:vivideconomics

Water resources and extreme events in the Awash basin: economic effects and policy implications

Report prepared for the Global Green Growth Institute

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Executive Summary

The project team was engaged by the Global Green Growth Institute (GGGI) to analyse the relationship between hydrological factors such as rainfall, drought and flooding and the economy of the Awash basin. The work seeks to complement existing research in the field by providing a quantitative analysis of the impacts of hydrological variability from an economic perspective. It explores three main questions:

- How do hydrological factors affect production in water-sensitive sectors of the economy?
- How do these impacts transmit through to other sectors of the economy to determine the basin's overall economic vulnerability to hydrological variation?
- What are the implications of this for water management policymakers in the basin?

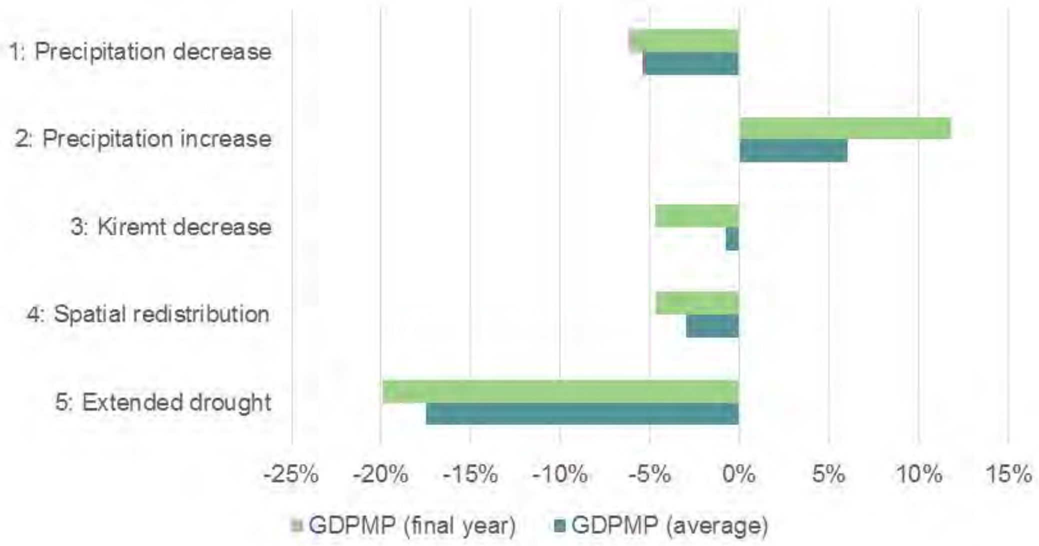
The economy of the Awash basin is highly exposed to hydrological variability: modest changes in rainfall lead to swings in the basin's GDP of 5-10 per cent, while a prolonged drought could reduce production by 20 per cent. Despite an apparently abundant supply of water in aggregate terms, the basin routinely suffers from localised water shortages at specific points in space and time, and is prone to destructive episodes of flood and drought. This represents a critical economic vulnerability for the basin.

Agricultural production incurs the direct impacts of water scarcity and extreme events. Crop output in the basin not only depends on the overall level of rainfall and incidence of flooding and drought, but is also sensitive to the timing of rains and their distribution across areas of the basin. As a consequence, large production losses are possible under a diverse range of plausible future climate scenarios: both where the level of rainfall decreases and where its distribution over space and time changes. Livestock production has a parallel vulnerability to changes in rainfall patterns and, though data constraints mean this is not evident in this study's quantitative results, is particularly threatened by drought.

Other sectors are affected indirectly and often negatively. Contractions in agriculture caused by hydrological variation have knock-on impacts elsewhere in the economy. Though the negative effects of hydrological factors on agriculture can be mitigated by growth in other sectors, as labour and other inputs switch away from agriculture to sectors where they are more productive, in most cases we consider the effects on agriculture are amplified, with reductions in the supply of agricultural produce leading to a fall in productivity in other sectors.

Under current conditions, the economic consequences of hydrological variability are therefore severe. Figure 1 below shows five illustrative scenarios, demonstrating how economic output in the basin might have been changed during the first Growth and Transition Plan (GTP) period, from 2011-15, if hydrological conditions had been different. The scenarios represent plausible future hydrological conditions, drawn from global climate models, and show very large swings in basin GDP of the order of 5-20 per cent per year by the end of the GTP. The non-poor tend to suffer the greatest proportional changes in income under these scenarios, though the impacts on poverty are understated by the study's focus on market goods.

Figure 1. **Macroeconomic impacts of five climate scenarios, deviation from GTP**



Source: *Vivid Economics*

The current level of sensitivity will increase steeply in coming years. The scenario analysis uses 2011-15 as a baseline but as the economy is projected to grow sharply in coming years so is the degree of water scarcity. Unless rapid and very substantial policy changes are enacted to mitigate this sensitivity, the results in Figure 1 should be treated as lower bound estimates of future impacts.

High levels of vulnerability imply a high value of water. A primary implication of this study's findings is that policies to improve the management of scarce water resources in the Awash basin deserve a very high priority in Ethiopia's development plans. This analysis shows how *agricultural* vulnerabilities propagate through the economy, and thus demonstrates that measures to improve resilience in this sector have substantial economic benefits. Such measures might include infrastructure projects that increase the supply of water, but should also feature tariff and permitting systems that increase the value extracted from the basin's water existing resources and incentivise commercial farmers to invest in more efficient technologies. The high value of water in the basin also underscores the importance of coordinating development activities using basin-wide water resource management plans: investment appraisals for projects in other spheres, such as energy and transport, should account for and value any water impacts, for example.

The value of water should be factored into water resource plans. The Awash Basin Authority (AwBA) has a programme to improve data collection, forecast supply-demand balances, and develop tariff and permitting schemes for water abstraction and wastewater discharges (Authority, 2014). The findings of this report provide strong support for all of these activities. However, a missing ingredient of its planning framework is an economic value of water, ideally at a temporally and geographically granular level, which can be used to quantify the costs and benefits of different programmes and thereby improve decision making over water allocation and investment policies. This study shows that the gains from such improvements could be very large indeed.

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1 Introduction

The project team was engaged by the Global Green Growth Institute (GGGI) to analyse the relationship between hydrological factors such as rainfall, drought and flooding and the economy of the Awash basin. The work seeks to complement existing research in the field by providing a quantitative analysis of the impacts of hydro-climatic variability from an economic perspective. It aims to explore three main questions:

- How do hydrological factors affect production in water-sensitive sectors of the economy?
- How do these impacts transmit through to other sectors of the economy to determine the basin's overall economic vulnerability to hydrological variation?
- What are the implications of this for water management policymakers in the basin?

The team comprised: Vivid Economics; hydro-climatic experts from the Oxford University Centre for the Environment, Addis Ababa University, and the Water and Land Resource Centre; and a team of economic modelling specialists directed by Dr Firew Bekele.

The project activities included both quantitative and qualitative research. The quantitative analysis involved the collection of hydrological and economic datasets for the Awash basin, econometric analysis of relationships in these data, the definition of a set of climate scenarios, and macroeconomic simulation using Computable General Equilibrium (CGE) modelling. This was supported by a parallel programme of qualitative research consisting of interviews with policy makers and academics, and a review of the relevant literature.

This report presents a precis of the work and its implications for a general reader. More detailed technical accounts of the methods, results and the data that informed it are laid out in accompanying annexes. The remainder of the report is structured as follows:

- Section 2 sets the scene, describing the economy of the basin, its dependency on water resources and how these dependencies are managed at present;
- Section 3 examines the relationship between crop output and water availability, floods and droughts;
- Section 4 shows how the sensitivity of crops to these hydrological factors could lead to substantial economic impacts;
- Section 5 draws together the implications of this study for water management and wider economic development in the basin.

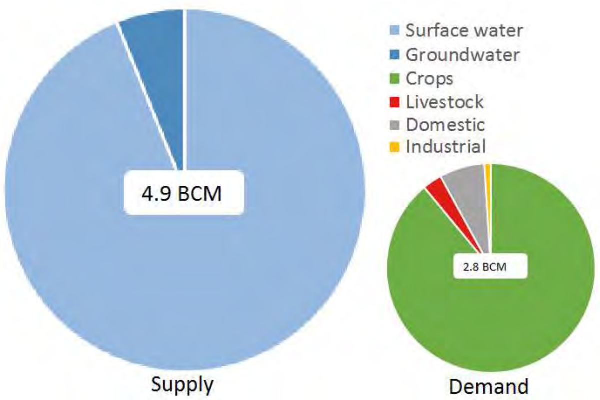
2 The economy of the Awash basin and its dependence on water resources

The Awash basin is rich in water resources, but they are variable, uncertain and becoming increasingly scarce as the local economy rapidly develops. Data collected for this study on hydrological and economic conditions in the basin[1], along with qualitative research, provide insights into the dependence on the economy on hydrological factors, such as water availability, flood and drought. To frame the quantitative analysis of Sections 3 and 4 and ground the conclusions presented Section 5, this section provides an overview this context.

2.1 Hydrology and economy of the Awash basin

At first sight, the basin's abundant water resources appear to suggest a low level of economic vulnerability to hydrological factors. Water resources can constrain economic growth when water is scarce (Sadoff et al., 2015), but the aggregate supply of 'blue' water[2], at around 4.9 billion cubic metres (BCM) per annum, greatly exceeds current consumptive withdrawals, which are estimated to be 2.8 BCM per year (Tiruneh, Berhanu, Ayalew, Tamrat, & Tesfaye, 2013).

Figure 2. **Estimated consumptive supply and demand of 'blue' water by source and sector, 2014**



Source: *Vivid Economics*

[1] The economic dataset used in this study was collected from Ethiopia's Central Statistics Agency, and hydrological data was gathered from the Global Precipitation Climatology Centre and metered data from the Ministry of Water, Irrigation and Electricity. Annexes B and C provide a detailed account of the sources used and data processing techniques employed.

[2] 'Blue' water includes groundwater and surface waterbodies. This is distinct to 'green' water, which is the proportion of precipitation that is evaporated and is the source of all rain-fed agriculture.

However, the region faces variability and uncertainty over water availability and is highly vulnerable to extreme events. This raises the possibility of water scarcity at particular points in time and space as well as significant adverse impacts from flooding and drought. In particular, the basin faces:

- Very significant seasonal and geographical variation in water availability that is not currently regulated by infrastructure, with aggregate surface water availability during the dry season around 28 per cent of the level during rainy season and a much more arid climate in the downstream, lowland areas in the east of the basin (Tiruneh et al., 2013);
- Current uncertainty over water availability, which, as the scenario analysis presented in Section 4 highlights, is set to be amplified by the effects of climate change; and
- Exposure to flooding and drought, which may also increase due to climate change.

As a consequence, there is reason to believe that the basin's rapidly growing economy is vulnerable to hydrological factors and it is set to become more so in the future. With a total GDP accounting for around 30 per cent of national production[3], the Awash basin comprises a major part of Ethiopia's economy, so any vulnerability is likely to be highly economically significant for the country as a whole. Rapid development, which includes the growth of commercial farming and urbanisation in centres such as Addis Ababa, Adama and Dire Dawa, will amplify this sensitivity.

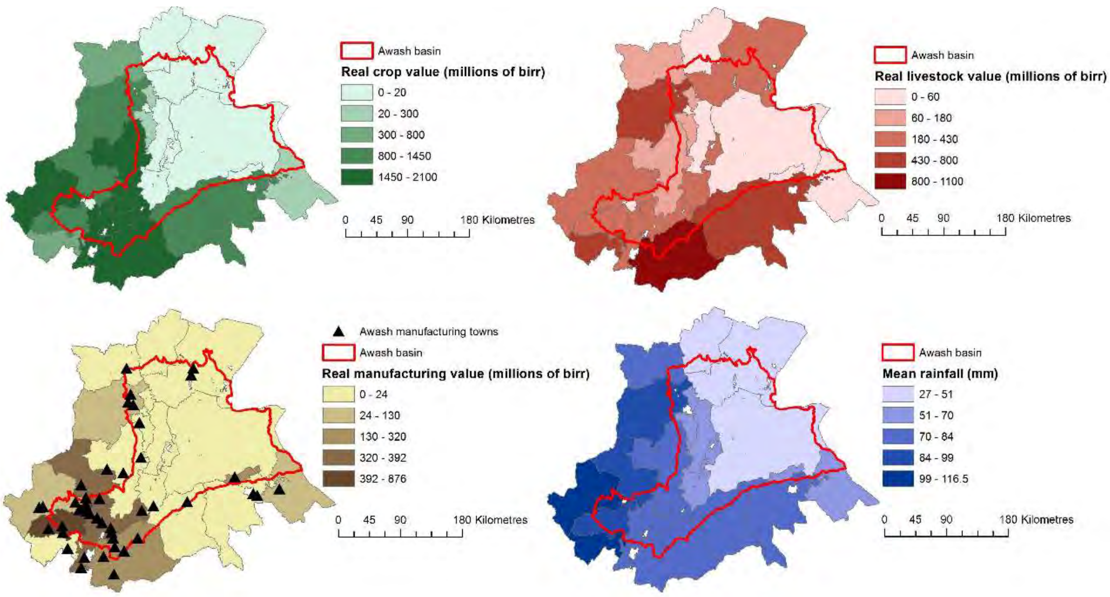
The geographical pattern of development in the basin may further exacerbate its vulnerability. The Awash basin is unusual in that the bulk of economic activity, including industrial production and most major cities, is sited upstream in the watershed. See the map in Figure 3 below. As a consequence, there is a risk that growing volumes of industrial effluent and urban wastewater will increase scarcity by reducing the quality of surface water available for downstream users, a risk that will be more acute if current commercial discharges remain unregulated and rates of connection to public sewers, currently below 7 per cent in Addis Ababa (Authority, 2014), stay low. Indeed, interviewees for this study reported cases where surface water in the Awash River has been unfit for use even in agriculture.

2.2 Sectoral dependence on water resources

Economic and hydrological data allows for the exploration of this vulnerability at the sectoral level. The data encompasses crop production, livestock herd size and manufacturing output. Due to the way data is collected in Ethiopia, zonal estimates of services output are not available. However, the relationship between this part of the basin's economy and hydrological conditions is largely mediated by impacts on sectors that require water directly as an input. Such indirect dependencies are assessed in Section 4.

[3] This is a highly approximate estimate based on CSA statistics showing the Awash basin accounts for around 36% of manufacturing value add and 25% of agricultural production. The sources of this are described in Annex C.

Figure 3. **Economic activity and water resources are concentrated in the more populated upstream western zones.**

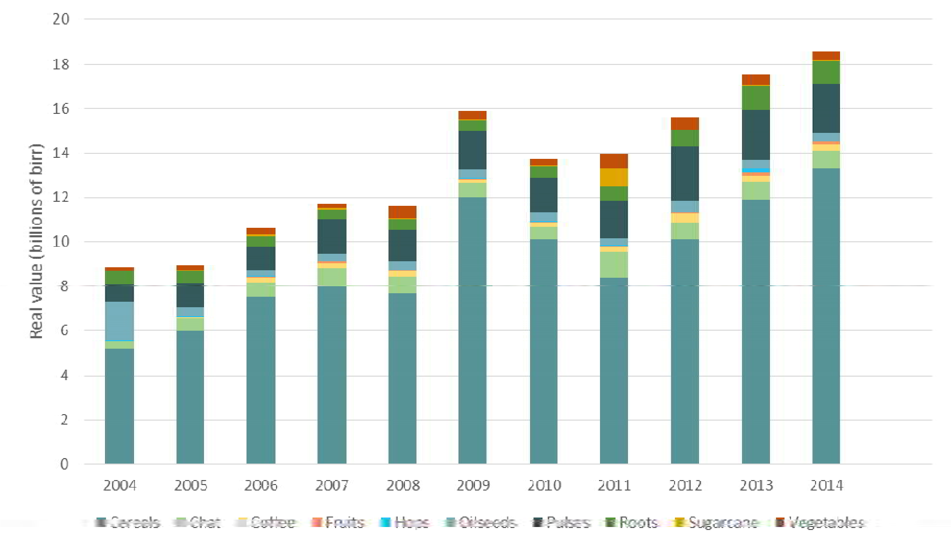


Source: *Vivid Economics hydrological and macroeconomic dataset*

Crop production is a major component of the basin's economy, which has grown strongly. The aggregate value of crop output for zones intersecting the Awash basin was 18.6 billion birr in 2014 and the sector has grown very rapidly, with the value of output expanding by 7.9 per cent per year in real terms from 2004 to 2014. Figure 4 shows the yearly breakdown by crop, making it clear that much of the sector's growth results from increasing production of cereals. This growth is explained in part by an extension of land under cultivation at 3.8 per cent per annum, as well as productivity growth driven by irrigation, the expansion of commercial farming, improved use of inputs such as fertiliser or selected grains, and increasing planned development by state owned enterprises.

The cultivation of crops accounts for the bulk of surface water use in the region and is obviously dependent on water availability. While production growth does not in itself signify increasing vulnerability to hydrological factors, current policies for water resource management reviewed below do not strongly encourage the development of water-resilient agriculture. Furthermore, increased unregulated usage of agrochemicals can impair downstream water quality, while land clearance can increase runoff and thus raise flood exposure.

Figure 4. **Rapid growth in the value of crop output has been led by cereals**

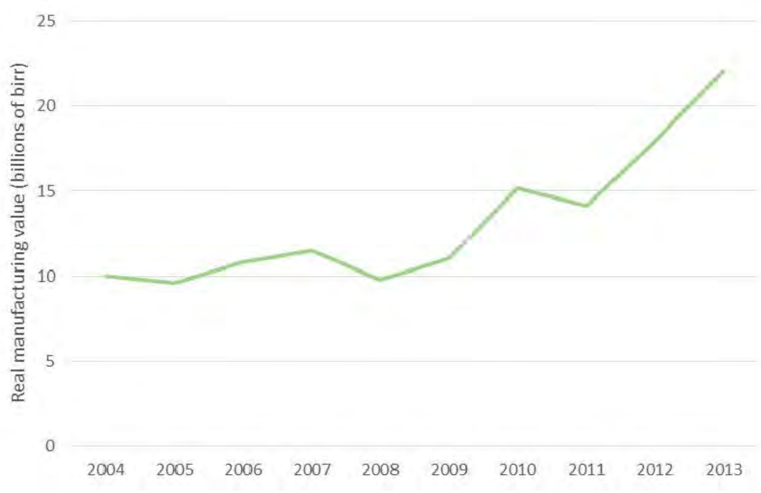


Source: Vivid Economics hydrological and macroeconomic dataset

Livestock production is growing more slowly than crops, but it remains an important component of many people's livelihoods and is of greatest economic importance in areas that face the greatest vulnerability to hydrological factors. Cattle herd size, which dominates the livestock sector by value, has increased at only 1.6 per cent annually over the period from 2006 to 2013, though the real-terms value of the stock increased more rapidly due to rising prices. For pastoralists in lowland regions, livestock holdings are the primary source of wealth and a major component of income and, as noted above, these areas are more vulnerable to water scarcity than other parts of the basin. Pastoralists, both nomadic and sedentary, are particularly vulnerable to drought events, during which many cattle can die, leading to long term falls in production potential.

Manufacturing is growing quickly, and though it is less immediately sensitive to hydrological factors, it relies on unregulated access to groundwater sources that may become scarce. Manufacturing accounts for a substantially smaller proportion of GDP in the basin than crops, but it grew at 8.8 per cent per annum from 2004 to 2013, as illustrated in Figure 5, and the Ethiopian government is targeting substantial further growth in this sector over the coming decade (Federal Democratic Republic of Ethiopia, 2015). Groundwater, which is more reliable than surface water sources, meets 95 per cent of the sector's water demand and thus makes the sector less immediately vulnerable to fluctuations in availability. However, limits to groundwater availability, which remain uncertain, mean the current pattern of growing unregulated extraction is likely to come against a constraint in the future if left unchecked. Furthermore, as noted above, present patterns of unregulated discharges of industrial effluents have an impact upon water quality and availability downstream.

Figure 5. **Nationally, the value of manufacturing output has grown strongly over the last decade**



Source: *Vivid Economics hydrological and macroeconomic dataset*

2.3 Water resource management in the Awash basin

The current water resource planning policies and institutions in place within the Awash will need further development to address the constraints set out in Sections 2.1and 2.2. Qualitative analysis and a literature review have identified four main issues to address, each discussed in detail in Annex A:

- insufficient quantity and quality of data collected results in uncertainty over water availability and water quality, and hampers efforts to enforce controls on abstraction and discharges;
- current water allocation and access policies encourage the over exploitation of ground and surface water resources and excessive pollution;
- an investment appraisal framework for water infrastructure underpinned by an economic valuation of water could reduce costs and improve coordination with other programmes; and
- a multiplicity of institutions with overlapping responsibilities for water resource management impairs coordination.

However, in order to prioritise policy measures that could address these issues, the nature and magnitude of the impacts that water constraints have in the basin must first be understood. This is the goal of the sections that follow.

3 Relationship between water and crop output

Crop production in the basin depends directly on hydrological conditions. However, as the contextual review in Section 2 suggests, the relationship is a multi-faceted one, potentially contingent on seasonality, crop-type, and production location. This section presents the econometric analysis used to test for and quantify the effects of various aspects of this relationship. Section 3.1 draws a distinction between direct and indirect impacts, Section 3.2 sets out the methodology used to analyse the direct relationship between crop production and hydrological variation, and then Section 3.3 summarises the main findings. A more complete technical discussion of this work is provided in Annex D.

3.1 Direct and indirect economic impacts of hydrological variability

The themes set out in Section 2 suggest water scarcity and extreme events have substantial direct and indirect impacts on economic outcomes in the Awash basin. Hydrological events propagate around the economy in two ways:

- directly, as hydrological events impact on sectors that require water for production or whose production is physically disturbed by flooding or drought; and
- indirectly, as direct effects increase or reduce the supply of inputs for other sectors. The indirect effect could be in the same direction as the direct effect if the indirectly affected sector relies on inputs from the directly affected one. For example, an increase in agricultural productivity is likely to increase the supply of inputs for a food processing plant. On the other hand, if common inputs move between sectors depending on where they are most productive the indirect and direct effects could have opposite signs. If agricultural productivity falls, for instance, so will wages in that sector, which will encourage workers to migrate to other parts of the economy, raising output elsewhere.

Sections 3.2 and 3.3 below assess the direct impacts of hydrological factors on the economy of the Awash basin, while Section 4 presents analysis of indirect effects.

3.2 Hypotheses and econometric methodology

Our assessment of the direct effects of hydrological factors in the basin focuses on crop production. The data is not used to measure direct effects on manufacturing or services, as doing so would risk double counting the indirect effects on these sectors, which are estimated separately in Section 4 and which, in any case, are expected to be substantially larger than the direct effects in these sectors.[4] Due to data constraints, the direct effects of hydrological factors on livestock production cannot be measured; instead, an assumed relationship between livestock and crop production serves as a proxy. Annex D provides more discussion of the methodology.

[4] This reflects the manufacturing sector's reliance on more stable groundwater sources as set out in Section 2 and the service sector's limited use of water as a production input.

The direct relationship between hydrological factors and crop production is complicated, and this assessment reflects the complexity as far as possible. As the review in Section 2 highlights, water scarcity in the basin is not uniform in space or time and it occurs in a context of rapid economic development. A straightforward, linear relationship between water availability and crop output is not therefore expected. Instead, we look for:

– crop output growing over time as the economy develops, with hydrological factors leading to deviations from the trend;
– seasonal variation in the sensitivity of crop production to water availability, with stronger positive impacts expected when water is scarce and when crop demand is high during growing seasons;
– geographical variation in the impact of extra water, with additional water increasing output by more in downstream, arid zones where water appears to be more scarce;
– variation in sensitivity across crops. This reflects both natural relationships, with crop groups having dissimilar demands for water across the seasons, and human responses, with farmers making choices over the crops they cultivate, taking into account current and expected hydrological conditions;
– additional adverse impacts on production during floods and droughts, reflecting the destructive effects of these events.

Econometric techniques isolate, test for and quantify the various aspects of these hypothesised relationships. However, the analysis was constrained by the quantity of the input data, which limited the number of explanatory factors that could be controlled for, and in particular limited the use of hydrological data to monthly observations of rainfall and annual indices of flood and drought. Annex D provides a more detailed exposition and justification of the methodology.

Table 1 below lists the principal hypotheses that were tested and reports whether the dataset supported them. Section 3.3 below expands upon each of these results.

Table 1. **Observed relationships between hydrological conditions and crop output largely conform to expectations**

Hypothesis: Water availability impacts…	Intuition	Supported?
1. depend on the season	crops use water differently throughout the year; water constraints differ through the year	✓
2. differ by crop	impacts of water vary by crop	✓
3. change in extreme events	floods and droughts alter the relationship between water availability and economic performance	✓
4. vary with region	the marginal value of water differs by region	✗

Source: *Vivid Economics*

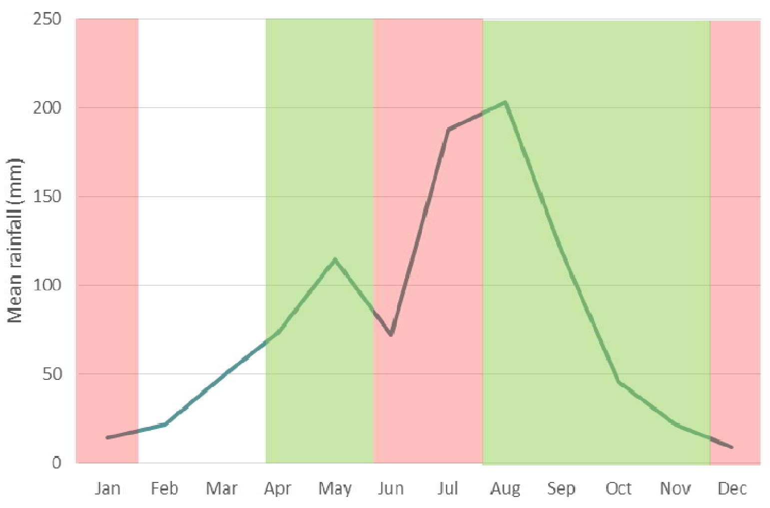
3.3 Econometric results

This section discusses each of the hypotheses in Table 1 in turn.

Water availability benefits crops during two critical periods, but can reduce output otherwise. Rainfall in the basin typically follows a bimodal pattern through the year, with an early, short rainy season in April and May, followed by a longer rainy period between July and October. Crops benefit from rainfall during their growing season, but precipitation during planting or harvest may harm yields.

Analysis indicates that additional precipitation has a positive impact during the first rainy season, and an even larger positive impact during the latter part of the longer rains. Additional water during these two positive critical periods increases crop output, while it otherwise has no impact or is negative. Increases in rainfall during July seems to be particularly detrimental to production, which we interpret as a reflection of July rainfall being associated with particularly adverse flood events.[5] See Figure 6 below.

Figure 6. **The marginal value of water varies substantially by season**



Note: *Red bands denote periods of negative and statistically significant impacts of additional rainfall, while green bands denote periods of positive and statistically significant impacts*

Source: *Vivid Economics hydrological and macroeconomic dataset*

Seasonal effects of rainfall differ by crop. The seasonal effects illustrated in Figure 6 differ substantially by crop, as Table 2 shows. Many crops are affected by water constraints during October and November, but

[5] We interpret adverse impacts from additional rainfall in July as being indicative of particularly adverse flooding for two reasons. First, the flood indicator variables used in the econometric estimation are *relative* to typical monthly rainfall (see the discussion in Annex B). This implies that floods in July are adverse in *absolute* terms, and that the econometric specification does not control for this. Second, auxiliary analysis controlling for land cultivation decisions shows strong collinearity between cultivation decisions and monthly rainfall observations for all months except July. This suggests July is a month in which cultivation decisions are fixed and in which unexpectedly high rainfall through flooding can therefore be more damaging.

this is not uniform to all crops. As expected, the months in which additional water has the greatest positive effect on crop production are similar to the periods of peak water demand for irrigated crops reported by FAO (Tiruneh et al., 2013).

Table 2. **Different crops benefit from greater water availability in different months of the year, in line with their growing season**

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cereals					✓					✓	✓	
Roots										✓		
Pulses							✓					
Chat	×						×			✓		
Oilseeds					✓					✓	✓	
Vegetables	✓				✓	✓						

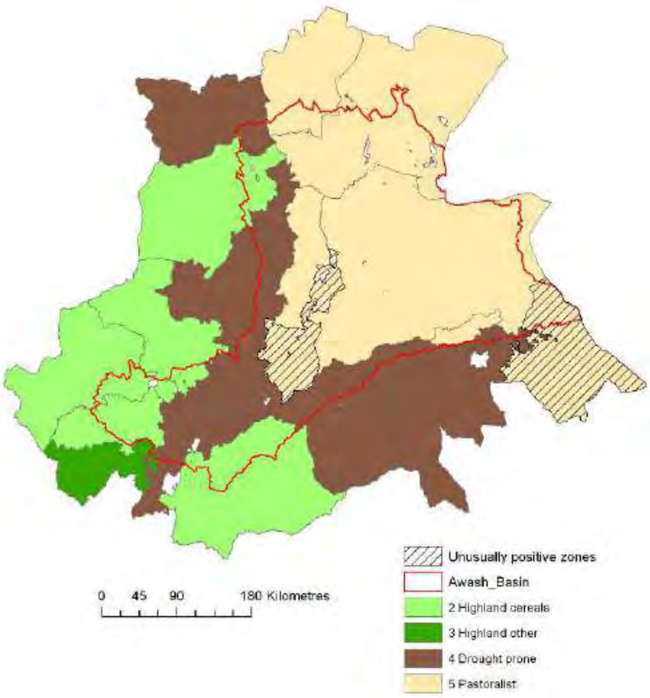
Note: *Green ticks denote a positive and significant relationship between rainfall and output, suggesting that output is constrained by water availability. Red crosses mark months in which the relationship is negative and significant.*

Source: *Vivid Economics*

Some crops are particularly sensitive to floods and droughts. Floods are short term events that cause crop loss in the affected area, while droughts can accumulate over time and cause crop reduction in the affected area. Annex B discusses the indices used to identify flood and drought events in the data. It appears that cereals, pulses and vegetables appear to be especially sensitive to floods, while oilseeds are the most susceptible to droughts.

We cannot discern geographical differences in the effect of water availability on crop production. We test this in a number of ways, for example allowing for zone specific effects and for effects to depend on agroecology type (see map in Figure 7), but find no significant geographic difference, consistent across crop groups. Given the context set out in Section 2, this is a surprising result. It may indicate that the expectation of significant geographical variation is incorrect, perhaps due to adaptive behaviour by farmers. Alternatively, it may reflect an insufficiently large dataset to identify a difference, if there is one.

Figure 7. **Agroecologies of the Awash basin**



Source: *Vivid Economics,* (Tebekew et al., 2009)

4 Relationship between water and wider economic performance

Considered as a whole, the basin's economy is highly vulnerable to hydrological variability. This section shows how the direct effects presented above tend to compound as they propagate through the economy, and quantifies the hypothetical effect on the basin's economy of five hydro-climatic scenarios. Section 4.1 introduces and motivates the modelling framework and hydro-climatic scenarios we use in these scenarios; Section 4.2 presents the results of the analysis, showing how overall production is affected, and how this breaks down between sectors, regions, and income groups; 4.3 considers how aspects of our methodology shape the interpretation of the results.

4.1 Scenario analysis and Computable General Equilibrium (CGE) modelling

The analysis presented so far illustrates one part of the full economic impact that hydrological variability has on the economy of the Awash basin. In addition to direct economic effects estimated in Sections 3.2 and 3.3, there are also indirect effects defined in Section 3.1. These reflect the impacts on secondary or tertiary sectors of reduced agricultural output: for example, in leading to lower output in food processing sectors, which may in turn have an effect upon food retailers.

Using a Computable General Equilibrium (CGE) model allows us to quantify these wider macroeconomic impacts of hydrological factors. CGE models represent the whole economy as a system of interlinked supply and demand equations, so all markets, sectors, industries and their corresponding interlinkages are modelled together. This allows the many potential indirect effects and feedbacks created throughout the economy from a change in rainfall to be captured. The technical details of how this is done are discussed in Annex F.

The period from 2011 to 2015 covered by Ethiopia's Growth and Transformation Plan (GTP) provides an illustrative basis for comparison. CGE modelling requires a base scenario that can be used as a comparison point. The GTP established ambitious targets for economic growth, implicitly relying on water availability, and it has a number of advantages as a baseline:

- it is covered by the datasets, meaning that the direct impacts estimated using this data can be used as an input; and
- it is recent and familiar to stakeholder audiences, and is relevant to future policy.

We model what might have happened during the GTP period using five climate scenarios spanning a range of possible futures. Table 3 provides a brief description of each scenario, which are discussed and illustrated in detail in Annex E. Though Ethiopia's future climate is uncertain, and though these scenarios are not exhaustive, they were chosen to be representative of the different types of near term futures that climate models predict.

Table 3. **Climate scenario descriptions**

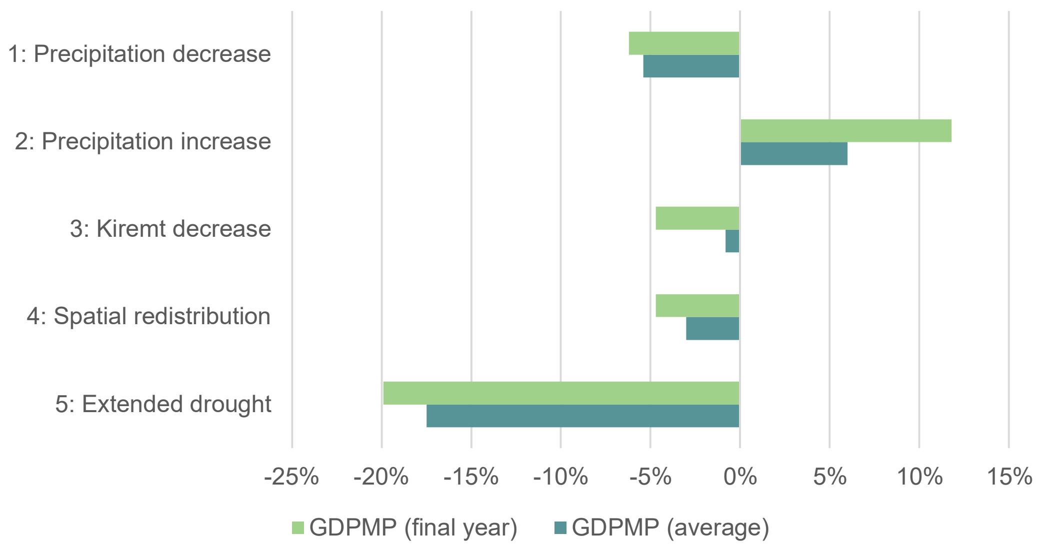
	Scenario	Description
1.	Precipitation decrease	a modest decrease in precipitation throughout the basin, relatively evenly distributed throughout the year
2.	Precipitation increase	a modest increase in precipitation throughout the basin, relatively evenly distributed throughout the year
3.	Kiremt decrease	a five per cent decrease in rainfall during the rainy season
4.	Spatial redistribution	a modest decrease in precipitation in the upper river basin, accompanied by an increase in precipitation in the lower basin to the east
5.	Extended drought	an extended version of the ongoing 2015-2016 drought. This uses current rainfall estimates, appended to estimates from 2002-2004, which was also a dry period.

Source: *Vivid Economics*

4.2 Results

Climate change poses a substantial threat to the economy of the Awash basin. Figure 8 outlines the impacts that the various scenarios have upon macroeconomic outcomes, showing the average annual decrease in production and the fall in final year GDP in the basin. All scenarios entail substantial decreases in GDP relative to the baseline with the exception of Scenario 2, where there is a moderate, uniform increase in precipitation. A more detailed discussion of how these results were derived can be found in Annex F.

Figure 8. **Macroeconomic impacts of five climate scenarios, deviation from GTP**



Source: *Vivid Economics*

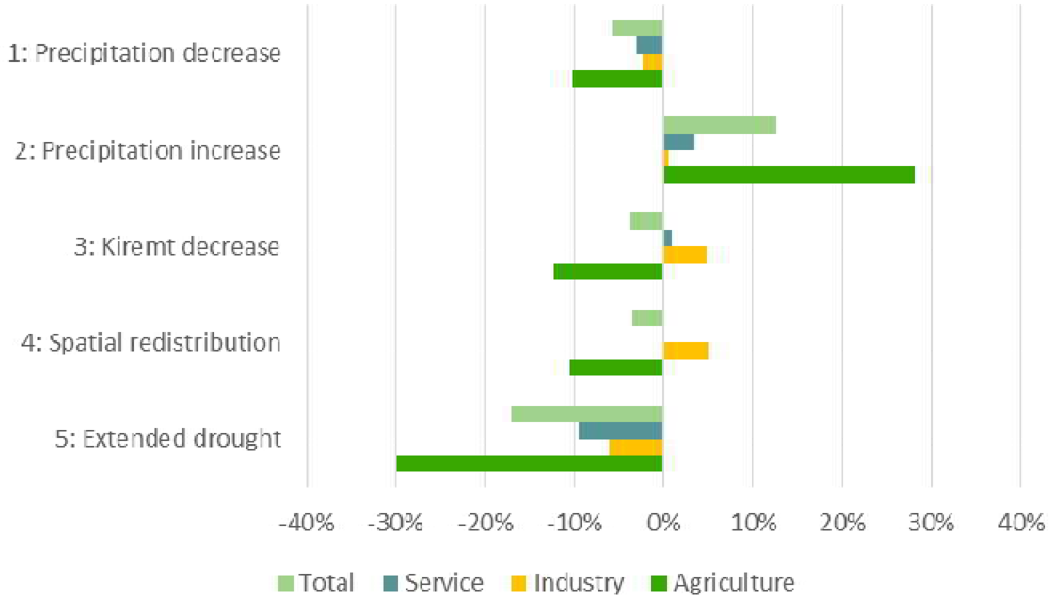
The drier scenarios illustrate the costs of failing to manage water well. Scenarios 1, 3, and 5 each represent a projection of a drier future in the basin, and all of them resulted in a substantial decrease in Ethiopia's GDP, a gap that widens over the course of the five year scenario.

The Awash basin is sensitive to spatial changes in rainfall patterns. Despite the finding that increases in water availability have similar *relative* impacts on crop production across zones in the basin, Scenario 4 results in a GDP loss, reflecting the greater *absolute* levels of production in upland areas. This shows the Awash economy's dependence on the output from the western highlands, because the increased water availability in the east is more than offset by losses associated with drying in the west.

The wetter scenario demonstrates the potential benefits of effective water management. Scenario 2 represents the lifting of a binding water constraint. Under an improved water management regime, the Awash basin could realise this improvement in growth even without the increased precipitation.

Impacts are concentrated in the agricultural sector, but services and manufacturing performance are also affected. Figure 9 displays the impacts on GDPMP by sector. It shows that, unsurprisingly, the impacts on agriculture are by far the largest in all five scenarios, but also that the service and manufacturing sectors are affected, sometimes substantially, by the indirect effects of the rainfall shocks propagating through the economy. Where there are offsetting impacts in manufacturing and service sectors, this reflects common inputs such as energy and raw materials being substituted between agriculture and other parts of the economy in response to shifts in productivity.

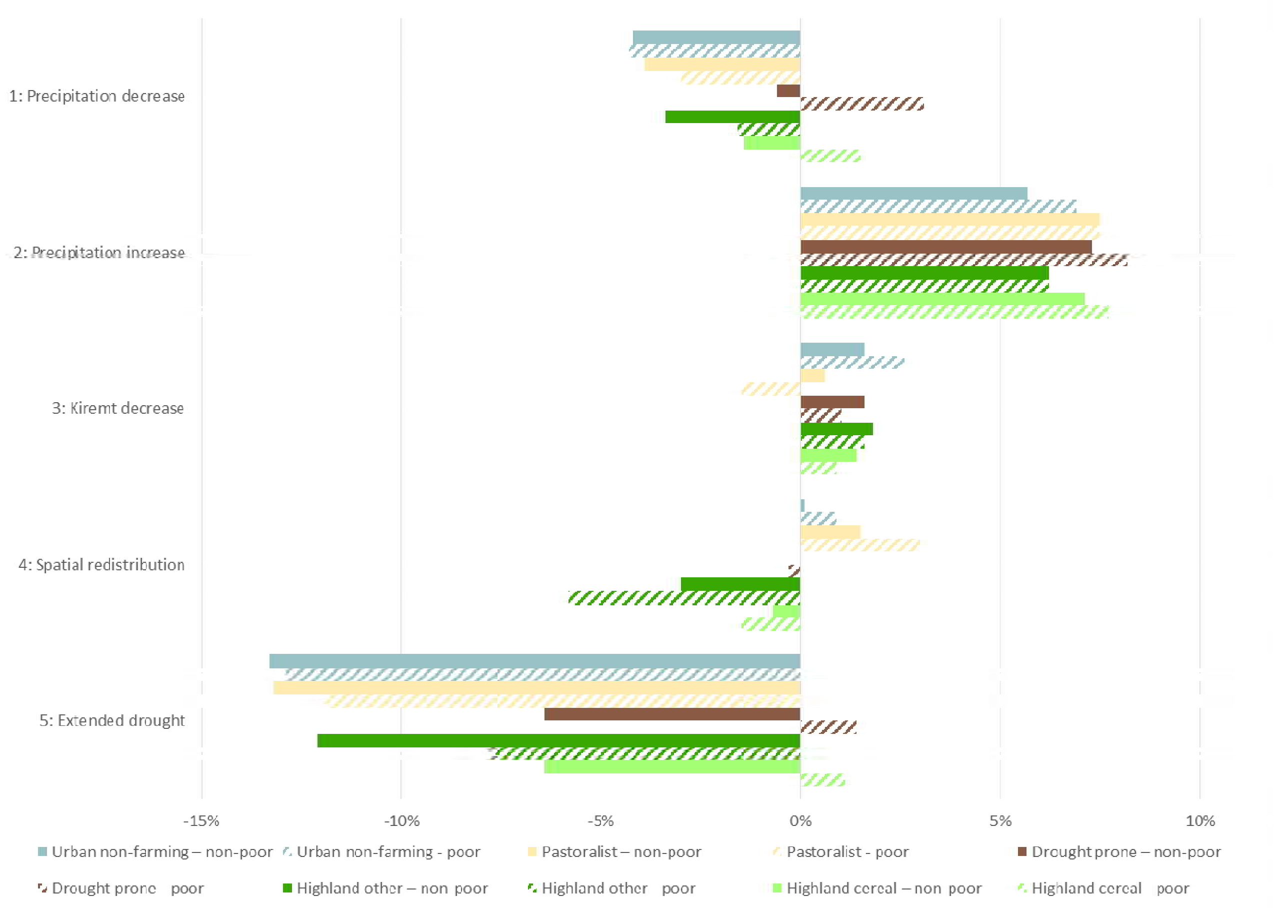
Figure 9. **Indirect effects tend to compound impacts on agricultural production**



Source: *Vivid Economics*

CGE modelling can examine the distributional effects of the five scenarios. Figure 7 above shows a map of agroecology classification by zone in the Awash basin, which when combined with the results shown in Figure 10, shows where gains and losses in household income are expected. The figure also distinguishes between the poor and the non-poor, allowing the analysis of distributional effects between socioeconomic groups.

Figure 10. **Five year cumulative impacts on household income for climate scenarios, deviation from GTP**



Notes: *Poor and non-poor categories are established based on their annual income according to the absolute poverty lines for 2009 and 2010, which is approximately 2590 birr per year. Scenario 3 reports increases in household income in the context of falling GDP due to movements in other parts of the economy.*

Source: *Vivid Economics*

The western highlands are most at risk in these climate scenarios. Substantial annualised losses are realised by most regions in the drying scenarios, but the highland areas, where there is the biggest concentration of people and productive agricultural land, suffer the most under adverse scenarios. The areas reliant on cereals, which are less drought sensitive than other crops, are not hit as hard as those relying on enset or other crops for their primary production. The drought prone regions appear to suffer least, perhaps because they are already better adapted to cope with extended dry periods.

Non-poor households tend to fare worse than poor households. This is due to the difference in crop mix in both production and consumption between the two classes of household. Poor households tend to be relatively more reliant on both the production and consumption of inexpensive cereals, which are more resilient to changing water availability than more expensive, water intensive products such as vegetables or meats that make up a bigger portion of non-poor income and consumption.

4.3 Interpretation

The impacts presents in Section 4.2 represent conservative estimates: on the basin's current trajectory, we would expect future impacts of these climate scenarios to be more dramatic.[6] The estimates are conservative for the following main reasons.

The economic scenarios are backward looking. The figures employ GTP I as a baseline. However, as already noted, the basin's economy is growing rapidly in a manner that does not efficiently conserve water resources. Water scarcity is therefore expected to become increasingly problematic in the future and the economic harms associated with hydrological factors in coming years to become more acute. Unless water management policies are reformed, expect the future economic impacts of the hydrological scenarios to be significantly more adverse than the results presented in Section 4 suggest.

Not all of the economic effects of water scarcity and extreme events are valued. The analytical work focuses on the immediate direct and indirect impacts on production resulting from fluctuations in water availability and extreme events. This means we do not consider the following two major ways in which hydrological factors may shape economic outcomes in the basin:

- Investment. Uncertainty over water availability and the risk of floods or droughts lowers the return on investment and therefore reduces long term GDP.
- Production of non-market goods, that is, goods which are not transacted on markets and that do not therefore appear in many economic statistics**.** Increased water availability may contribute to the production of such goods in various ways. For instance, access to more reliable public water supplies may yield benefits to public health and increased leisure time for users who would otherwise travel to collect water supplies, and greater water resources may better sustain ecosystems, improving biodiversity and other environmental goods.

The climate change scenarios are conservative, with the exception of Scenario 5. Many climate projections predict more extreme weather patterns in the area, so that both floods and droughts are expected to increase in frequency.

[6] On the other hand, the fact that the CGE model does not allow for adaptive responses by producers is a reason why it may overstate negative impacts.

CGE models do not fully account for the costs associated with increased volatility. There is a considerable human cost to rapid adjustment and the impacts associated with these climate scenarios fluctuate substantially from year to year (see Annex E). The CGE model has to assume that individuals can not only rapidly understand change and respond, but also that they have the financial capacity to do so. In practice, we would expect scenarios such as those we present to feature some transitional unemployment and production losses as workers and firms struggle to adjust to changing circumstances.

Various technical assumptions in our methodology err towards conservatism for a variety of reasons:

- We do not model the effects of a drought beyond reduced rainfall. The data does not include any economic information from widespread droughts, such as the one that the country is currently afflicted by, so we were not able to accurately estimate the additional detrimental impact on crops beyond the common decrease in rainfall. This is therefore not this included in the prediction. Losses would be even more extreme if droughts could be fully accounted for.
- We restricted the effects to be no larger than those observed in the last ten years in order to ensure that we were not overstating the predictive power of the limited data. This necessarily reduces the magnitude of the impacts, compared to extrapolating observed relationships beyond the historical record, especially given that the period covered by the data was one of relative prosperity and stability in the basin.
- For reasons we explain in Annexes D and E, we regard the econometric specifications we use to estimate the direct productivity impacts as conservative.

Furthermore, the finding that poor households' incomes are less sensitive to hydrological factors than nonpoor households may not signify reduced vulnerability. Again, there are a number of reasons for this:

- As well as having lower incomes, poor households have less wealth than nonpoor households, so they are less able to smooth out the effects of income fluctuations in order to meet their basic needs;
- Poor households may be more reliant on non-market goods that are sensitive to water availability, such as domestic labour to collect water from more distant watercourses; and
- By not accounting for the effect of droughts on livestock herd size, the modelling work omits a major channel through which the poor can be adversely affected by hydrological variability (see Mosello et al., 2015).

5 Implications for water resource management policy

The findings of this study have a number of important implications for water resource management policy in the Awash basin. This final section outlines these and suggests a variety of avenues of potentially fruitful further research.

The value of water, and hence of water management projects, is very high in the basin and is set to increase steeply in coming years. Despite the basin's abundance of water resources, the scenario analysis of Section 4 highlights extremely large potential economic costs of reduced availability of water and very substantial benefits from alleviating current localised scarcity. These impacts are of the order of 5 – 20 per cent of the basin's GDP. Further economic growth will increase the gains from reducing this vulnerability, especially if management policies do not control groundwater use and the effect of pollution on water quality, and may also raise the basin's vulnerability to extreme events.[7] All of this means that the benefits of interventions that more efficiently manage hydrological vulnerabilities will be substantial in coming years.

Policies to improve the management of scarce water resources in the Awash basin therefore deserve a very high priority in Ethiopia's development plans. The impacts quoted above are indicative of the value that could be derived from initiatives to better manage water resources. Not only do they highlight the value of *more* investment to reduce hydrological vulnerability, but they also underline how better decisions on *how to invest* could yield very substantial gains. Improved decision making is relevant both to water-specific initiatives and to programmes in adjacent areas, such as energy and agriculture. The results of this study show the economic gains from recognising water impacts and adapting planning decisions accordingly could be very substantial in all areas of the economy.

Our results strongly support current efforts to build resource-management capacity. Efforts led by the AwBA are underway to improve water resource management in the basin, including through better data collection, assessments of groundwater sustainability, more granular forecasting of supply-demand balances and developing tariff and permitting schemes for water abstraction and wastewater discharges (Authority, 2014). All of these will improve the authority's ability to make investment and allocation decisions, and thus contribute substantially to improving the basin's economic resilience. As Mosello et al. (2015) point out, building sufficient capacity to implement efficient water resource management policies will take time: given the increasing economic importance of water in the basin, it is thus imperative that capacity building continues to proceed rapidly.

Quantitative information on the economic value of water should be used to assist water resource management decisions. Such information allows policy-makers to trade of the costs and benefits of different allocation and investment strategies. This study shows that the economic stakes in making these

[7] Though catchment management initiatives planned under the GTPII and led by MEFCC may also alleviate this vulnerability.

trade-offs are high, and thus that better information on the true value of water is itself of considerable value. Our results provide such information, though at the impacts are for indicative scenarios and reflect only those economic impacts that are mediated through agricultural production. Further quantitative information on issues such as the costs of drought and the benefits of access to public water supply systems could complement the findings of this study.

The value of flexibility in water management strategies is very substantial. This study exposes a wide range of economic outcomes associated with different hydro-climate scenarios, a range that is widened by inevitable uncertainty over the future trajectory of the basin's economic development. This means that, while the future value of water is expected to be very large, it is also highly uncertain. One way of responding to uncertainty is through adaptive water management strategies, where management decisions respond flexibly to emerging information on the value of water. See Mosello et al., (2015) for a discussion of how this could be implemented in Ethiopia.

Agricultural vulnerability should be addressed through a combination of infrastructure and allocation policies. The scenarios show how direct impacts on agriculture from hydrological variation can have very substantial effects on the wider economy of the Awash basin. Investment in infrastructure such as storage and more efficient irrigation could therefore substantially improve the basin's long-term economic performance. However, the results also show the potential benefits from policies that allocate water to the users who value it most. These may include permits for withdrawals or discharges, or metered abstraction tariffs. Though such policies can be unpopular with users when introduced and require authorities to establish and operate monitoring and enforcement systems, they also have two critical advantages over infrastructure spending, in that they do not entail significant capital outlays, and that they can be used to incentivise more efficient investment in agricultural production.

Further research in a number of areas could usefully build on or complement this study. Notable topics include:

- collecting more economic and hydrological data. As discussed in Annexes B and C, this study faced substantive data constraints on a number of fronts, and the following data would have been particularly useful: livestock production; services output; more granular economic statistics by woreda or kebele; more complete and accurate metered hydrological data; information on water use by sector; information on groundwater supply and demand; environmental demand for water.
- work to quantify the economic value of water in areas not covered by this study. Information that might be particularly useful to resource planners include: the effect of hydrological variation on investment and the production of non-market goods; the economic impact of drought; the economic value of connection to public water or wastewater systems; the economic value of improved water quality.
- an economic evaluation of the institutional framework governing water management and investment in the basin. This is discussed briefly in Annex A.
- work to develop the indicative impacts presented in Section 4 into forward-looking estimates of the expected value of water; and
- parallel exercises to this one at a national level, or focusing on other natural resources or dimensions of climatic variability.

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