User Manual for the Projections Software

Agricultural Water Use Projections in the Nile Basin to 2030: Comparison with Food For Thought Scenarios

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Information Products for Nile Basin Water Resources Management
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Background and introduction

Background

FAO project GCP/INT/945/ITA has developed a set of information products to inform decisions on water policy and water resources management in the Nile basin. This required the consolidation of a wide array of natural resource and remote sensing data across the Nile Basin. Key information products have been a suite of cropping calendar data compiled at district level for Egypt, Sudan, Eritrea, Ethiopia, Uganda, Kenya, Tanzania, Rwanda and Burundi[1]. In addition, a component of the Project has been concerned with the crafting of four possible water use scenarios, the so-called Food for Thought (or F4T) scenarios. These scenarios examined the implications of changes in governance and terms of international trade. These implications were subsequently considered in terms of water resource allocation and productivity projections by comparing the scenarios with the situation in 2030 as anticipated by the study "Agricultural Trends to 2030/2050" (FAO, 2006) which itself i) compiled data for 93 developing countries, including all the riparian countries of the Nile Basin; ii) established a 2005 baseline and then iii) projected areas and yields for each crop in countries where they are grown, for 2030 and 2050.

A suite of excel files, hereafter referred to as "The Model", was compiled in order to make the productivity projections and this document comprises a User Manual for The Model as it has been developed so far.

Architecture of the model

The model comprises three modules as shown in Figure 1.1.

Module 1: "data and projections" contains the AT 2030/2050 data, the evapotranspiration and cropping calendar data; distributes the cropping calendars at district level for the baseline (2005) and for 2030 (based on the AT2030/2050 projections) and estimates the unit agricultural productivity of water for each crop/location/water use efficiency combination[2].

Module 2: "scenario builder" is the interface by which the user defines the scenarios to be tested.

And

Module 3: "calculation platforms" manipulates the AT2030 projections in terms of different scenarios and analytical themes.

Report structure

Section 2: describes the inner workings of Module 1, which essentially comprises a distributed model of cropping systems, yields and water use at District level for the 2005 baseline and as suggested by the AT2030 and 2050 projections.
Section 3: describes Module 2 by summarising the analytical approach adopted for the study, defining the variables and illustrating the information flow through the model.

Section 4: summarises the analyses so far carried out using The Model and does so by describing the suite of excel files that apply the variables to the distributed model.

Finally, several possibilities for increasing the suite's versatility have already been discussed in Rome, – not least as regards economic rather than water productivity projections.

Section 5: therefore identifies what these, and other possibilities might be, and where possible, suggests what might be involved.

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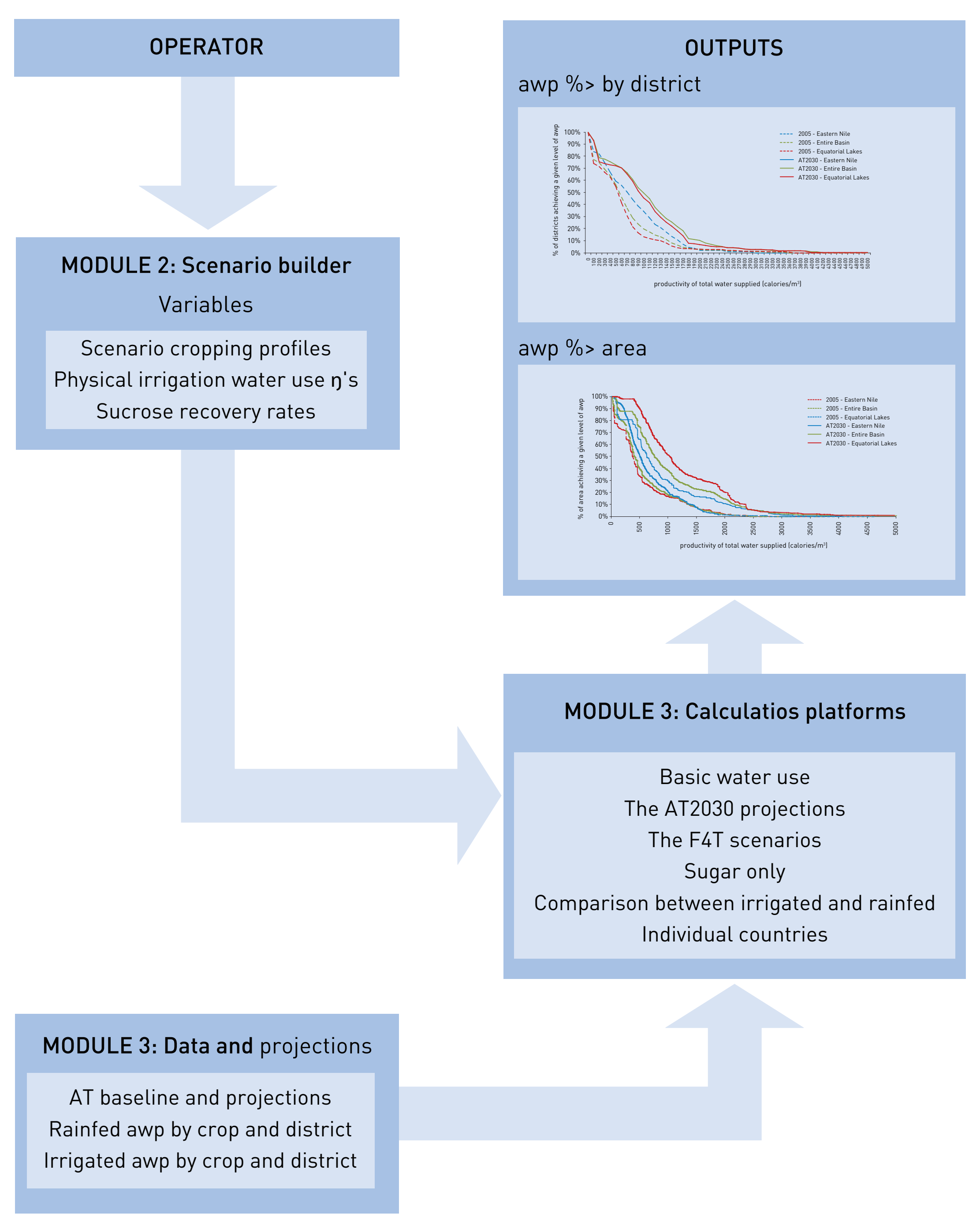
[1] It is assumed that the small areas within the basin in the DRC and the Central Africa Republic have no meaningful agriculture

[2] It also does this for 2050, but the since the F4T scenarios apply only to 2030, the longer term projections were not used for the analysis.

Figure 1: Architecture of “the model”



Module 1 – Cropping systems and agricultural water productivity

This module comprises three files, they are described in the following sub-sections.

Baseline and projections.xls

Baseline and projections is used for taking updates of the AT2030/2050 projections and reformatting them such that the data can be accessed by VLOOKUP functions elsewhere in the Model. The information provided in this file includes area and yield estimates for the AT baseline of 2005, which is not to be confused with the Project baseline – see below.

Unfortunately, there is no quick way to import any revised AT projections data, since it has to be copied country by country. But as the basic data is formatted the same in both the AT2030/2050 source file and Baseline and Projections, it is nonetheless merely a matter of copying and pasting from one to the other.

Thus, with Baseline and Projections open at worksheet "Source Data"; and the AT2030/2050 projections open at worksheet "LN93":

Worksheet **"Reformatted Data"** automatically carries out the reformatting.

Rainfed agriculture projections.xls

This file has 23 worksheets. The first of these is simply an index to the rest of the worksheet; but the next five concern information or data:

"Baseline and Projections" simply picks and mirrors exactly, the data in baseline and projections.xls, which means that any updates made to the source file are automatically carried through to this projections file.

"Administrative Layers" identifies which lower level administrative units (standardised in adopted nomenclature as "districts"), belong to which higher level districts (*ditto* as "provinces or regions"). Except in the case of Uganda which continues to go through a decentralised civil administration fragmentation process, these are unlikely to change and are therefore included for reference only. Any changes to the Ugandan civil administrative cascade would in any case be problematic here, unless the cropping systems would have to be disaggregated in like manner – but for more on that see below.

"Admin GIS" lists the basin's entire districts alphabetically, allowing a VLOOKUP function in the next worksheet first to find a specific district's reference number, and then, by using another VLOOKUP function, also in the next worksheet, to look up the relevant Et data. This sheet should never require updating, except once again in the case of sub-divisions, or other political changes.

"Et Source data" provides monthly evapotranspiration rates under natural circumstances over rainfed land (Eta) and for reference crops (Et0). This data is agglomerated at district level, country by country. Each country is encountered in alphabetic order, and each district within a particular country also listed alphabetically. Although this means that updating the Et data is straightforward, it also means that at basin level, the districts are not encountered in alphabetic order in the cropping calendars (see below). This means in turn that it is not possible to use the VLOOKUP function directly when accessing the data, because the lookup column has to be sorted either alphabetically, or smallest to largest. Accordingly, this worksheet also allocates a reference number to each of the districts in the order that they are listed (these reference numbers are consistent with district numbers in the FAO GIS system).

"Rainfed Cropping Calendars" is the last of the data sheets in that as suggested by its title, it sets out the rainfed cropping calendars for each district. It also provides data concerning the areas planted to each of the crops in a district, when the crop is planted and reported yields. More specifically:

- The crops are specified in column E
- The harvested areas are provided in column F
- Production is stated in column G and yields (tonnes/ha) in column H
- Percentages of the total cropped area planted to each crop are calculated in column I and
- Distributed throughout the year in columns J to U

All of these data represent a best-fit of information gathered in the field during the course of the project and hence comprise the Project Baseline. With the exception of the actual cropping patterns, it is a simple matter to change the other variables, ie the underlined data, including the months in which a particular crop is planted in a given district. All that is required is merely to change the variable directly in the cell in which it is encountered. In principle it would be possible also to change the cropping patterns, in other words to alter the crops appearing in each district. But this would be a major and complex task which fortunately, in the absence of major structural changes to the basin's various agriculture sectors, would be meaningless because:

- The data as given comprises a baseline developed as the best fit of actual, real time data collected in the field by The Project: as such therefore, an update is a meaningless concept.
- Equally as will be seen, the model is predicated on the use of indicator crop clusters, thus crop by crop specificity is not required.

In addition, if it is decided to apply the model to another river basin, this worksheet – and those that follow would have to be rebuilt from scratch.

The rest of this worksheet comprises the calculations necessary to estimate the total amount of water used by a particular crop in a particular district (column CH) as suggested by the Project Baseline.

The remainder of the file consists of paired worksheets, one pair for each of the countries having rainfed agriculture (ie all those considered except Egypt). The first worksheet *"country name – Districts"* in each pair indicates the specific country's 2005 baseline by district, in terms of area, yield, agricultural water productivity (in kg/m^3) as per the Project baseline for 2005 and as per the values in or suggested by the AT2030/2050 assumptions provided in worksheet *"baseline and projections"*. Yield assumptions for the AT2030 and 2050 projections are taken from *"Baseline and Projections"* and hence correspond to the yields assumed in the AT studies, whereas yields for the baseline are taken wherever possible from the Project source data. In some cases these are suspect whereupon the 2005 yields given in *"Baseline and Projections"* are used instead.

However, there were wide ranging inconsistencies between the baseline cropping data and the assumptions behind the AT2030/2050 projections. Also,

- the latter are agglomerated by country, some of which do not lie entirely within the basin, meaning that a crop might appear in the AT2030/2050 projections, but not in the basin (coconuts in Tanzania for example);

and

- national areas planted to a specific crop do not necessarily mean that every district in that country has the crop, even where the entire country lies within the basin (sugar beet in Egypt for instance).

This necessitated the adoption of a projections protocol as follows:

- since the projections, when distributed at district level, are intended to form part of a water allocation tool, they must have a temporal as well as spatial component. In other words they must be based on cropping data that indicate not only how much of a particular crop is grown **at district level**, but also **when it is grown**.

Then,

- **the projection protocol** assumes that the cropping calendars (which were derived from Project sources) determine the quantity of Et from rainfed crops and

to import data for	copy "LN93" rows		and paste over "Source Data" rows	
	from	to	from	to
Egypt	11 109	11 280	9	184
Sudan	11 475	11 650	189	364
Eritrea	16 840	17 015	372	547
Ethiopia	17 025	17 200	555	730
Uganda	6 295	6 470	738	913
Kenya	4 630	4 805	1 103	1 278
Tanzania	6 110	6 285	1 287	1 402
Rwanda	5 740	5 915	1 470	1 645
Burundi	4 445	4 620	1 653	1 828

the quantity of irrigation water withdrawn from surface and groundwater sources. The protocol also requires that a 2005 baseline[3] can be set for all districts in the basin and from which national projections in harvested areas and yields can be projected to 2030. Hence the cropping calendars remain fixed for both the 2005 baseline and the subsequent projections to 2030.

But:

- since i) projections can only be made in respect of crops appearing in the projections data; and ii) since the projections can only be distributed, and their distributed water requirements estimated in respect of crops appearing in the cropping calendars data, then it is necessary that the crops themselves have to be common to both model and scenario. This was often not the case. Therefore, as with the consolidation of Project data this required "expert judgement", the application of which is described in an unpublished interim report while some of the measures necessary are made clear directly in the worksheets.

Based on this, the function of the *"country name – Districts"* worksheets is to estimate the agricultural productivity of water for each of the protocol compliant crops as encountered in the field by the Project, and as suggested in 2030 and 2050 by the AT2030/2050 projections.

District level projections for 2030 and 2050 take the %areal changes predicted by AT2030/2050 and apply them to the country project baseline and distribute them pro-rata to the districts. The following hypothetical example explains this more clearly.

If the Nile basin portion of country "w" planted to wheat, was found by the project to be planted a% in district "x", b% in district "y" and c% in district "z"; and if the AT2030/2050 predicts a national increase by 2030 of say 10% for that crop, then in 2030 the cropped area in district "x" would be a% of 110% of the baseline area. Clearly this is a something of a blunt instrument, because there is no reason to expect the crop to increase by the same amount in each district hence the second worksheet in each pair *"country name – shadow file"*, which allows the 2030 area for a particular crop to be redistributed between any or indeed all of the districts. As yet this has not yet been done, so the factors in the shadow file simply represent the pro-rata situation.

Before closing this section, it is necessary to note two further points.

First, each of the *"country name – Districts"* allow the rainfall efficiencies to be modified. So far they have been kept at unity whereas they are in fact determined by land use practices meaning that some districts will have lower rainfall efficiencies than others, equally, land use practices can be improved such that rainfall efficiencies could be increased in the future. Secondly, some of the data produced water productivity figures that were clearly nonsense, in which case they were replaced by more realistic assessments suggested by the AT2030/2050 figures.

Irrigated agriculture projections.xls

This file also has 23 worksheets and differs from the rainfed file only in that:

- Egypt is included;
- because the water use is found in column DH (not CH) of the worksheet irrigated cropping calendars;
- and because rainfall efficiency is replaced by physical irrigation water use efficiency, baseline values for which have been supplied by FAO: given however, that these are likely to change with governance, one of the T4T axes, these are included as a variable in Module 2.

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[3] It should be understood that there is no direct quantitative significance in this baseline since its use is only to drive the pro-rata distribution of the national projections at the district level. Nonetheless unless otherwise stated, from here on, the term "baseline" refers to that suggested by the farming system/cropping calendars and not the Projection data. The percentage increases are self correcting in that if the district baseline has been under-estimated, the percentage changes will be larger, and vice-versa.

Module 2 – The scenario builder

In theory, the distribution of crop production and yield data by district and time afforded by Module 1 could be used as the basis of a considerable range of analyses. Section 4 is necessarily limited however, to describing those that have been undertaken so far. There have been six such analyses so far four of which have been inspired by the F4T scenarios. But before proceeding to describe them it is necessary first to understand the basics of the analytical approach adopted.

Basics of the analytical approach

On first consideration, the most obvious water use parameter for scenario comparison purposes might:

in the case of irrigated crops be, the amount of water withdrawn from watercourses and aquifers;

and

for irrigated and for rainfed crops, their Et rates.

But for several reasons such an approach would be somewhat limited in value.

First, so as long bulk water withdrawals by themselves are within the water resource limits of the basin[4], then unless there is competition for water and since there is no analytically relevant connection between volumes of water and scenarios that are defined by governance and terms of trade, they are effectively irrelevant as far as the F4T scenarios are concerned. If there is competition moreover, then the issue would be more concerned with allocation priorities and criteria than with actual quantities.

Second – in the absence of land management changes[5] at the landscape level, the Et used by rainfed crops has no impact on overall basin water balances since the Et difference between climax or rangeland vegetation and annual cropping patterns is negligible at basin level.

Third, the scenarios are concerned with results or outcomes. In this context therefore, it is not the water withdrawals themselves that are of interest, but rather the productive impact of those withdrawals.

Accordingly and as far as the analyses to date have been concerned, it was decided to think in terms of a key parameter that captures the productive rather than quantitative aspect of water allocation and does so in a way that represents the scenario dynamics. The ideal parameter is economic productivity which would be particularly useful because of the links between high economic water allocation efficiencies and increased socio-economic and environmental benefits. The socio-economic benefits in particular are relevant to the F4T scenarios.

However, to use economic efficiency would require projections for each crop not only in terms of its specific commodity price but also of any specific added value, which itself may involve the allocation of additional water that would need to be accounted for. There would also be the matter of the costs of capital investments necessary to secure a given level of productivity and of stepped tariffs which could apply in respect of in-country added value for export crops. Given that some 45 different crops are common to both the Projections and Project data each of which could in theory be included in this study, an economic indicator would have been beyond the time and resources available at this stage of the study. Accordingly, it has been necessary to work with a proxy and this required crafting of an indicative analytical framework. As explained in the Project *"Agricultural Water Use Projections in the Nile Basin to 2030; Comparison with Food For Thought Scenarios"*, the adopted approach has therefore been first to use indicator crop clusters and to consider the implications of each in terms of the agricultural productivity of water (AWP) implied by the AT2030 projections and each of the F4T scenarios. Because the AWP of a particular crop does not depend

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[4] In the context of this study only. Other studies for instance may question this assumption if the questions of scale or seasonality are an issue, because plentiful water at basin level is not always plentiful at the points of use, or all year round.

[5] Such as terracing, contour or conservation tillage etc

on how the crop is used, its adoption here avoids the need to account for uses other than food separately. This is particularly helpful in avoiding the need to address biofuels as a separate issue.

All of the 45 different crops common to both the AT2030/2050 projections and Project data could theoretically be included in this study. But in addition to problems raised by inconsistencies between the two sources as mentioned above, there is also the fact that the crops themselves fall into several categories (eg basic foods, other foods, industrial, fodder, biofuels etc) each of which would require separate analysis and commentary. Furthermore, for reasons developed in the sub-study report mentioned above, the adopted analytical framework suggested that – so long as the agricultural productivity of water is expressed in common units – changes in the ratio between subsistence and cash cropping provide a meaningful indicator of changes in water productivity for a given scenario. In this case the common unit is calories per unit of water supplied (AWPcal).

Accordingly, the analyses so far have been limited to indicator crop clusters one of which captures selected staple food crops that when clustered comprise a surrogate for subsistence farming; the other capturing oil crops, sugar cane and sugar beet (the latter in Egypt only) and therefore comprising a surrogate for cash cropping.

The two crop clusters are set out in Table 3.1 along with the calorific values assumed for each. But it should be noted that the use of calories as a means by which to compare different crops prevents the inclusion of fodder crops in the study. In certain key locations, these are unquestionably cash crops, and can be expected to become increasingly important under certain conditions. In fact they are already very significant in parts of Egypt. But they are difficult to represent in calorific terms and in any case, the AT2030 data is very unspecific in respect of such crops which are assumed to be subsumed in "other lands" for which neither yield nor production projections are provided.

Variables

Cropping systems profiles

The model changes the ratio of indicator subsistence to cash crops by allowing the user to alter the percentage of the total harvested area that each of these crops occupies, both rainfed and irrigated. This is done simply by increasing or decreasing the area allocated to a given crop. Although that means the "scenario adjusted" total harvested area in a given district or country would differ from that suggested calculated in Module 1 Projections files, it is of no consequence in the context of The Model because i) the parameter being quantified is the AWP_{cal} of a unit of water as it varies with changes in the above mentioned ratio; and ii) the AWP_{cal} is calculated as a weighted mean - as illustrated in the following example – which does not vary with actual area, but rather the cropping profile within the area.

Physical irrigation water use efficiencies

It will be recalled that the F4T Scenarios reflect possible changes in governance and terms of trade. Given that

Table 3.1: Indicator crop clusters

"Subsistence" crops	Calorific value$^{/1}$	"Cash" crops	Calorific value$^{/1}$
wheat	2 904	sesame	574
rice	2 408	sunflower	284
maize	3 148	unspecified oil crops	9 586
barley	2 563	Sugar (beet and cane)	436
millet	2 831		
sorghum	2 880		
other cereals	3 253		
potatoes	713		
sweet potatoes	991		
cassava	968		
other root crops	1 156		
pulses	3 375		

Notes:

[1] *calorific values taken from AT2030/2050 source files*

Table 3.2: Example weighted mean AWP calculation

Crop	Calorific value	Projected area at 2030	Agricultural productivity of water			Scenario adjustment		Agricultural productivity of water		
			Kg/m^3	Cal/m^3	W/av	Factor	Area	Kg/m^3	Cal/m^3	W/av
subsistence crops										
wheat	2 904	16 000	0.56	1 630		25%	4 000	0.56	1 630	
rice	2 408	5 000	0.51	1 232		25%	1 250	0.51	1 232	
maize	3 148	450	0.66	2 083		25%	113	0.66	2 083	
barley	2 563	3 000	0.18	469		25%	750	0.18	469	
cash crops										
sunflower	284	2 000	0.38	108		200%	4 000	0.38	108	
sesame	9 586	500	0.25	2 406	1 336	200%	1 000	0.25	2 406	1 033

it is not unreasonable to posit that physical irrigation water use efficiency is likely to improve as governance improves, and vice-versa; and given also that the AWP_{cal} of irrigation water is dependent on the physical efficiency of irrigation water use, then it is necessary to include the parameter as a variable in the context of The Model.

Sucrose content

And since like physical irrigation water use efficiency, sucrose recovery rates are likely to improve with governance, and since also the AWPcal varies directly with sucrose recovery rates, The Model treats it as a variable.

Sugar is also interesting because it is the only potential biofuel crop currently produced at any significant level in the Nile Basin, where it is grown under both irrigated and rainfed conditions. It is additionally interesting because of the involvement of the private sector by which the crop is produced under a variety of models, including public private partnerships and nucleus estate and outgrower programmes.

The AT2030/2050 projections suggest that the cropped areas under sugar will expand. Although the analytical framework is such that a single crop scenario analysis would be meaningless in scenario terms because since it is not possible to have a weighted mean for a single crop[6], the projections files in Module 1 can nonetheless be used to estimate the changes AWPcal of a single crop over the period in question implicit in the AT2030/2050 projections – hence Analysis 4 below, where sugar, because of its particular interest, is the single crop analysed.

Changing the variables

The variables are changed in the excel file **"Variable.xls"**. It has a single worksheet, which is illustrated in Figure 3.1, where the values indicated are those that have so far been used to model the F4T scenarios.

For convenience, icon representations of the output charts are provided on the worksheet where they are live-linked to the analysis files which are described in the next section.

Information flow

The flow of information between the three modules is shown in Figure 3.2.

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[6] It is of course noted that there is a second crop in the form of sugar beet. But it since its calorific value/m3 is almost the same as for sugar cane as far as weighted means are concerned it is effectively the same crop. And even if it were not, it would be meaningless to apply the scenarios adjustment factors to it, because its production is highly localized and unlikely to change under any reasonable scenario.

Figure 3.1: The variables.xls worksheet

Country	Case	Subsistence crops												Cash crops					Physical irrigation water use efficiency	Sucrose recovery rate
		wheat	rice	maize	barley	millet	sorghum	other cereals	potatoes	sweet potatoes	cassava	other root crops	pulses	sugar beet	sugar cane	sesame	sunflower	unspecified oil crops		
Egypt	% baseline	100%	100%	100%	100%		100%		100%	100%		100%	100%	100%	100%	100%	100%		53%	12%
	% scenario 1	100%	100%	100%	100%		100%		100%	100%		100%	100%	100%	100%	100%	100%		53%	14%
	% scenario 2	50%	50%	50%	25%		25%		150%	100%		100%	200%	150%	150%	150%	150%		55%	14%
	% scenario 3	150%	100%	150%	100%		100%		100%	100%		150%	200%	75%	75%	100%	100%		53%	12%
	% scenario 4	200%	50%	200%	200%		200%		75%	75%		75%	150%	75%	50%	75%	75%		53%	12%
Sudan	% baseline	100%	100%	100%		100%	100%		100%				100%		100%	100%	100%		40%	12%
	% scenario 1	100%	200%	100%		100%	100%		150%				150%		125%	125%	125%		45%	14%
	% scenario 2	100%	200%	100%		75%	75%		200%				200%		200%	200%	200%		50%	14%
	% scenario 3	100%	75%	150%		150%	150%		75%				100%		100%	75%	75%		35%	12%
	% scenario 4	75%	50%	150%		200%	200%		50%				75%		100%	50%	50%		30%	12%
Eritrea	% baseline			100%		100%	100%									100%			32%	no sugar
	% scenario 1			150%		100%	100%									150%			35%	
	% scenario 2			200%		50%	50%									200%			40%	
	% scenario 3			75%		125%	125%									50%			32%	
	% scenario 4			50%		200%	200%									10%			32%	

(Continued)

Figure 3.1: *(Continued)*

Country	Case	Subsistence crops												Cash crops					Physical irrigation water use efficiency	Sucrose recovery rate
		wheat	rice	maize	barley	millet	sorghum	other cereals	potatoes	sweet potatoes	cassava	other root crops	pulses	sugar beet	sugar cane	sesame	sunflower	unspecified oil crops		
Ethiopia	% baseline	100%		100%	100%	100%	100%	100%					100%		100%			100%	22%	12%
	% scenario 1	150%		150%	100%	125%	100%	100%					150%		150%			125%	30%	14%
	% scenario 2	200%		150%	100%	150%	100%	100%					200%		200%			200%	35%	14%
	% scenario 3	100%		100%	100%	125%	125%	100%					75%		75%			75%	22%	12%
	% scenario 4	100%		100%	100%	200%	200%	100%					50%		75%			75%	22%	12%
Uganda	% baseline	100%	100%	100%		100%	100%		100%	100%	100%		100%		100%	100%	100%		30%	12%
	% scenario 1	150%	150%	150%		100%	100%		150%	150%	100%		125%		150%	150%	150%		35%	14%
	% scenario 2	200%	200%	200%		100%	100%		200%	200%	100%		150%		200%	200%	200%		40%	14%
	% scenario 3	100%	100%	100%		125%	125%		75%	75%	125%		75%		75%	75%	75%		30%	12%
	% scenario 4	75%	75%	125%		150%	150%		50%	50%	125%		50%		50%	50%	50%		25%	12%
Kenya	% baseline	100%	100%	100%	100%	100%	100%		100%	100%	100%		100%		100%	100%	100%		30%	12%
	% scenario 1	150%	150%	150%	125%	75%	100%		125%	125%	100%		125%		150%	150%	150%		35%	14%
	% scenario 2	150%	200%	150%	125%	50%	100%		150%	150%	150%		150%		200%	200%	200%		40%	14%
	% scenario 3	100%	100%	100%	100%	125%	125%		75%	75%	125%		75%		75%	75%	75%		30%	12%
	% scenario 4	75%	50%	125%	125%	150%	150%		50%	50%	125%		50%		50%	50%	50%		25%	12%

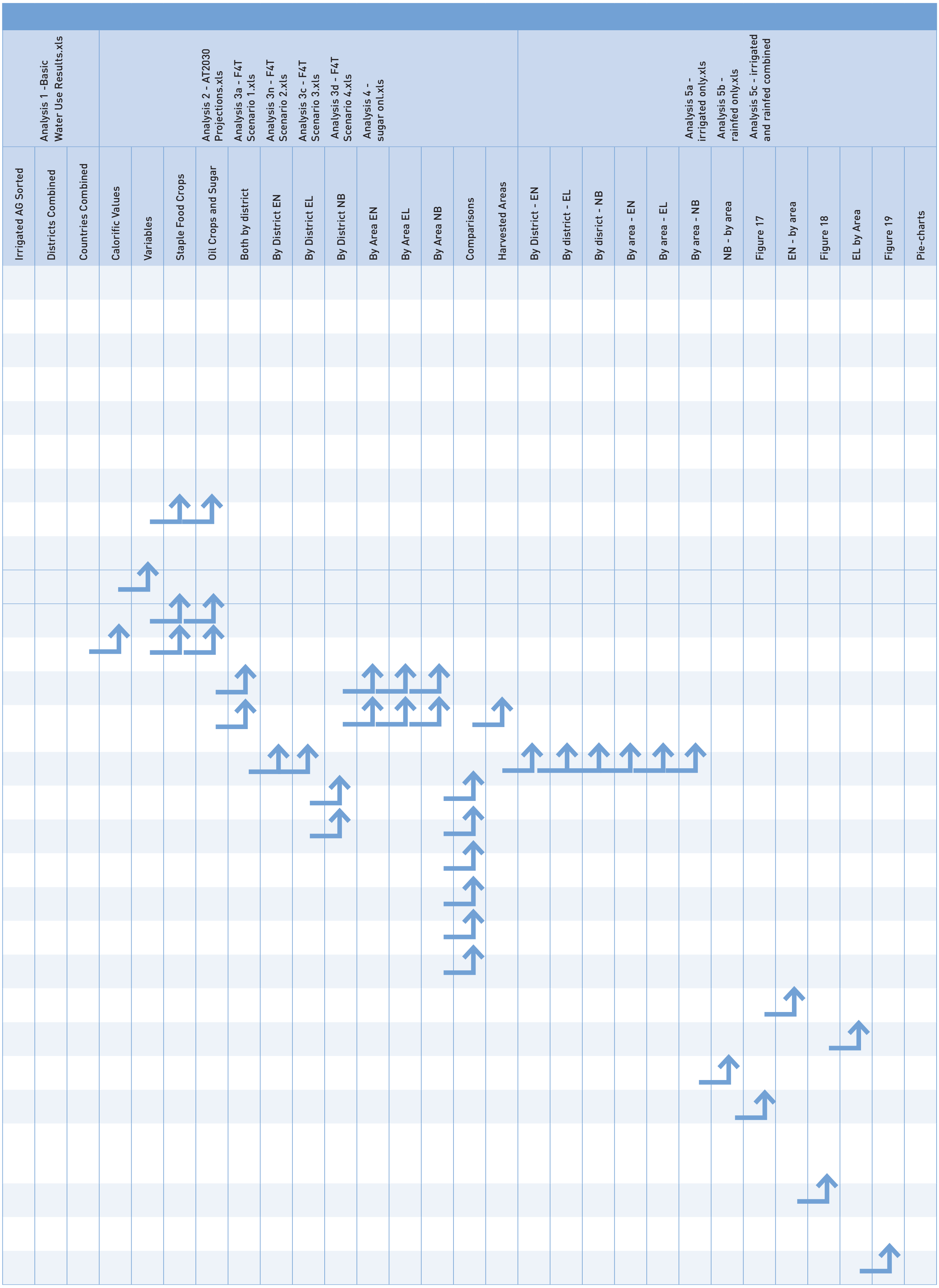
(Continued)

Figure 3.1: *(Continued)*

Country	Case	Subsistence crops												Cash crops					Physical irrigation water use efficiency	Sucrose recovery rate
		wheat	rice	maize	barley	millet	sorghum	other cereals	potatoes	sweet potatoes	cassava	other root crops	pulses	sugar beet	sugar cane	sesame	sunflower	unspecified oil crops		
Tanzania	% baseline		100%	100%		100%	100%		100%	100%	100%	100%	100%		100%	100%	100%		30%	12%
	% scenario 1		150%	150%		75%	100%		125%	125%	100%	100%	125%		150%	150%	150%		35%	14%
	% scenario 2		200%	150%		50%	100%		150%	150%	150%	100%	150%		200%	200%	200%		45%	14%
	% scenario 3		100%	100%		125%	125%		75%	75%	125%	100%	75%		75%	75%	75%		30%	12%
	% scenario 4		50%	125%		150%	150%		50%	50%	125%	100%	50%		50%	50%	50%		25%	12%
Rwanda	% baseline	100%	100%	100%			100%		100%	100%	100%	100%	100%						30%	no sugar
	% scenario 1	100%	125%	100%			75%		150%	150%	100%	100%	125%						35%	
	% scenario 2	100%	150%	100%			50%		200%	200%	100%	100%	150%						40%	
	% scenario 3	75%	75%	125%			150%		75%	75%	125%	100%	75%						30%	
	% scenario 4	75%	50%	150%			200%		50%	50%	150%	100%	50%						30%	
Burundi	% baseline	100%	100%	100%			100%		100%	100%	100%	100%	100%						30%	12%
	% scenario 1	100%	125%	100%			75%		150%	150%	100%	100%	125%						35%	14%
	% scenario 2	100%	150%	100%			50%		200%	200%	100%	100%	150%						40%	14%
	% scenario 3	75%	75%	125%			150%		75%	75%	125%	100%	75%						30%	12%
	% scenario 4	75%	50%	150%			200%		50%	50%	150%	100%	50%						30%	12%

Figure 3.2: Information flow through the model

										Baseline and Projections.xls		Irrigated Agriculture Projections.xls Rainfed Agriculture Projections.xls							Analysis 1 -Basic Water Use Results.xls		
Module	File		Worksheet	Worksheet reference						source data	reformatted data	baseline and - projections	administrative layers	admin-GIS	ET source data	rainfed/irrigated cropping calendars	country - districts rainfed/irrigated	country - shadow file	Rainfed Ag Unsorted	Rainfed Ag Sorted	Irrigated Ag Unsorted
1	Baseline and Projections.xls		source data								↱										
			reformatted data									↱									
			baseline and - projections														↱				
	Irrigated Agriculture Projections.xls Rainfed Agriculture Projections.xls		admin-GIS													↱					
			ET source data													↱					
			rainfed/irrigated cropping calendars														↱		↱		↱
			country - districts rainfed/ irrigated															↱			
			country - shadow file														↱				
2	Variables.xls		variables														↱				↱
			Calorific Values	2	3a	3b	3c	3d	4												
		worksheet reference	Variables		3a	3b	3c	3d													
			Staple Food Crops	2	3a	3b	3c	3d	4												
	Analysis 2 - AT2030 Projections.xls	2	Oil Crops and Sugar	2	3a	3b	3c	3d	4												
	Analysis 3a - F4T Scenario 1.xls	3a	Both by district	2	3a	3b	3c	3d	4												
	Analysis 3b - F4T Scenario 2.xls	3b	By District EN	2	3a	3b	3c	3d	4												
	Analysis 3c - F4T Scenario 3.xls	3c	By District EL	2	3a	3b	3c	3d	4												
	Analysis 3d - F4T Scenario 4.xls	3d	By District NB	2	3a	3b	3c	3d	4												
	Analysis 4 - sugar only.xls	4	By Area EN	2	3a	3b	3c	3d	4												
			By Area EL	2	3a	3b	3c	3d	4												
			By Area NB	2	3a	3b	3c	3d	4												
		worksheet reference	By area - EN	5a	5b																
			By area - EL	5a	5b																
	Analysis 5a - irrigated only.xls	5a	By area - NB	5a	5b																
	Analysis 5b - rainfed only.xls	5b	NB - by area			5c															
	Analysis 5c - irrigated and rainfed combined.xls	5c	Figure 17			5c															
			EN - by area			5c															
			Figure 18			5c															
			EL by Area			5c															


Analysis 1 -Basic Water Use Results.xls
Analysis 2 - AT2030 Projections.xls
Analysis 3a - F4T Scenario 1.xls
Analysis 3n - F4T Scenario 2.xls
Analysis 3c - F4T Scenario 3.xls
Analysis 3d - F4T Scenario 4.xls
Analysis 4 - sugar onl.xls
Analysis 5a - irrigated only.xls
Analysis 5b - rainfed only.xls
Analysis 5c - irrigated and rainfed combined
Irrigated AG Sorted
Districts Combined
Countries Combined
Calorific Values
Variables
Staple Food Crops
Oil Crops and Sugar
Both by district
By District EN
By District EL
By District NB
By Area EN
By Area EL
By Area NB
Comparisons
Harvested Areas
By District - EN
By district - EL
By disrict - NB
By area - EN
By area - EL
By area - NB
NB - by area
Figure 17
EN - by area
Figure 18
EL by Area
Figure 19
Pie-charts

Module 3 – The calculation platforms

Analysis 1 – Basic water use results

This analysis is not actually concerned with the projections but has been included in the suite because it makes use of the consolidated project cropping calendar to make an estimate of how much water was actually used by the basin's agriculture sector in the AT projections base year, ie 2005. "Analysis 1 – Basic Water User Results.xls" has eight worksheets.

"Rainfed Ag Unsorted" takes the harvested area and the unit annual water use for each crop calculated in the rainfed and irrigated projections files in Module 1 and from them estimates the total amount of water used by each crop in each district. The results are then totaled by district in "Rainfed Ag Sorted" which also applies spatial reduction factors in order to account for the fact that not every district lies entirely within the basin. The same worksheet also calculates country totals and presents them by country, by sub-basin (Eastern Nile and Equatorial Lakes) and for the basin as a whole.

"Irrigated Ag Unsorted", and **"Irrigated Ag Sorted"** do much the same for irrigated agriculture, but in addition, apply assumed national values for physical irrigation water use efficiency which have been supplied by FAO.

"Districts Combined" simply totals the rainfed and irrigated for each district, while **"Countries Combined"** does the same at the national level with the results comprise sub-study report Table 2.

"**AT Projections"** takes weighted mean unit water use or withdrawals (ie per ha) for each country and applies them to the projected areas for rainfed and irrigated as projected in the AT2030/50 files to provide an indication of water use with no changes to current assumptions, ie non-scenario projections. The results comprise sub-study report table 4.

"District Breakdown" compiles the rainfed and irrigated water use/withdrawals for 2005 at district level and comprises Annex 2 of the sub-study report.

It will be clear that any changes to the data in the Module 1 projections files will be automatically picked up here. In addition, if considered necessary, it is also possible to change the irrigation water used efficiencies from the Scenario Builder. But this would only be necessary in the unlikely event that it were considered necessary to revise the historic values assumed for 2005.

Analysis 2 – The AT2030 projections

This analysis simply uses the distributed cropping systems data to assess the changes in AWPcal implicit in the AT2030 projections. It uses spreadsheet *"Analysis 2 – AT2030 Projections"* and plots the results as exceedence percentages by district and by area. In other words, it assesses the number of districts - expressed as a percentage of the total number - that exceed a certain level of AWP_{cal}, similarly the total area that exceeds a certain level of AWP_{cal}, as percentage of the total cropped area in the Eastern Nile, Equatorial Lakes[7] and entire Nile Basin. Separating out the two sub-basins is considered worthwhile because of their differing climatic characteristics and farming systems. However, since the cropping profile is fixed in the AT2030 projections, it is not necessary to change any of the variables. In effect, the results represent the situation that is expected in the event of no changes in governance and terms of trade and hence provide the baseline against which scenarios that do anticipate such changes can be compared, as will be shown later.

There are 11 worksheets.

"Calorific Values" which is used by VLOOKUP functions on the following two sheets, to provide the calorific values in per kilogram terms for each of the crops analysed.

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[7] These are defined in consistency with the Nile Basin Initiatives demarcation, thus Eastern Nile comprises Egypt, Sudan, Eritrea and Ethiopia, while Equatorial Lakes comprises Uganda, Kenya, Tanzania, Rwanda and Burundi. The Central African Republic and the DRC being ignored as having no significant agriculture within the basin.

"Staple Food Crops" picks up the distributed areas and AWPs (in terms of kg/m^3) from the rainfed and irrigated projections files for each of the subsistence indicator crops, and using the calorific values calculates AWPcal for each crop at district level for each of them for 2005 and as projected by AT2030. It also calculates mean AWP$_{cal}$ values weighted by area, for each district and time slice.

"Oil Crops and Sugar" does the same for indicator cash crops.

"Both by District" combines the subsistence and cash crops district weighted AWPcal values into a single district weight mean that automatically reflects the subsistence/cash crop ratio. It also separates out irrigated from rainfed values.

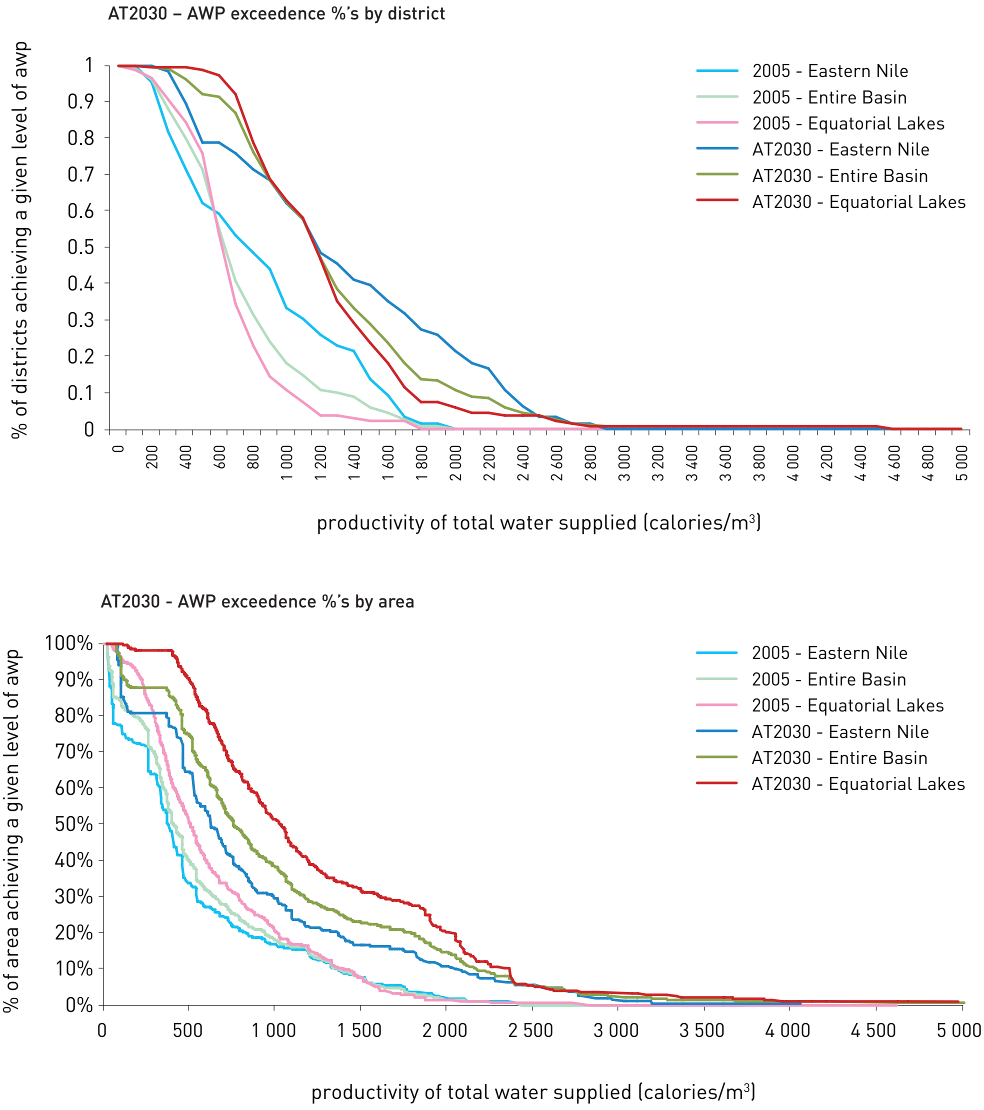
"By District EN" reads the combined Eastern Nile district level AWP$_{cal}$ from "Both by district" for 2005 and 2030, sorts the results for each time slice into exceedence increments and calculates the exceedence percentages.

"By District EL" does the same for Equatorial Lakes districts, as does "By District NB" for the basin as whole.

"By Area EN", **"By Area EL"**, **"By Area NB"** do much the same, but for areas rather than districts. Unlike districts however, because it is not necessary to count the numbers falling within an exceedence increment but rather to calculate cumulative total areas, the results are processed directly.

"Comparisons" simply plots the results, as shown in Figure 4.1.

Figure 4.1: Results from the AT2030 projections analysis



Analysis 3 – The F4T scenarios

This analysis simply uses the distributed cropping systems data to assess the changes in AWP$_{cal}$ implicit in the F4T Scenarios. It uses four spreadsheets:

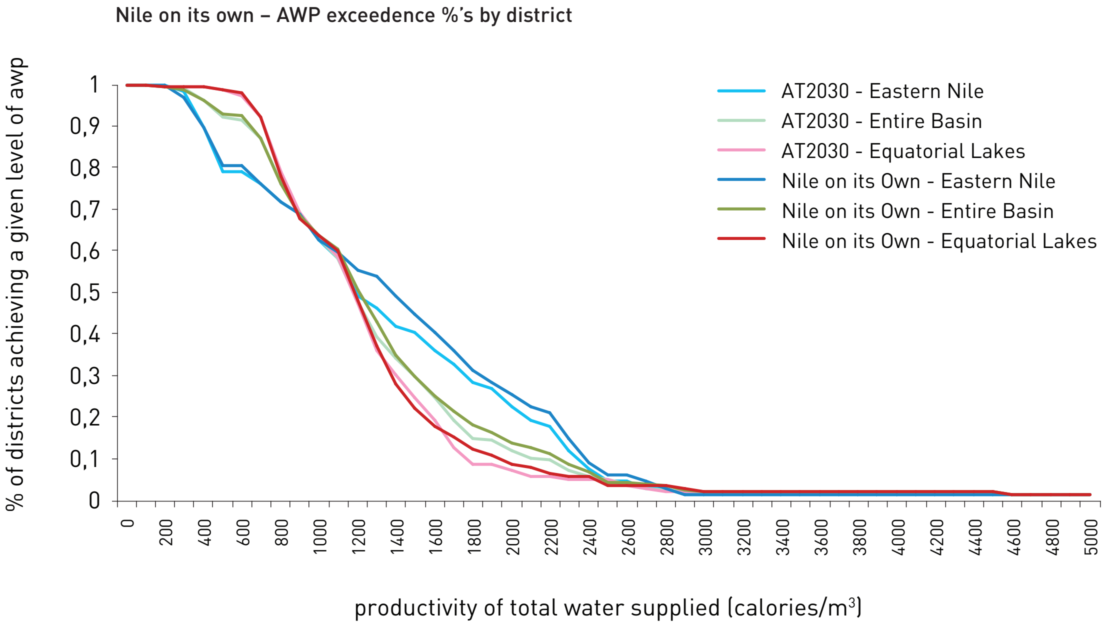
- **"Analysis 3a – F4T Scenario 1"**
- **"Analysis 3b – F4T Scenario 2"**
- **"Analysis 3c – F4T Scenario 3"**
- **"Analysis 3d – F4T Scenario 4"**

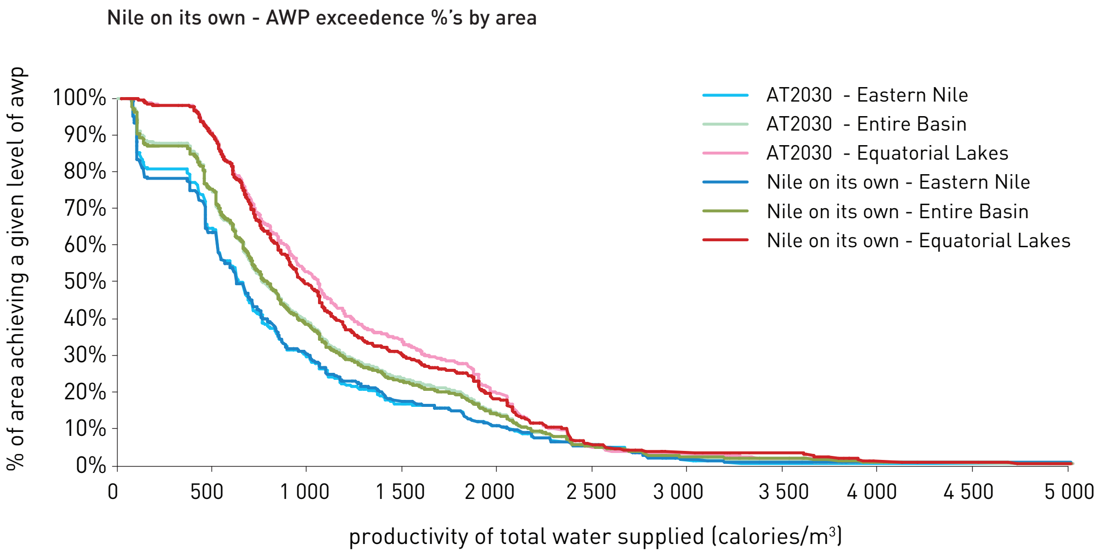
As with Analysis 2, the results are also plotted as exceedence percentages by district and by area. Each of these files has 12 worksheets, 11 of which are the same as for Analysis 2 and fulfill the same functions.

The additional worksheet is **"variables"**, which automatically picks up all the changes in cropping profiles, physical irrigation water use efficiency and sucrose recovery rate that the user makes in **"Variables.xls"** (Module 2).

The current results for Scenario 1 are provided by way of illustration in Figure 4.2 below.

Figure 4.2


Nile on its own – AWP exceedence %'s by district


Nile on its own - AWP exceedence %'s by area

Analysis 4 – Sugar (or single crop) only

We have already seen that sugar is a crop of particular interest. However, since the scenario analyses concern the redistribution of a range of crops throughout district level farming systems, and since also sugar beet and sugar cane have the same calorific content, it would be meaningless to analyse the scenarios in respect of sugar alone. Accordingly, excel file **"Analysis 4 – sugar only"** simply plots the exceedence percentages of the AWP$_{cal}$ of sugar in the baseline year 2005, and for the areas projected by the AT2030 data. The results are plotted for the two sub-basins and the basin as whole in terms of districts and areas – no changes to the sucrose recovery rate have been assumed.

The architecture of the sugar only file is based on that of the Scenario files (although the algorithms are more complex) and can in fact be applied to any of the crops include in the model – this is why the entire calorific look up table is retained in the file. All that is required is to delete the entries for sugar on the worksheet *"variables"* and enter 100% in the cells relevant to any of the countries where the new crop of interest is grown. The difference with the Scenario files is the inclusion of an additional worksheet *"harvested areas"* which separates rainfed from irrigated and tabulates the results by time slice, country, sub-basin and basin. Obviously, if the file is used for another crop, the table would have to be relabelled.

Analysis 5 – Individual countries

Individual countries are easily analysed – in fact Sudan was analysed for use in the sub-study report. For any particular analysis, all that is necessary is to take the excel file for the particular analysis required and:

1. Delete the rows containing the unwanted countries in worksheets:
   - "staple food crops – sfc"
   - "oil crops and sugar – ocs"
   - "by district" for the sub-basin containing the country being analysed
2. Sort Columns B to H, on H largest to smallest , on the "by area" worksheet for the country in question.
3. Delete the compromised cells which will occupy the uppermost rows of columns B to I, whereupon the exceedence %'s will be restored in Column I
4. Delete the unwanted plots on the "by district" and "by area" charts on worksheet "comparisons'

BUT DO NOT SAVE THE FILE AT ANY STAGE unless to a new name at any stage, otherwise the original will be over-written with all the countries omitted.

Analysis 6 – Comparison between irrigated and rainfed agriculture

It should be self evident that rainfed agriculture will generally be associated with higher AWP's than irrigated. This is because there are no distribution or application losses associated with rainfall and was confirmed by the study with the exception of a few examples (sugar in Uganda and Kenya; rice in Uganda and Tanzania and maize in Kenya and Tanzania) for which irrigated agriculture displays higher AWP's, and very significantly so in some cases. But the story does not end there because the advantages that accrue to irrigation are less concerned with agricultural productivity of water, than with i) obviating the risks of inadequate or mistimed rainfall; ii) justifying increased investments in farm inputs and more sustainable farm practices; iii) crop diversification; and iv) the concentration of service provision (information, extension, markets and communications etc). It is interesting therefore to see how this is played out in the Nile Basin – hence this analysis.

Three files are involved:

"Analysis 5a – irrigated only.xls" and **"Analysis 5b – rainfed only.xls"**, which read results from analyses 2 to 5 separately for irrigated and rainfed regimes respectively. Each has six worksheets which are self-explanatory, except to say that each sheet deals with six analyses (2005, AT2030 and Scenarios 1 through 4). The worksheets are as follows:

- "By district – EN"
- "By district – EL"
- "By district – NB"
- "By area – EN"
- "By Area – EL" and
- "By Area – NB"

"Analysis 5c – irrigated and rainfed combined.xls", then reads the by area results from the 5a and 5b sheets and plots the results by sub-basin and the basin as a whole. The file does not as yet plot the results by district, although the data is there in the 5a and 5b files should it be decided to do so in the future. Six worksheets are again involved:

- "NB – by area" which compares the data from both 5a and 5b as it concerns the basin as a whole;
- "Figure 17", which plots the comparison at basin level;
- "EN - by area" *ditto* for the Eastern Nile Sub-Basin;
- "EL – by area" *ditto*;
- "By area – EN" *ditto* for the Equatorial Lakes Sub-Basin;
- "By Area – EL" *ditto*.

There is also a seventh worksheet, **"Pie-charts"** which makes a comparison of rainfed and irrigated areas in the Entire Basin, the Eastern Nile and the Equatorial Lakes Sub-Basins in 2005 according to the consolidated project data.

With the exception of **"Pie-charts"** in the 5c file, all worksheets are updated automatically and accordingly need no input from the user. Equally, since **"Pie-charts"** uses baseline data, it is fixed, so again needs no input from the user and is included only because it sheds some light on the exceedence charts as discussed in the in the Project sub-study report **"Agricultural Water Use Projections in the Nile Basin to 2030".**

Output graphics

Module 3 is completed by **"Projection Report Graphics.xls"** which merely captures, for convenience, the charts produced by Analyses 2 to 6[8]. These charts are live-linked to the analytical files and so are updated automatically whenever the variables and other inputs are changed by the user.

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[8] Along with the illustrations used in the sub-study report.

Enhancing or adapting the model

In accordance with the writer's ToR, this manual has been prepared only with respect to the analyses to date[9]; but this does not mean that the possibilities have now been exhausted. This closing section therefore introduces other possible analyses that could use the distributed cropping calendars in Module 1 and modified or enhanced versions of the calculation platforms comprising Module 3.

Rainfall efficiency

It was mentioned above that although rainfall efficiency has been kept at unity throughout the basin and the analyses, in reality this is not likely to be the case. Where land has been badly managed, denuded, wrought into hard pans and rendered devoid of trees for instance, rainfall efficiencies will be lower than where land has been terraced, better tilled and with sufficient trees remaining to achieve noticeable reductions in advective energy. Clearly, as with physical irrigation water use efficiency there will be a link between governance and rainfall efficiency.

It would be possible therefore to reflect this in the model simply by adding a column to the variables matrix presented as Figure 3.1, and to add additional columns to the **"staple food crop"** and **"oil crops and sugar"** worksheets in the F4T Scenario files and to the **"rainfed ag unsorted"** worksheet in the basic water use file.

Non-linear projections

At present, The Model applies the projected percentage changes in the area planted to a given crop in a given country equally to each of the districts in which the crop is encountered. This is unlikely to be the case in reality. Construction perhaps, of a large commercial sugar factory may catalyse expansion of the local sugar cane crop at a rate which is significantly faster than average. The same might be true of a large cannery, juicing facility or rice mill etc.

The Model already provides for this eventually by means of the shadow files which allow the user to change the district distributions of spatial changes in the Module 1 projections files (both rainfed and irrigated). The user will see that each of the shadow files contains a column marked Check (column D). This is because regardless of how the spatial changes are redistributed between the districts, the Check values should always equal 100% for a given crop in order that the national total remains as suggested by the projections.

Changing the indicator crops/clusters

The analyses carried out so far, assume that the ratio of AWPcal values for subsistence and cash crops is a suitable proxy for assessing the water allocation implication of scenarios that are defined by different combinations of governance and terms of trade. But other scenario frameworks might be crafted in the future, in which case other proxies might be more suitable.

It is theoretically possible to select other indicator crops, or even clusters, so long as whatever is chosen is included in the crops that are included in the distributed projections (ie crops that appear in both the Project baseline and the AT2030/2050 projections and therefore protocol compliant).

No changes to the distribution projections would be necessary; but other extensive changes would be needed as follows:

- The variables matrix would have to be changed to reflect the new set of indicators
- Columns E and F in the "cluster crop" sheets (currently **"staple food crops"** and **"oil crops and sugar"**) would have to be changed, with additional rows added, or rows deleted as required.
- In the event that rows are added or deleted for a given district, the weighted mean algorithms in columns N and T would have to be modified accordingly.
- In the event that districts are included in either of

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[9] The assignment also required him i) to tidy up and streamline the spreadsheets which remain cluttered with redundancies at the end of the study; and ii) to set them up so that the four scenarios could be analysed simultaneously, which they could not beforehand.

the current cluster crop sheets but do not have any of the new indicator crops, they would have to be deleted, and vice-versa if there are districts that have the new crops but are not included in the current sheets, they would have to be added, along with the algorithms for columns I to T.

- **"Both by districts"** would have to be revised in accordance with any changes to the cluster crop sheets
- If districts are neither added nor deleted from the cluster sheets, then no change is necessary with respect to the **"by district"** worksheets but if there have been such changes, the **"by district"** worksheets will have to be changed so that each district's weighted means are included.
- The **"by area"** worksheets will almost certainly need to be changed – first in order that they pick up every crop's area and AWP_{cal} value and secondly, the results need to be sorted as per steps 2-4 in section 4.5 above.

Economic

The value and applicability of the model would be vastly enhanced if it could calculate the economic agricultural productivity of water – AWP_{ec}; but for the reasons explained earlier, unlike the other enhancements or adaptations suggested in this section, this would require a significant amount of additional work involving not only an agricultural water use specialist (as has been the case so far), but also an agricultural/added value economist. At the level of The Model changes to would be quite minor requiring only changes to the algorithm which calculates AWP_{cal} – there is one single such algorithm and it would just be a case of replacing it with the new one everywhere it is encountered in The Model, with the caveat that it will itself be dependent on a whole suite of new variables.

It is the incorporation of these new variables into the algorithm that would comprise the greater part of the additional work, not least because of the additional variables that would need to be included, quantified and capable of being updated as economic conditions change. These variables would include:

- the economic value of a given crop, which may be location and time specific;
- added value benefits, again priced in economic terms;
- an estimate of what proportion of added value applies to what proportion of a given crop;
- where necessary, the effect of stepped tariffs which are likely to change from time to time, and will be especially sensitive to changes in the terms of trade;
- the amount of water needed to add value along with the capital and recurring costs of supplying that water;
- the capital and recurring costs associated with changes in equipped irrigated areas, again expressed in economic not financial returns;
- the economic costs of crop production;

and,

- since terms of trade is one of the scenario variables, the FoB prices of export crops.

All this is nonetheless doable, and if done, would provide a powerful decision making tool of relevance to any large river basin – see section 5.6.

Fodder crops

As has already been mentioned, The Model cannot as yet handle fodder crops. Yet although these are important cash crops in some locations, especially for instance on the Nile Delta, the direct use of AWP_{cal} in the case of fodder crops would be questionable because its value in ruminant digestion is as a medium in which the gut fauna on which the animal itself feeds can itself feed and more importantly, multiply. At which stage therefore should the AWP_{cal} be quantified?

However, if The Model is adapted to work with the AWPec then the matter is greatly simplified such that this important cash crop can be included as one of the indicators.

Adaptation to other river basins

In terms of its architecture and algorithms, The Model is perfectly adaptable for other river basins; but not in any sense of plug and play because it would in fact need to be rebuilt from scratch. This however, need not necessarily be a killer condition. Most of the effort involved in producing this version of The Model went into consolidating and rationalising the baseline cropping calendar and yields data, and in applying the projections protocol to the results. The overall architecture and information flow is not basin specific.

The AT2030/2050 projections are effectively a given, so if a user in another basin already has a reliable and acceptable baseline, construction of a new model would be a straightforward, though rather repetitive task.