PnET-BGC model software tutorial

1. Overview

PnET-BGC is a fully integrated biogeochemical model that is used to evaluate the effects of atmospheric deposition, land disturbance and climatic conditions or change on soil and surface waters in forest ecosystems [*Chen and Driscoll*, 2004]. The forest-soil-water model PnET-CN [*Aber et al.*, 1997], [*Aber and Driscoll*, 1997] was linked with a biogeochemical (BGC) submodel [*Gbondo-Tugbawa et al.*, 2001] to form PnET-BGC. It allows the simultaneous simulation of major element cycles (e.g., C, N, P, S, Al, Ca, Mg, K, Na). This model considers the interactions of the atmosphere with vegetation, soil and water drainage. It has been used to evaluate element cycles in forest ecosystems, and considers different biotic and abiotic processes, including atmospheric deposition, CO_2 fertilization, canopy interactions, plant uptake, litterfall, hydrology, soil organic matter dynamics, mineral weathering, nitrogen mineralization and nitrification, chemical reactions involving solid and solution phases, wetland processes, and surface water processes (see Figure 1). The interaction of the processes in atmospheric deposition, soil, vegetation, and water determines the hydrology and ultimate chemical characteristics of surface waters because water and solutes interact with the forest vegetation and soil before emerging as runoff [*Gbondo-Tugbawa et al.*, 2001].

Model inputs include climatic data (solar radiation, precipitation, maximum and minimum temperature), atmospheric CO_2 concentration, atmospheric deposition (wet and dry), vegetation type and element stoichiometry, soil characteristics, element weathering rates, soil cation exchange and anion adsorption coefficients, and historical land disturbance [*Gbondo-Tugbawa et al.*, 2001], [*Chen and Driscoll*, 2004], [*Zhai et al.*, 2008]. The model simulates hydrology, concentrations and fluxes of major elements in ecosystem pools and losses. A

detailed description of PnET-BGC is provided in [*Aber and Driscoll*, 1997], [*Aber et al.*, 1997] and [*Gbondo-Tugbawa et al.*, 2001], including a sensitivity analysis of parameters. The model is typically run with a monthly time-step under "background" conditions, of climate and atmospheric deposition and without any land disturbance starting in the year 1000 as a spin-up period. Changes in atmospheric deposition and land disturbance events were initiated after 1850. This allows the model to come to steady-state prior to hindcasts. Hindcast projections are typically initiated starting in the year 1850 and include consideration of historical climate, atmospheric deposition and land-disturbance. Early values for these inputs are recreated from historical records ([*Aber and Federer*, 1992], [*Driscoll et al.*, 2001]) and matched with measured values later in the record.

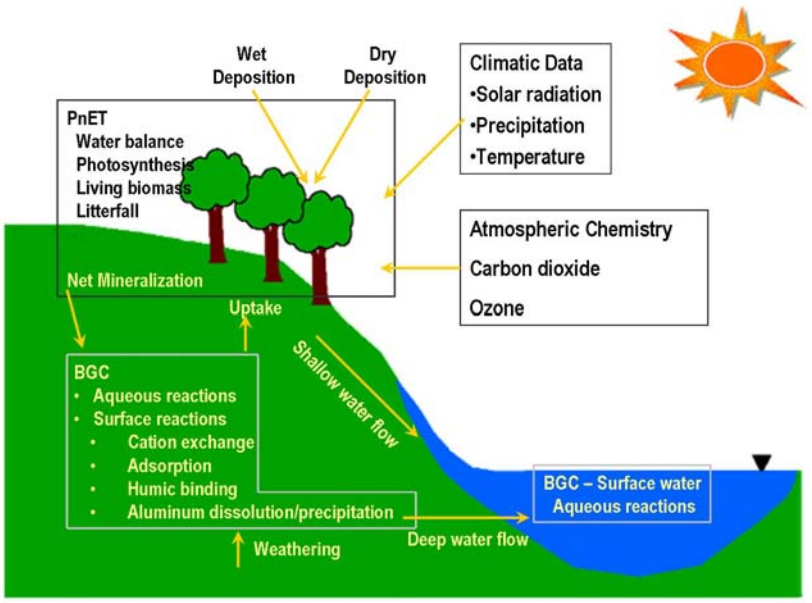

Figure 1. Schematic illustration of inputs, processes, interactions and outputs of PnET-BGC.

The current version is programmed in Microsoft Visual C++ and uses a set of standard input files to allow easy access to data files required to run the models, and rapid development of new files for additional sites. The current package for distribution contains example files which will allow the user to run the model using data acquired at the Hubbard Brook Experimental

Forest (HBEF) in the White Mountains, New Hampshire. These inputs and parameter files are intended to give the user examples of model application. The package includes two sets of code; one is the general module (non CO_2) and the second is the latest advancement in the model which considers the effects of rising atmospheric CO_2 on forest ecosystem processes and tropospheric ozone on photosynthesis. Both sets of code can be applied to any forest watershed especially in the Northeast region of the U.S. User needs Microsoft Visual C++ 2005 or later version in order to run the model. In order to make the model more public accessible, both versions in this package are modified and specified so the user can run them with FREE version of Microsoft Visual C++ EXPRESS version from Microsoft website (http://www.microsoft.com/express/Downloads/#2010-Visual-CPP). Therefore, user can obtain some insight on the model application, inputs, outputs and functionality. If user wants to apply the model for any research purposes they can purchase the license for Visual C++. Although a user can apply the simplified models for any watershed of interest by changing some input files and configuration.

Extensive documentation is not provided in this package. A complete description of model is provided in several published papers (List of PnET-BGC papers). For a more detailed description on PnET model, refer to published papers of Aber et al. ([*Aber et al.*, 1995], [*Aber et al.*, 1996], [*Aber et al.*, 1997]) and more recent model additions are described in [*Aber and Driscoll*, 1997], [*Ollinger et al.*, 1997] and [*Ollinger et al.*, 2002]. Detailed photosynthesis processes and parameters have been described in [*Ollinger et al.*, 2009]. Source code, precompiled binaries and online papers are available at http://www.ecs.syr.edu/faculty/driscoll/personal/PnET%20BGC.asp.

The PnET models are designed to utilize relatively few and generally available input data, to run quickly, and to produce outputs that can be validated against available field data. The input requirements are limited so that the models can be run with the types of summary data generally available for most long-term forest watershed studies. Whenever possible, generalized relationships are used so that many parameters remain the same for all runs within a broad vegetation type. This means that these general inputs could be applied across many sites. Generic parameter files for broad-leaved deciduous, spruce-fir and other vegetation classes, along with site-specific climate drivers, obtain very reasonable predictions of carbon and water balance and soil and surface water chemistry.

The model assumes homogenous spatial distribution of properties over the Environmental Monitoring and Assessment Program (EMAP) watersheds. PnET-BGC was initially applied to the Adirondack Long-Term Monitoring (ALTM) sites where detailed time-series data were available. This time-series of lake chemistry data provided a good opportunity to evaluate model performance. All model inputs, and vegetation, soil and hydrologic parameters were either directly available for model application or could be derived or estimated from field data or values in the literature, with the exception of element mineral weathering rates. Element mineral weathering rates were determined for each site through model calibration and held constant for model simulations.

2. Distribution Contents

The packages are in ZIP format. First unzip or extract the folders. Inside the folder there are following subdirectories:

\Code1-HB-Final - General source code (non CO_2)

\Code1-HB-Final CO_2 - Latest code (CO_2 fertilization)

3. Input Files

This section is intended to help with the construction of input datasets for the user. There are 12 main files which are climate, wet deposition, dry deposition, site characteristic, biogeochemistry, vegetation list, vegetation type (4 files), tableau, and PnET-BGC site names. These input files were developed under the assumption of a monthly time step; if the model would be run with a different time step then the format for these files would need to be changed accordingly. Below are the descriptions of each input file.

A. Climate

Climate file includes monthly values for precipitation, maximum and minimum temperature, solar radiation (PAR) and CO_2 concentration (only in CO_2 fertilization code). Below is the sample of climate file over one year period. DOY stands for day of year, Tmax and Tmin are mean monthly maximum and minimum temperatures (°C), respectively. PAR is daily solar radiation (μmol m^{-2} s^{-1}), Prec is monthly precipitation (cm), and CO2c is mean monthly atmospheric CO_2 concentration in ppm (in CO_2 fertilization code).

Sample ".prn" file format: This is Hubbard Brook Experimental Forest (HB3Xbgc.prn).

DOY	Tmax	Tmin	par	Prec	CO2c
15	-4.94	-13.45	258.12	7.96	378.08
46	0.11	-9.43	436.98	9.90	378.25
76	2.13	-7.52	581.97	9.29	378.41
107	11.37	0.80	603.35	19.18	378.58
137	13.00	3.84	519.43	9.26	378.74
168	24.00	13.57	666.65	19.09	378.91
198	25.00	14.71	683.51	7.88	379.08
229	23.77	14.32	633.83	22.06	379.25
259	20.13	10.73	615.69	7.64	379.41

290	11.32	4.77	350.06	32.23	379.58
321	5.23	-2.90	279.79	18.36	379.75
351	-2.29	-9.16	209.34	10.75	379.92

B. Wet Deposition

Wet deposition file includes major cations and anions monthly wet deposition with the units $g/m^2/mo$. Below is sample data input files for year 1000.

Sample ".prn" file format: These data are for HBEF (HBInput1000.prn).

Year	Month	DOC	Na	Mg	Al	K	Ca	NH_4	Cl	NO_3	SO_4	F	PO_4	SiO_2
yr	mon	$g/m^2/mo$												
1000	1	0.0292	0.0040	0.0024	0.0005	0.0022	0.0073	0.0010	0.0114	0.0039	0.0119	0.0001	0.0005	0.0018
1000	2	0.0263	0.0040	0.0024	0.0004	0.0022	0.0073	0.0011	0.0114	0.0032	0.0119	0.0001	0.0005	0.0016
1000	3	0.0308	0.0040	0.0024	0.0005	0.0022	0.0073	0.0016	0.0114	0.0044	0.0119	0.0001	0.0006	0.0019
1000	4	0.0297	0.0040	0.0024	0.0005	0.0022	0.0073	0.0026	0.0114	0.0047	0.0119	0.0001	0.0005	0.0018
1000	5	0.0323	0.0040	0.0024	0.0005	0.0022	0.0073	0.0026	0.0114	0.0041	0.0119	0.0001	0.0006	0.0019
1000	6	0.0325	0.0040	0.0024	0.0005	0.0022	0.0073	0.0026	0.0114	0.0040	0.0119	0.0001	0.0006	0.0020
1000	7	0.0316	0.0040	0.0024	0.0005	0.0022	0.0073	0.0022	0.0114	0.0037	0.0119	0.0001	0.0006	0.0019
1000	8	0.0348	0.0040	0.0024	0.0006	0.0022	0.0073	0.0022	0.0114	0.0040	0.0119	0.0001	0.0006	0.0021
1000	9	0.0312	0.0040	0.0024	0.0005	0.0022	0.0073	0.0017	0.0114	0.0033	0.0119	0.0001	0.0006	0.0019
1000	10	0.0327	0.0040	0.0024	0.0005	0.0022	0.0073	0.0015	0.0114	0.0036	0.0119	0.0001	0.0006	0.0020
1000	11	0.0368	0.0040	0.0024	0.0006	0.0022	0.0073	0.0016	0.0114	0.0046	0.0119	0.0001	0.0007	0.0022
1000	12	0.0348	0.0040	0.0024	0.0006	0.0022	0.0073	0.0011	0.0114	0.0041	0.0119	0.0001	0.0006	0.0021

C. Dry Deposition

The dry deposition file contains dry to wet deposition ratios for all elements in wet deposition file. Note that generally the dry to wet deposition ratio is fixed over time. However, if data are available for time-variable values, these values can be applied. Below is the sample data input file for year 1000.

Sample ".prn" file format: These data are for HBEF (HBD1000dwr44.prn).

year	month	DOC	Na	Mg	Al	K	Ca	NH_4	Cl	NO_3	SO_4	F	PO_4	Si
yr	mon	ratio	ratio	ratio	ratio	ratio	ratio	ratio	ratio	ratio	ratio	ratio	ratio	ratio
1000	1	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	2	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	3	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	4	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	5	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	6	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	7	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	8	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	9	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	10	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	11	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0
1000	12	0	0.300	0.300	0	0.300	0.30	0.11	0.0	0.12	0.067	0	0.0	0

D. Site Characteristics

In this file the user can enter the data for the specific watershed for model application. LAT is latitude of the site. WHC is water holding capacity (cm) which is assumed to be 12 for New England. The name of climate file that model will read (HB3Xbgc.prn) should be define in this file. Note that this file name should be the same as the user climate input file. If these file names are not consistent there will be an error. Initial conditions define the first values for the model to start the run. These values should be modified for each site following characteristics that are available for the site. If there is no value available the user could use values from literature, similar site, current values in input file or calibration. Note initial conditions do not matter if the equilibration period is long enough and the model achieves steady-state. The units for BudC, WoodC, PlantC, PlantN, HumusM, Folmass, WoodMass, RootMass, HumusN, Deadwood are g C /m^2/yr.

A calculated variable (NRatio) is central to the interactions between carbon and nitrogen cycles and expresses the degree of N limitation on plant function [*Aber et al.*, 1997]. This in turn

affects both the nitrogen concentration in foliage, and so maximum rates of photosynthesis, and also the fraction of mineralization N which is nitrified [*Aber et al.*, 1997]. NRatio is determined by the amount of mobile N in the plant (PlantN) relative to a specified maximum value (MaxNStore) [*Aber et al.*, 1997]. An additional variable (FolNConRange) limits the range of NRatio, which is calculated as:

NRatio = 1.3991= 1 + (PlantN/MassNStore)*FolNConRange

SnowPack = 13 cm

DWater = 1, 1 = no problem, 0 = water stress (degree of H_2O availability)

"*Run Model From/To*" define the start and end of the run for the model. In case of future climate change scenarios the user can change the end year to intended future years (e.g. 2100). Note that the start year of running the model should be consistent with the first year of climate and wet/dry deposition data files. "*Model Output From/To*" defines the start and end of the year that the user wants the results from the model. If user does not want any ramp in climate change conditions DO NOT CHANGE ANY of values below.

DelTMax	DelTmin	DelPrec	DelPar	DelWUE	Ramp	Start	End
0	0	1	1	1	0	0	0

DelTMax = 0 1900 2000. Degree C changes. 0 is no increment.

DelTMin = 0 1900 2000. Degree C changes. 0 is no increment.

DelPrec = 1 1 1900 2000 Precipitation changes as fraction of current. 1 is no change.

DelPar = 1 1 1900 2000 PAR changes as fraction of current. 1 is no change.

DelWUE = 1 1 1900 2000 WUE (water use efficiency) changes as fraction of current. 1 is no change.

It is important to make sure that wet and dry deposition files, and climate file names are exactly the same as the one read into the model. The model also has the ability to consider nitrogen fertilization. This treatment is considered as a step input to the deposition file.

FertNO3 = 0 g/m^2 per application. If 0, no fertilization

FertNH4 = 0 g/m^2 per application. If 0, no fertilization

The last portion of the file is historical land disturbance, includes hurricane, ice storm, fire, or forest harvesting.

(Sample of hurricane/ice storm/fire/clear-cut)

Year= 1904 the year of forest disturbance

Intens = .2 the fraction of the watershed that is disturbed by the disturbance event (e.g. 20%)

RemFrac = .8 the fraction of the forest biomass removed from the watershed during the disturbance event (e.g. 80%)

SlossFrac = 0 Quantity of soil forest floor removal during disturbance event.

Folregen = 100 years. Total number of years to regenerate the forest.

The next line is used to consider any agricultural activity in the watershed.

(Agriculture sample)

From 1750 Year forest cleaning occurs.

To 1850 Year agricultural activity ends.

Removal .1 Average annual fraction of biomass removal.

Sample ".SIT" file format: This is HBEF (HB.SIT)

File Diretory **********
E:\Wu\PnETBGC\data\

```
Site Variables **********************************************************
LAT     WHC     Climate file
45      12      HB3xbgc
Initil Conditions *******************************************************
BudC    WoodC   PlantC  NRatio  PlantN  FolMass  WoodMass  RootMass
130     300     900     1.3993  1       0        47000     6
SnowPack  Dwater  Water  HumusM  HumusN  NH4   DeadWood
13        1       12     13500   390      .001  11300
Scenario - for CN *******************************************************
Run Model From/To  Model Output  From/To
          1000  2100              1000  2100
DelTMax  DelTmin  DelPrec  DelPar  DelWUE  Ramp?  Start  End
0        0        1        1       1       0      0      0
Wet File          Dry File              Combined Dep File
HBInput1000       HBD1000dwr44          HB3xbgc
FertNO3  FertNH4  YrStart  YrEnd  MonStart  MonEnd
0        0        0        0      0         0
 AgFrom  AgTo  Remove
0        0     0
# of Harvests
4
Year  Intens  RemFrac  SLossFrac
1904  .2      .8       0
1919  .59999  .8       0
1938  .2      .4       0
1998  .1      0.2      0
FolRegen
100
```

E. Biogeochemistry

This file includes all biogeochemistry information used in model applications including element content of soil organic matter, element content of plant tissue, weathering inputs, soil chemistry parameters (WHAM), element foliar exchange/uptake, and reaction year (the year that slow reaction are allowed to proceed e.g. weathering, mineralization, uptake, and nitrification). It is VERY IMPORTANT for the user to use observed values for these parameters from previous research and literature values for the site. In cases that observations are not available for the study site, the user should use values available from sites with similar calculations and the last solution is to use calibration. Weathering inputs are parameter values that likely would be

obtained through calibration. "*Reaction year*" is the year that model starts the simulation. This is the point in time that user defines as "*Reaction year*" and it should always be the same as starting year for climate and atmospheric deposition input files (in examples files the "*Reaction year*" is 1000). The element inputs are added to existing soil constituents, and slow reactions start to proceed. Changing "*Reaction year*" to later years (e.g. 1700) will cause problems in making the ecosystem to reach to steady state conditions. The model is run for an extended period (e.g., 700 years), initially using background inputs of atmospheric deposition and estimates of weathering. Once the vegetation and soil come to steady state, the user increases atmospheric deposition according to historical scenarios to current deposition values.

Sample ".BGC" file format: This is HBEF (HB.BGC)

Element Organic MATTER Content in g/gN

Na	Mg	Al	K	Ca	Cl	S	P	F	Si
0.00	0.03	0.00	0.04	0.19	0.00	0.10	0.06	0.00	0.00

Element Plant Tissue Content in g/gN

Na	Mg	Al	K	Ca	Cl	S	P	F	Si
0.00	0.094	0.000	0.039	0.79	0.00	0.11	0.158	0.00	0.00

Weathering Inputs in g/m2/mo

Na	Mg	Al	K	Ca	Cl	S	P	F	Si
0.042	0.011	0.0375	0.004573	0.032	0.00	0.022	0.00	0.004	0.283528

WHAM Parameters

SO4Ad	SiteDOC	SoilMass	Tolerance	CEC	DocFrac
0.001	0.0035	350	1e-12	0.062758	0.14

Foliar Exchange/Uptake

H	Mg	K	Ca	NH4
0.64929	0.08	0.71	0.21	0.2548

Reaction year

1000

F. Vegetation List

The type of vegetation 1, 2, 3, and 4 is linked to the PNETVEG.LST dataset and the order that the user creates that. In this example, vegetation type 1 is Northern Hardwoods. The

user should indicate the dominant vegetation type to be used in the simulation in the first line in this file (in this case Northern Hardwoods).

```
4
Northern Hardwoods      NHWDS
Spruce - Fir            SF
Red Oak - Red Maple     RORM
Red Pine                PINE
```

G. Vegetation

This file includes vegetation characteristics. It is not necessary to change the parameter values for this file. Four vegetation types developed and parameterized for PnET-BGC include; Northern Hardwoods (NHWDS), Spruce – Fir(SF), Red Oak-Red Maple (RORM), and Red Pine (PINE). The user needs to select the dominant vegetation in the watershed through PNETVEG.LST file.

Sample ".VEG" file format: This is Northern Hardwoods (NHWDS.VEG)

```
Northern Hardwoods
AmaxA   AmaxB   HalfSat  BFolResp  RespQ10  PsnTMin  PsnTOpt  AmaxFrac
-46     71.9    200      .1        2        4        24       .75
FolRet  SLWmax  SLWdel   GDDFolS   GddFolE  GDDWoodS GDDWoodE SenescStart
1       100     .2       100       900      900      1600     270
FolMsMx FolMsMn k        FolNCon   FolRelGMax
300     0       .57999   2.3999    .94999
CFracB  RootAlA RootAlB  GRspFrac  WdMRespA RootMRF  PCReserv MinWoodFol
.45     0       2        .25       .07      1        .75      1.5
DVPD1   DVPD2   WUECnst   PrecIntF  FFlowFr  f
.05     2       10.9     .11       .1       .04
FLPctN  RLPctN  WLPctN   FolNConR  FolNRet  MaxNStore
.00898  .012    .002     .59999    .5       20
WoodTrn RtTrnA  RtTrnB   RootTrnC
.025    .789    .191     .0211
WdLitLs WdCLoss Kho      NImmobA   NImmobB  SoilRespA SoilRespB SoilMoistFact
.1      .8      .07499   151       -35      27.46     .06844    0
```

H. Tableau

The tableau file (Tableaux3_b.dbs) is an important input file. It contains the equilibrium constants (K values) for all reactions used in the model. Also it contains a list of species used in the calculation of ANC and their stoichiometric coefficients, a list of species for organic Al and their stoichiometric coefficients, and list of species for dissolved inorganic carbon (DIC) and their stoichiometric coefficients. This file is the main source for ALL chemical reactions used in the model. There is NO NEED to change the values in this file unless there is specific reaction with different K value that the user would like to consider. Reactions that users would most likely change in this file include the formulation of organic acids (DOC), soil sulfate adsorption or other soil anion adsorption reactions, or cation exchange formulation (e.g. Gapon vs. Gaines-Thomas).

I. PnET-BGC Site Names

This file gives the user the abbreviations for some watersheds that the model has been applied. For example, HB stands for Hubbard Brook or HUNT stands for Huntington Forest (Adirondacks, NY). The sites abbreviations (e.g. HB, BISC, HUNT, CONST) are linked to the PNETSITE.LST dataset. The user should indicate the name of the site to be used in the simulation in the first line in this file (e.g. HB). The name in the first line of this file should be consistent with names of input files (climate, dry and wet deposition, site and biogeochemistry) or an error will occur. Therefore if the user wants to run the model for Hubbard Brook, the first line in the file should be "*Hubbard Brook : HB*" with following abbreviation in the names of input files; **HB**3Xbgc.prn, **HB**.BGC, **HB**.SIT, **HB**D1000dwr44.prn, **HB**Input1000.prn. The user can add new names and corresponding abbreviations to this file.

4. Running PnET-BGC

To run PnET-BGC model the user needs to create a folder on the hard drive and choose the version to be used (Code1-HB-Final or Code1-HB-Final CO_2). In order to run the model the user needs Microsoft Visual C++ which normally comes in the package called Microsoft Visual Studio. Both of the code sets can be run under Microsoft Visual Studio EXPRESS and this version can be downloaded FREE from Microsoft website. The model can be run under any version after 2005. Both codes are in 2005 version and if the user is using a later version (e.g. 2008 or 2010) the code should be upgraded which the software will automatically do it when the file is opened for the first time. There are settings for both codes under general properties, runtime libraries, precompiled headers, optimization and etc. which are set in a way that the model will work in optimized manner. PLEASE DO NOT CHANGE these settings unless the user is FAMILIAR WITH C++. Below is detailed description about how to run both codes. For additional assistance or to report bugs, please contact Afshin Pourmokhtarian (apourmok@syr.edu).

A. Code1-HB-Final

The folders Code1-HB-Final and Code1-HB-Final CO_2 include all input files for Hubbard Brook Experimental Forest, HB folder, and the assembly folder. The principals for running both codes are the same as described below and the only difference is that Code1-HB-Final CO_2 includes the latest advancement to the model as described before. HB folder is the place that model record the output in CSV format which the user can use Microsoft Excel to open the output files (sample of complete run is available inside the folder). Folder assembly contains all codes for the model. The user should open the source code called “assembly.sln”.

After opening the file, the user should use the “solution explorer” (on the left) and open “assembly.cpp”. On the 18th line from the top there is an address for input files that model will read in (FileDir = "D:\\Afshin\\PnET-BGC Tutorial\\Code1-HB-Final\\ "; for CO_2 module it should be FileDir = "D:\\Afshin\\PnET-BGC Tutorial\\Code1-HB-Final CO2\\"). The user should change these to the address on the users hard drive to capture the input files. Then the user should go to the menu “Build” and click on “Build assembly”. The software will compile the code and the user MUST obtain this message:

1>assembly - 0 error(s), 0 warning(s)

========== Build: 1 succeeded, 0 failed, 0 up-to-date, 0 skipped ==========

After this the user has the code ready to use. In order to run the model the user should press F5 button or go to “Debug” menu and choose “Start Debugging” and the model will start to run. Depends on the users system, it takes 3-5 minutes to run the model from year 1000 to 2100. After the model run ends, the window of the run will be closed and the user should go to the “HB” folder and look at the output. The current input files are calibrated for HBEF-W6 (biogeochemical reference watershed).

The output files show the values from year 1000 which is the “reaction year” that are defined in the biogeochemistry input file. The table 1 shows the numbers correspondent to each element and is the same for all output files.

Table 2. Correspondent numbers to each element in output files.

Output	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Name	Stream Flow	pH	DOC	Na	Mg	Al	K	Ca	NH4	Cl	NO3	SO4	DIC	F	PO4	Si	AlOrg	ANC

The user will obtain nine different output files; Adsorption, dep, month, NPP_NEP, soil, SoilCation_m, SoilCation_y, strm and water with the extension of CSV. The file

Adsorption.CSV shows the net adsorption of sulfate in mol/L on monthly basis. Volume [1] shows the volume of soil solution (mm/m^2/month) that used in the calculation.

Totals[18] = SO_4AdCapacity (mmol/kg) * SoilMass / VolSoil

The dep.CSV file shows the monthly deposition and throughfall values for the all inputs of wet and dry deposition files (g/m^2/year).

The month.CSV gives the user the monthly output of the streamwater. The numbering for elements is described in Table 1. The units for streamwater discharge is mm/m^2/month, for elements 2 to 16 are μmol/L, and for element 17 (ANC) is μeq/L. The last four columns are soil Al/Ca ratio, percent soil base saturation (%BS), soil temperature (TEMP), and aluminum precipitation (ALPPT), respectively. The value 0 for ALPPT indicates saturation index higher than 1 and therefore precipitation of Al.

The NPP_NEP.CSV gives the annual values for foliage NPP, wood NPP, root NPP, and NEP and the unit is gC/m^2/year.

The soil.csv gives annual values for soil chemistry pools/fluxes including humus (EHumus), litterfall (ELitF), total plant assimilation (EPtot), pool of total exchange sites and anion adsorption sites available in the soil chemical reactions (Soild), mineralization (EMin), uptake (EUp), and stream (EStr), respectively. The corresponding numbers are the same as other output files. The last 2 columns give the user percent soil base saturation (BS%) and soil Al/Ca ratio. Units for fluxes and pools are g/m^2/year and g/m^2, respectively.

The SoilCation_m.CSV shows the monthly concentrations of Na^+, Mg^{2+}, Al^{3+}, K^+, Ca^{2+}, NO_3^-, SO_4^{2-} on exchanger sites available for the soil chemical reactions. The SoilCation_y.CSV shows the annual concentrations of those elements. The units are mol/kg.

The strm.CSV shows the annual values for streamwater flow (Stream[0]) and chemistry (Table 1).

The Water.CSV gives the monthly values for precipitation (Precip), Stream (Strm-Water), transpiration (Trans), evaporation (Evap), drainage, inflow, water use efficiency (WUE), snow pack, and snowmelt, respectively. The units are cm/m^2/month for all except for stream water (Strm_Water) which is mm/m^2/month.

The Code1-HB-Final CO_2 produces one extra output called Al_Saturation.CSV which is exclusively to track aluminum dissolution/precipitation and saturation index with respect to solubility of $Al(OH)_3$ in soil.

Outputs from PnET-BGC will accumulate (and overwrite each other if the user does not rename them) in the same folder (HB directory). Make sure that the user copies the output files from each run to another folder before starting a new run. If user wants to run the model for other sites, the user should make all appropriate changes to the input file names otherwise the model will give an error (e.g. replace HB with CONST in input files names). Also the user should change the name of the output folder from HB to CONST. Make sure in PNETSITE.LST to put the name of the site for which the model is to be run at first line or if does not exist in the file, add it to the top of the list. An easy way to do this is to open input files and change the contents for other sites and then run the model. In this case the user does not need to change any name.

5. Undergoing improvement for PnET-BGC

The current model considers soil as single layer. Currently we are coding new algorithms in to the model to consider a multi-layer soil module in order to better capture seasonal variations of important elements (e.g. NO_3^-). Also we are working on implementing wetland/lake

algorithms to consider function of wetland/lake retention time on nutrients cycling and elements attenuation to mitigate climate change effects for watersheds that have wetlands or lakes.

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