

FAO-FRAME Toolbox – Supporting calculation of Water Productivity (Ben Maathuis-Oct.2019)

Introduction

FAO has launched the WaPOR which allows the retrieval of various types of remote sensing based products, facilitating the calculation of the Water Productivity at different spatial resolutions. At African continental level data is available at 250 meters resolution (level 1) and for selected regions at 100 meters resolution. Some products are daily, but mainly the data is provided at dekadal temporal resolution.

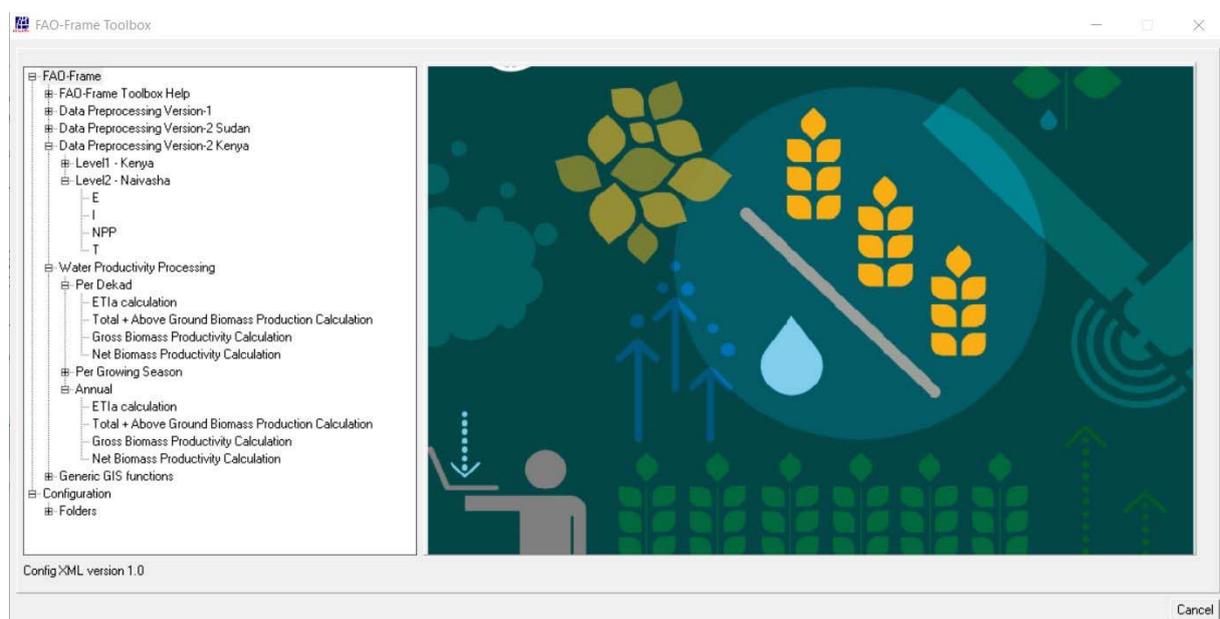
In order to efficiently process the time series data a small extension under ILWIS was developed, the FAO Frame toolbox. This utility allows structured pre-processing of version 1 and version 2 data provided through WaPOR of both level 1 and level 2. Based upon the products provided, subsequently the Water Productivity can be calculated. This is done at dekadal time step and these maps can be aggregated showing the (user defined) seasonal or annual water productivity.

Here based on (MSc and PhD) research preference and validation requirements two level 1 regions, namely Kenya and Sudan, as well as 2 level 2 regions, the Naivasha Basin (Kenya) and the Gezira irrigation scheme (Sudan) have been pre-defined. Other regions can be added once the bounding coordinates are defined, based on the ILWIS service objects 'georeference' and 'coordinate system'.

Once ILWIS is installed, current version used is ILWIS386b, the toolbox zip file can be copied into the folder under the ILWIS main directory \extensions. When ILWIS is started, the zip file is automatically extracted and the toolbox plugin is added to the main ILWIS menu. The toolbox can be opened subsequently and an initial pop-up menu, as given in the figure below is provided. The main menu is consisting of various sub menus allowing the pre-processing of the relevant WaPOR data and calculations with respect to the water productivity at various levels.

The product generation for the various levels is detailed in the manuals available from the WaPOR portal, e.g.: FAO (September 2018): *“Using Remote Sensing in support of solutions to reduce agricultural water productivity gaps. WaPOR Database methodology: Level 1 data. V1 release”*.

Figure 1: FAO-FRAME Toolbox menu.



The toolbox assumes that the input data is locally available, at ITC it is provided by consortium members who directly transfer the data to the allocated server at ITC-Utwente. Data can also be downloaded from the WaPOR webserver (https://wapor.apps.fao.org/home/WAPOR_2/1). Main difference is that data provided directly by consortium members is having start of decade as time reference, if retrieved from WaPOR the end of decade time stamp is used.

To efficiently create the required time series data the products can be imported via the toolbox menu, the ILWIS command line generated can be pasted into a batch routine and based on batch (loop) processing the required data can be (pre-) processed. Also ILWIS scripts, used to calculate the Water Productivity can be executed using batch routines. This requires minimum efforts by the user once the batch routines are created and all data is processed using identical routines, minimizing user errors.

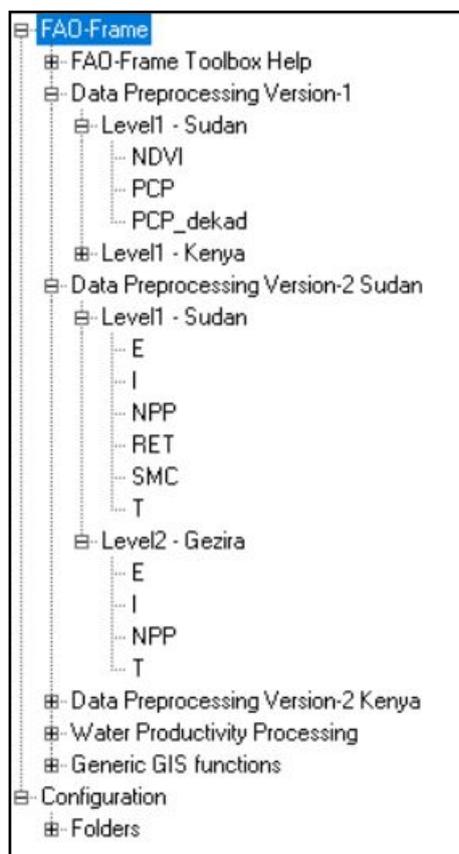
Initial functionality

Once data is locally available under the toolbox menu option “Configuration” > “Folders” the input and output folders can be specified. As multi-temporal data is processed, folders remain valid for multiple data processing events and the user does not need to specify these time and again.

Within WaPOR currently 2 versions are provided, version 1 and version 2. Routines are available that allow the processing of Version 1 data if this version is still supported within the WaPOR Webserver. Else for the more recent version 2 data, routines are available.

Note that within the toolbox level 1 data is extracted for the 2 countries indicated and level 2 data is extracted for selected regions within the country. The user can define their own regions of interest.

Figure 2: Pre-processing and versions for different areas of interest, example Sudan and Gezira scheme



For the “Data Preprocessing Version-1” the two products still at this level are the NDVI and the CHIRPS PCP products. The NDVI is at dekadal temporal interval, the PCP product has a daily time step. To facilitate dekadal time steps the daily data could be aggregated by the user, once the data is imported. Also the dekadal data, available from ftp://chg-ftpout.geog.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/africa_dekad/tifs/ can be used. The routine “PCP_dekad” has been created to obtain the precipitation from CHIRPS at dekadal time step directly.

Other products are based on version-2, both for level 1 and level 2, like Evaporation (E), Interception (I), Net Primary Productivity (NPP), Reference Evapotranspiration (RET), Soil Moisture Content (SMC) and Transpiration (T). The RET is produced at daily time step, all other products are having a dekadal time interval.

The Water Productivity is defined as the quantity of output (Total Biomass or Above Ground Biomass) in relation to the total volume of water consumed. By relating the biomass to total water consumption (which is the sum of E+I+T) an idea

is obtained on vegetation development in relation to the water used.

It should be noted that currently for WaPOR Version 1 the Water Productivity is expressed as the ratio AGBP/ETI (the above ground fraction being 0.65 as the root / shoot ratio), as for Version 2 it has changed to TBP/ETI (using the total biomass). See for further details: Version 1.1 description: https://wapor.apps.fao.org/catalog/WAPOR/1/L1_GBWP_A, and for the Version 2 description: https://wapor.apps.fao.org/catalog/WAPOR_2/1/L1_GBWP_A.

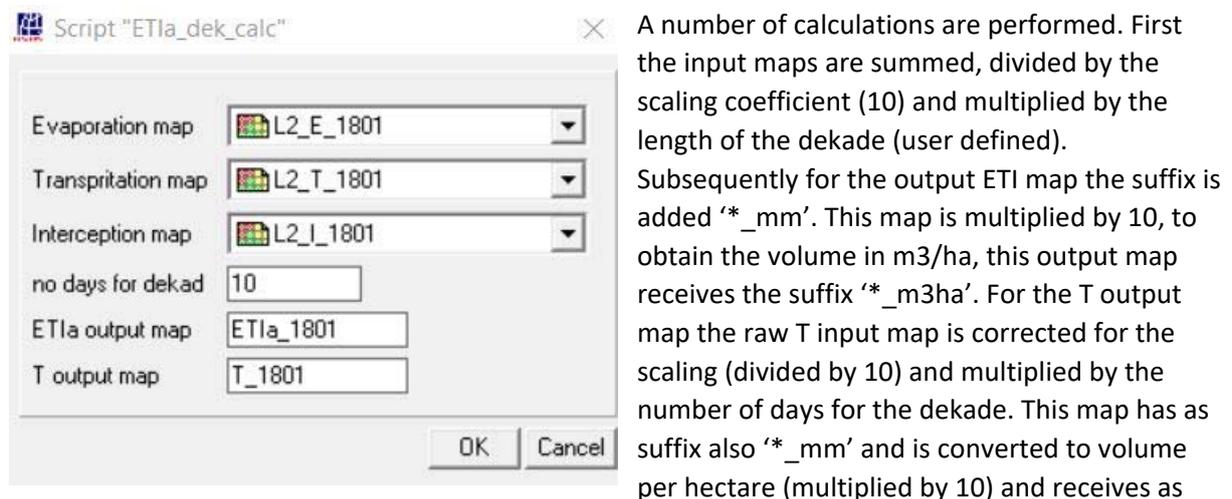
Calculation of Water Productivity per decade

In order to calculate the dekadal water productivity a number of script routines are created. Prior to the use of these routines for the E, I, NPP and T data, per decade should be locally available.

Script 1: Calculating the sum of the ETI.

This script (see figure 3) requires the raw dekadal input maps for E, I and T as well as the length of the decade, furthermore the user needs to specify the output map names for the ETI and T maps.

Figure 3: ETI calculation

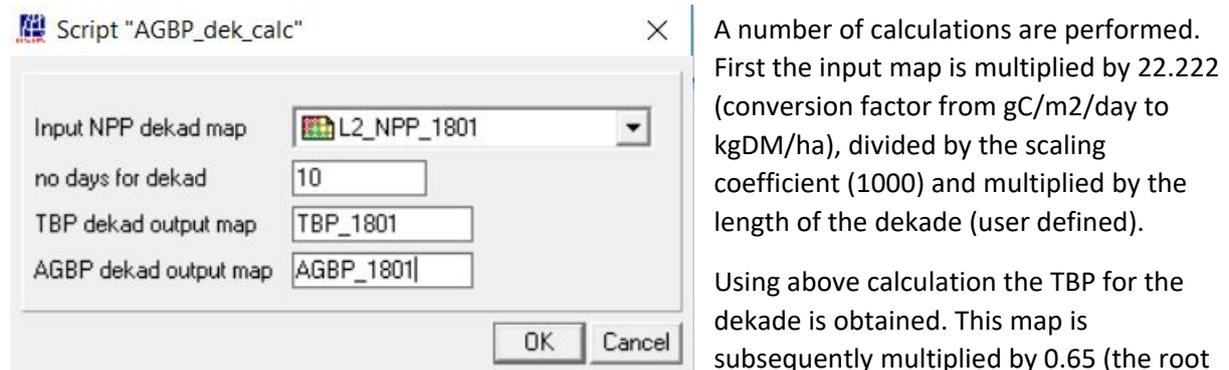


suffix '*_m3ha'. This procedure should be repeated for each decade for the time series under consideration and a map list should be created.

Script 2: Calculating the Total and Above Ground Biomass

This script (see figure 4) requires the raw NPP dekadal map, as well as the length of the decade, furthermore the user needs to specify the output map names for the TBP and AGBP maps.

Figure 4: Biomass calculation

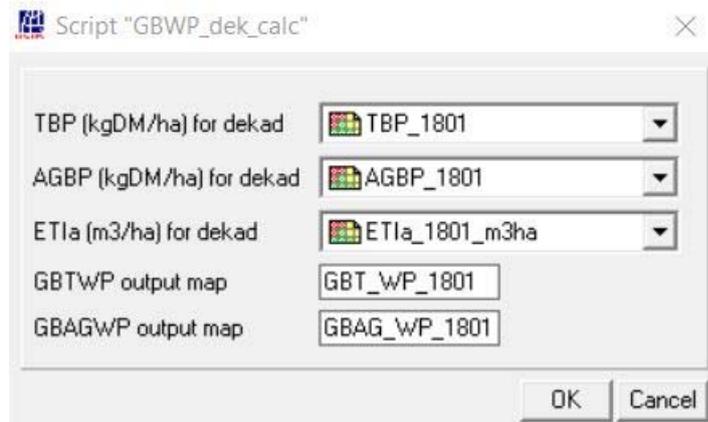


/ shoot ratio) to obtain the AGBP, the unit of both maps are in kgDM/ha. This procedure should be repeated for each decade for the time series under consideration and a map list should be created.

Script 3: Calculating the Gross Biomass Water Productivity

Once the dekadal biomass production and the water consumption is known the gross biomass water productivity can be calculated. This is the ratio of the dekadal sum of TBP or AGBP (in kgDM/ha) over the dekadal sum of ETI (in m3/ha).

Figure 5: Gross Biomass WP calculation



In this script the following calculations are performed, based on the output of the results obtained from the previous scripts:

$$\text{GBWP_TBP} = \text{TBP} / \text{ETIa}$$

$$\text{GBWP_AGBP} = \text{AGBP} / \text{ETIa}$$

For the AGBP a ratio of 0.65 is applied to the TBP, unit of all output maps is in kg/m3. This procedure should be

repeated for each decade for the time series under consideration and a map list should be created.

Script 4: Calculating the Net Biomass Water Productivity

Once the dekadal biomass production and the water consumption is known also the net biomass water productivity can be calculated. This is the ratio of the dekadal sum of TBP or AGBP (in kgDM/ha) over the dekadal sum of T (in m3/ha).

Figure 6: Net Biomass WP calculation



In this script the following calculations are performed, based on the output of the results obtained from the previous scripts:

$$\text{NBWP_TBP} = \text{TBP} / \text{T}$$

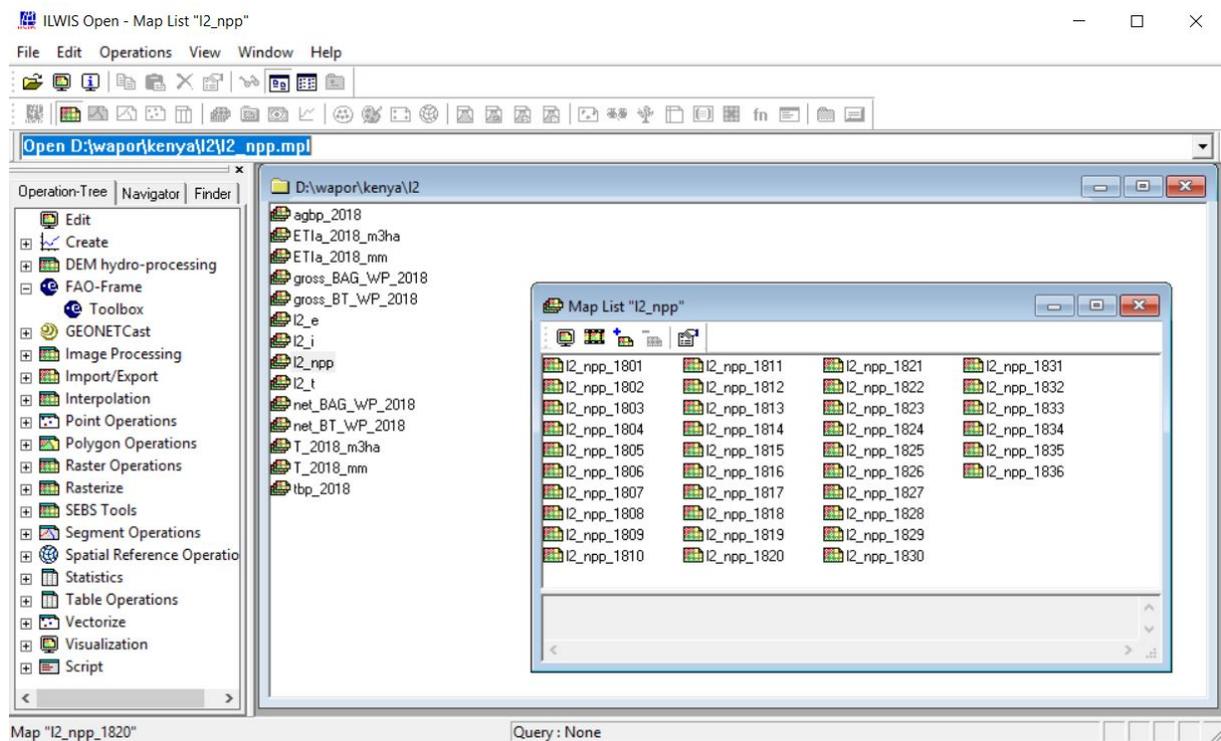
$$\text{NBWP_AGBP} = \text{AGBP} / \text{T}$$

For the AGBP a ratio of 0.65 is applied to the TBP, unit of all output maps is in kg/m3. This procedure should be

repeated for each decade for the time series under consideration and a map list should be created.

Once these calculations are performed per decade, over the time series, various map series are obtained, like the ETI and T (both in mm and m3/ha), TBP and AGBP (both in kgDM/ha), GBTWP and GBAGWP, NBTWP and NBAGWP (all in kg/m3). The various input and output map lists are given in the figure below, the map list for the initial NPP product is expanded and shown on top of the ILWIS catalog window.

Figure 7: Dekadal processing results for 2018



Calculation of Water Productivity per growing season or annually

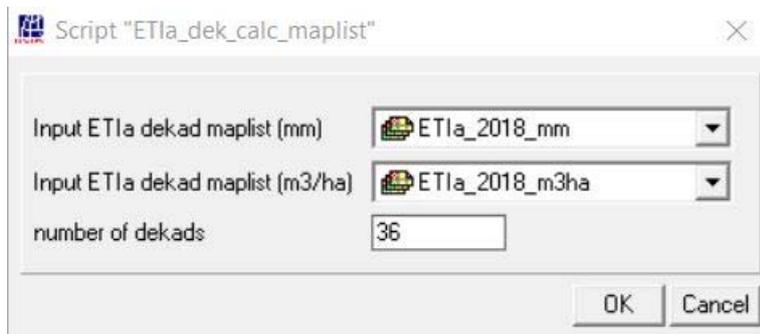
The user can create map lists according to their preference, e.g. over a growing season or yearly. These map lists, with identical time steps, are required to perform the aggregation and calculate the water productivity of the given time.

The procedures described below are based on the results obtained using the dekadal products created in the previous steps described. In order to utilize the same scripts the user is required to enter the number of dekades in the first two scripts described below.

Script 5: Calculating the sum of the ETI over the aggregation period

The example used here is using as aggregation period a calendar year. Identical steps are followed as with respect to the dekadal computations and the starting point is the overall sum of the ETI.

Figure 8: Calculate aggregated ETI over time



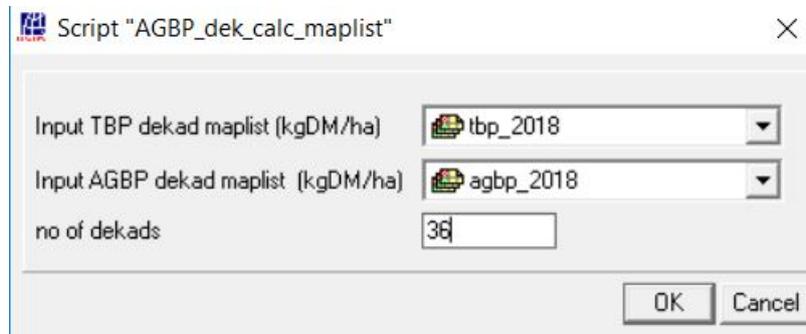
The routine requires 2 map lists, the ETI in mm and in m3/ha. The map lists is consisting of maps representing a certain time period, in this case a year, therefore 36 dekades. As output 2 maps are calculated representing the sum over the aggregation period of ETI in mm and in m3/ha., the suffix

'*_sum' is added in both cases.

Script 6: Calculating the Total and Above Ground Biomass over the aggregation period

Next step is the aggregation of the biomass production over the aggregation period.

Figure 9: Calculate biomass production over time



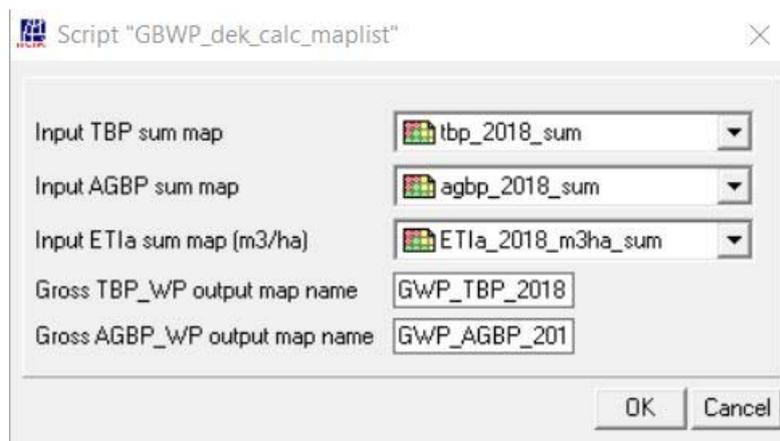
The routine requires 2 map lists, the total biomass production and the above ground biomass production (both map lists should contain maps in kgDM/ha). The map lists is consisting of maps representing a certain time period, in this case a year,

therefore 36 dekades. As output 2 maps are calculated representing the sum over the aggregation period of TBP and AGBP in kgDM/ha., the suffix '*_sum' is added in both cases.

Script 7: Calculating the Gross Biomass Production over the aggregation period

Next step is the calculation of the gross biomass production over the aggregation period.

Figure 10: Calculate Gross Biomass production over time



Same steps are executed as for the dekadal time step, only here the aggregated maps are used as input. The gross water productivity map is calculated as:

$$\text{GWP_TBP} = \text{TBP_sum} / \text{ETIa_m3ha_sum}$$

$$\text{GWP_AGBP} = \text{AGBP_sum} / \text{ETIa_m3ha_sum}$$

Note that in this example calendar year 2018 is used. The unit of the output maps for the gross total biomass and the gross above ground biomass water productivity maps is kg/m³.

Script 8: Calculating the Net Biomass Production over the aggregation period

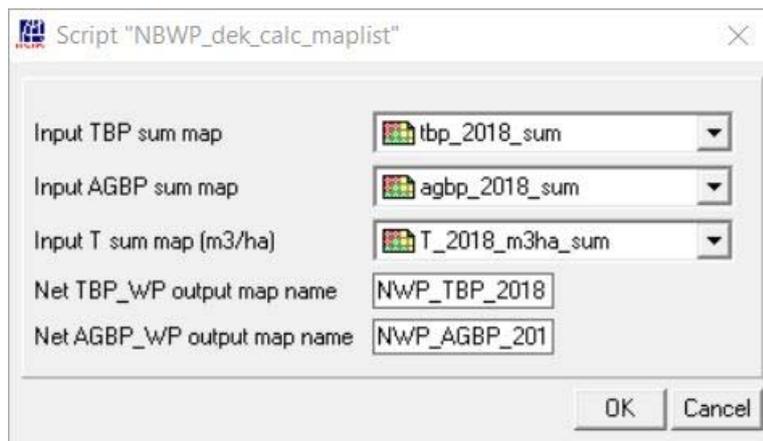
The final step is the calculation of the net biomass production over the aggregation period. Same steps are executed as for the dekadal time step, only here the aggregated maps are used as input. The net water productivity map is calculated as:

$$\text{NWP_TBP} = \text{TBP_sum} / \text{T_m3ha_sum}$$

$$\text{NWP_AGBP} = \text{AGBP_sum} / \text{T_m3ha_sum}$$

The unit of the output maps for the net total biomass and the net above ground biomass water productivity maps is kg/m³.

Figure 11: Calculate Net Biomass production over time



Application of these scripts facilitate easy and error free computation of the required output. As all the time the dekadal (and number of days per dekade) or yearly time stamp is the only change, the computations can also be performed by modifying the expression in the ILWIS command line. As example, for the last script, the following command line is generated:

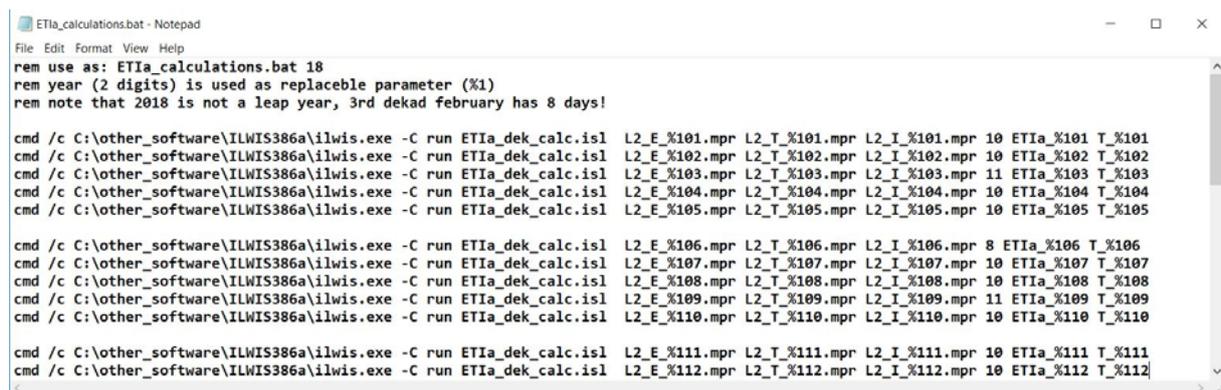
```
run NBWP_dek_calc_maplist tbp_2018_sum agbp_2018_sum T_2018_m3ha_sum
NWP_TBP_2018 NWP_AGBP_2018
```

To run the script for 2017, only the input and output year time stamp has to be modified. It is therefore important to use appropriate and consistent file name conventions!

Use of external processing routines

The scripts can also be run using a batch file, basically automating the full processing. The figure below is showing a sample of a batch file which is executing the script as used for the ETI calculation of a dekade.

Figure 12: running scripts from MS-DOS batch file



Within notepad at text file is create, and saved with an extension *.bat. In the example shown the first 3 lines are remarks, line 1 indicates how to use the batch file from the Command Line Interpreter window, the second line indicates that there is one replaceble parameter used, here 18, to process the data from 2018. The 3rd line indicates that 2018 is not a leap year and therefore the last dekade of February has 8 days.

The subsequent lines are created based on the command line string generated in the ILWIS command line. Reviewing again figure 3, 6 parameters are needed: E, T, I, no. days per dekade, ETIa and T output map names.

The batch file is just a sequence of 36 lines, executing the script for each dekade of the year. This is preceded by the strings "cmd /c" which instructs the DOS command line interpreter that after execution of the command it should continue to the next line in the batch file. Subsequently the location of the ILWIS.exe is required. The next item is "-C", this instructs ILWIS to run from the command interface. The "ETIa_dek_calc.isl" is the script to be executed. The remainder are the parameters as required by the script.

In this example all required data and the script are situated in the working directory and ILWIS is opened / closed in the same folder before starting the batch file.

Closing remark

A large number of files / maps are created. It is therefore extremely important that appropriate file management and file naming conventions are considered straight from the start. Advice is to create per year or growing season a folder structure and perform the calculations within each of these folders. The final Water Productivity output maps can then be copied to a common output folder to check the WP performance over the various growing seasons or years. At this moment 10 years of data is at the user disposal.

Annex 1: Manual computation of the water productivity

number dekad	Category dekad	days/ dekad	NPP raw by 1000	NPP scaled	TBP-day	TBP-dek	AGBP	I ratio=0.65	I mm/day	E mm/dek	E mm/day	T mm/dek	T mm/day	ETIa_day mm/day	ETIa_Dek mm/dek	T_Dek mm/dek	ETIa_Dek m3/ha	T_Dek m3/ha	GBWP_dek kg/m3	NBWP_dek kg/m3	Chirps-P mm/dek	SMC
1	10-1-2018	10	687	0.687	15.26651	152.6651	99.23234	0	0	0.6	6	0.6	6	1.2	12	6	120	60	0.827	1.654	19	65.00
2	10-1-2018	10	797	0.797	17.71093	177.1093	115.1211	0	0	0.7	7	0.7	7	1.4	14	7	140	70	0.822	1.645	15	68.00
3	10-1-2018	11	764	0.764	16.97761	186.7537	121.3899	0	0	0.6	6.6	0.6	6.6	1.2	13.2	6.6	132	66	0.920	1.839	21	62.00
4	10-2-2018	10	586	0.586	13.02209	130.2209	84.6436	0	0	0.4	4	0.3	3	0.7	7	3	70	30	1.209	2.821	14	54.00
5	20-2-2018	10	280	0.28	6.22216	62.2216	40.44404	0	0	0	0	0.2	2	0.2	2	2	20	20	2.022	2.022	12	38.00
6	28-2-2018	8	474	0.474	10.53323	84.26582	54.77279	0	0	0.4	3.2	0.4	3.2	0.8	6.4	3.2	64	32	0.856	1.712	9	52.00
7	10-3-2018	10	481	0.481	10.68878	106.8878	69.47708	0.1	1	0.5	5	0.3	3	0.9	9	3	90	30	0.772	2.316	114	69.00
8	20-3-2018	10	619	0.619	13.75542	137.5542	89.41022	0.1	1	0.7	7	0.5	5	1.3	13	5	130	50	0.688	1.788	119	73.00
9	31-3-2018	11	1107	1.107	24.59975	270.5973	175.8882	0	0	0.4	4.4	0.7	7.7	1.1	12.1	7.7	121	77	1.454	2.284	16	71.00
10	10-4-2018	10	1429	1.429	31.75524	317.5524	206.409	0.1	1	0.5	5	1	10	1.6	16	10	160	100	1.290	2.064	70	71.00
11	20-4-2018	10	1315	1.315	29.22193	292.2193	189.9425	0.2	2	0.5	5	1	10	1.7	17	10	170	100	1.117	1.899	124	77.00
12	30-4-2018	10	1549	1.549	34.42188	344.2188	223.7422	0.1	1	0.5	5	1.1	11	1.7	17	11	170	110	1.316	2.034	139	77.00
13	10-5-2018	10	1767	1.767	39.26627	392.6627	255.2308	0.1	1	0.4	4	1.1	11	1.6	16	11	160	110	1.595	2.320	70	76.00
14	20-5-2018	10	1641	1.641	36.4663	364.663	237.031	0.1	1	0.5	5	1.1	11	1.7	17	11	170	110	1.394	2.155	167	83.00
15	31-5-2018	11	1693	1.693	37.62185	413.8403	268.9962	0	0	0.4	4.4	1	11	1.4	15.4	11	154	110	1.747	2.445	39	76.00
16	10-6-2018	10	1273	1.273	28.28861	282.8861	183.8759	0	0	0.3	3	0.8	8	1.1	11	8	110	80	1.672	2.298	51	74.00
17	20-6-2018	10	1489	1.489	33.08856	330.8856	215.0756	0	0	0.4	4	0.8	8	1.2	12	8	120	80	1.792	2.688	27	70.00
18	30-6-2018	10	1310	1.31	29.11082	291.1082	189.2203	0	0	0.4	4	0.7	7	1.1	11	7	110	70	1.720	2.703	14	70.00
19	10-7-2018	10	1165	1.165	25.88863	258.8863	168.2761	0	0	0.3	3	0.6	6	0.9	9	6	90	60	1.870	2.805	8	66.00
20	20-7-2018	10	1145	1.145	25.44419	254.4419	165.3872	0	0	0.4	4	0.7	7	1.1	11	7	110	70	1.504	2.363	6	65.00
21	31-7-2018	11	1100	1.1	24.4442	268.8862	174.776	0	0	0.3	3.3	0.6	6.6	0.9	9.9	6.6	99	66	1.765	2.648	12	61.00
22	10-8-2018	10	1286	1.286	28.57749	285.7749	185.7537	0	0	0.4	4	0.8	8	1.2	12	8	120	80	1.548	2.322	4	66.00
23	20-8-2018	10	1109	1.109	24.6442	246.442	160.1873	0	0	0.3	3	0.5	5	0.8	8	5	80	50	2.002	3.204	4	60.00
24	31-8-2018	11	802	0.802	17.82204	196.0425	127.4276	0	0	0.3	3.3	0.4	4.4	0.7	7.7	4.4	77	44	1.655	2.896	35	60.00
25	10-9-2018	10	959	0.959	21.3109	213.109	138.5208	0	0	0.4	4	0.5	5	0.9	9	5	90	50	1.539	2.770	10	66.00
26	20-9-2018	10	622	0.622	13.82208	138.2208	89.84355	0	0	0.3	3	0.4	4	0.7	7	4	70	40	1.283	2.246	8	49.00
27	30-9-2018	10	578	0.578	12.84432	128.4432	83.48805	0	0	0.3	3	0.3	3	0.6	6	3	60	30	1.391	2.783	13	49.00
28	10-10-2018	10	449	0.449	9.977678	99.77678	64.85491	0	0	0.3	3	0.3	3	0.6	6	3	60	30	1.081	2.162	16	50.00
29	20-10-2018	10	564	0.564	12.53321	125.3321	81.46585	0	0	0.5	5	0.4	4	0.9	9	4	90	40	0.905	2.037	9	61.00
30	31-10-2018	11	509	0.509	11.311	124.421	80.87364	0	0	0.4	4.4	0.3	3.3	0.7	7.7	3.3	77	33	1.050	2.451	23	58.00
31	10-11-2018	10	626	0.626	13.91097	139.1097	90.42132	0	0	0.3	3	0.3	3	0.6	6	3	60	30	1.507	3.014	21	52.00
32	20-11-2018	10	776	0.776	17.24427	172.4427	112.0878	0	0	0.3	3	0.4	4	0.7	7	4	70	40	1.601	2.802	21	52.00
33	30-11-2018	10	1081	1.081	24.02198	240.2198	156.1429	0	0	0.3	3	0.6	6	0.9	9	6	90	60	1.735	2.602	24	57.00
34	10-12-2018	10	782	0.782	17.3776	173.776	112.9544	0	0	0.2	2	0.5	5	0.7	7	5	70	50	1.614	2.259	38	48.00
35	20-12-2018	10	1145	1.145	25.44419	254.4419	165.3872	0	0	0.6	6	0.8	8	1.4	14	8	140	80	1.181	2.067	69	70.00
36	31-12-2018	11	1394	1.394	30.97747	340.7521	221.4889	0	0	0.5	5.5	0.9	9.9	1.4	15.4	9.9	154	99	1.438	2.237	17	69.00
365						7998.831	5199.24		8	14.6	148.1		225.7		381.8	225.7	3818	2257	1.386	2.343	1378	63.47

Annual WP	ETIa	381.8		
from WAPOR WWW	use TBP	use AGBP	AGBP-use mean for each dekad	
GBWP	2.095	2.09503	1.3618	1.3857
NBWP	3.544	3.54401	2.3036	2.3433

