------------------------------------------
#  Basic Variable                    ( 3 - 6 )
#
#  line 1 : number of lines                              e.g. 120
#  line 2 : number of columns                            e.g. 120
#  line 3 : time interval used in computation in (h)     e.g.  24
#  line 4 : total time step in computation               e.g. 365
# ----------------------------------------------------------------------------
 120
 120
 24
 365
# ----------------------------------------------------------------------------
```


Figure 4.3.2 Project details in Lines 1-6 of the fujikawa.cnd file.

Figure 4.3.3 shows BTOP simulation settings of available modules (Lines 7-11) and data input format temperature (Line 13) and precipitation (Line 14). The evaporation setting (Line 12) only indicates the input file format as the evaporation module is not available in the current version of the BTOP model.

The optional modules can be turned off with the option “0” (excluded from the BTOP simulation) and consists of: the Hortonian overland flow (Line 9), soil freezing model (Line 8), the snow model (Line 10), and reservoir model (Line 11).

The default option of river flow routing is “2” (Line 9), which indicates the modified Muskingum-Cunge routing method. The evaporation option (Line 12) is also mandatory and has “0” value, which indicated the input in the YHyM volume format. For the fujikawa project, the option “0” of both precipitation (Line 13) and temperature (Line 14) indicates gauge-based data, see “Forcing input” section.

```
#  Sellecting some calculation method           ( 7 - 12 )
#
#  line 1 : srmax/horton flow
#       column 1: on/off switch      :<0> off
#                                    :<1> on
#                                    :<2> parameterization for srmax
#       column 2: optional val       :<value> adjustment_coefficient
#       (*option for 1)              :
#  line 2 : soil freezing model      :<0> off  <1> : on
#  line 3 : routing model
# column 1: flow routing method:<0> MC (Ao et.al, 1999, JSCE)
#       (*required)                  :<1> modified Manning's method (by Hapu)
#                              :<2> Mod MC (Masutani et.al, 2009)
# column 2: threshold area     :<0>     : all grids
#       (*option for 1)              :<value> : contributing area,<v> will be discarded
#  line 4 : snow model               :<0> off          <1> : on
#  line 5 : reservoir model          :<0> off          <1> : simple operation
#  line 6 : evaporation file format(pet0,pet,lai)
#                  <0> volume input
#                  <1> shuttleworth_model  * not integrated yet, (offline)
#                  <2> read asc/bin file
#                  <3> 4 file (binary .flt) + ep/pet0/lai
#                  <4> 5 file (binary .flt) + ep/pet0/lai + pplsit
#                  <5> 4 file (binary .flt) + ep/pet0/lai *read at once(sceua)
# -------------------------------------------------------------------------------  Overland flow switch (Line 7)
 0                                                                                 Soil freezing switch (Line 8)
 0                                                                                 River flow routing option (Line 9)
 2  0                                                                              Snow process switch (Line 10)
 0                                                                                 Dam/reservoir switch (Line 11)
 0                                                                                 Evaporation file option (Line 12)
 0
# -------------------------------------------------------------------------------
#  line 1: Input File Switch (temperature   file .tmpt)                ( 13 )
#  line 2: Input File Switch (precipitation file .prec)                ( 14 )
#
# 0      :2 files (ascii table *suitable for station data)    +(AAIGRID .sit)*0
# 1      :1 file  (volume file format)
# 2      :N files (AAIGRID, timestep)    + (data_list.txt)
# 3      :N files (binary, 4 byte float) + (data_list_bin.txt)
# 4      :N files (binary, 4 byte float) + (data_list_bin.txt)+(AAIGRID .sit)
# 5      :N file  (binary, 4 byte float * timestep)
# 6      :N files (binary, 4 byte float * timestep)           +(AAIGRID .sit)*1
# 7      :N file  (binary, 4 byte float * timestep)                          *1
# 8 n1   :N file  (binary, 4 byte float * timestep)           +(AAIGRID .sit)*8
# 9 n1 n2:N file  (binary, 4 byte float * timestep)           +(AAIGRID .sit)*9
#
#  note: *0 : for temperature, spatial interporation using rapse ratio is
#                  also available, when aditional option(column 2) is set.
#                 (current available setting is as follows)
#            0 : normal (not apply spatial interporation  .tmpt(std fmt)
#            1 : normal (not apply spatial interporation  .tmpt(ext fmt)
#            2 : spatial interporation (required .tmptsit .tmpt(std fmt) .tmptcor)
#            3 : spatial interporation (required .tmptsit .tmpt(ext fmt) .tmptcor)
#
#  note: *1 : read at once, good for sceua
#  note: *8 : read only target grids from large domain.
#                  data file : 1 binary file  + sit file pointing reading area.
#                  n1  = ncols * nrows in precipitation file. e.g. 8 200
#  note: *9 : read only target grids from large domain.
#                  data file : N binary files + sit file pointing reading area.
#                  n1  = ncols * nrows in precipitation file. e.g. 9 200
#                  n2  = max. num of layer in each float binary file.
#                  (ex) 9 200 366
# -------------------------------------------------------------------------------
 0                                                                                 Temperature file option (Line 13)
 0                                                                                 Precipitation file option (Line 14)
# -------------------------------------------------------------------------------
```

Figure 4.3.3 Selecting BTOP modules (Lines 7-12) and temperature (Lines 13) and precipitation (Line 14) file formats.

The output options of the BTOP simulation are demonstrated in Figure 4.3.4 and are summarized below:

Time step of outputted initial values (Line 15)

Line 15 specifies a time step to output BTOP simulation results that can be used as initial values, see figure below. The specified time step is “364” to record *.qo, *.qi, *svz, *.srz, *.suz, and *.swe files at the “output/final/” folder. The “0” time step indicates no output of these files.

Outputting BTOP variables for each block (Line 16)

Line 16 choses to record internal variables and simulation results for each BTOP model block by specifying “1”. The recorded values are outputted in the *.brt file at “output/final/” folder and follow the number of blocks in the *.bk file. This option allows the user to evaluate BTOP performance at each block.

Outputting Upper basin of output point (Line 17)

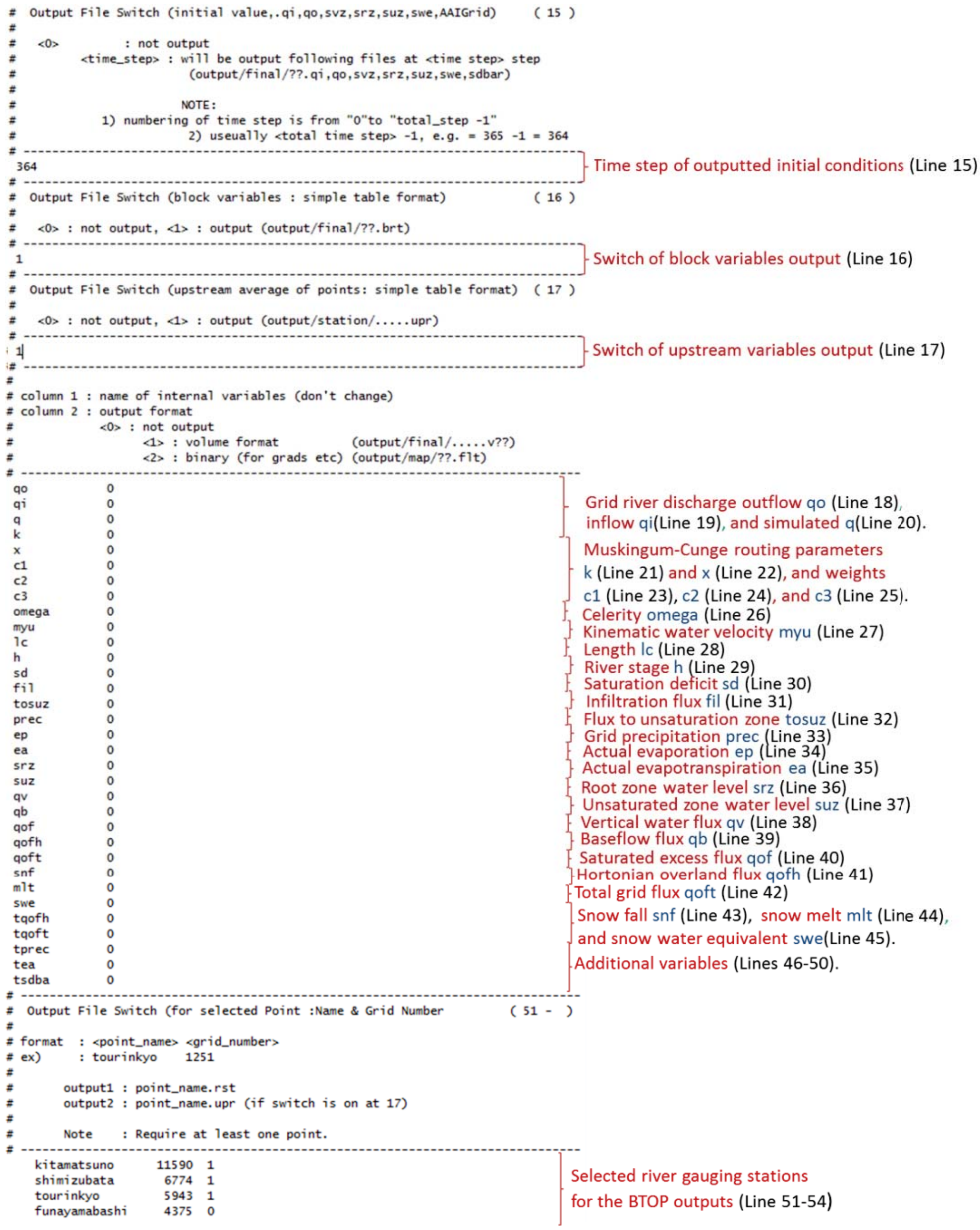
Line 17 choses to record BTOP results and internal variables at the user selected area by specifying “1”. The recorded values are outputted in the *.upr file, which contains spatial average values specified by the user in the *.umsk file.

Output of selected internal variables (Lines 18-50)

Lines 18-50 chose to output BTOP internal variables at each active BTOP grid for each time step of the simulation by specifying “1”. Each variable is recorded in a separate file, which has the YHyM package volumetric format (*.v*) and provided in Appendix 1. This is a very useful feature to evaluate the BTOP model performance and results. However, a large of model grids and a large number of simulation time steps will create large size output files, which will slow down BTOP model computation and may only be prepared with BTOP executable compiled for the 64-bit Linux OS.

Outputting BTOP results at selected grids (Lines 51-)

From Line 51, the user can select to output the BTOP simulation results at a specified grid in the *.rst file by specifying a location name and BTOP grid number of the selected location (Line 51). This grid number has to be updated by the user to include the actual location of the constructed project. In addition, the user can select additional points to specify locations of river gauging station as shown later in the manual. These user specified points can used for the BTOP model calibration with the use of BTOP output files for river (*.rst) and an average values for the upstream drainage area (*.upr). The option “1” in the third column of the *.cnd file indicates that the observed river discharge is used in calculating statistical BTOP model performance.



```
#  Output File Switch (initial value,.qi,qo,svz,srz,suz,swe,AAIGrid)     ( 15 )
#
#   <0>          : not output
#        <time_step> : will be output following files at <time step> step
#                      (output/final/??.qi,qo,svz,srz,suz,swe,sdbar)
#
#                      NOTE:
#           1) numbering of time step is from "0"to "total_step -1"
#                      2) useually <total time step> -1, e.g. = 365 -1 = 364
# ---------------------------------------------------------------------------
 364
# ---------------------------------------------------------------------------
#  Output File Switch (block variables : simple table format)           ( 16 )
#
#   <0> : not output, <1> : output (output/final/??.brt)
# ---------------------------------------------------------------------------
 1
# ---------------------------------------------------------------------------
#  Output File Switch (upstream average of points: simple table format)  ( 17 )
#
#   <0> : not output, <1> : output (output/station/.....upr)
# ---------------------------------------------------------------------------
 1
# ---------------------------------------------------------------------------
#
# column 1 : name of internal variables (don't change)
# column 2 : output format
#            <0> : not output
#                  <1> : volume format           (output/final/.....v??)
#                  <2> : binary (for grads etc)  (output/map/??.flt)
# ---------------------------------------------------------------------------
qo          0
qi          0
q           0
k           0
x           0
c1          0
c2          0
c3          0
omega       0
myu         0
lc          0
h           0
sd          0
fil         0
tosuz       0
prec        0
ep          0
ea          0
srz         0
suz         0
qv          0
qb          0
qof         0
qofh        0
qoft        0
snf         0
mlt         0
swe         0
tqofh       0
tqoft       0
tprec       0
tea         0
tsdba       0
# ---------------------------------------------------------------------------
#  Output File Switch (for selected Point :Name & Grid Number        ( 51 -  )
#
# format   : <point_name> <grid_number>
# ex)      : tourinkyo    1251
#
#       output1 : point_name.rst
#       output2 : point_name.upr (if switch is on at 17)
#
#       Note    : Require at least one point.
# ---------------------------------------------------------------------------
    kitamatsuno      11590  1
    shimizubata       6774  1
    tourinkyo         5943  1
    funayamabashi     4375  0
```


Figure 4.3.4 Specified BTOP output options and variables (Lines 15-54).

4.4. Topographic Preprocessing

Model grid files (*.gn, *.dx, *.dy, *.1ga)

The **y_gridsize.sh** tool prepares the BTOP grid files with the simplest usage demonstrated in Box 2. The tool reads the grid size in the degree format [op1], takes ASCII header from the dem file [op2] and requires the location of input *.dem file, which is placed in the “topo” folder for the fujikawa project.

Box 2 Preparing BTOP grid files with the y_gridsize.sh tool.

```
Usage: y_gridsize.sh [op1] [op2] project_name
-$y_gridsize.sh –l –m input/topo/fujikawa
```

The tool outputs four files with extensions *.gn, *.dx, *.dy, and *.1ga in the "topo" folder, see Figure 4.4.1. The *.gn file contains a unique BTOP grid number. The grid number, *gn[-]*, is calculated from the upper left to the bottom right corner from

$$gn = x + ncol * y \quad (32)$$

where x- and y- are the coordinates of the grid center and ncol is the column number. The *.dx and *.dy files are the grid size in x- and y- directions in meters, respectively. The *.1ga file refers to one grid area in km^2 calculated with *.dx and *.dy files.

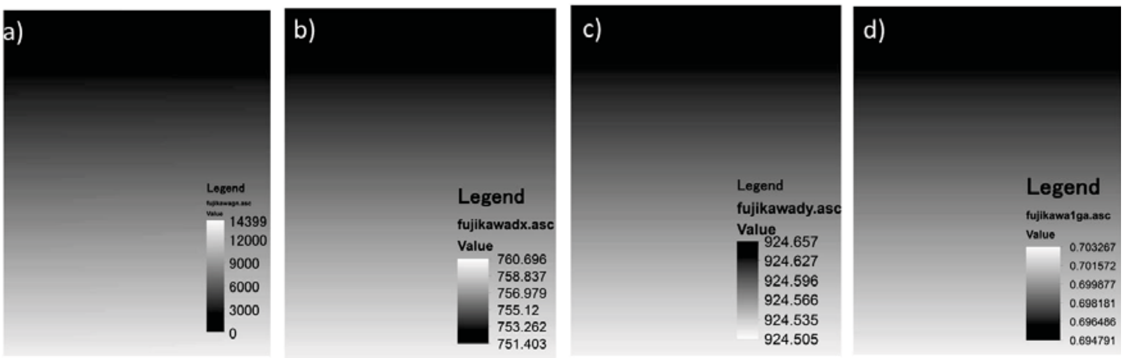


Figure 4.4.1 Generated BTOP files: grid number fujikawa.gn a), grid size in x-direction fujikawa.dx b), grid size in y-direction fujikawa.dy c), and the grid area fujikawa.1ga d).

River network files (*.fil, *.dhv, *.dhd, *.fd, *.facc, *.bsn, *.otl, *.gen)

In the first DEM pre-processing step, the tool **y_rivernet.sh** is used with four arguments as shown in Box 3. The first two arguments specify the location [pro_i] of the input files and the location to output files [pro_o]. The other two arguments specify the flow direction [op1] and the DEM correction method [op2]. The sw1 specified the expected flow direction in the generated topography and has four choices: 1 - upper left to lower right (UL2LR), 2 - upper right to lower left (UR2LL), 3 - lower left to upper right (LL2UR), and 4 - lower right to upper left (LR2UL). The sw2 specifies the DEM fill method based on 1 -maximum slope (recommended) or 2-minimum elevation.

Box 3 DEM pre-processing with the y_rivernet.sh tool.

```
Usage: y_rivernet.sh [pro_i] [pro_o] [op1] [op2]
-$y_rivernet.sh input/topo/fujikawa input/topo/fujikawa 2 1
```

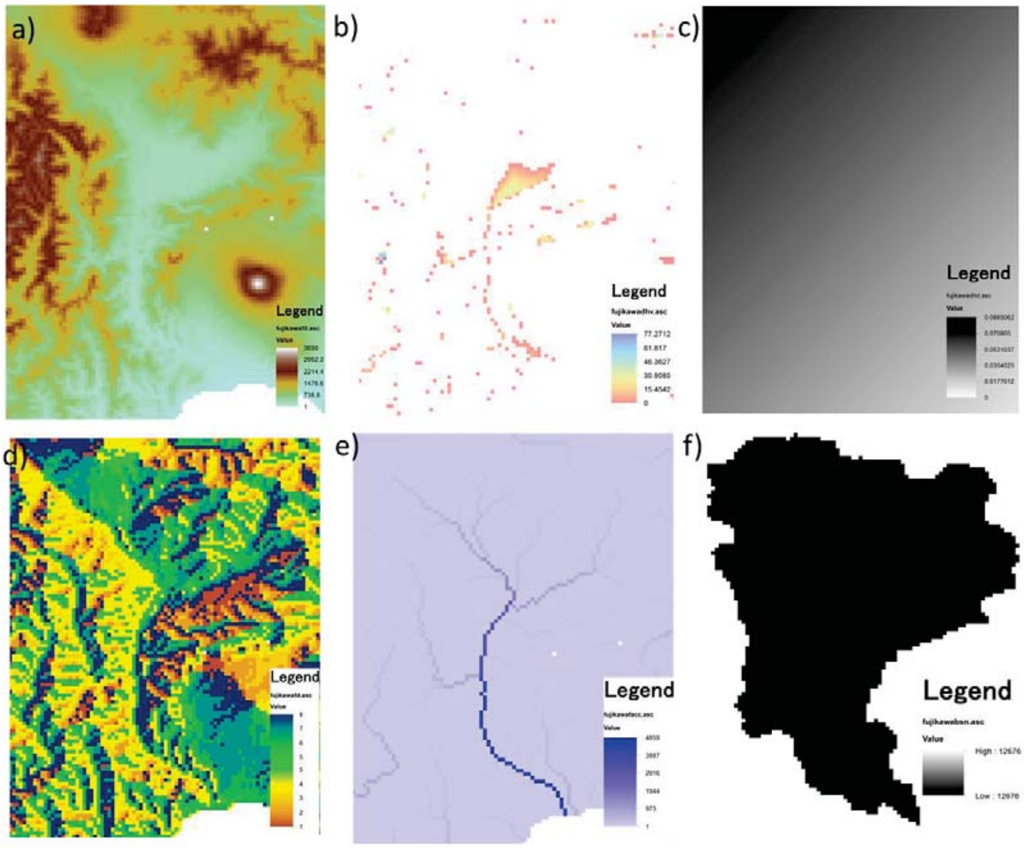


Figure 4.4.2 Corrected DEM fujikawa.fil a), the vertical difference between the original and corrected DEM fujikawa.dhv b), the horizontal difference between the original and corrected DEM fujikawa.dhd c), 8-way flow direction fujikawa.fd d), flow accumulation fujikawa.facc e), and BTOP active grids fujikawa.bsn f).

The tool generates *.otl, and *.gen files in table format, and ASCII format files (Figure 4.4.2): *.fil, *.dhv, *.dhd,*.fd, *.facc, and *.bsn. The *.otl file stores parameters of the river basin outlet. The *.fil file contains DEM with corrected elevation values and is produced from the original DEM *.dem by filling artificial pits. The *.dhv and *.dhd files are vertical and horizontal differences between original and *.fil DEMs, respectively. The *.fd file contains flow directions from 1 to 8 assigned clockwise starting at the upper left corner. The *.facc file represents the flow routing scheme and contains flow accumulation IDs with the maximum ID value at the basin outflow. The *.bsn file indicated the active watershed are of the BTOP model calculation.

Basic DEM files (*.dh, *.dl, *.ii, *.area, *.bb, *.facc2, *.rto, *.li, *.ai, *.atb)

The tool **y_basics.sh** is used in the second DEM preprocessing step (Box 4). The tool uses files prepared the previous DEM pre-processing step and requires a path of the “topo” folder for both input [i_path] and output [o_path] location values.

Box 4 The y_basics.sh tool for the DEM pre-processing.

```
Usage: y_basics.sh [i_path] [o_path]

-$y_basics.sh input/topo/fujikawa input/topo/fujikawa
```

The tool produces a table of flow routing calculation order (*.rto) and ASCII format files: *.dh, *.dl, *.ii, *.area, *.bb, *.facc2, *.li, *.ai, and *.atb. Figure 4.4.3 shows first five rows of the fujikawa.rto file. The *.dh file is the terrain slope file, which is calculated from corrected DEM (*.fil) and 8-flow direction (*.fd) files (Figure 4.4.4). The *.dl file is the river channel length in meters. The *.ii file is the slope, *tan β*, and equals to

$$\tan \beta = ii = dh/dl \tag{33}$$

The *.area file refers to the catchment area of each grid and is calculated based on *.ii, *.fd, and *.1ga files. The *.bb file is the channel width, *w*[m], calculated as

$$w = \alpha A^{C} \tag{34}$$

where $A[km^2]$ is contributing area obtained from the *.area file, and α[-] and *C*[-] are the constant parameters related to a river basin shape. The default parameters of the **y_b.exe** tool are α = 10 and *C* = 0.5. The river width of the *.bb file can be adjusted by manually modifying the *.bb file or re-running the **y_b.exe** tool with new parameters.

The *.facc2 files is a cropped flow accumulation file, which is produced from *.bsn and *.facc files. The *.rto file is the calculation order of grid in the flow routing and is calculated based on *.facc2 and *.fd files. In the *.li file, the unit contour length, *li*, is calculated from *.facc, *.fd, *.dx and *.dy files using single flow direction algorithm:

$$li = dx \quad \text{when vertical} \tag{35a}$$

$$li = dy \quad \text{when horizontal} \tag{35b}$$

$$li = 0.5 * (dx^2 + dy^2)^{0.5} \quad \text{when diagonal} \tag{35c}$$

where dx[m] and dy[m] are distance in the x- and y-directions, respectively. The *.atb file is the topographic index multiplied by the parameter "b".

ord_dept	ord_dept_g	ord_y	ord_x	ord_dest	ord_dest_g
0	404	3	44	2104	525
1	513	4	33	2107	632
2	514	4	34	2108	633
3	521	4	41	3242	520

Figure 4.4.3 First five lines of the flow routing order in the fujikawa.rto file.

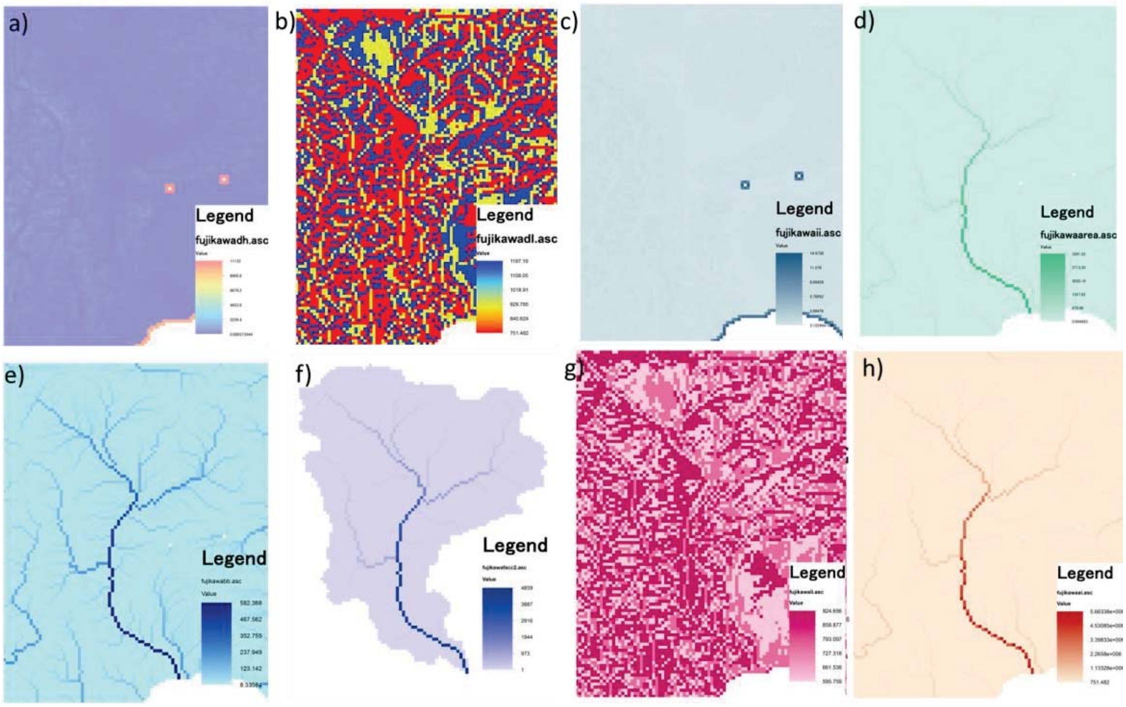


Figure 4.4.4 The terrain slope fujikawa.dh a), river channel length in meters fujikawa.dl b), river bed slope fujikawa.ii c), the grid catchment area in km² fujikawa.area d), channel width in meters fujikawa.bb e), active model area flow accumulation the fujikawa.facc2 f), unit contour length in meters fujikawa.li g), and the contributing area fujikawa.ai h).

Effective contributing area files (*.fa, *.afa, *.gx, *.check)

In Box 5, the **y_afa.exe** tool reads *.fd, *.bsn, *.dx, *.dy, *.area, and *.dl files and produces four ASCII files (Figure 4.4.5): *.fa, *.afa, *.gx, and *.check. The tool calculates effective flow contributing area and requires a project name [i_project], a path to the input folder [i_path], a path to the output folder [i_output], and a value of the b parameter [i_b], which ranges from 0.1 km to 10 km with default value of 1 km. The *.gx file contains values of the g(x) [1/m] computed using the equation [2]:

$$\text{tot\_gx}=-\exp(-(\text{dl}+\text{increment})/b)+\exp(-\text{dl}/b) \quad (36)$$

The *.check file is a spatial check of the g(x) function. The *.fa file contains ratios of the contributing area between 0 and 1 and is computed as

$$f(a_i)\,(\text{locc},\text{locr})= f(a_i)\,(\text{locc},\text{locr})+ a_0*\text{tot\_gx}/a_i \quad (37)$$

where locc and locr are the column and rows to identify the location of grid i, respectively. The effective contributing area in km^2 is prepared in the *.afa file by multiplying *.fa file.

Box 5 Calculating effective contributing area using y_afa.exe

```
Usage: y_afa.exe [i_project] [i_path] [i_output] [i_b]
-$y_afa.exe fujikawa input/topo/ input/topo/ 1.0
```

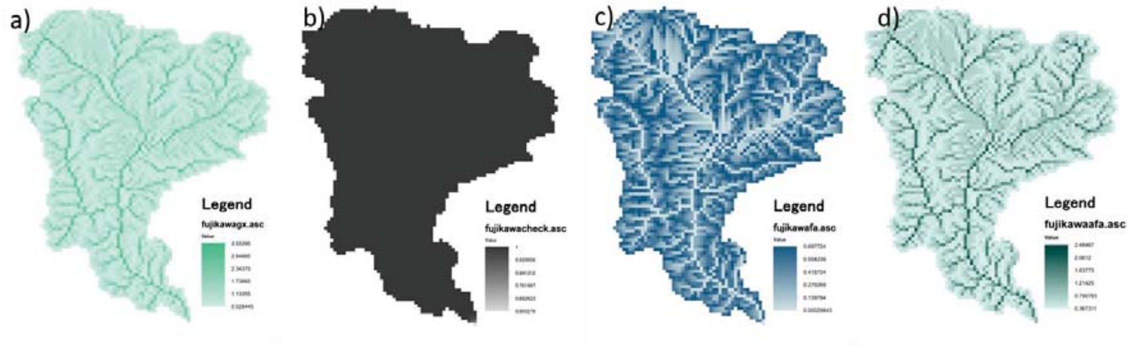


Figure 4.4.5 The g(x) function in 1/m fujikawa.gx a), check of the g(x) function fujikawa.check b), contributing area between 0 and 1 fujikawa.fa c), and contributing area in km² fujikawa.afa d).

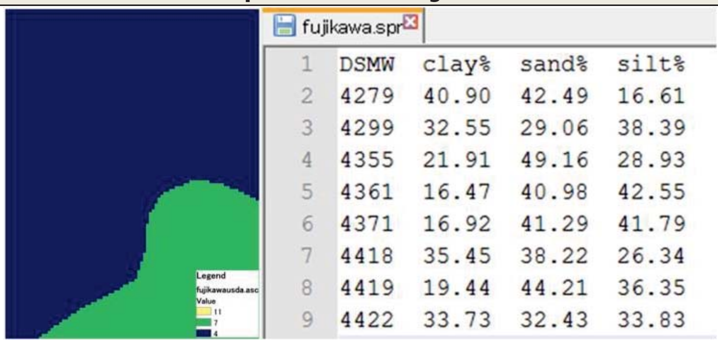
Soil property based on USDA Classification (*.spr, *.usda)

The **y_fao.asc2spr.exe** and **y_fao.asc2usda.exe** tools are used to prepare USDA soil property and type files is demonstrated in Box 6. The tool uses the *.fao file, which was created by the user and copied to the "soil" folder. To use the tool, run **y_fao.asc2spr.exe,** then *.spr, as soil property data file, will be generated. Then, **y_fao.asc2usda.exe** is used to get USDA classification ID using *.fao file. The arguments are: infile is the name of input file (i.e. *.fao data file), nrows is the numbers of rows in the file, ncols is the numbers of columns in the file, lut is the look up table for a conversion of soil properties, and out_usda_file is the name of output file (*.usda).

Box 6 Preparation of soil files with y_fao.asc2spr.exe and y_fao.asc2usda.exe tools.

```
Usage: y_fao.asc2spr.exe [infile] [nrows] [ncols] [lut]
[out_spr_file]
-$y_fao.asc2spr.exe input/soil/fujikawa.fao 120 120
/opt/YHyM/data/fao-usda-translate.txt2

Usage: y_fao.asc2usda.exe [infile] [lut] [out_usda_file]
[input/soil/fujikawa.spr]
-$y_fao.asc2usda.exe input/soil/fujikawa.fao /opt/YHyM/data/fao-
    usda-translate.txt2 input/soil/fujikawa.usda
```



1	DSMW	clay%	sand%	silt%
2	4279	40.90	42.49	16.61
3	4299	32.55	29.06	38.39
4	4355	21.91	49.16	28.93
5	4361	16.47	40.98	42.55
6	4371	16.92	41.29	41.79
7	4418	35.45	38.22	26.34
8	4419	19.44	44.21	36.35
9	4422	33.73	32.43	33.83

Figure 4.4.6 USDA soil property fujikawa.usda a) and type fujikawa.spr b) files.

4.5. Specifying BTOP blocks and output area (*.dis, *.cnd)

In the BTOP model, selected river gauging stations can be used for specifying BTOP blocks and masking output area of the BTOP model. The default BTOP project has one block and output area are specified and should be updated by the user in the *.dis and *.cnd files depending on the user's intent. Additional river gauging stations can be also specified in both files. These *.dis and *.cnd files are not related with each other allowing a greater flexibility in the BTOP simulation and evaluation of model results. For example, the user can run one block BTOP model while evaluating several sub-basin areas as well as can have several BTOP blocks while outputting BTOP results for the entire model area.

Prior updating the *.dis and *.cnd files, the user should confirm that the river gauging station is located in the main river channel indicated in the *.facc2 file and record the BTOP grid number in the *.gn file of the corresponding river gauge station location. The location of the gauging stations can be identified with the use of Geographical Information System (GIS) software, e.g. ArgGIS, QGIS, etc. The user should visually inspect the locations of river gauging stations with the clipped flow accumulation *.facc2 file and grid number *.gn file. Once the correct BTOP grid is selected, the grid number has to be recorded to update in the *.dis and *.cnd files.

For the block sub-division, the user has to update *.dis file at the "initial" folder, see Figure 4.5.1a-b. The BTOP blocks are used for soil moisture deficit calculation and allow the user to introduce more calibration parameters describe variations in topography. The *.dis file has three columns: station name, BTOP grid number and the initial discharge value in m^3/s. Note that the total number of lines in the *.dis file should be equal to the header plus the number of entries by the user.

In the updated *.cnd file (Lines 51-54), four river gauging stations are selected with the BTOP grid numbers evaluating only four sub-basin area, see Figure 4.5.1c-d.

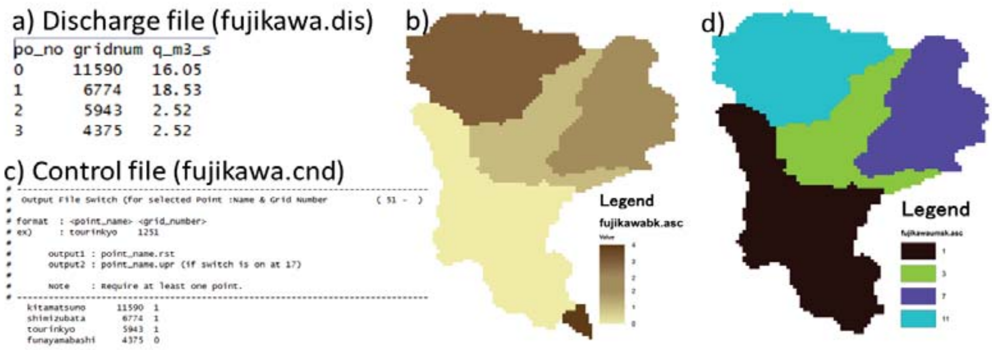
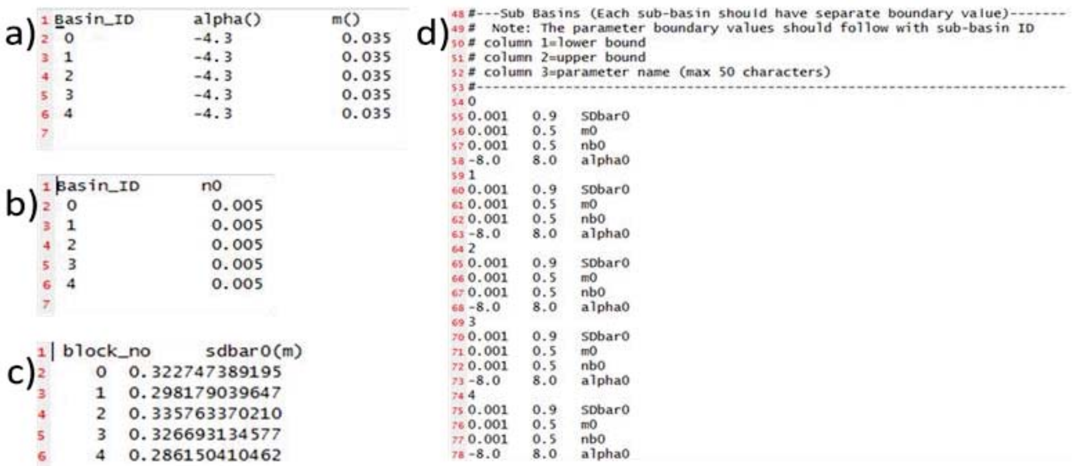


Figure 4.5.1 Grid numbers of block outlet fujikawa.dis a), five blocks fujikawa.bk b), four selected river gauge stations in fujikawa.cnd c), and mask fujikawa.umsk d).



a)
```
Basin_ID	alpha()	m()
0	-4.3	0.035
1	-4.3	0.035
2	-4.3	0.035
3	-4.3	0.035
4	-4.3	0.035
```

b)
```
Basin_ID	n0
0	0.005
1	0.005
2	0.005
3	0.005
4	0.005
```

c)
```
block_no	sdbar0(m)
0	0.322747389195
1	0.298179039647
2	0.335763370210
3	0.326693134577
4	0.286150410462
```

d)
```
#---Sub Basins (Each sub-basin should have separate boundary value)-------
#  Note: The parameter boundary values should follow with sub-basin ID
# column 1=lower bound
# column 2=upper bound
# column 3=parameter name (max 50 characters)
#---------------------------------------------------------------------
0
0.001	0.9	SDbar0
0.001	0.5	m0
0.001	0.5	nb0
-8.0	8.0	alpha0
1
0.001	0.9	SDbar0
0.001	0.5	m0
0.001	0.5	nb0
-8.0	8.0	alpha0
2
0.001	0.9	SDbar0
0.001	0.5	m0
0.001	0.5	nb0
-8.0	8.0	alpha0
3
0.001	0.9	SDbar0
0.001	0.5	m0
0.001	0.5	nb0
-8.0	8.0	alpha0
4
0.001	0.9	SDbar0
0.001	0.5	m0
0.001	0.5	nb0
-8.0	8.0	alpha0
```

Figure 4.5.2 Four BTOP files with block-dependent parameters: fujikawa.bp a), fujikawa.n0c b), fujikawa.sdbar c), and fujikawa.acp d).

Block sub-division (*.bk)

The **y_bk.exe** tool sub-divides the BTOP model area into blocks based on specified river gauging stations in the *.dis file or just replacing basin boundary file (*.bsn) as one whole block. The tool is demonstrated in Box 7. The tool requires the station location *.dis file (i_pnt), the flow direction *.fd file (i_fd) and the basin *.bsn file (i_bsn) of the active BTOP model area and outputs the block sub-divided *.bk file (o_bk). A visual check of the *.bk file is needed to confirm a proper sub-division of blocks, see Figure 4.5.1. Several iterations of visual checks may be required to achieve the proper basin sub-division. For example, the user should check grid numbers in *.dis file and verify that the grid points lie on model generated river lines (by overlaying the station with *.facc data file).

Box 7 Block sub-division with y_bk.exe tool.

```
Usage: y_bk.exe [i_pnt] [i_fd] [i_bsn] [o_bk]

-$y_bk.exe input/initial/fujikawa.dis input/topo/fujikawa.fd
input/topo/fujikawa.bsn input/topo/fujikawa.bk
```

Block-dependent parameter files (*.bp, *.n0c, *.sdbar and *.acp)

The parameter *.bp, *.n0c, *.sdbar, and *.acp files must be modified manually to match total number of blocks in the *.bk file. For each block, a new line should be started with the first column indicating a block ID starting from 0 and parameters in the rest of the columns. In the fujikawa project, the *.bk file has five blocks in each *.bp, *.n0c, *.sdbar and *.acp files, see Figure 4.5.2. The *.bp and *.n0c files are located in the "parameter" folder, the *.sdbar file - in the "initial" folder, and the *.acp file - in the "sce_ua" folder.

Masking a selected area (*.umsk)

The tool **y_point_mask.exe** allows the user to mask an area for the output of BTOP variables using river gauging stations, see Box 8. The tool is demonstrated in the Box below and uses *.cnd and *.fd files to produce the *.umsk file in the "output/station" folder. The switch "-14" indicates the file format of the BTOP model version 1.4.*

The user specified area, the masked area is used by the BTOP model to output river discharge at the river station, to calculate the spatial average of BTOP variables upstream of the station and to give a statistical summary for the masked area.

Box 8 Selecting BTOP output area with the y_point_mask.exe tool.

```
Usage: y_point_mask.exe [-14] I_CND I_FD O_UMSK

-$y_point_mask.exe -14 input/fujikawa.cnd input/topo/fujikawa.fd
output/station/fujikawa.umsk
```

4.6. Initial conditions (*.msk, *.qi, *.qo, *.srz, *.suz)

The **y_mkinits.sh** tool uses three files (*.dis, *.fd, *.area) to produce BTOP model initial condition files, see Box 9. The location of input and output files is given by the first (i_path) and second (o_path) arguments, respectively. The additional option should be used as "-14" and indicates the 1.4.* version of the BTOP model.

Box 9 Preparation of initial values with the y_mkinits.sh tool.

```
Usage: y_mkinits.sh [i_path] [o_path] [option:-14]

-$y_mkinits.sh input/topo/fujikawa input/initial/fujikawa -14
```

After a successful use of the tool, five initial condition files are produced (*.msk, *.qi, *.qo, *.srz, *.suz). The *.msk file is a mask file for the initial discharge calculations. The *.qo and *.qi file are the output and input initial river discharge from a grid, respectively. The *.srz file is the root storage in meters for the initial time step. The *.suz file is the unsaturated zone storage in meters for the initial time step.

4.7. Forcing Input Data

Precipitation (*.prec) / Temperature (*.tmpt)

The current version of the BTOP model can utilize nine formats for precipitation and temperature data (Table 4.7.1). These formats are selected in Line 13 and 14 of the *.cnd file and the summary of these file formats is provided below.

Gauging station data (Option 0)

The gauging station data of precipitation and temperature is used with "0" option. For the "0" option, a time-series of gauging station data is requires with a Thiessen polygon of the respective stations. The precipitation (*.prec) and temperature (*.tmpt) files need to be prepared in the format, see Figure 4.7.1. For the fujikawa project, the *.prec file contains daily precipitation of 14 observation stations and consists of 14 columns (number of observation stations) and 366 rows (1st row is ID of observation stations and 365 rows for gauging values of daily rainfall in a year).

Table 4.7.1 File formats of precipitation and temperature data.

ID	Data Type	# of files	Grid size	Location	Additional files	Comment
0	Station	One	Same	climate/	*.precsit/*.tmptsit	Mask of grid size
1	YHyM			climate/	*.precsit/*.tmptsit	Mask of grid size
2	ASCII	Time steps		climate/prec/	data_list_.txt	List of input files
3	Binary 4 byte float			climate/prec/	data_list_bin.txt	List of input files
4		One	Less	climate/	data_list_bin.txt *.precsit/*.tmptsit	List of input files Mask of grid size
5			Same	climate/	-	-
6			Less	climate/	*.precsit/*.tmptsit	Mask of grid size
7				climate/	-	-
8				climate/	-	-
9				climate/	Additional files	

The **y_thiessen.exe** tool makes the Thiessen polygon from precipitation and temperature observation stations from manually prepared files. The rainfall (*.precpnt) file needs to be prepared in the input/climate directory for Thiessen polygon calculation, see figure below. The point file consists of station ID in 1st column, longitude in the 2nd column and latitude in the 3rd column.

For the temperature files, the *.tmpt file has the same format, but the number of stations and their locations can be different in the temperature point (*.tmptpnt) file. Note that the Thiessen polygons in the fujikawa.precsit file can be also different from the fujikawa.tmptsit file.

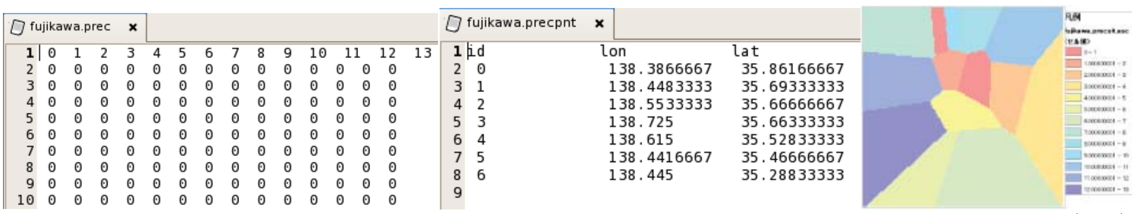


Figure 4.7.1 Precipitation time-series data for each station in the fujikawa.prec file(left), location of the rainfall gauging stations in the fujikawa.precpnt file (middle) and Thiessen polygons in the fujikawa.precsit file (right).

The **y_thiessen.exe** tool usage is demonstrated in Box 10. The tool creates the Thiessen polygons of precipitation (*.precsit) or temperature (*.tmptsit) files in the ESRI ASCII format. Note that these Thiessen polygons can be different for temperature and precipitation stations. The `I_PNTFILE` is the point data input file name such as *.precpnt or *.tmptpnt. The number of columns and rows are specified by `I_NCOL` and

I_NROW, respectively. The **I_XLL** and **I_YLL** are the x- and y-coordinates of the lower left corner, respectively. The cell size is given by **I_CS** and the nodata value - **I_ND**. The output file name of *.precsit or *.tmptsit is specified by **O_OUT**.

Box 10 Precipitation/temperature data with the y_thiessen0.exe tool.

```
Usage:y_thiessen.exe [i_pntfile] [i_NCOL] [i_NROW] [i_XLL]
[i_YLL] [i_CS] [i_ND] [o_OUT]

Example 1: -$y_thiessen.exe fujikawa.precpnt 120 120 138 35
        0.00833 -9999  fujikawa.precsit
Example 2: -$y_thiessen.exe fujikawa.tmptpnt 120 120 138 35
        0.00833 -9999  fujikawa.tmptsit
```

YHyM format (Option #1)

The YHyM format file is extended AAIGrid format and contains all time steps in one file.

ASCII format with several files (Option #2)

The ASCII format file has one file for one simulation step in the AAIGRID (ESRI ACCII raster file format). The spatial resolution of the data and grids is the same.

Binary format with several files (Option #3)

The option #3 requires several 4 byte float binary files with the same resolution.

Binary format with one file (Option #4)

The option #4 requires two ASCII files. The data file includes all time steps and can have data resolution larger than the BTOP model cell. For example, the BTOP model is 0.1 degree (deg) resolution while the prepare file has 0.2 deg resolution. The ASCII file (*.precsit/*.tmptsit) has to have the same resolution as the BTOP model.

Binary format with one file (Option #5)

The option #5 requires 4 byte float binary file with data resolution equal to the BTOP grid resolution. For example, the grid of 0.1deg will require *.prec/*.tmpt files of 0.1deg.

Binary format with ASCII file (Option #6)

The option #6 requires two files: 4 byte float binary and ASCII file. The binary file includes all time steps and can have data resolution larger than the BTOP model cell. For example, the BTOP model is 0.1 deg resolution while the binary file has 0.2 degree resolution. The ASCII file has to have the same resolution as the BTOP model.

Binary format in one file (Option #7)

The option #7 requires 4 byte float binary file with data resolution equal to the BTOP grid resolution. For example, the grid of 0.1deg will require *.prec/*.tmpt files of 0.1deg. This option is read at once before time loop and is good for SCEUA optimization.

Special format (Option #8)

The option #8 is developed for special cases of Global BTOP application [8].

Evaporation / Evapotranspirtion / Leaf Area Index (*.ep, *.pet0 and *.lai)

Potential interception evaporation (PET_o) (*.pet0), potential evapotranspiration (PET) (*.ep), and leaf area index (LAI) (*.lai) files need to be prepared for the BTOP model simulation with the supplementary Shuttleworth-Wallace tool or obtained from other sources. In the BTOP model, these files can be read from several format options, which are specified in the *.cnd file. For the "0" option, the ASCII and 4 byte binary format files can be prepared with the use of **yhym_pet.exe** or **yhym_pet_bin.exe** tool, respectively.

Shuttleworth-Wallace yhym_pet*.exe tool

The tool **yhym_pet.exe** or **yhym_pet_bin.exe** uses Shuttleworth-Wallace formula to produce *.ep, *.pet0, *.lai output files (O) using seven input files (I) with parameters: mean daily temperature, diurnal temperature range, average actual vapour pressure, wind speed measured at weather station, cloud cover, daily sunshine duration, extraterrestrial radiation, mean daily temperature in previous month, and the Normalized Vegetation Index (NDVI). For each parameter, a file needs to be prepared in the "input/climate" folder. In the YHyM/PET tool, the *.ep, *.pet0, *.lai files can be created in the ASCII format using and in the 4 byte binary (Box 11).

Box 11 Precipitation/temperature data with the yhym_pet*.exe tool.

```
Usage: yhym_pet_bin.exe [arg 1] – [arg 18]
 -$yhym_pet_bin.exe [1] – [18]
```

The tool **yhym_pet.exe** or **yhym_pet_bin.exe** requires the following <1> is the number of rows, <2> is the number of columns, <3> is the binary file type (2byte signed integer) .dem file (m), <4> is the binary (1byte signed integer) .igbp file (17 classes); <5> is the binary: (binary: 2byte signed integer) .ndvi file (-1000..+1000); <6> is the binary (4byte float *1 col) .Ra file ($MJ/m^2/day$); <7> is the binary (4byte float) .cloud file (%/10); <8>: is the binary (4byte float*1 col) .day file (hour); <9>: is the binary (4byte float) diur.T file (C); <10> is the binary (4byte float) mean T file (^oC); <11> is the binary (4byte float) mean T_mon file (^oC); <12> is the binary (4byte float) vapour p.vap file (kPa); <13> is the binary (4byte float) wind speed file (m/s); <14> is the binary (4byte float) delta t file (hour); <15> is the binary (4byte float) total step file (step); <arg 16> is the outout directory; <17> is the output prefix; <18> is the option (0,1,2).

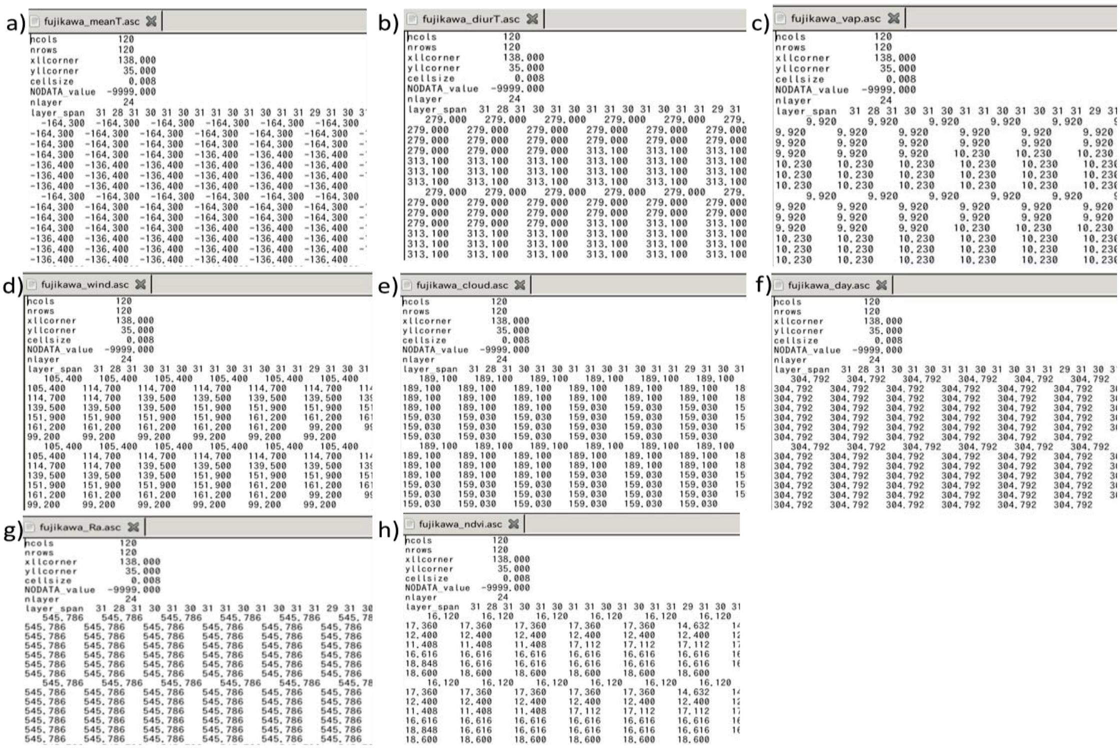


Figure 4.7.2 Input forcing data files of the yhym_pet.exe tool: the mean daily temperature fujiakawa.meanT a), the diurnal temperature range fujikawa.diurT b), the average actual vapour pressure fujikawa.vap c), wind speed measured fujikawa.wind d), cloud cover fujikawa.cloud e), daily sunshine duration fujikawa.day f), extraterrestrial radiation fujikawa.Ra g), and the NDVI index fujikawa.ndvi h).

YHyM Volume file format (Option #0)

The YHyM volume format file is extended AAIGrid format and contains all the time steps in one file, see figure below.

Special file format (Option #1)

The option #1 format is reserved for BTOP module calculation of climatic input within each BTOP time step and is not utilized in the current BTOP version.

Binary or AAIGrid format with multiple files (Option #2)

The option #2 is 4 byte float binary or AAIGrid format, which have multiple files. The data resolution equals to the BTOP grid resolution.

Binary format with one file (Option #3)

The option #3 is 4 byte float binary with one file, which has the data resolution equals to the BTOP grid resolution.

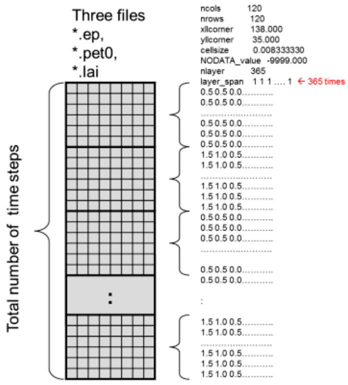


Figure 4.7.3 YHyM format of fujikawa.ep, fujikawa.pet, and fujikawa.lai files.

4.8. Check of the prepared BTOP files

Table 4.8.1 summarizes locations of BTOP project files by the project directory. The user should utilize the **y_CheckInputFiles.exe** tool to check the correctness of the prepared *.ii, *.fao, *.afa files (Box 12). The tool requires the name of condition file and has two options: file modification with "–m" and the water ID in the FAO map.

Box 12 Check of BTOP files with the y_CheckInputFiles.exe tool.

```
Usage: y_CheckInputFiles.exe [-m ] [-w water_id ] cnd_file_name
-$y_CheckInputFiles.exe fujikawa
```

Table 4.8.1 The BTOP project files, see description of BTOP files in Appendix 1.

Folder/file		Files
input	channel	*.n
	climate	*.prec, *.precsit, *.precpnt, *.tmpt, *.tmptpnt, *.pplsit, *.tmptsit, *.ep, *.pet0
	common	igbp.rtdpt, usda.theta0
	initial	*.dis, *.msk, *.qi, *.qo, *.sdbar, *.srz, *.suz, *.svz, *.sto, *.swe
	parameter	*.bp, *.n0c, *.stc, *.thd
	sce_ua	*.acp, *.scein
	soil	*.spr, *.fao, *.usda, *.d0_tanb, *.dba, *.gm, *.gmb, *.k0, *.srm, *.t0
	station	-
	topo	*.rto, *.ii, *.bk, *.1ga, *.li , *.bb, *.dl, *.area, *.fd, *.bsn, *.dx, *.dy, *.afa, *.dh, *.facc, *.facc2, *.gen, *.gn, *.otl, *.fa
	vegetation	*.igbp, *.lai
	reservoir	*.res, *.rid, *.wu
	*.cnd	-
output	final	*.brt, *.d0_tanb, *.sdbar, *.qi, *.qo, *.sd, *.srz, *.sto, *.suz, *.svz, *.vqo, *.vsd, *.swe
	station	<station#1>.obs, <station#2>.obs ….., *.umsk
	*.crit	<station#1>.rst, <station#2>.rst…..
	outlet2.rst	<station#1>.upr, <station#2>.upr…..

Note: * is the project name. Blue shading indicates manually prepared files and the gray shading indicates automatically generated files by the successful BTOP run. The yellow shading indicates that these file are created depending on the selected options in the cnd file.

5. Fujikawa BTOP project simulation

5.1. Running fujikawa project with BTOP executable file

Box 13 demonstrates the simulation of fujikawa project with the BTOP executable file, BTOP1.4.*.exe, by specifying the fujikawa.cnd file, which is located in the “input” folder of the project. The BTOP executable file is located in the “opt/YHyM/bin” folder or can be copied in the project directory with “input” and “output” folders.

When starting the BTOP simulation, the user can specify four options (see Box 13). The first option [op1] is specified by “–a” and produces an image file of simulated and observed discharges at the river basin outflow. This file is stored in the “autoplot” folder. The second option [op2] specifies β_{coeff} (Eq. 22) for calculating the Manning coefficient at each BTOP grid with three choices: 1) no value (β_{coeff} equals to a slope value of the block outlet), 2) “–n”, “-14” or “0” (β_{coeff}=1), and the user specified value of β_{coeff}. We recommend the second choice in the current version of the BTOP model. The third [op3] and fourth [op4] options allow the user to specify the minimum and maximum values of the modified topographic index (Eq. 1), respectively. These specified values will provide a cut off values during the topographic index calculation by the BTOP model.

Box 13 Running BTOP model with the BTOP executable file.

```
Usage: BTOP1.4.*.exe input/*.cnd [op1] [op2] [op3] [op4]

-$BTOP1.4.*.exe input/fujikawa.cnd –a –n –gl=-1 –gu=12
```

Figure 5.1.1 contains the BTOP model messages of a complete fujikawa project run. These BTOP messages are outputted to indicate the status of the BTOP model simulation and to handle potential errors that may occur due to incorrect set up of the input files or other errors during the simulations. These messages are divided in the following stages of the BTOP simulation: reading control file, file preparation, simulation of the BTOP project, and writing output files.

The use of the first option [op1] is indicated by the BTOP model with the “auto plot mode” line (Figure 5.1.1). The user’s choice of second option [op2] is shown by the BTOP model message “new n0c”. These Manning coefficient values are calculated for each BTOP grid, see “preparing n” and are recorded in the “channel” folder as the fujikawa.n file. Next, the BTOP model indicates a successful input of the *.cnd file with 54 lines and four specified river gauging stations.

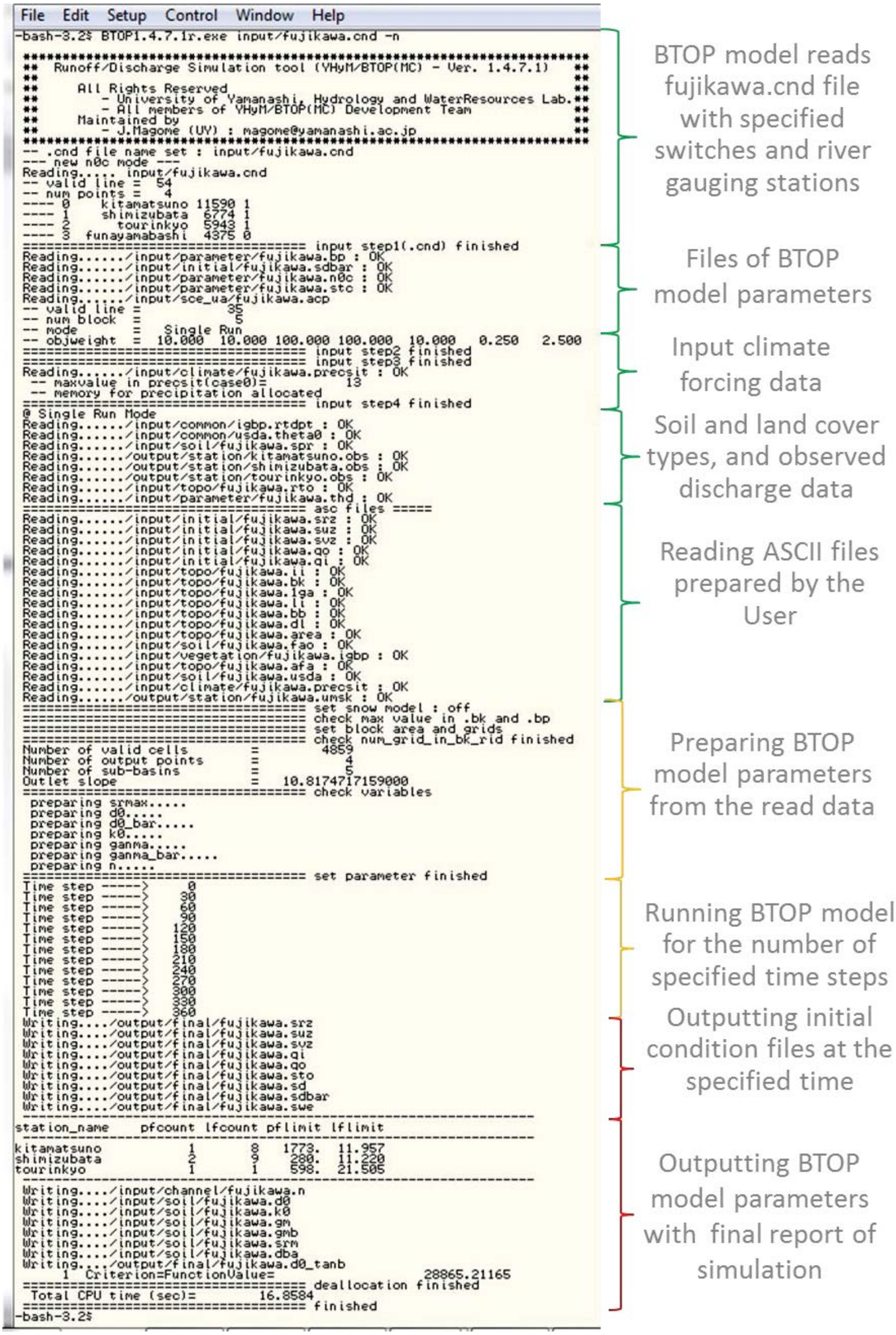


Figure 5.1.1 Successful BTOP model simulation of the fujikawa project.

In the next steps, the BTOP model reads the input files of the BTOP project and calculates (Figure 5.1.1). For the newly created BTOP project, it is may be possible that the user-prepared input files have some formatting inconsistencies. In that case, the BTOP model stops with an error message that provides information about the potential cause of the error. The user should resolve the issue and re-start the BTOP simulation (see Box 13).

In Figure 5.1.1, step 1 of the BTOP model reads the user specified parameters such as m, α, $n0c$, and D_o from the "parameter" folder and an initial average soil moisture deficit, *SDbar*, from the "initial" folder. The *.acp file, which is used for the SCE-UA calibration and is read from the "sce_ua" folder, indicates 35 lines in the file, 5 blocks of the fujikawa model, a run mode "single run" mode (manual calibration) and the weights assigned by the user for the block-wise parameters. Since the manual calibration is selected in the *.cnd file, the BTOP model does not output any messages in step 3, which echoes the SCE-UA file preparation.

For step 4, the BTOP model reads the precipitation option, which is selected "0" in the *.cnd file, and allocates memory to store the precipitation data. For "0" case, the BTOP model identifies the number of rain gauge stations in the *.precsit file and the number of stations in the *.tmptsit, when the user selects the temperature related processes in the *.cnd file. Note that the BTOP model allows the user to specify a different number of precipitation and temperature stations. This step finishes the preparatory steps of the BTOP model and the BTOP prepares for the simulation.

In Figure 5.1.1, the BTOP starts with the BTOP run mode message "Single Run Mode" and reads the table project files such as the land cover classes (*.igbp), soil properties (*.spr), observed river discharge (*.obs), the flow routing order (*.rto) and the soil freezing temperature threshold (*.thd). After that, the BTOP start to read the ASCII format files that is indicated by the "asc files" message. The description of these and other files is listed in in Appendix 1. Next, the BTOP model reports the status of optional modules such as snow model (Line 10 in the *.cnd file) and checks the consistency of the number of block-wise parameters specified by the user. The BTOP model also conducts a check of the entire model cells and reports a brief summary. For example, the fujikawa project has 4934 active cells, 4 points to output files, and 5 blocks. The terrain river slope of the basin outlet is reported and this step is concluded by "check variables" message. The final step of this part is the calculation of seven BTOP parameters and resulting in "set parameter finished" message.

The BTOP model starts the simulation as shown by the "time step" messages from time step 0 to the total number of time steps specified in Line 6 of the *.cnd file (Figure 5.1.1). Note that the BTOP model has a default hourly time step and the user can chose daily simulation by specifying the 24 hours in Line 7 of the *.cnd file. After the BTOP simulation is finished, initial BTOP variables (*.srz, *.suz, *.svz, *.qi, *.qo, *.sto, *.sd, *.sdbar and *.swe) are recorded into the "final" folder at time step "364" as specified in the *.cnd file. From the *.cnd file, the user can select four options to output BTOP model files: 1) specify the time step of the BTOP values in the ESRI ASCII format (Line 15), 2) block-wise variables (Line 16), 3) upstream variables (Line 17), and 4) BTOP variables in the YHyM volumetric format for all active BTOP cells and time steps (Lines 18-50). The user can check the BTOP model result and use these files as initial condition files for the next BTOP simulation. In addition, default files are recorded in the "channel", "soil" and "final" folders by the BTOP model. The BTOP model finishes the simulation by reporting the criterion and deallocation of dynamic memory, which is indicated by "deallocation finished" message. In the final step, the BTOP model displays the used CPU time in seconds and "finished" message as a successful BTOP model simulation.

5.2. BTOP output files

Summary statistics (*.crit file)

The *.crit file is a statistical summary of the BTOP simulation for the specified locations in the *.cnd file. Figure 5.2.1 shows the fujikawa.crit file after the BTOP simulation. The BTOP model outputs a statistical summary (*.crit file) for each of the four sub-catchment with the outflow locations specified in the fujikawa.cnd file. Note that the funayamabashi location does not have statistics shown by "-999.9" (Lines 4-14, 18) because the "0" option was selected in Lines 51-54 of the fujikawa.cnd file.

Station	kitamatsuno	shimizubata	tourinkyo	funayamabashi
Grid_No	11590	6774	5943	4375
Area_km2	3350.8132	2187.8087	727.9673	870.2381
NashShutcliffe%	32.6	29.4	-55.2	-999.9
VolE%	69.7	352.2	123.1	-999.9
Qobs/P%	46.6	32.3	206.3	-999.9
Qsim/P%	79.2	146.3	460.3	-999.9
EA/P%	30.1	31.4	32.3	-999.9
ET0/P%	3.3	3.6	4.0	-999.9
Qoft/P%	43.5	38.7	32.3	-999.9
Qv/P%	40.6	36.8	32.3	-999.9
Qb/P%	41.9	37.7	31.8	-999.9
(Qv-Qb)/P%	-1.4	-0.9	0.6	-999.9
Water_Balance%	99.6	99.7	99.8	-999.9
P___[mm/period]	1442.5	1195.6	1141.8	1199.8
ET__[mm/period]	434.6	375.1	368.3	375.2
ET0_[mm/period]	46.9	42.8	46.1	40.1
Qsim[mm/period]	1141.8	1748.7	5255.6	4396.3
Qobs[mm/period]	672.6	386.7	2355.5	-999.9
----------Criterion	28865.211652----------			

Figure 5.2.1 Summary of the BTOP model simulation in the fujikawa.crit file.

Each location has station name (Line 1), grid number (Line 2), upstream drainage area (Line 3), the percent Nash-Sutcliffe coefficient (Line 4), volumetric percent error (Line 5), and the block-wise water balance (Line 14). Several ratios of parameters to precipitation (P) are reported in percent: the observed discharge Q_{obs} (Line 6), the BTOP simulated discharge Q_{sim} (Line 7), actual evapotranspiration EA (Line 8), actual evaporation EA0 (Line 9), excess runoff Q_{oft} (Line 10), subsurface recharge Q_v (Line 11), subsurface discharge Q_b (Line 12), and the change in the subsurface storage (Q_v-Q_b) (Line 13). In addition, the area averaged data are computed for the simulation period (Lines 15-19). These values are estimated using *.rst and *.upr files described below.

Grid-based parameters (*.rst file)

The *.rst file stores grid-based BTOP parameters listed from Line 18 to Line 50 in the *.cnd file at each time step of the entire simulation. The *.rst file is located the “outputs/station” folder and is named as each location in the *.cnd file from line 51.

Upstream drainage area average parameters (*.upr file)

The *.upr file stores the spatial average of 22 BTOP parameters calculated at the respective grid locations in the *.cnd file from line 51. The first 5 time steps of parameters are imported into excel file, see Figure 5.2.2. These parameters include effective precipitation (Effec.P), potential evaporation (ET0), potential evapotranspiration (PET0). intercepted storage (INCP.DEP), Leaf Area Index (LAI), negative SD (NegSD), root zone drainage flux (Qvrz) and 15 parameters between Lines 30 and 45 in the *.cnd file.

#t	P(mm)	SNF(mm)	EFFEC.P(mm)	ET0(mm)	PET0(mm)	ET(mm)	PET(mm)	INCP.DEF(mm)	LAI	SD(mm)	NegSD(mm)	SWE(mm)	SVZ(mm)	SRZ(mm)	SUZ(mm)	QOF(mm)	QOFH(mm)	QOFT(mm)	QV(mm)	QB(mm)	MLT(mm)	QVRZ(mm)
0	0	0	0	0	4.856813	0	0.230724	0.451338	2.25669	323.190595	0.428501	0	0	0	0	0	0.000177	0.593459	0	0.593459	0	0
1	0	0	0	0	4.856813	0	0.230724	0.451338	2.25669	323.773657	0.421761	0	0	0	0	0	0.000174	0.583061	0	0.583061	0	0
2	0	0	0	0	4.856813	0	0.230724	0.451338	2.25669	324.346685	0.415389	0	0	0	0	0	0.000171	0.573029	0	0.573029	0	0
3	0	0	0	0	4.856813	0	0.230724	0.451338	2.25669	324.910018	0.409516	0	0	0	0	0	0.000168	0.563333	0	0.563333	0	0
4	0	0	0	0	4.856813	0	0.230724	0.451338	2.25669	325.463976	0.404151	0	0	0	0	0	0.000165	0.553957	0	0.553957	0	0
5	0	0	0	0	4.856813	0	0.230724	0.451338	2.25669	326.008873	0.399	0	0	0	0	0	0.000163	0.544898	0	0.544898	0	0

Figure 5.2.2. Upstream area average parameters of kitamatsumono.upr file.

Block-wise parameters (*.brt file)

The block-wise parameters are also outputted by the BTOP model in *.brt file for each block. The *.brt file has the same 22 BTOP parameters as listed the *.upr file, see Figure 5.2.2, but it has an extra first column with block number. For example, fujikawa.brt file has five blocks with number of blocks from 0 to 4 in Column 1 for the time step 0 in Column 2, which is Column 1 in the *.upr file (Figure 5.2.2). As a result, the *.brt file is five times longer than the *.upr file of the same model.

Parameters (*.n, *.t0, *.k0, *.gm, *.gmb, *.srm, *.dba, *.d0_tanb)

Several internal BTOP parameters are stored in "channel", "soil" and "final" folders at the end of simulation in the ESRI ASCII format (Figure 5.2.3). The "channel" folder contains *.n file, which is the BTOP estimated equivalent Manning coefficient, and the "final" folder - *.d0_tanb file, which is a product of dischargebility, *D0*, and *tan β*. For the "soil" folder, the files contain dischargebility *.t0, hydraulic conductivity *.k0, the maximum root zone soil moisture *.srm, the topographic index *.gm, the block average topographic index *.gmb, and the *.dba file, which is right hand side of the equation (2).

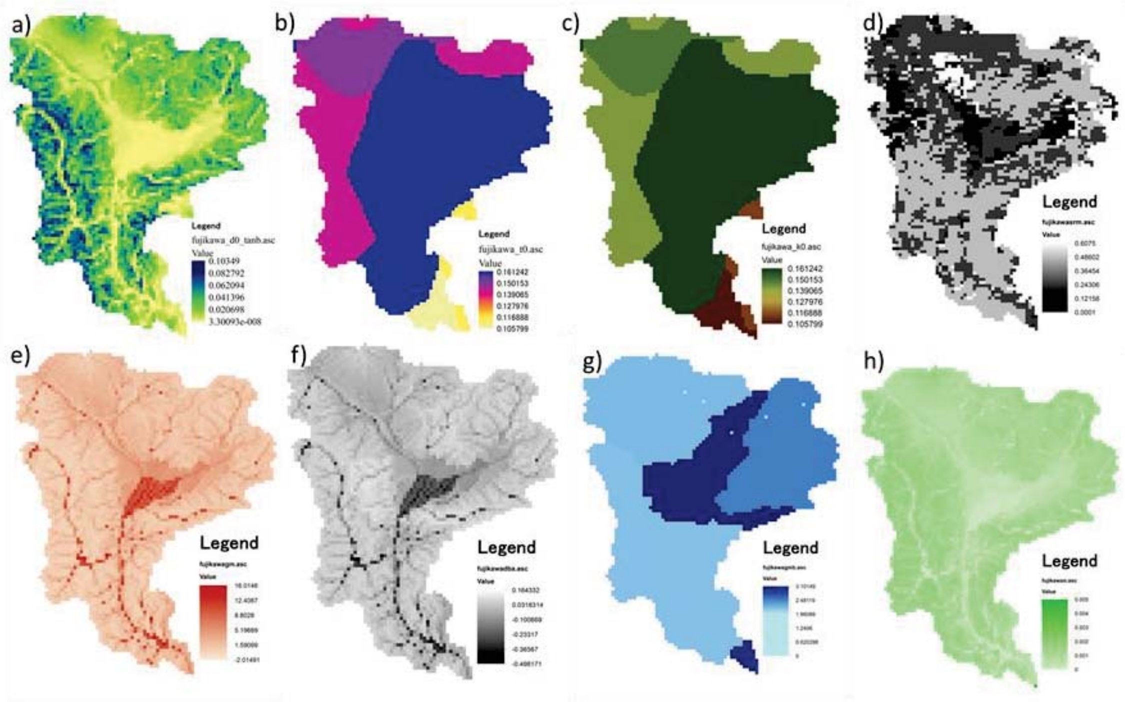


Figure 5.2.3 The BTOP output files: product of d0 and tan beta fujikawa.d0_tanb a), dischargebility fujikawa.t0 b), hydraulic conductivity fujikawa.k0 c), maximum root zone soil moisture fujikawa.srm d), topographic index fujikawa.gm e), block-wise average topographic index fujikawa.gmb f), the topographic index difference fujikawa.dba g), and the Manning's coefficient fujikawa.n h).

5.3. Visualization of BTOP results

The **y_plot14.sh** tool visualizes BTOP model outputs, see Box 14. The tool reads *.rst, *.obs, and *.upr files and prepares a *.png file using gnuplot software for the specified location. The commands of default (or full) and plain modes are demonstrated for the kitamatsuno station in Figure 5.3.1. The tool is run in the project directory with the user specified input: mode switch (-s), project name, station name and type of output file.

Box 14 Visualization of BTOP results with the y_plot14.sh tool.

```
Usage: y_plot14.sh –s [projectname] [output file_format]
Example 1: -$ y_plot14.sh fujikawa kitamatsuno png
Example 2: -$ y_plot14.sh –p fujikawa kitamatsuno png
```

In the default mode (example 1), BTOP simulated parameters are plotted in each panel from top to bottom: the unsaturated zone water storage (Suz); the root zone water storage (Srz); a sum of simulated discharges from s (Q_{oh}+Q_b+Q_{ovh}) and vertical flow between unsaturated and saturated zone (Q_v) at the specified station grid; block-average soil moisture deficit (sdb), block-average actual evaporation (ET) and evapotranspiration (PET); block-average potential evaporation (ET0); block-average potential evapotranspiration (PET0); block-average precipitation (P); simulated (sim) and observed (obs) river discharges (Figure 5.3.1). The plain mode usage with less outputted parameters is given in Example 2.

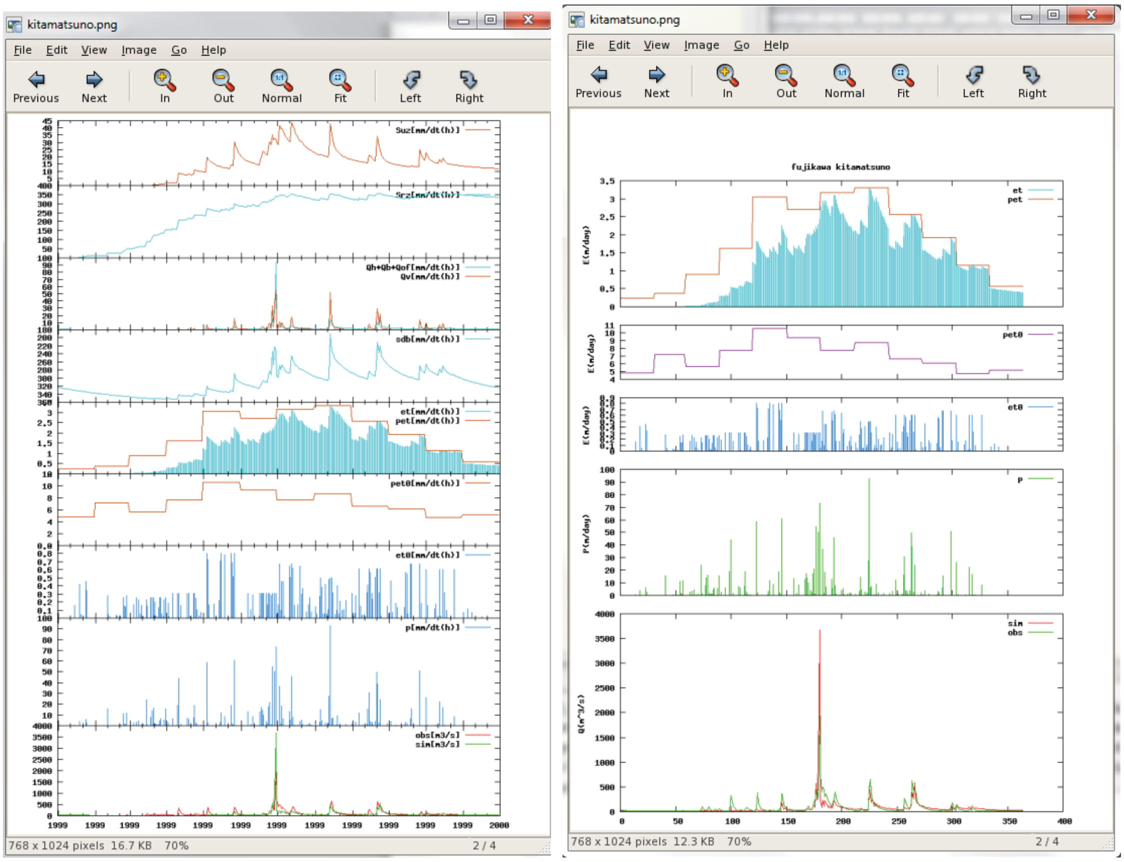


Figure 5.3.1 The png files produced with default (left) and simplified (right) modes.

5.4. Calibration of BTOP model

The current version of the BTOP model has the following calibration parameters: *n0c*, *m*, *α*, *SDbar*, and D_o. Table 5.4.1 summarizes a range of parameter values and provides the default BTOP model parameters obtained for the Mekong River basin by Takeuchi et al. [3]. The user specifies *n0c*, *m*, *α*, and *SDbar* values for each block and defines D_o values for the entire river basin. Note that block-wise n0c parameter depends on the choice of β_{coeff} to estimate Manning's roughness coefficient in Equation (22), see Section 2. If β_{coeff} equals to "1", the Manning's roughness coefficient should be less than 1 leading to the maximum n0c value of 0.8. The estimated Manning's coefficient values at each grid are stored as the "*.n" file at "channel" folder. When the snowfall and snowmelt module is included in the BTOP simulation, the threshold values described in Section 2.5 can also be adjusted during the calibration. Other parameters, e.g., b, W, etc., can be also adjusted, but these are prepared as the input files.

Table 5.4.1 Parameters for the BTOP model calibration from [3].

Zone	**Parameter**	**Unit**	**File**	**Folder**	**Value of parameters**		
					Default	**Lowest**	**Highest**
Channel	n0c	$s/m^{1/3}$	*.n0c	Parameter	0.0006	0.00001	0.8
Root	α	-	*.bp		-6	-10	10
Unsaturated/Saturated	m	m			0.057	0.01	0.1
Unsaturated	SDbar	m	*.Sdbar	Initial	0.048374	0.001	0.9
Saturated	D_{0clay} D_{0clay} D_{0silt}	m/hr	*.stc	Parameter	0.01 0.09 0.04	0.01 0.01 0.01	2.0 2.0 2.0

The BTOP model calibration is conducted by adjusting BTOP parameters. This can be done with manual trial-and-error, a batch R script and an automatic the SCE-UA method. Depending on the selected module, temperature threshold and dam operation can be also investigated. In addition, the user can modify the input files to adjust BTOP parameters (e.g. river width, groundwater travel distance, etc.).

The sensitivity and uncertainty analyses are conducted to determine the influence of model parameters on modelled outputs such as root zone soil moisture, soil moisture deficit and river discharge, etc. The sensitivity analysis is conducted by changing one model parameter at a time keeping other parameters at calibrated values. The model is re-run and new model outputs are evaluated. For the uncertainty analysis, the all parameters are changed at the same time to establish a band of uncertainty for the desired model output. Both sensitivity and uncertainty analyses can be accomplished by Monte Carlo or the trial-and-error methods.

6. BTOP model applications of water dam infrastructure

In the BTOP model, the user can utilize a multipurpose operation of dam and reservoirs for flood control, electricity generation and water supply as described in Chapter 2. Dams and reservoirs play a critical role in the Integrated Water Resource Management (IWRM) of watersheds and can have a single- or multi-purpose dam operation. In a single purpose dam operation, a flood control, electricity generation, or water supply is considered the primary purpose that defines the standard operation procedure of the dam. For the multi-purpose operation, several demands are also considered in addition to dam's primary purpose. For example, the electricity generation requires a constant water release from the dam specified by the capacity of electricity generators. The water supply of municipal and irrigation purpose requires a constant water diversion from the dam to meet municipal and irrigation water requirements, respectively. The multi-purpose dam operation has been incorporated in the research code of the BTOP model [12] and is a briefly summarize below:

1) Flood control

- Dam with constant outflow discharge (Type 1)

In case of flood control, the dam captures flood inflows and reduces the flood peak discharge, see schematic diagram in Figure 2.3.1A. The dam inflow (solid blue line) equals the dam outflow (dashed red line) until it reaches a flood threshold (QF), which starts the dam flood operation. In the flood operation, dam flood control capacity is utilized to fully capture the flood peak flows (hatched area) by the constant outflow shown in red in Figure 2.3.1A. When the flood inflow drops below the flood threshold, the dam resumes normal operation and flood control operation stops.

- Dry dam with flow through (Type 11)

The type has been applied at the Ba River basin, Fiji [22]. The dam has no gates to control flow and allows the river discharge to flow through below a certain river discharge threshold. Once the threshold is exceeded, the dam releases the threshold river discharge while storing the rest of river water utilizing the dam storage capacity.

- Flood retention pond (Type 12)

The pond captures the flood peak and stores it in the retention area. Once the volume of the pond is fully utilized, the pond operation of storing the flood water stops. For this type, the user specifies the area and volume of the pond, the threshold of flood operation and the discharge from the pond.

2) Electricity generation and variable flood control discharge

- Dam with variable flood discharge (Type 2)

The dam release is as a constant discharge for the electricity generation and has a flood control function. This type of flood control dam operation is designed to use a variable discharge from the dam for the reduction of the flood peak inflow (Figure 2.3.1B). As in the Type 11, the flood threshold level indicates the start of flood control operation of the dam. In this type, the dam discharge follows a relationship of two flood threshold levels specified by the user. When the flood inflow drops below the flood threshold, the dam resumes normal operation and flood control stops (demonstrated in Chapter 6 of this manual). The user identifies the reservoir volume, constant dam discharge for electricity generation, a desired volume of the reservoir, and lower and upper flood operation thresholds.

3) Irrigation water supply and diversion

- Irrigation and electricity generation releases with flood control (Type 31)

The multi-purpose dam operation was developed for the Pantabangan Dam in the Pampanga River basin, the Philippines [12, 20].

- Irrigation release and flood control from the dam (Type 32)

This operation has been implemented for the proposed dam in the Malwathoya river basin, Sri Lanka [21]. The purpose of the proposed dam is flood control during wet seasons and irrigation water supply during dry seasons.

- Irrigation diversion from the reservoir (Type 32)

This type of operation has been developed to simulate existing water tanks in Sri Lanka [21]. The water is diverted from the reservoir to the irrigated area supplied by the reservoir. The user specifies the irrigated area, reservoir storage volume and surface water area, and a constant discharge from the dam. The BTOP computes the irrigation water requirement that is released from the reservoir.

- Municipal diversion from the reservoir (Type 33)

The municipal diversion from the reservoir was implemented for the proposed dams at the North Ngiro River basin, Kenya [17]. The user specifies a reservoir storage volume and surface water area as well as the release from the dam to meet other water supply requirements downstream.

- Irrigation diversion from a flood retention pond (Type 34)

This operation has the same flood operation of Type 12 and irrigation water supply of Type 32. For this type, the user specifies the area and volume of the pond, the threshold of flood operation, the discharge from the pond and irrigation area [17].

6.1. Flood control operation of dams and reservoirs (*.res, *.wu, *.rid)

For the fujikawa project, two types of flood control operation are demonstrated for the Hirose, Daimon, Arakawa, Kotokawa and Shiokawa dams located in the headwaters of the Fujikawa River basin (Figure 6.1.1). In Figure 6.1.1, the locations of these dams are shown by green squares with the dam's name next to it. In order to include these dams, the *.res, *.rid and *.wu files need to be created by the user and placed in the "reservoir" folder, which is also created by the user. In the current BTOP version, the "reservoir" folder needs to be created manually in the "input" directory by the user.

The reservoir *.res file is shown in Figure 6.1.1 and contains the dam ID number (Column 1), the BTOP grid number of the dam site (Column 2), and the dam/reservoir type (Column 3). The grid number of the dam location is identified in the same way as for the river gauging stations described earlier. For each dam, the dam information file needs to be prepared using dam's name and has to contain general information as well as specific dam's parameters relevant to the dam's purpose. For the general information, the maximum volume of reservoir, *max_v*[10^6 m^3], the maximum area of reservoir, *max_a*[km^2], the minimum dam's release, *min_o*[m^3/s], and the initial volume of reservoir, *ini_v*[10^6 m^3], see Figure 6.1.1. For the type #2 flood control operation, the Hirose and Arakawa dams require three additional parameters: lower threshold of reservoir volume, *thl_v*[10^6 m^3], upper threshold of reservoir volume, *thu_v*[10^6 m^3], target release from the dam, *tar_o*[m^3/s], and maximum release from the spillway, *max_o*[m^3/s].

In the *.rid file, it has ESRI ASCII format and contains the dam ID information from *.res file and no data values everywhere else, see Figure 6.1.2. The dam and reservoir are specified in the water use *.wu file. The water use *.wu file has the ESRI ASCII file format and contains the land use type information for the BTOP model: land (0), reservoir (1), dam site (3), and mixed dam site with reservoir placed at one cell (7), which is used for large grid sizes. The values outside of the active basin area are "no data" values. Note that agricultural field and/or other water use type. For the five dams in the Fujikawa river basin, the land use type is 3.

To run BTOP dam/reservoir, Line 5 should be changed from 0 to 1 in the *.cnd file.

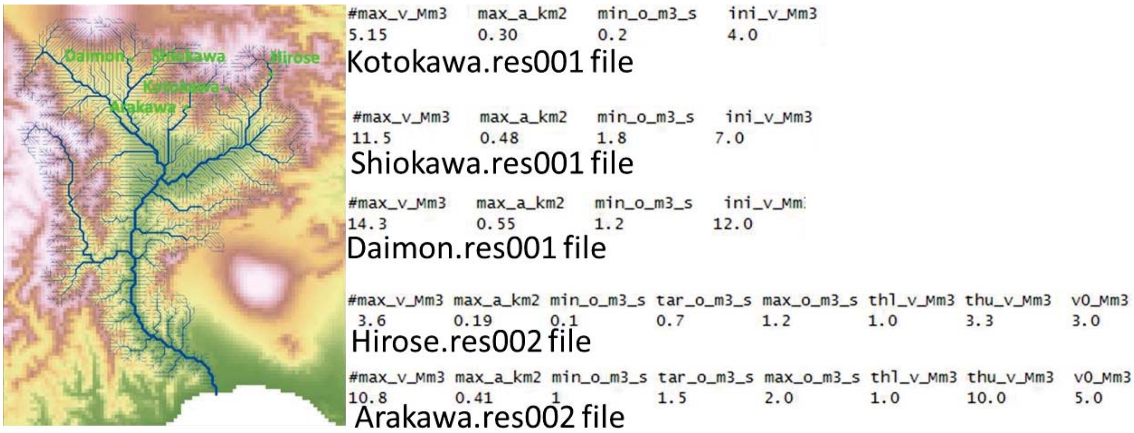


Figure 6.1.1 Location of five dams in the Fujikawa river basin (left) with their description in *.res001 files for Kotokawa, Shiokawa and Daimon dams and *.res002 files for Hirose and Arakawa dams.

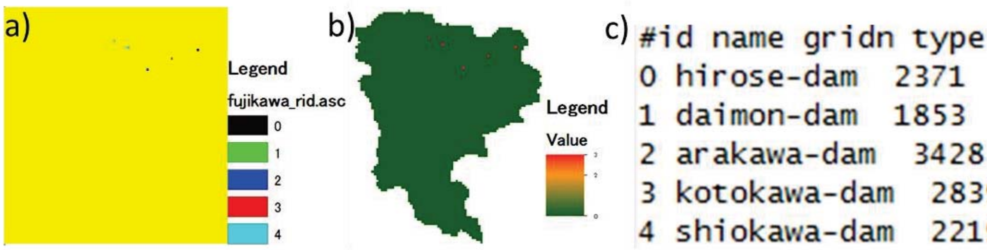


Figure 6.1.2 The reservoir ID fujikawa.rid file a), the water use fujikawa.wu file b), and dam/reservoir information fujikawa.res file c).

6.2. Dam/reservoir simulation results (*.rrt)

After the successful BTOP model simulation with dam operation, the dam output *.rrt file is produced, see Figure 6.2.1. The *.rrt file is structured similarly to the *.brt file. In the *.rrt file, the first row is a header of the columns such as the time step (#t), reservoir id (rid), precipitation on the reservoir (p1), evaporation (ep1) and evapotranspiration(ea1) from the reservoir, inflow in the reservoir (in1), the water release from the dam (out1), the reservoir volume at the time step t (v1) and t-1 (v0), and the percent change of reservoir storage between two time steps.

In the Row 2-6, five dams are listed from 0 to 4 (Column 2) at the time step 0 (Column 1). In the first time step (t=0), the inflow for all five dams is less than the specified release the dams and the BTOP model discharges reservoir storage to meet the specified release. In the second time step (t=1), the Daimon dam, which has the rid of 1 and the maximum storage of 3.6 MCM, and the Shiokawa dam, which has the rid of 4 and the maximum storage of 11.5 MCM experience the flood peak inflows. In the Daimon dam, the high dam inflow of 30.07 cms completely fills the flood control capacity of the dam and results in the spill way discharge of 22.68 cms. For the Shiokawa dam, the dam experiences even larger inflows of 58.54 cms, but it is able to adsorb the flood peak due to larger storage capacity and continues normal operation.

#t	rid	p1(m/dt(h))	ep1(m/dt(h)	ea1(m/dt(h)	in1(m3/s)	out1(m3/s)	v1(10^6m3)	v0(10^6m3)	v1/max_v_%
0	0	0.000000	0.000168	0.000168	0.396051	1.200000	11.930447	12.000000	83.429696
0	1	0.000000	0.000198	0.000198	0.256047	0.700000	2.961605	3.000000	82.266799
0	2	0.000000	0.000173	0.000173	0.478060	1.500000	4.911633	5.000000	45.478086
0	3	0.000000	0.000281	0.000281	0.051690	0.200000	3.987102	4.000000	77.419448
0	4	0.000000	0.000196	0.000196	0.519508	1.800000	6.889271	7.000000	59.906706
1	0	0.000000	0.000168	0.000168	5.944834	1.200000	12.340308	11.930447	86.295860
1	1	0.000000	0.000198	0.000198	30.074221	22.684952	3.600000	2.961605	100.000000
1	2	0.000000	0.000173	0.000173	7.279721	1.500000	5.410930	4.911633	50.101206
1	3	0.000000	0.000281	0.000281	0.791080	0.200000	4.038086	3.987102	78.409446
1	4	0.000000	0.000196	0.000196	58.843841	64.321675	6.415892	6.889271	55.790366
2	0	0.000000	0.000168	0.000168	5.501516	1.200000	12.711867	12.340308	88.894173
2	1	0.000000	0.000198	0.000198	7.230649	7.230213	3.600000	3.600000	100.000000
2	2	0.000000	0.000173	0.000173	6.640989	1.500000	5.855041	5.410930	54.213339
2	3	0.000000	0.000281	0.000281	0.697564	0.200000	4.080992	4.038086	79.242556
2	4	0.000000	0.000196	0.000196	14.566600	1.800000	7.518832	6.415892	65.381149
3	0	0.000000	0.000168	0.000168	4.079024	1.200000	12.960522	12.711867	90.633022
3	1	0.000000	0.000198	0.000198	2.809662	2.809226	3.600000	3.600000	100.000000
3	2	0.000000	0.000173	0.000173	4.684905	1.500000	6.130145	5.855041	56.760606
3	3	0.000000	0.000281	0.000281	0.545876	0.200000	4.110791	4.080992	79.821183
3	4	0.000000	0.000196	0.000196	5.308162	1.800000	7.821843	7.518832	68.016027
4	0	0.000000	0.000168	0.000168	4.119317	1.200000	13.212659	12.960522	92.396216
4	1	0.000000	0.000198	0.000198	4.651768	4.651333	3.600000	3.600000	100.000000
4	2	0.000000	0.000173	0.000173	4.797366	1.500000	6.414967	6.130145	59.397841
4	3	0.000000	0.000281	0.000281	0.521170	0.200000	4.138456	4.110791	80.358360
4	4	0.000000	0.000196	0.000196	9.435895	1.800000	8.481490	7.821843	73.752089
5	0	0.000000	0.000168	0.000168	3.115426	1.200000	13.378059	13.212659	93.552863

Figure 6.2.1 Summary of the BTOP dam simulation fujikawa.rrt file.

7. Summary

This manual is the first document of the BTOP model to combine theoretical as well as practical information from various BTOP related materials such as peer-reviewed papers, reports, and lecture notes. The Fukikawa River basin, Japan, is selected as an example of the BTOP model project, which was introduced at the University of Yamanashi in the previous BTOP model versions. In addition, we discussed the essential use of the supplementary tools needed to setup the BTOP model project in this document.

Since there is an on-going development and many applications of the BTOP model, it is impractical to include all new features and to describe many examples in the manual, e.g. [12, 15, 17, 20-22, 34-35]. These features were left out from this manual and could be obtained directly from the authors. Therefore, the manual draws a line between the officially released version of the BTOP model and the research code with recent updates. Depending on the users' feedback and future BTOP applications, we plan to reflect some of these updates in the next version of the manual as well as in the next officially released version of the BTOP model.

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Appendix 1. Description of BTOP files

A complete list of BTOP project files is listed in Table below in alphabetical order by the file extension. For each file, a short description is provided with units of variable in the file and a source used to create the file. The files created by the user are indicated by “user” in the “Source” column. The “BTOP” indicates that the file is created by the BTOP model and “Tools” – by supplementary tools.

File	Units	File Description	Format	Source
1ga	km^2	Area of grid	ASCII	Tools
acp	-	Parameter set-up file for sce_ua (for automatic calibration)	Table	Tools
afa	km^2	Effective contributing area	ASCII	Tools
ai	-	Area of a BTOP grid i	ASCII	Tools
area	km^2	Catchment area for the BTOP grid i	ASCII	Tools
atb	-	Topographic index	ASCII	Tools
bb	m	Channel width	ASCII	Tools
bk	ID	Sub-basin/block number	ASCII	Tools
bp	-	Alpha and m parameters for each block	Table	Tools
brt	-	Result for each sub-basin for each time step	Table	BTOP
bsn	ID	Basin shape (value means the grid number at the outlet)	ASCII	Tools
check	-	Check of gx function values	ASCII	Tools
cnd	-	Condition file of the BTOP model	ASCII	Tools
crit		Statistical results of the BTOP model simulation	ASCII	BTOP
dba		Coefficient of topographic index, see Eq. (5)	ASCII	BTOP
dem	m	DEM data of the river bain	ASCII	user
dh	m/m	Terrain elevation	ASCII	Tools
dhd	m	Horizontal difference of the original and corrected DEMs	ASCII	Tools
dhv	m	Vertical difference of the original and corrected DEMs	ASCII	Tools
dis	m^3/s	Discharge values at user specified grids	Table	user
dl	m	River channel length	ASCII	Tools
d0_tanb	m/hr	Product of dischargeability (D0) and slope (ii)	ASCII	BTOP
dx	m	Cell size in x-direction (latitudinal distance)	ASCII	Tools
dy	m	Cell size in y-direction (longitudinal distance)	ASCII	Tools
ep	mm	Potential evapotranspiration (PET) from the root zone	ASCII	user/Tools
fa	0-1	Contributing area ratio	ASCII	Tools
facc	ID	Flow accumulation file	ASCII	Tools
facc2	ID	Flow accumulation file clipped by the active model area	ASCII	Tools
fao	ID	Soil type data (from FAO digital soil map of the world)	ASCII	user
fd	ID	Flow direction file with 8 directions	ASCII	Tools
fil	-	Corrected DEM by filling artificial pits	ASCII	Tools
gen	-	Log file	ASCII	Tools
gm	-	Calculated topographic index at each active cell	ASCII	BTOP
gmb	-	Average topographic indexof each block	ASCII	Tools
gn	ID	Grid number of the BTOP model	ASCII	Tools
gx	1/m	Function value of g(x)	ASCII	Tools
igbp	m	IGBP land use data	Table	Tools
igbp.rtdpt	m	Root depth by IGBP data in GLCC dataset 17 class	Table	Tools
ii	m/m	River bed slope calculated as dh/dl	ASCII	Tools
k0	m/hr	Vertical conductivity of soil at the surface	ASCII	BTOP
lai	-	Leaf area index (LAI) data	-	user
li	m	Unit contour length	ASCII	Tools
msk	ID	Mask for making initial values based on specific discharge	ASCII	Tools

File	Units	File Description	Format	Source
n	-	Manning's roughness at each grid from n0c and ii values	ASCII	BTOP
n0	-	Block average Manning's roughness earlier BTOP version	ASCII	Not used
n0c	-	Manning's roughness of each block	Table	Tools
obs	m^3/s	Observed discharge at each user specified station in *.cnd file	Table	user
otl	-	Parameters for the outflow point	ASCII	Tools
pet0	mm	Interception evapotranspiration	-	Tools
prec	mm	Precipitation data	-	user
precsit	-	Thiessen polygon around a set of data points	ASCII	Tools
qi	m^3/s	Initial/Input discharge to a grid at one time step	ASCII	Tools
qo	m^3/s	Initial/Output discharge from a grid at one time step	ASCII	BTOP
rst	-	Time series BTOP results for the discharge observation point	Table	BTOP
rto	ID	Calculation order of grids in flow routing model phase	ASCII	BTOP
.scein	-	Input file for auto calibration	-	user
.sceout	-	Output file for auto calibration	-	BTOP
sd	m	Saturation deficit from a grid for the selected time step	ASCII	Tools
sdbar	m	Block average saturation deficit	Table	user
spr	%	Percentage of clay, sand and silt for each soil type	Table	user
srm	m	Srmax values for all grids within a basin	ASCII	BTOP
srz	m	Root zone storage for the selected time step	ASCII	Tools
stc	m/hr	Dishargebility (D0) values of clay, sand and silt	ASCII	user
sto	m	River channel storage for the manning's equation routing	ASCII	Tools
suz	m	Unsaturated zone storage for the selected time step	ASCII	Tools
svz	m	Vegetation zone storage for the selected time step	ASCII	Tools
swe	m	Snow water equivalent for the snow module	ASCII	BTOP
thd	ºC	Threshold temperate value for snow model	ASCII	user
umsk	ID	Mask file for upstream of each output station	ASCII	Tools
usda	ID	USDA soil type data calculated based on FAO data	ASCII	Tools
usda.theta0	(m^3/m^3)	Field capacity and wilting point by USDA classification	Table	Tools
upr	-	Block average values of upstream user specified area	Table	BTOP
vc1	-	Muskingum-Cunge routing coefficients at each active grid	Volume	BTOP
vc2	-	Muskingum-Cunge routing coefficients	Volume	BTOP
vc3	-	Muskingum-Cunge routing coefficients	Volume	BTOP
vea	m^3/s	Actual ET time-series at each active grid	Volume	BTOP
vep	m^3/s	Potential ET time-series at each active grid	Volume	BTOP
vfil	m^3/s	Infiltration flow time-series at each active grid	Volume	BTOP
vh	m	River state time-series at each active grid	Volume	BTOP
vk	-	Muskingum-Cunge routing parameter at each active grid	Volume	BTOP
vmyu	-	Kinematic water velocity time-series at each active grid	Volume	BTOP
vof	m^3/s	Excess flow time-series at each active grid	Volume	BTOP
vofh	m^3/s	Hortonial flow time-series at each active grid	Volume	BTOP
voft	m^3/s	Total flow time-series at each active grid	Volume	BTOP
vqo	m^3/s	Outflow river discharge time-series each active grid	Volume	BTOP
vqi	m^3/s	Inflow river discharge time-series at each active grid	Volume	BTOP
vsd	m	Soil moisture deficit time-series at each active grid	Volume	BTOP
vomg	-	Celerity time-series at each active grid	Volume	BTOP
vpre	mm	Precipitation results at each active grid	Volume	BTOP
vq	m^3/s	Difference between inflow and outflow discharge	Volume	BTOP
vqb	m^3/s	Baseflow discharge time-series at each active grid	Volume	BTOP
vqv	m^3/s	Groundwater recharge time-series at each active grid	Volume	BTOP
vsrz	m	Root zone moisture time-series at each active grid	Volume	BTOP
vsuz	m	Unsaturated zone time-series at each active grid	Volume	BTOP
vtsz	m^3/s	Unsaturated flow time-series at each active grid	Volume	BTOP
vx	-	Muskingum-Cunge routing parameter at each active grid	Volume	BTOP

Appendix 2. Useful LINUX commands

-$ **cd file_name**: change to new directory '**file_name**'. > **cd** move to home directory.
-$ **cd ..** (one space between cd and two dots): one directory back. > **cd ../../..** : 3 directory back.

-$ **cp**: to make a copy of a file. > "**cp f.old f.new**" will make exact copy of **f.old** and name it **f.new**.
-$ **cp -r * /temp** will copy everything in the directory and RECURSIVELY (-r) everything in the subdirectories underneath that directory to the /temp directory.
-$ **cp file1 ~smith** will copy file1 to the home directory of "smith". **cp *** /temp copy everything in the directory to the /temp directory.

-$ **ls**: list all the directories and files
-$ **pwd**: displays path to the working directory
-$ **exit**: quit

-$ **mv**: will move a file to a different location or will rename a file:
-$ **mv f.old f.new** would rename **f.old** to **f.new**.
-$ **mv f.old ~/Desktop** will move the file **f.old** to your **Desktop** directory but will not rename it. You must specify a new file name to rename a file.

-$ **rm**: to remove (or delete) a file in your directory. To delete directories (which have files in them), use **rmdir** command. To delete directory with contents use **rm -r** followed by file name.
-$ **mkdir**: to create a new directory. E.g., "> **mkdir music**" will create a music directory.
-$**tar**: file zip/unzip
-$ **makefile**: for compiling the files to make executable program
-$ **lftp username@host** (e.g. **lftp vishnu@toci.cee.yamanashi.ac.jp**): connect and data transfer between server and linux/mac-based PC.
For Windows-based PC, install '**winscp**', '**coreftp**' or other similar software to transfer data between the server and PC.

Checking either an existing text file is a linux-based or dos-based:
(1) execute **> wc -l test.txt** --> it would display number of lines in the text file (test.txt); (2) execute **> od -c test.txt** --> it would display line separators for all the lines in the text file test.txt. If the line separator is a set of "**/r /n**", this is a dos-based text file. If the line separator is a set of "**/n**", this is a linux-based text file. The line separators are also called line feed (lf) or carriage-return. Sometimes, even a dos-based text file may fit well in a linux system, in that case no need to change it.
-$ y_asc2ppm2.exe file_name (it would output an image file with the same name but with ppm extension), and then visualize it using image viewer (eog)
-$ eog *.ppm. Like in text editor (gedit), one can always include "&" at the end of command to let the command run in background.

File conversion

Convert a LINUX text file into DOS text file and vice versa:
1st Method: using unix2dos and dos2unix command: > **unix2dos test.txt** would convert test.txt from unix system to dos system;
2nd Method: Copy the file to Linux, rename the file, create a new file with the old name, paste the text into it, delete the old file; (3)
3rd Method: > **tr -d '¥r' <test.txt> test01.txt** (translate command followed by option -d (delete)): it would delete '**¥r**' (line feed in Linux format) from **test.txt** and save into **test01.txt**.
-$ **q**: to quit foreground window and go to the background one.
-$ **gedit**: it would display a text editor window. The editor can be used to make a new text file, open existing file, etc. Also try > **gedit &**. > **gedit test.txt** will open an existing file test.txt.

>**gedit .bash_profile**: it opens a text file, which can be used to set path for particular tool (e.g. **PATH=$PATH:$HOME/bin:/opt/YHyM/bin**) or typing any commands than needs to be called automatically (e.g. language setting, **LANG=C** will set language to English).
-$ **gedit +x test.txt**: will open test.txt and go to the line "x".
-$ **up arrow/down arrow** can be used to search for already typed commands.
-$ **Tab** can be used for searching closely matching commands after typing initial letters. It auto completes any commands or filenames, if there is only one option, or else gives you a list of options.
Switching between foreground and background: while a program (or job) is running in foreground, there might be other displays or jobs in the background. Try to search for the commands related to foreground and backgrounds;

Keep a command or Shell Script running even after you logout: > **nohup command-with-options &**. Example: **nohup y_0_grid_distribut.sh &**. The term "hup" stands for "Hangup". The output is saved at **nohup.out** (if we see list of available files by typing **ls** followed by enter, we could see that file name). To see the progress in processing, we can see that file by > **gedit nohup.out**. Alternately, > **tail.nohup.out** will take you at the end of **nohup.out** file.
-$ **display**: it is an image viewer. It opens image magic.
-$ **jobs**: This command lists how many jobs are running.
-$ **ps** (process status): lists currently running processes; > **ps -ef**: displays full information about each of the processes. Also try > **ps -ox**.
-$ **history**: displays history of all the commands used with ID for each of the commands.
Running any command (command ID = **x**) from history: **!x**.
-$ **gedit fname &**: The "**&**" helps to run the **gedit** command in the background and enables us to use other commands on foreground.
-$ **which command-with-options**: displays path location for that command. Information of path are sometimes important.
-$ **gedit filepath &**: display shell script. We can make our own shell script as per need.
-$ **gedit 'which command' &**: it is equivalent to two commands: > **which command + gedit filepath**. That is, out of the two commands, the first one displays file path and the second one uses that path along with gedit to display "Shell Script". However, the gedit 'which command' & does exactly the same job. Therefore, by keeping some command inside back-quotes **'command'** allows it to execute first and them merge with other commands typed before it. Please note that the quotes are not normal quotes**, but back-quote**. Example: -$ **gedit `y_0_grid_distribut.sh`**.
Output can be redirected in a file using: **command > ofname**.
-$ **./fname** refers to **fname** in current directory; **../fname** refers to **fname** in parent directory
-$ detect and remove "tab delineation" in unix: If you see '¥t' in a text file, that refer to tab delineated. To remove that > **tr -d '¥t' < ifname > ofname**. It would take input from **ifname**, delete '**¥t**' in that file, and outputs the final content into **ofname**. "**<**" and "**>**" refer to redirecting input and output, respectively. If one wants to replace tab with a space; > **expand fname > nfame**. It would replace tabs in **fname** with space and yields the output as **nfname**.
-$ **dos2unix ktm_01.*** coverts all the files starting from ktm_01 into unix-compatible text file.

Other Commands and Shortcuts:
-$ **cat test.txt**: opens test.txt on the screen.
-$ **od -c test.txt**: damping tool
If we can't type somehow, we can type "&". It would let us to type.
-$ **cat f1 f2 > f3**: concatenate (or combine) f1 and f2 into f3.
-$ **sort f1**: sort f1 alphabetically; > sort –n f1: sort f1 numerically
-$ **less**: to view a data/text file. Example, > “less fname”.
-$ **clear**: to clear the terminal screen
-$ **ping**: to Ping network host
-$ **ps –e**: displays currently running processes.
-$ **man**: to show the manual of other commands. E.g. “man rm” to see the manual of **rm** command and “**man man**” to get the manual of manual itself.

Appendix 3. Global Data sets

Digital Elevation Model (DEM) data
GTOPO30: http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/gtopo30.html
SRTM: http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp
GLOBE: http://www.ngdc.noaa.gov/mgg/topo/globe.html

The Digital Soil Map of the World (DSMW), Food and Agriculture Organization (FAO) provides a harmonized soil type datasets from the digital soil map of the world

http://www.fao.org/nr/land/soils/harmonized-world-soil-database/en/

http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116

The land cover of the Global Land cover dataset can be obtained from the USGS Land Cover Institute

(LCI) at the following locations http://landcover.usgs.gov/landcoverdata.php
Or http://edc2.usgs.gov/glcc/tabgeo_globe.php

Land cover	Description
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Water Bodies
99	Interrupted Areas (Goodes Homolosine Projection)
1000	Missing Data

For YHyM/PET tool, the climatic forcing data are required: 1) Mean Daily Temperature(°C), 2) Mean Diurnal Temperature Range(°C), 3) Cloud Cover(%/10), 4) average actual Vapor Pressure (kPa) and 5) Wind Speed (m/s)**.** To download monthly average climatic datasets, please use the urls below.
http://ipcc-ddc.cru.uea.ac.uk/obs/get_30yr_means.html
http://ipcc-ddc.cru.uea.ac.uk/java/visualisation.html

The CRU TS2.0 climatic database from the Climate Research Unit, University of East Anglia in UK provided upon request, see http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_0.html:
http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html
Normalized Difference Vegetation Index (NDVI)
NOAA-AVHRR NDVI from http://www.landcover.org/data/gimms/

Appendix 4. Supplementary tools

A list of supplementary pre- and post-processing tools with a description is given below:

y_mkproject.sh	Prepares project structure and default files with one block
y_mkcnd.sh	Makes a default BTOP project file (*.cnd)
y_mkacp.sh	Makes an input file for the SCE-UA run (*.acp)
y_gridsize.sh	Creates BTOP grid files using the following tools aka **y_0_grid_distribut.sh**
y_dxdy1ga.exe	Creates *.dx, *.dy and *.1ga files
y_mkasc.exe	Creates an ASCII file with one value
y_grida.exe	Generates a file with an area of each grid in ASCII format
y_gn.exe	Generates a grid number file (*.gn)
y_rivernet.sh	Makes a distributed grid network using the following tools aka **y_1_rivernet.sh**
y_dem_mod.exe	Modifies DEM ASCII file (*.dem)
y_fill.exe	Processes DEM ASCII file (*.fill)
y_fdir.exe	Creates flow direction file (*.fd)
y_fdir_check.exe	Checks correctness of the flow direction file (*.fd)
y_facc.exe	Calculates flow accumulation file (*.facc)
y_basin.exe	Generates an active basin area file (*.bsn)
y_subset.exe	Masks an active BTOP model area
y_fd2gen.exe	Generates general format flow direction file (*.gen)
y_basics.sh	Basic data generation aka **y_2_basics.sh**
y_dh.exe	Generates an elevation difference file (*.dh)
y_dl.exe	Calculates the river segment length file (*.dl)
y_ii.exe	Calculates slope file (*.ii)
y_area.exe	Calculates grid area file (*.area)
y_b.exe	Creates river width file (*.bb) based on upstream area formula
y_rto_fast.exe	Generates flow accumulation text file (*.rto)
y_li.exe	Generates contour line file (*.li)
y_ai.exe	Generates area per unit contour length file (*.ai)
y_lnatanb.exe	Calculates topographic index file (*.atb)
y_mk_inits.sh	Prepares initial files based on specific-discharge approach aka **y_6_mk_inits.sh**
y_head.exe	Displays header of ASCII file
y_init_qio.exe	Prepares initial discharge files (*.qo and *.qi)
y_area2sto.exe	Generates river storage file (*.sto)
y_point_mask.exe	Masks the upstream area based on specified grid number
y_bk.exe	Generates BTOP blocks based on specified grid number
y_afa.exe	Calculates effective contributing area
y_fao.asc2spr.exe	Prepares soil property file (*.spr)
y_fao.asc2usda.exe	Prepares USDA classification soil file (*.usda)
y_thiessen0.exe	Creates Thiessen polygons in ASCII format file (*.rst)
y_tcor.exe	Corrects temperature based on terrain elevation
y_conv_proj_w132to14x.sh	Converts project file from BTOP version 1.3.x to version 1.4.x format
y_conv_proj_w132to14x.sh	Converts *.cnd file from BTOP version 1.3.x to version 1.4.x format
	Post-processing tools
y_plot14.sh	Plots hydrograph and other output variables
y_aggregate_result.exe	Prepares an output file of the specific time step
y_aggregate_tbl.exe	Aggregates volume output file by a specified time step
y_ganma.exe	Calculates topographic index (*.gm)
y_n.exe	Calculates Manning coefficient n file (*.n) from n0c and slope
y_count_asc.exe	Counts zero values in an ASCII file
y_stat_asc.exe	Calculate and prints statistics value(s) from AAIGrid file to screen
y_mod_rto.sh	Generates *.rto file for grid number specified at sellected point in *.dis
y_asc2bin.exe	Converts file from ASCII to binary format

y_asc2ctl.sh	Converts file from ASCII to GRADS control format
y_asc2hist.r	Converts ASCII file into a histogram
y_asc2ppm2.exe	Converts ASCII data file to picture format
y_asc2xyz.exe	Converts ASCII data file to a file with x, y, and z values
y_bin2asc.exe	Converts file from binary to ASCII format
y_gn2ij.sh	Converts grid number to i and j values
y_gn2ord.sh	Returns a simulation order of a specified grid number
y_gn2val.exe	Returns value of a specified grid number
y_gn2xy.sh	Returns x- and y- coordinates of a specified grid number
y_ord2gn.sh	Returns a grind number of a specified simulation order number
y_ov2asc.exe	Converts BTOP output from volume to ASCII format
y_ov2flt.exe	Converts BTOP output file from volume to binary format
y_fd2shp.exe	Converts flow direction ASCII file to a GIS shape file
y_xyz2asc.exe	Converts table values of x, y and z to ASCII format
y_zone_stat.exe	Calculates statistics of an area

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