RESEARCH PROGRAM ON Water, Land and Ecosystems

LED BY: IWMI International Water Management Institute

Assessing impacts of agriculture and dams on hydrological ES to people and dams in the Volta basin using the WaterWorld hydrological model

Mark Mulligan, Arnout van Soesbergen

Scope and objective

This guide focuses on how to run a baseline analysis using the WaterWorld hydrological model (Mulligan, 2013) with a particular focus on using two WaterWorld metrics to examine the impact of agriculture on hydrological ecosystem services to people and small dams and then the impact of small dams on hydrological ecosystem services provided to people. The former is assessed using the model results-based hydrological footprint - which calculates the hydrological footprint (downstream influence) of cropland based on modelled water balance and runoff. This assesses the volume of water potentially influenced by a land cover type in relation to the total volume of water in flow. The latter is assessed using the model results-based flow footprint (WWFF) - which calculates the flow footprint (downstream influence) of small dams based on modelled water balance and runoff. The flow footprint is a special case of the hydrological footprint for in-stream features such as dams rather than on-land features such as land uses, but is calculated in the same way. The number of people affected are calculated as the first (dis-)beneficiaries of these footprints according to the spatial distribution of population in relation to the footprints. This accounts for the footprints influence on these first beneficiaries (water users, irrigators, fishers) but not for the impact of these footprints on supply chain beneficiaries through for example increased prices as a result of reduced availability.

WaterWorld is a testbed for the development and implementation of land and water related policies for sites and regions globally, enabling their intended and unintended consequences to be tested *in silico* before they are tested *in vivo*. WaterWorld can also be used to understand the hydrological and water resources baseline and water risk factors associated with specific activities under current conditions and under scenarios for land use, land management and climate change. It incorporates detailed spatial datasets at 1-square km and 1 hectare resolution for the entire world, spatial models for biophysical and socio-economic processes along with scenarios for climate, land use and economic change. A series of interventions (policy options) are available which can be implemented and their consequences traced through the socio-economic and biophysical systems. The model integrates with a range of geobrowsers for immersive visualisation of outcomes.

Input data for application of this model anywhere globally (from remote sensing and other global sources) is included in the system. However, users can also use this model with their own datasets. Application with the provided datasets takes only half an hour and requires no GIS capacity. Bringing in your own datasets will take much longer depending on the availability, level of processing, format and consistency of those datasets and also requires GIS capacity.

Typical applications of the model include, water resources assessment, water security analysis and hydrological ecosystem services accounting. Also climate impacts analysis and land and water management.

Audience: Conservation and development NGOs, GO and NGO Policy analysts, agriculture and industry (e.g. extractives), education and academic research.

Description and application

To access the tool, go to http://www.policysupport.org/waterworld and click on the relevant link to create a free account which can be used with the scientist user level interface. This guide uses the superuser and mega user level interfaces as some of the features described are not available for the free user version. Access to this user level can be granted on a case basis. For more information please contact Mark Mulligan at King's College London (mark.mulligan@kcl.ac.uk)

After logging in, there are four easy steps to run the model for a baseline simulation. All these steps are also documented in training video's. At each step you can find the link for the relevant video.

Running a baseline analysis in WaterWorld

Step 1: Define study area

Video: here

The model can be run at 1-km and 1-ha resolutions with a tiled extent of 1-degree (~100 km) or 10-degrees (~1000 km). The 1-ha resolution can only be run within the 1-degree tiles. The 1-km resolution can be run within tiles of 10 degrees or at country or large river basin level. To select your study area, you can either move the map until your area is within the highlighted tile (blue for 1-km, 10 degrees and pink for 1-ha, 1 degree) or select a country or basin from the dropdown list (Figure 1, A). Once you have selected your area, you need to give it a name (Figure 1, B) and click on Step 1: Define area.

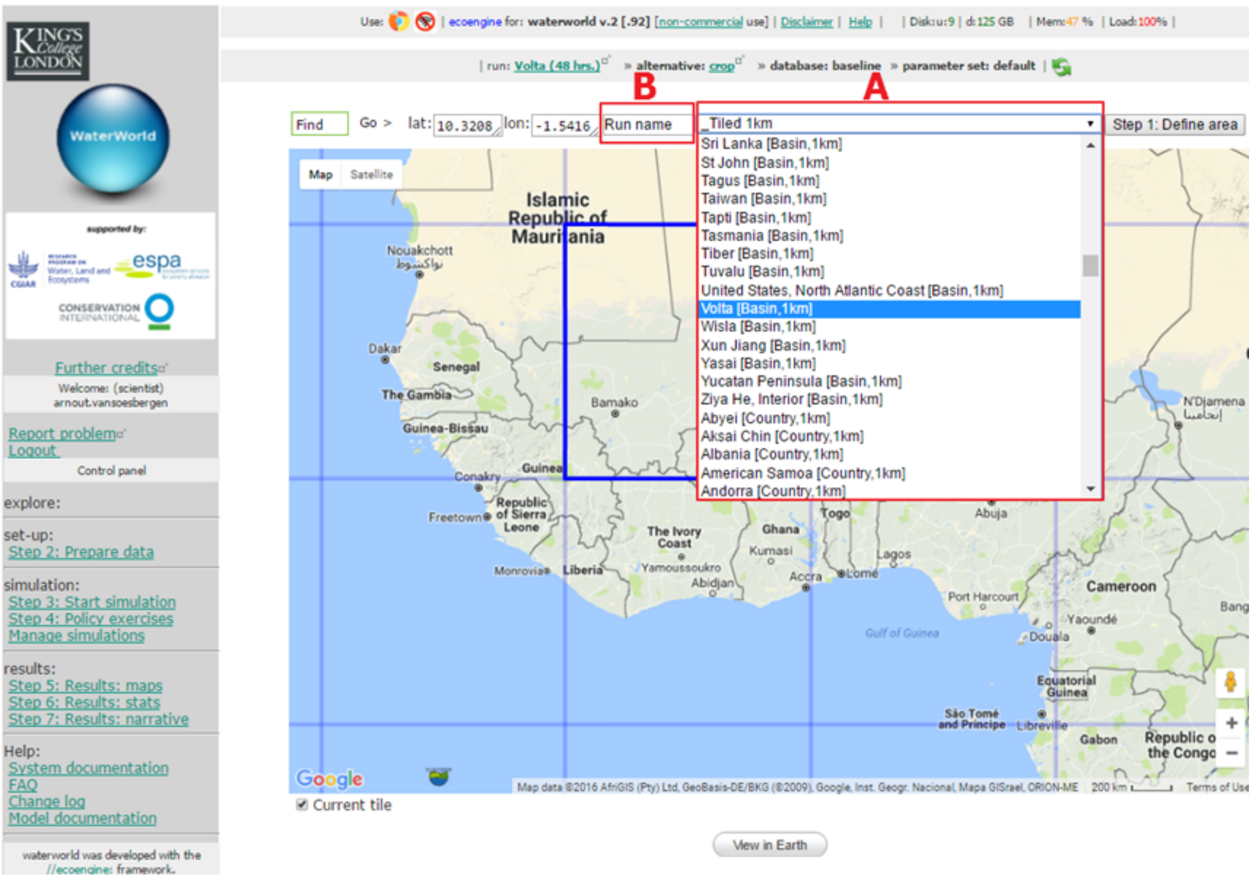

Figure 1: Define area for running the model

Step 2: Prepare data

Video:[here]

Step 2 is about preparing the data. WaterWorld comes with all necessary data included to run the model. For each model run however, data will have to be prepared and copied to your personal workspace (linked to your account). To set up data for a model run, click on Step 2: Prepare data (Figure 2, A). This will then open up a window where you can view the list of data (list baseline workspace data) or Copy data to your workspace (Figure 2, B) which is required to run the model. When clicking on this, the system will take a few minutes to gather and copy the necessary data to your workspace on the servers. When the data is ready you can view the workspace data by clicking on the +/- next to show workspace data (Figure 2, C).

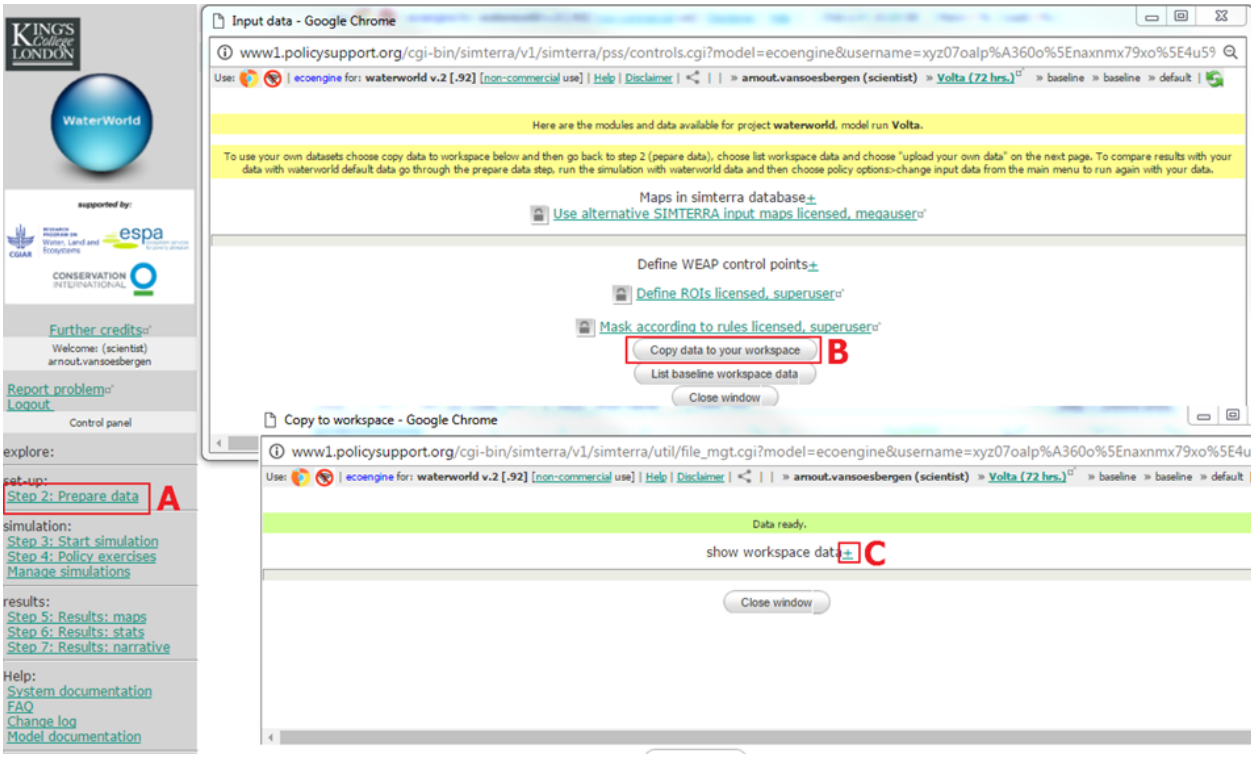

Figure 2: Step 2: prepare data

Visualising data

Opening up the list of workspace data (Figure 2, C) will show the list of all datasets necessary to run the model. Around 140 spatial datasets are required for a run. Maps that have a license to redistribute can be downloaded in a variety of GIS formats (Figure 3, A), or can be viewed (Figure 3, B), depending on the license.

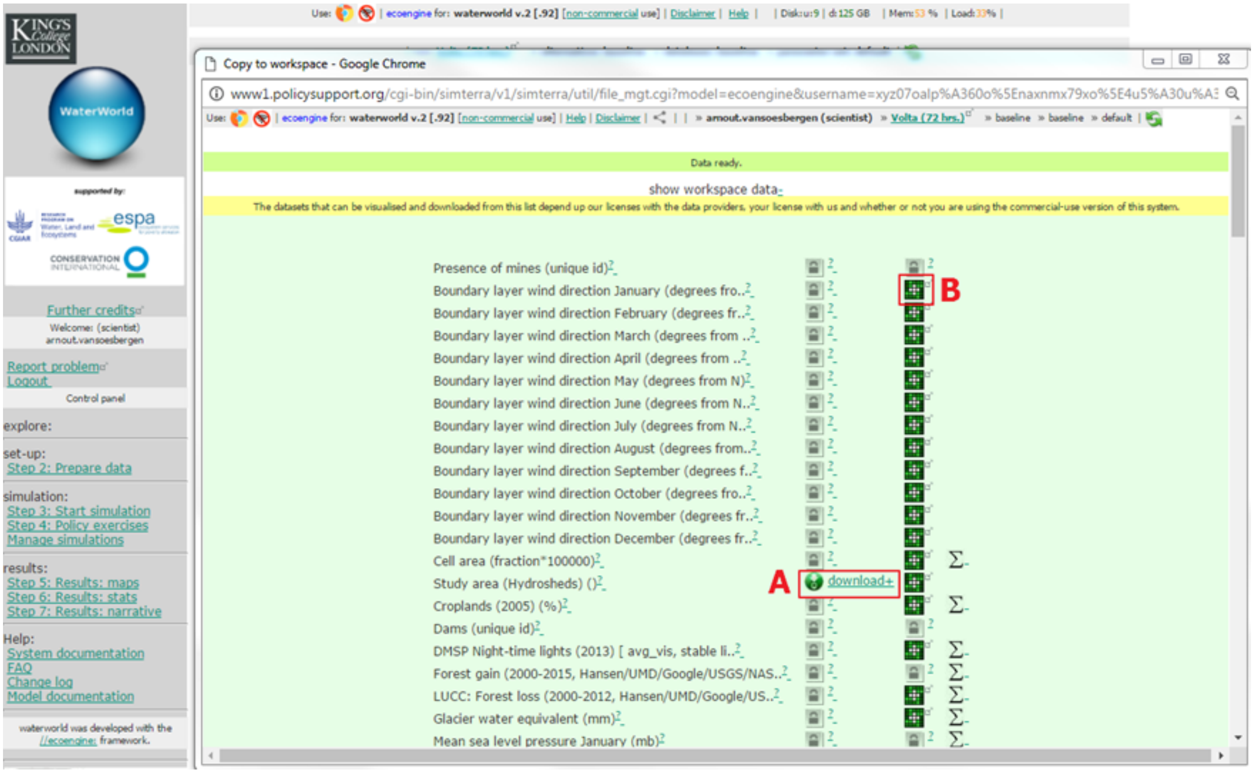

Figure 3: Download or visualise maps in workspace

Clicking on the green view map icon (Figure 3, B) will open up a map viewer window with a number of options similar to those in a GIS. Any map (input or output) can be overlaid on Google Earth or Google maps. Some of the options are shown in Figure 4, showing a pixel based map of tree cover (A), and overlaid on Google Maps (B) for which you can query individual pixel values by moving the map until the crosshair overlays your pixel of interest and clicking on Query. Maps can also be aggregated over other maps by selecting a map from the View by dropdown above the main map, e.g. select protected areas (C) to view the mean tree cover percentage in protected areas (D)

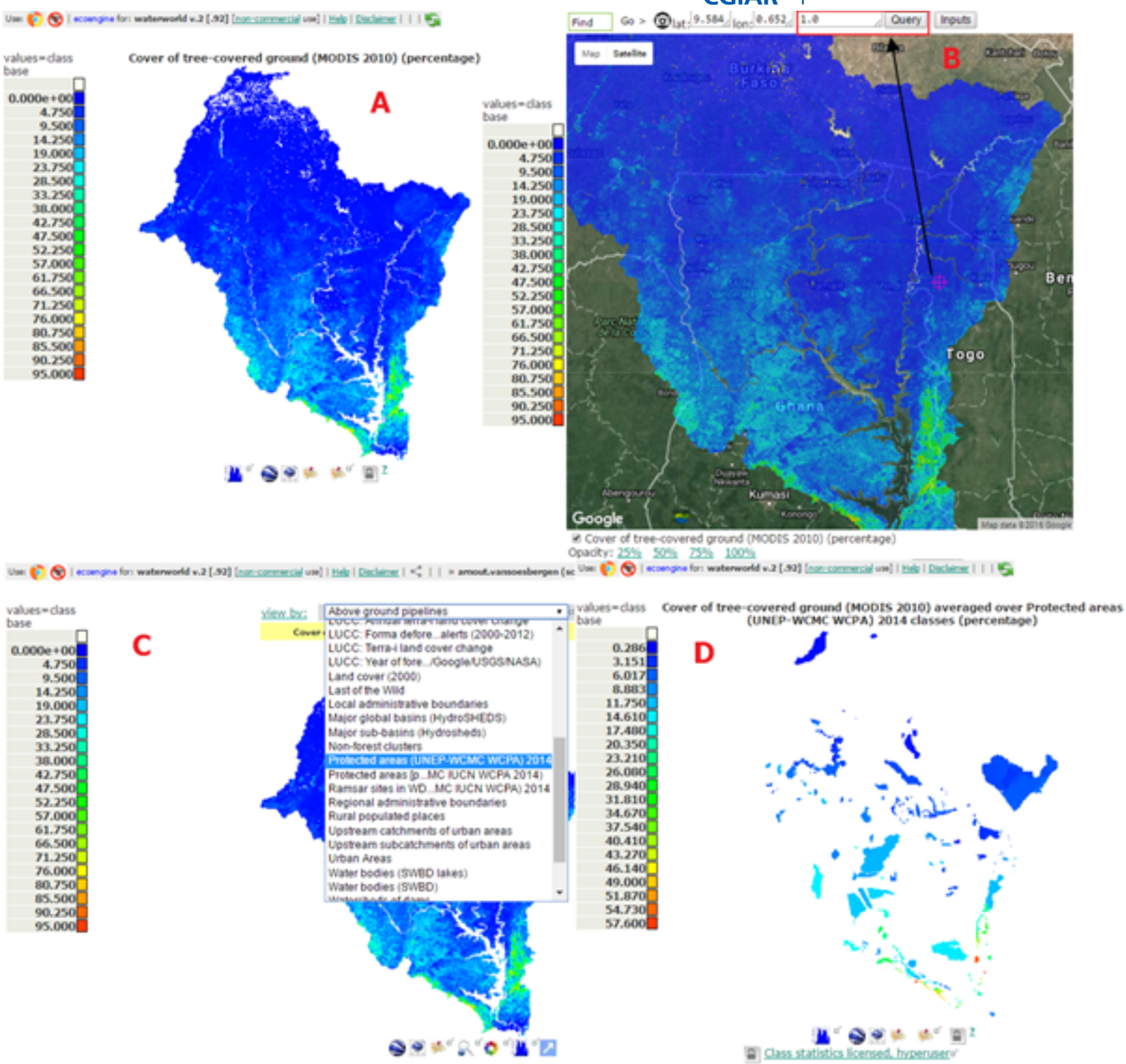

Figure 4: visualising input and output maps

Step 3: Start simulation
Video: [here]

Once all data has been copied over to your workspace, you can start the simulation by clicking on Step 3: start simulation in the left hand control panel on the main page (Figure 4). This will then open a simulation window where you can choose whether you want to write monthly maps or not. Clicking on Write maps will create monthly output maps. The default is not to write monthly maps as these are not always necessary and take up a lot of space on the servers however to calculate a seasonality map it is necessary to run monthly maps. After you have selected to write monthly maps, click on Start to set the simulation running. A simulation will take around 10 minutes to run a sophisticated hydrological baseline. If the area has never been run before by anyone else, this can take 24 hours (because of preprocessing) but once started, window or computer can be switched off. The run will complete without user interaction.

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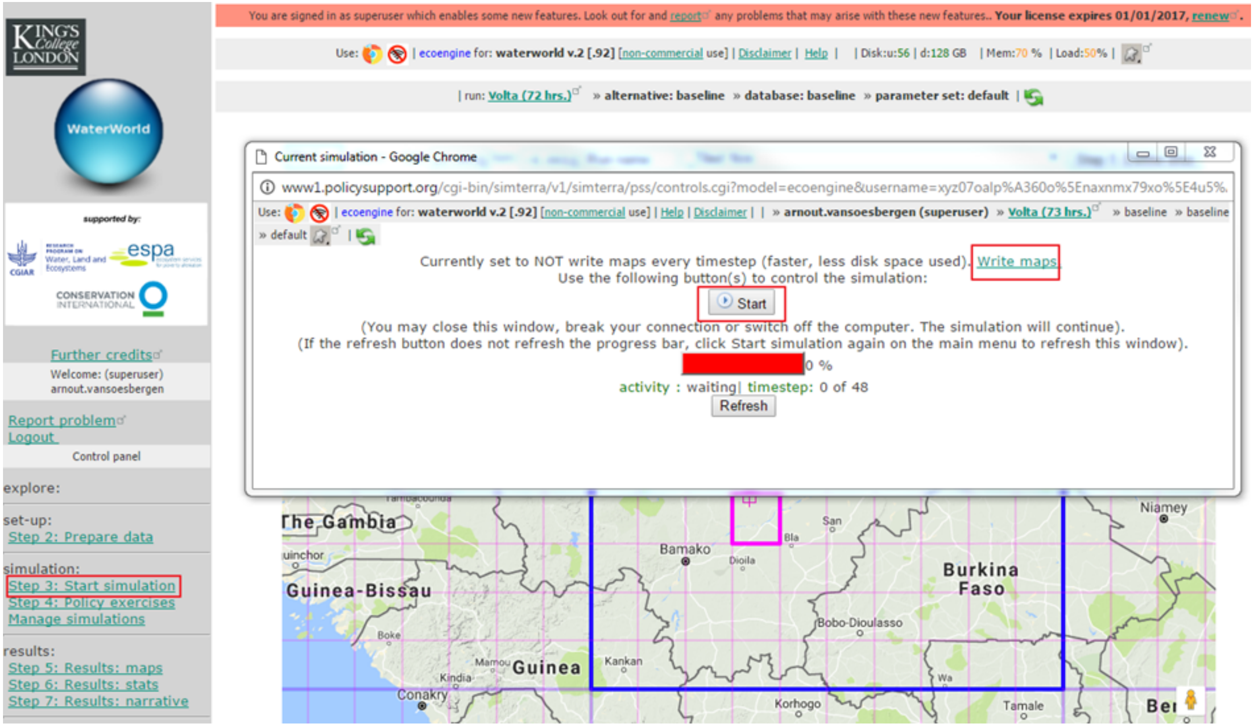


Figure 5: Step 3: start simulation

Step 5: Results maps
Video: here

Once the simulation has finished you can look at the results by clicking on Step 5: results maps in the left control panel on the main page. Step 4 is skipped as that step is for scenario simulations which can only be run after a baseline run has been done. Map outputs from all runs (baseline and scenario) are always in step 5. This will open up a new window showing all the map results as shown in Figure 5. You can view and interrogate the output maps by clicking on the green view map icon (A) which gives you all the options to view and analyse the maps as discussed in the previous section.

Figure 6: Step 5: results: maps

Examine the impact of agriculture on hydrological ecosystem services to people

WaterWorld's results-based hydrological footprint analysis can be used to assess the impact of agriculture on hydrological ecosystem services to people. The hydrological footprint calculates the hydrological footprint (downstream influence) of cropland based on modelled water balance and runoff. This assesses the volume of water potentially influenced by a land cover type in relation to the total volume of water in flow.

Once a baseline has been calculated, this analysis can be run from the cropland map found in the input data. Click on Step 2: Prepare data and select 'List baseline workspace data' (Figure 7, A). Expand the list of data by clicking on the +- (B) and scroll to the crop map and click on the green visualise icon (C).

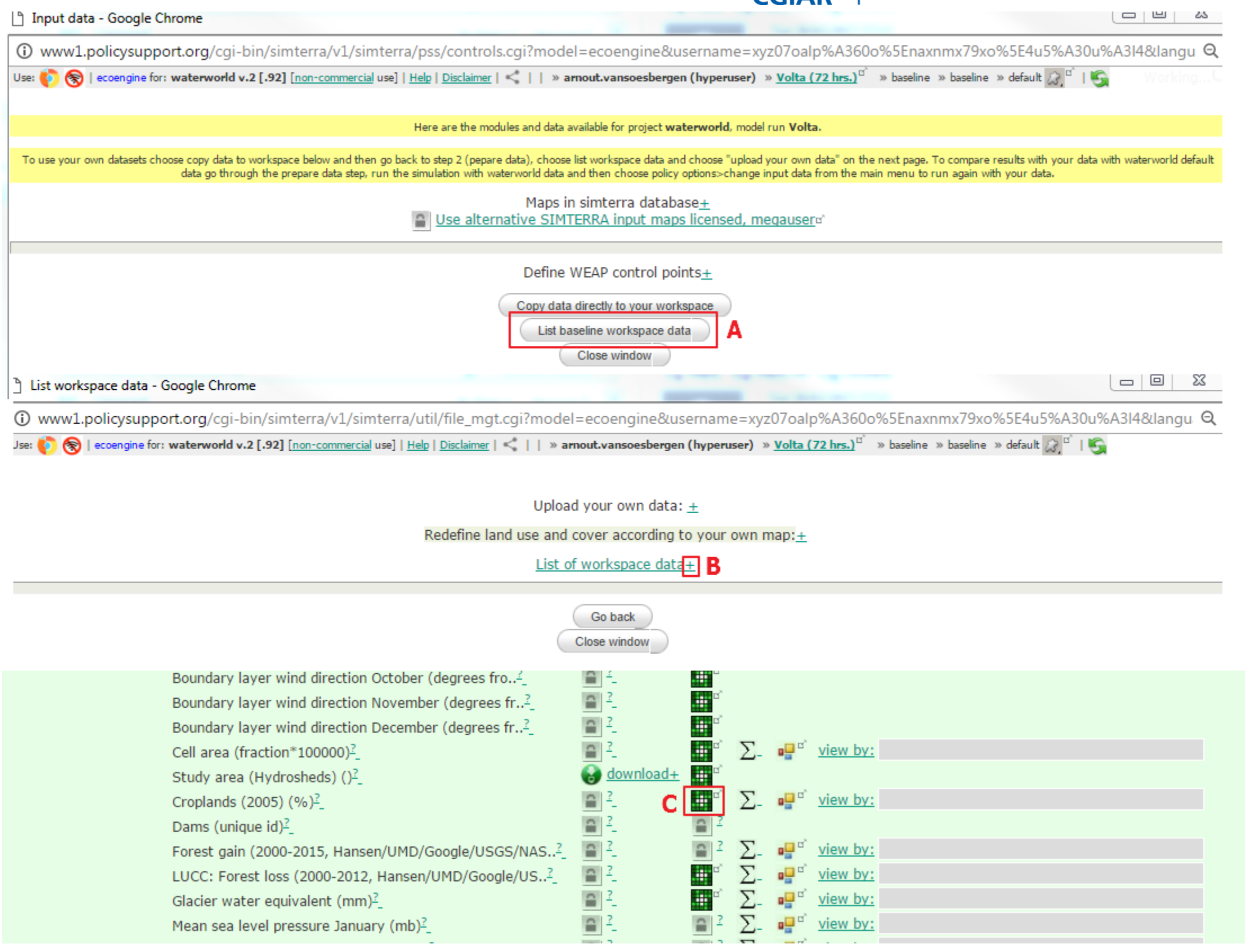


Figure 7: Selecting input map for calculation of hydrological footprint

From the crop map, select Calculation from the options underneath the map (Figure 8)

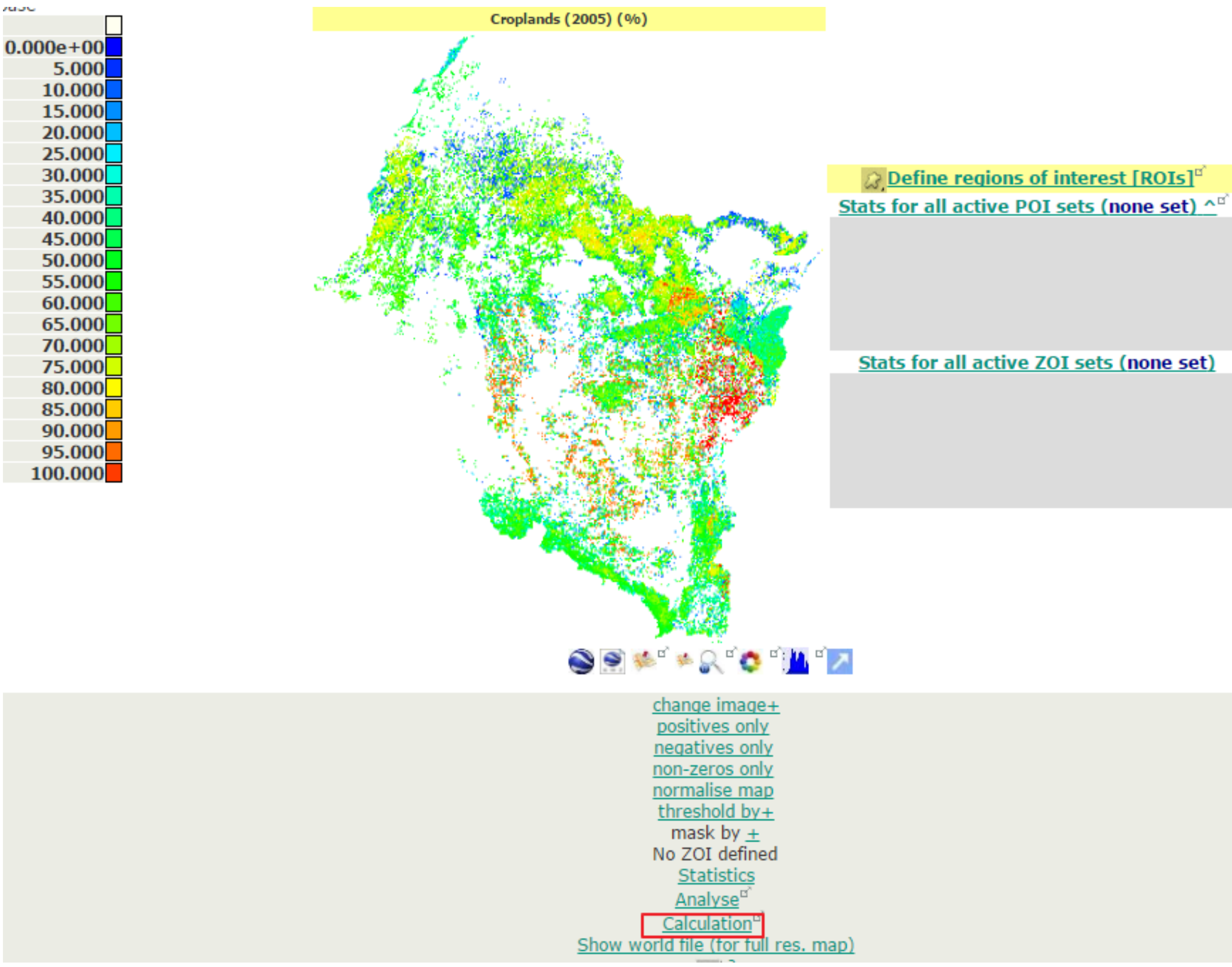
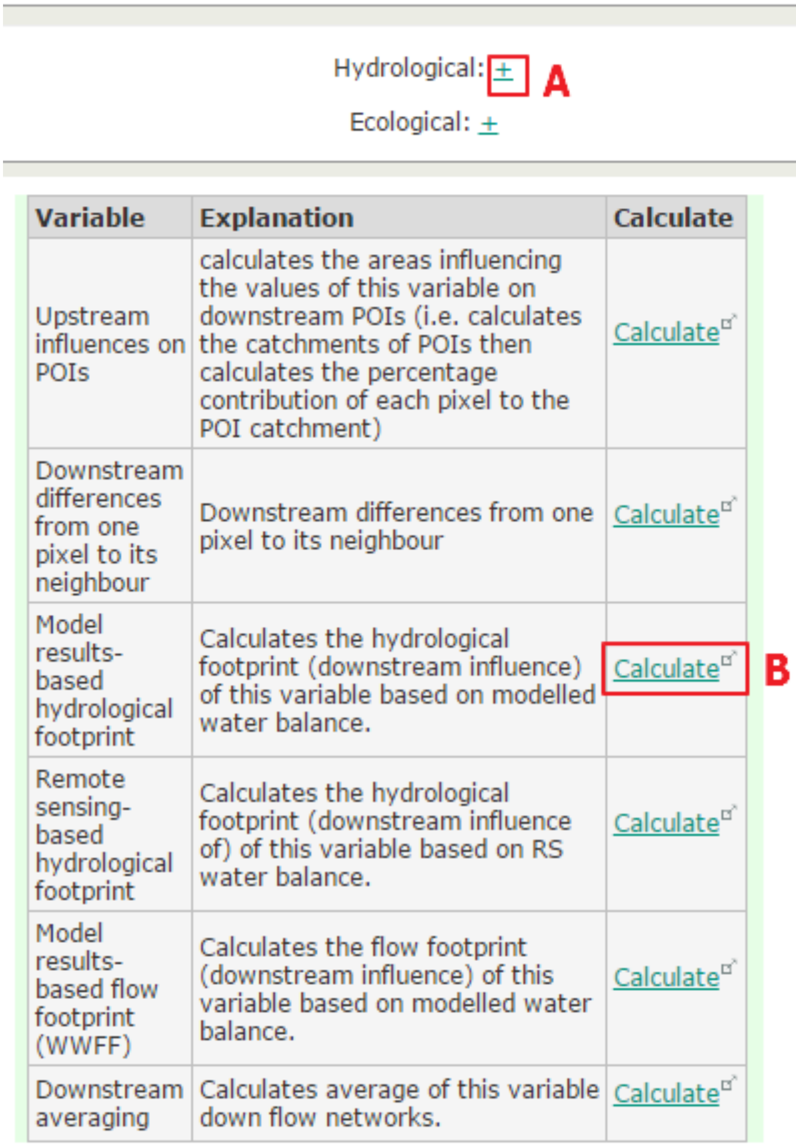


Figure 8: Calculation options for maps

From the window that opens, expand the hydrological options by clicking on the +- next to Hydrological (Figure 9, A) and click on Calculate the model results based hydrological footprint (Figure 9, B)



Variable	Explanation	Calculate
Upstream influences on POIs	calculates the areas influencing the values of this variable on downstream POIs (i.e. calculates the catchments of POIs then calculates the percentage contribution of each pixel to the POI catchment)	Calculate
Downstream differences from one pixel to its neighbour	Downstream differences from one pixel to its neighbour	Calculate
Model results-based hydrological footprint	Calculates the hydrological footprint (downstream influence) of this variable based on modelled water balance.	Calculate
Remote sensing-based hydrological footprint	Calculates the hydrological footprint (downstream influence of) of this variable based on RS water balance.	Calculate
Model results-based flow footprint (WWFF)	Calculates the flow footprint (downstream influence) of this variable based on modelled water balance.	Calculate
Downstream averaging	Calculates average of this variable down flow networks.	Calculate

Figure 9: calculate model results based hydrological footprint

This will open up a new window showing the list of annual and monthly maps (if run with monthly maps option). Opening up the annual hydrological footprint map (Figure 10, A) shows the annual downstream influence of cropland in percent shown on the right in Figure 10 (as Google map overlay view).

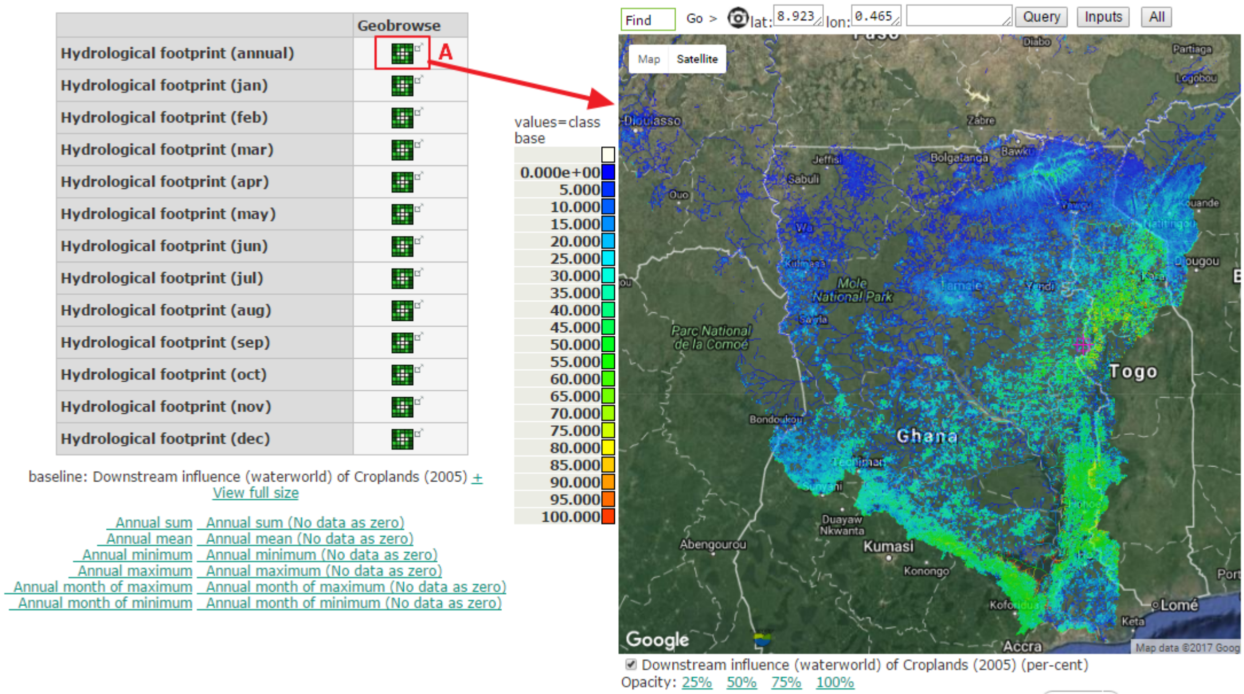


Figure 10 Hydrological footprint (downstream influence) of croplands

NOTE: the steps below are only available at the mega user interface of WaterWorld

To calculate the number of people affected by water regulation and water quality issues from runoff from agricultural land, the hydrological footprint can be overlaid with a spatially distributed map of population density. WaterWorld uses the Landscan population density dataset (Oak Ridge National Laboratory) which is widely regarded as one of the best available population datasets.

In order to overlay this map with the downstream influence of croplands map, the population data needs to be set as a metric of interest. To do this in WaterWorld, go back to Step 2: prepare data and select the list of input data similar to the selection of the crop map (See Figure 7). Once the list is open, scroll down to the population (2007, Landscan) map and click on: Set as MOI (Figure 11).

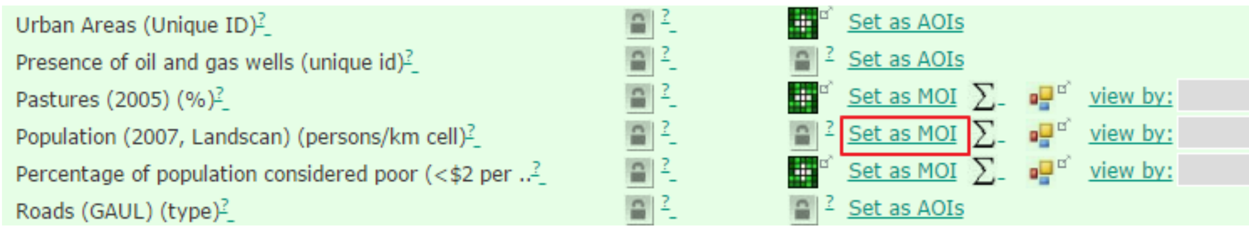
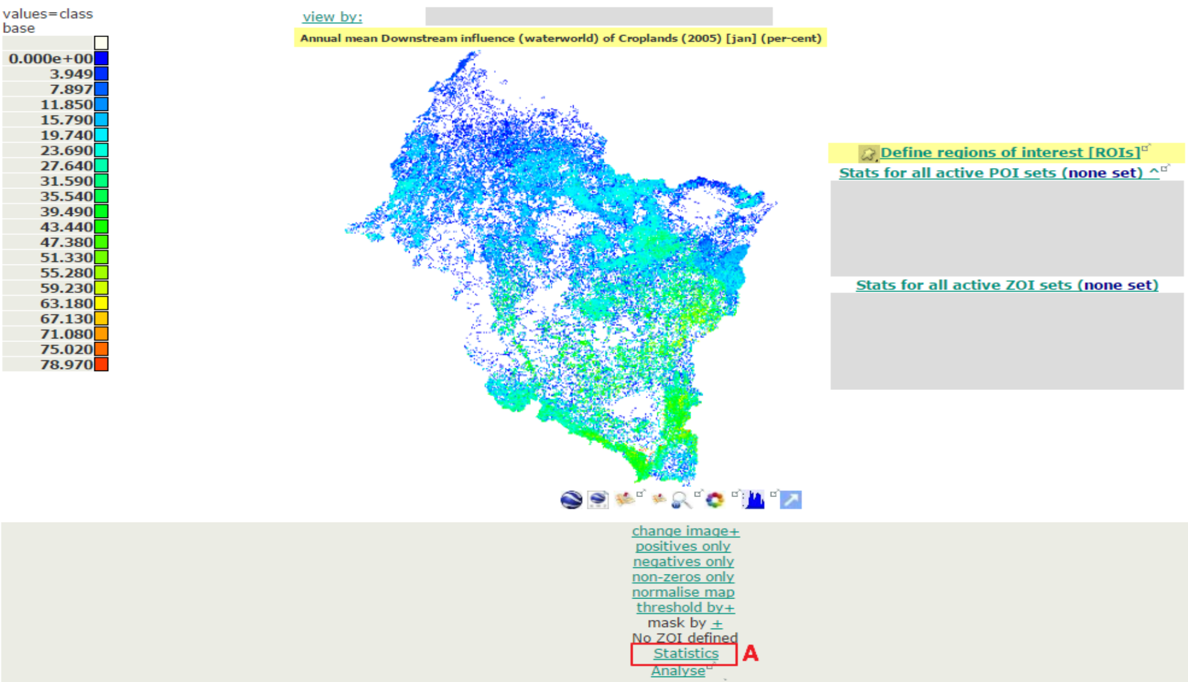


Figure 11: setting a map as a metric of interest.

Once the map is set as MOI, return to the downstream influence of crop map, or follow the steps above. Then click on Statistics below the downstream influence map (Figure 12, A). In the table that opens, the sum of the MOI map (population density) for zero and non-zero values is shown, i.e. the zero sum is the total number of people not affected (B) which amounts to 5,952,390 whereas a total of 12,659,200 people (C) are affected by upstream croplands at some point through the year. The total population in the basin according to the Landscan dataset is 18,616,384 people (All). Therefore, on an annual basis the vast majority of people are not affected by water regulation and quality issues from runoff from agricultural land becuase either they do not live downstream of agriculture or none of their water is derived from that land.



Areas	Min	Max	Grid Sum	Count	Grid Mean	SD	CoV	Area Frac.	km^2	Area Mean	Area Sum
All	0.0	85.4947	4,373,620.0	491,248.0	8.90307	11.7445	131.916	1.0	406,968.0	8.94	3,638,300.0
Zero	0.0	0.0	0.0	225,018.0	0.0	0.0	nan	0.458054	186,265.0	0.0	0.0
Non-zero	0.00127343	85.4947	4,373,620.0	266,230.0	16.428	11.4293	69.5723	0.541946	220,500.0	16.5002	3,638,300.0
Positives	0.00127343	85.4947	4,373,620.0	266,230.0	16.428	11.4293	69.5723	0.541946	220,500.0	16.5002	3,638,300.0
Negatives	-	-	-	-	-	-	-	-	-	-	-
All (MOI: popct_landsc)	0.0	43037.0	22518214.0	491429.0	45.8219071321	309.666910412	675.805373007	1.00036844934	407118.40625	45.7271980687	18616384.0
Zero (MOI)	0.0	43,037.0	7,229,720.0	225,018.0	32.1295	339.97	1,058.12	0.458054	186,265.0	31.9565 B	5,952,390.0
Non-zero (MOI)	0.0	37,355.0	15,277,200.0	266,230.0	57.3835	281.574	490.688	0.541946	220,500.0	57.4112	12,659,200.0
Positives (MOI)	0.0	37,355.0	15,277,200.0	266,230.0	57.3835	281.574	490.688	0.541946	220,500.0	57.4112 C	12,659,200.0
Negatives (MOI)	-	-	-	-	-	-	-	-	-	-	-

Figure 12: calculating number of people affected as MOI statistics.

Using the threshold option in the downstream influence map, it is also possible to assess the number of people affected to a certain extent. For example, a downstream influence of more than 50% can be considered severely affected. To threshold the map, click on the threshold by link under the map and select to show values greater than (>) 50 in native values (as the map is already in percent). Then click Check and submit. This will generate a new showing only values above 50%.

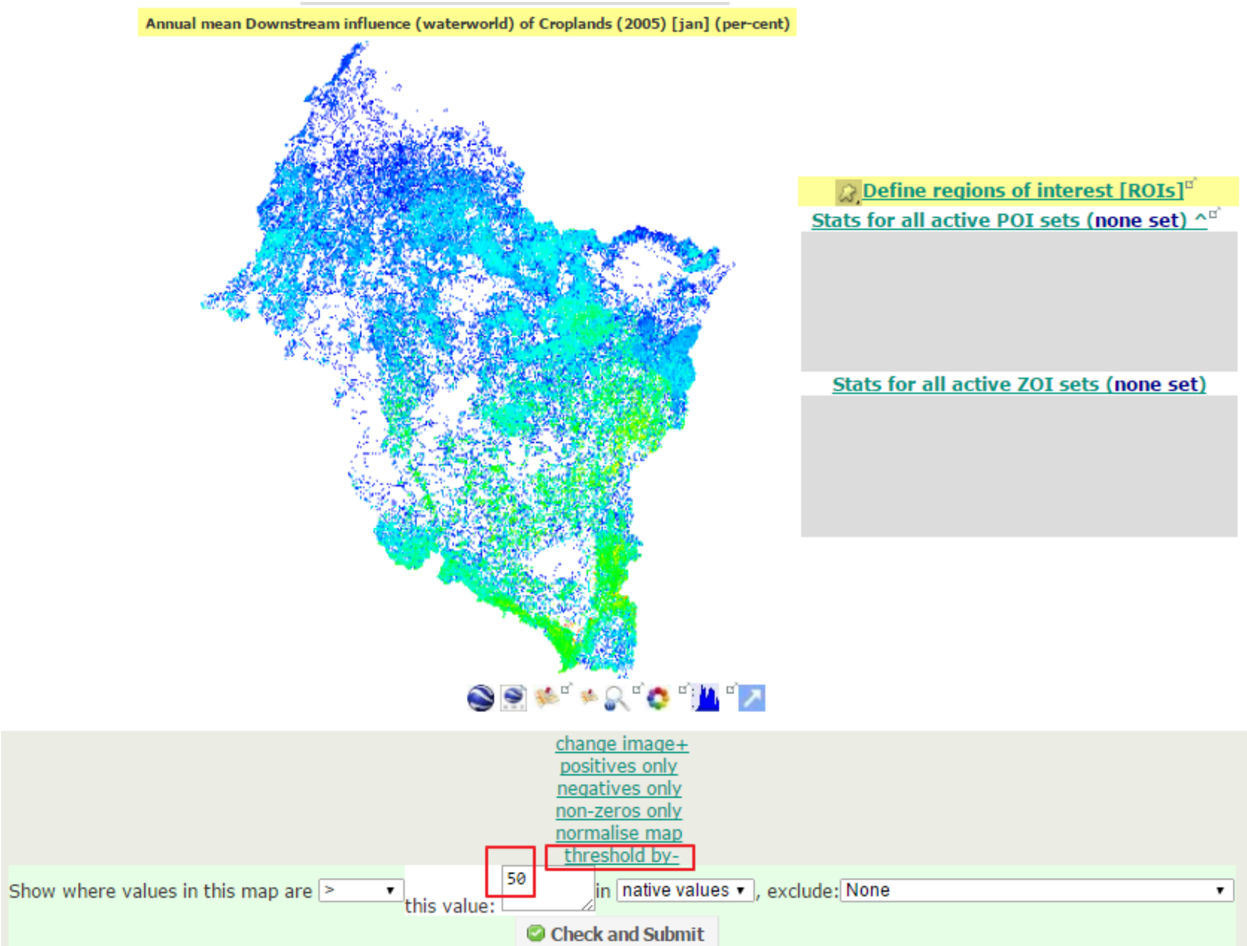


Figure 13: thresholding a map

Clicking on the green view map options icon underneath the thresholded map (Figure 14) then gives you all the same options as the full results map, i.e. you can click on statistics, and the number of people severely affected will be shown in the row: MOI positives. Doing this will show the number of people severely affected to be 137,451 people. Therefore, around a third of people in the Volta basin are affected by agriculture but only around 140,000 severely so.

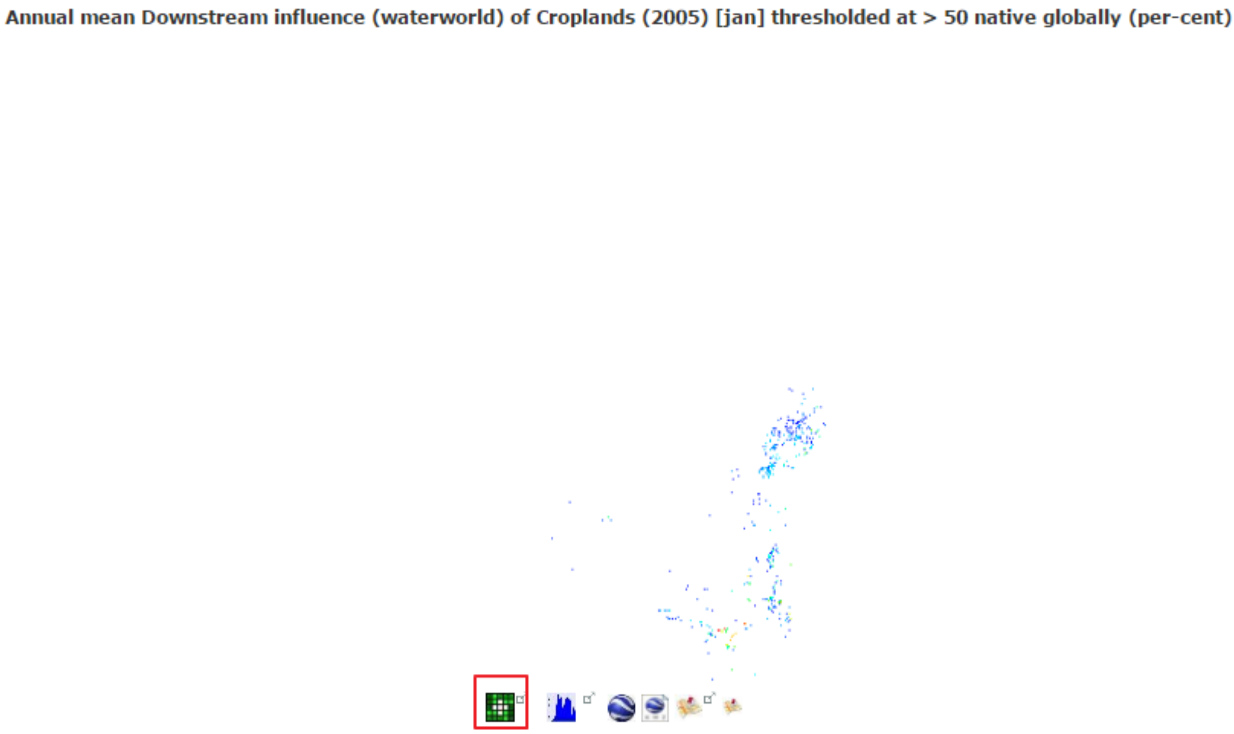


Figure 14: accessing map options from thresholded map

In a similar fashion, the minimum and maximum number of people affected by the hydrological footprint of agriculture throughout a year can be calculated by selecting the annual minimum and annual maximum hydrological footprint maps from the hydrological footprint calculation window (Figure 15, A).

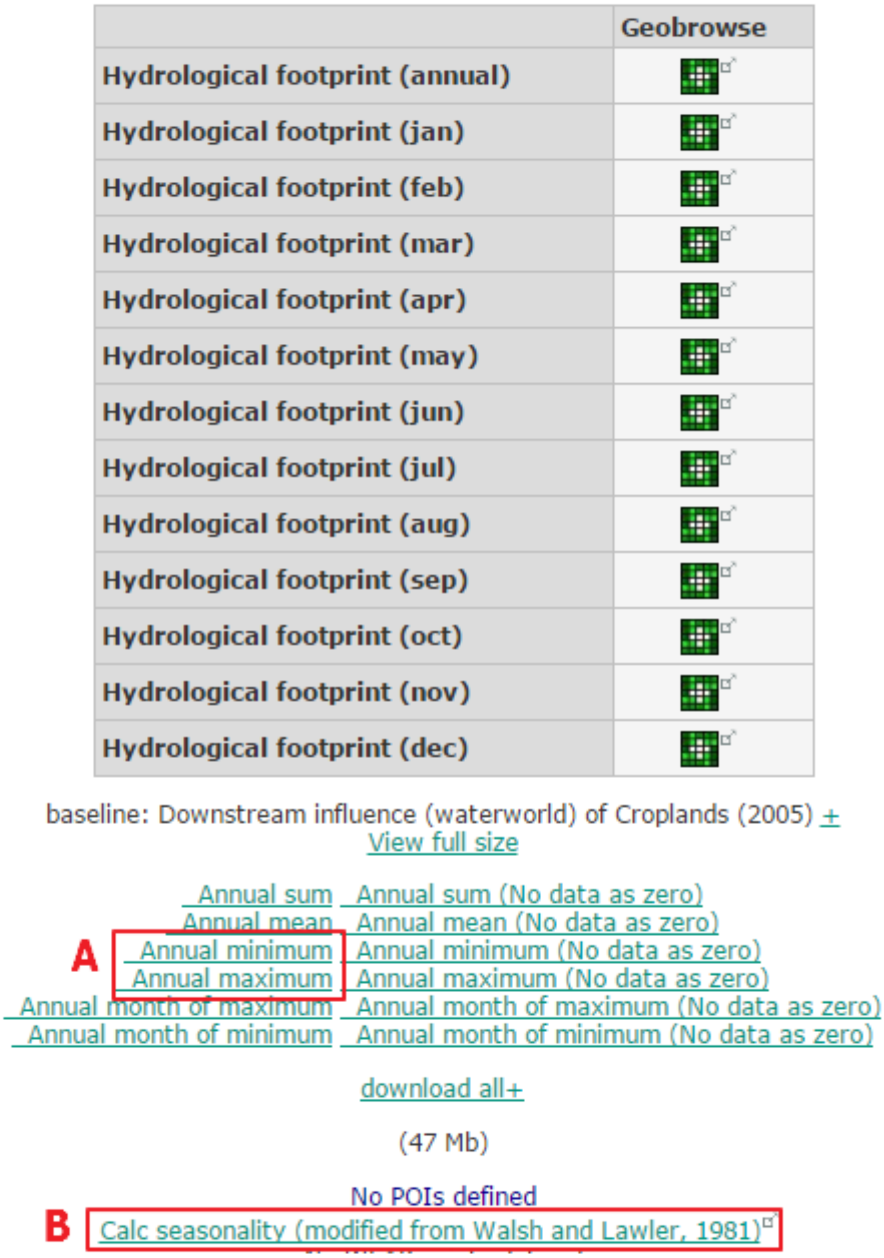


Figure 15: calculating the annual minimum and maximum hydrological footprint.

Doing this shows the minimum number of people affected to be quite low (262,474). This will occur during the dry season when there is no runoff from agricultural land to have an influence downstream. The annual maximum hydrological footprint of agriculture however is quite extensive and affects around two thirds of the population in the basin (12,659,000) with almost a third severely affected (5,863,540) This will occur during the wet season when there is runoff from agricultural land to downstream populations.

Calculating the seasonality index of the downstream influence of croplands

The extent to which people are affected by agriculture depends on how seasonal the flows are. To calculate the seasonality of the downstream influence of croplands, a seasonality index based on Walsh and Lawler (1981) can be calculated by WaterWorld. To do this, simply click on the Calc seasonality link in the hydrological footprint calculation window (Figure 15, B).

The resulting map (Figure 16) shows that the downstream influence of agriculture is highly seasonal in the north but much less so in the south. Therefore, the impact of agriculture on downstream ecosystem services to people depends strongly on season and seasonality.

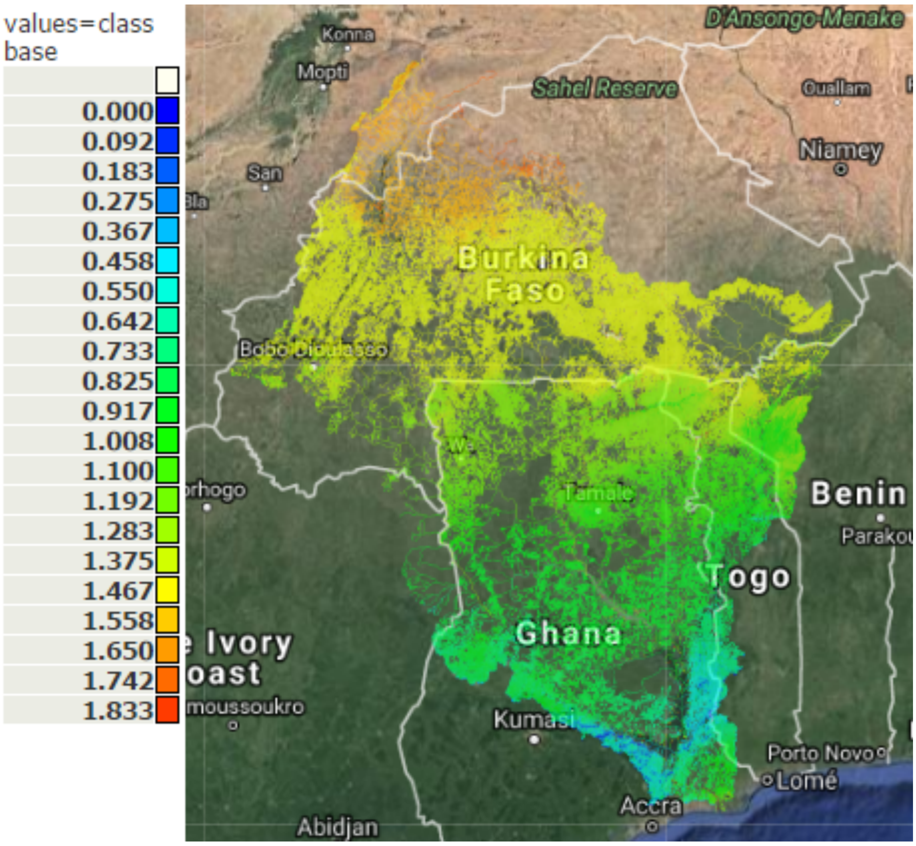


Figure 16: seasonality index (modified from Walsh and Lawler, 1981) for downstream influence of croplands

Examine the impact of small dams on hydrological ecosystem services to people and dams

To assess the impact of small dams on hydrological ecosystem services to people and dams, the hydrological footprint analysis can be applied to a map of the locations of small dams. Therefore, this analysis requires the latitude and longitude information on such dams. This data can be obtained from analysis on identifying and mapping small reservoirs or from existing data. A workflow for gathering this data for the Volta basin is provided in the methodological guide on mapping reservoirs here

Once a list of locations of small dams is available, these can be added to WaterWorld as Points of Interest (POIs). To do this, click on define region of interest in the top bar of the main model window (Figure 17, A). This will open up a window with a number of options. Select to expand the copy and paste new POI list (B). Here you can simply copy and paste the locations of dams as a tab delimited (e.g. copy from Excel) list in the format: latitude, longitude, ID or name. Make sure to name the list of POIs and click on Submit

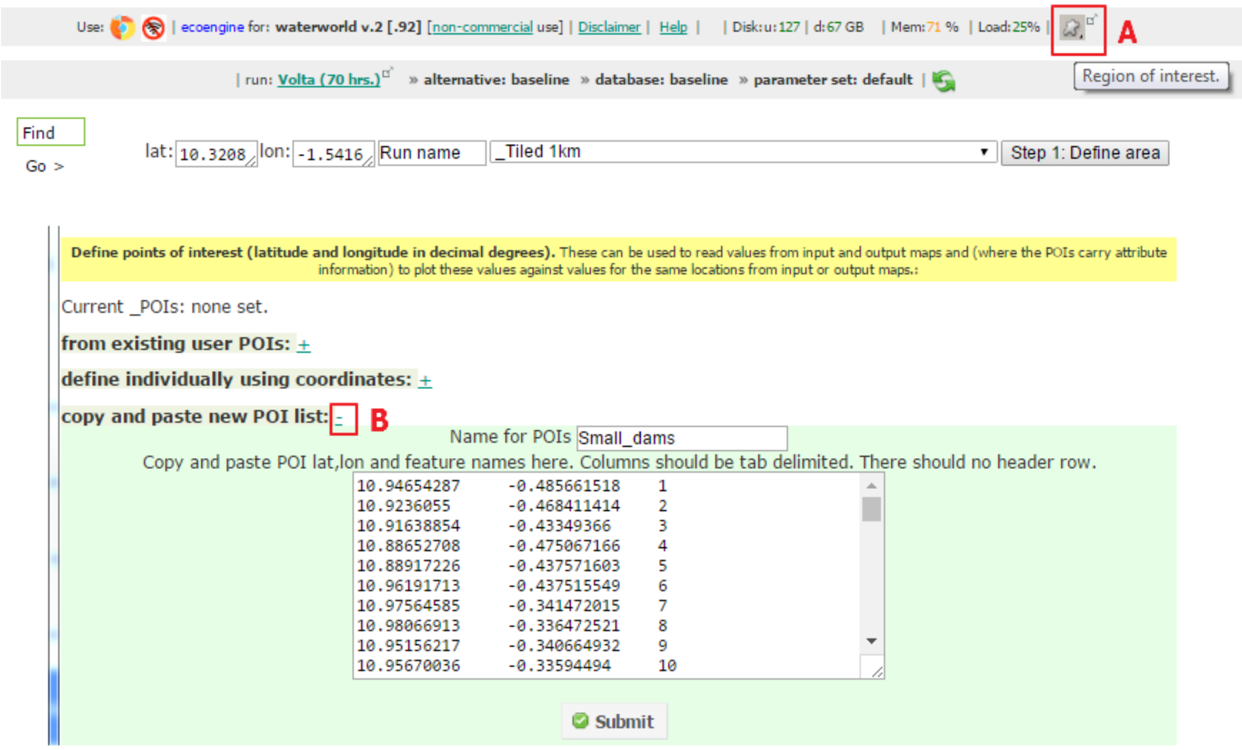


Figure 17: define points of interest in WaterWorld

The next step is then to convert the points of interest to areas of interest. This also needs to be done in the region of interest window. Expand the new AOIs from POIs option (Figure 18, A), then select the previously defined list of POIs (B). This will create a map from the small dams points which can then be used for downstream flow metric analysis.

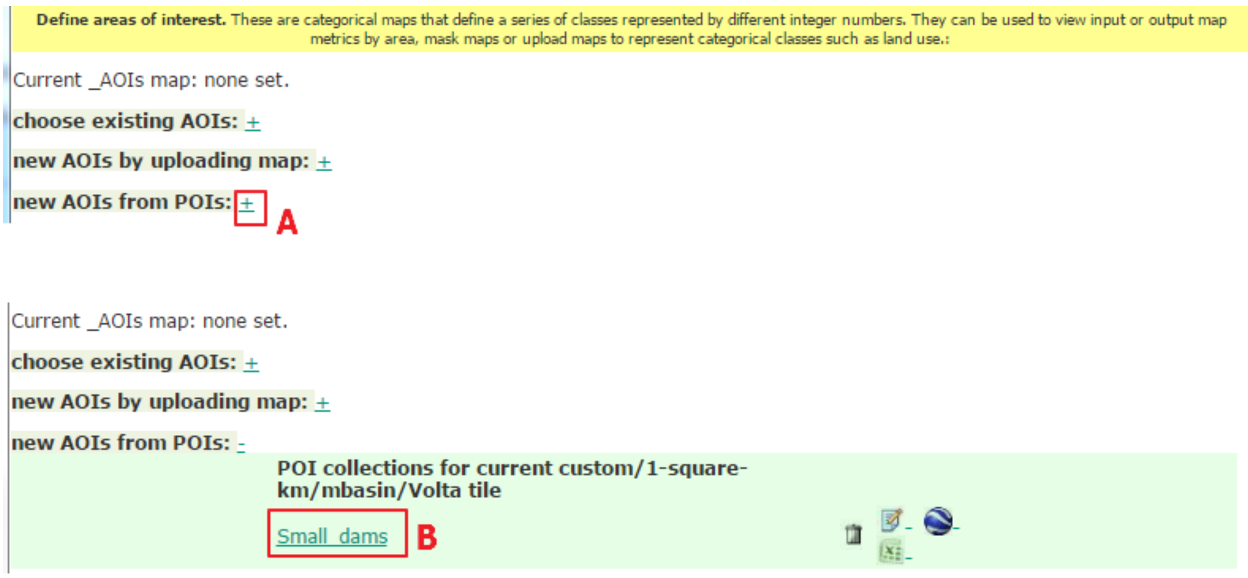


Figure 18: creating area of interest from points of interest.

Clicking on the green map icon (Figure 19, A) will then open up a map of all the small dams. Clicking on calculation (B) will then open up the window where the downstream influence metric can be calculated (see steps above, Figure 9).

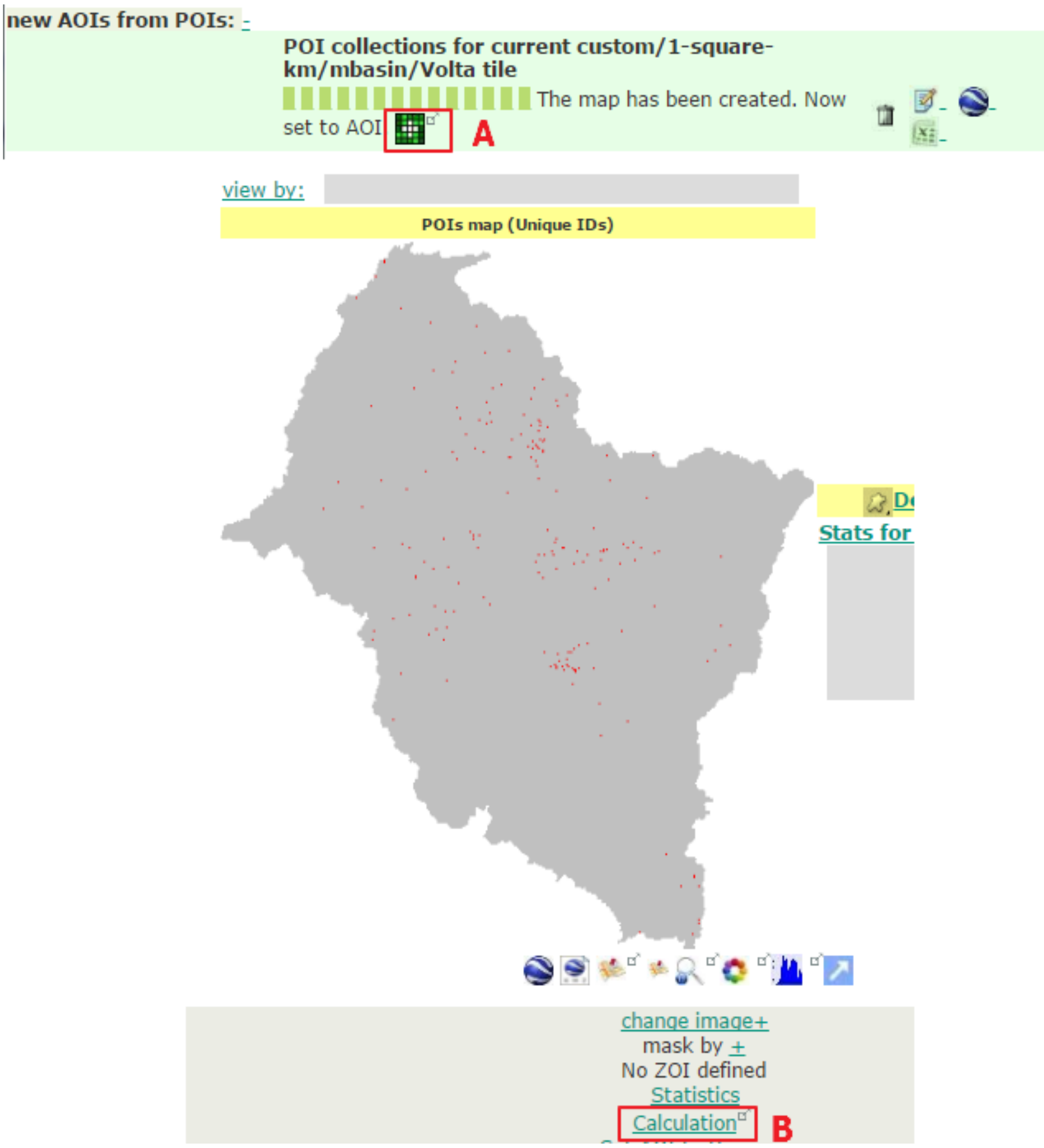


Figure 19: Area of interest map from points of interest of small dams

In addition to the downstream influence metric, the results-based flow footprint (WWFF) of small dams can be calculated (Figure 20, A) This metric is essentially the inverse of the flow metric, calculating for each pixel 100 - the flow footprint. Therefore, this can be considered a measure of how free-flowing a river is.

Variable	Explanation	Calculate
Upstream influences on POIs	calculates the areas influencing the values of this variable on downstream POIs (i.e. calculates the catchments of POIs then calculates the percentage contribution of each pixel to the POI catchment)	Calculate
Downstream differences from one pixel to its neighbour	Downstream differences from one pixel to its neighbour	Calculate
Model results-based hydrological footprint	Calculates the hydrological footprint (downstream influence) of this variable based on modelled water balance.	Calculate
Remote sensing-based hydrological footprint	Calculates the hydrological footprint (downstream influence of) of this variable based on RS water balance.	Calculate
Model results-based flow footprint (WWFF)	Calculates the flow footprint (downstream influence) of this variable based on modelled water balance.	Calculate
Downstream averaging	Calculates average of this variable down flow networks.	Calculate

Figure 20: calculating the model result-based flow footprint (WWFF) in WaterWorld.

Following the steps described in the section on assessing downstream influence of agriculture on people, the number of people hydrologically affected by small dams upstream can be assessed on an annual and seasonal basis.

Documentation and further reading:

Model and data documentation for version 1 can be found here and system (interface and functionality) documentation is here. A presentation on the science behind the PSS can be found here (English) and here (Spanish) [opens in Google docs viewer]. Download: (EN, ES). A powerpoint demo of the system functionality is here (English) and here (Spanish) [opens in Google docs viewer]. Download: (EN, ES)

References:

Model description:

Mulligan, M., & Burke, S. M. (2005). FIESTA: Fog interception for the enhancement of streamflow in tropical areas, Appendix 4a to Final Technical Report of DFID-FRP Project no. R7991.

Mulligan, M. (2013). WaterWorld: a self-parameterising, physically based model for application in data-poor but problem-rich environments globally. *Hydrology Research*, *44*(5), 748-769.

Example applications:

Mulligan, M., Rubiano, J., Hyman, G., White, D., Garcia, J., Saravia, M., ... & Leonardo Saenz-Cruz, L. (2010). The Andes basins: biophysical and developmental diversity in a climate of change. *Water International*, *35*(5), 472-492.

Bruijnzeel, L. A., Mulligan, M., & Scatena, F. N. (2011). Hydrometeorology of tropical montane cloud forests: emerging patterns. *Hydrological Processes*, *25*(3), 465-498.

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Data and methods:

LandScan. 2007. Global Population Database for 2007, Oak Ridge, TN: Oak Ridge National Laboratory. Available at http://www.ornl.gov/landscan/

Walsh, R. P. D., & Lawler, D. M. (1981). Rainfall seasonality: description, spatial patterns and change through time. Weather, 36(7), 201-208.

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