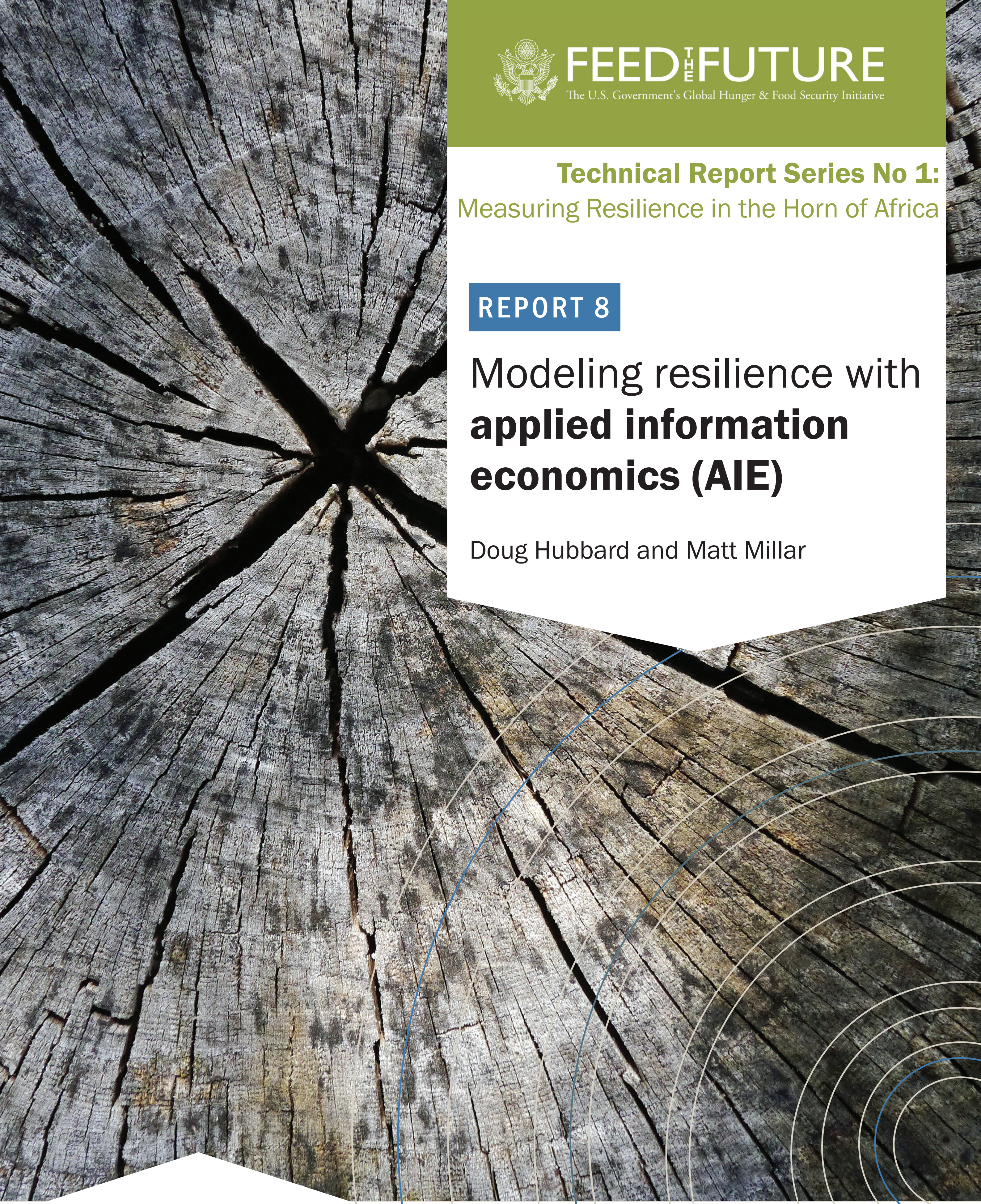

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**Technical Report Series No 1:**
Measuring Resilience in the Horn of Africa

REPORT 8

# Modeling resilience with **applied information economics (AIE)**

Doug Hubbard and Matt Millar

technical consortium
Building Resilience in the Horn of Africa
CGIAR

ILRI
INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

Hubbard Decision Research

USAID
FROM THE AMERICAN PEOPLE

**Authors:** Doug Hubbard[a] and Matt Millar[a]

**Edited by:** Katie Downie[b]

*[a] Hubbard Decision Research; [b] Technical Consortium*

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This report is prepared by experts for the Technical Consortium for Building Resilience in the Horn of Africa. For more information on the Technical Consortium contact Dr. Katie Downie - k.downie@cgiar.org.

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# Executive summary

We created a probabilistic decision analysis tool to model the issue of resilience in the Horn of Africa through a cooperative effort between the Technical Consortium for Building Resilience in the Horn of Africa (TC) and Hubbard Decision Research (HDR). The work was carried out under the guidance of Katie Downie from the International Livestock Research Institute (ILRI). The objective was to provide a modeling framework to provide guidance for what should be measured to best support future decisions related to household and community resilience in the Horn of Africa. The quantitative methods used are supported by published research showing how these methods provide a measurable improvement on expert decisions done without the aid of such models.

The process we use for improving decision quality is based on a probabilistic risk return analysis called Applied Information Economics, which uses Monte Carlo simulations to produce a distribution of potential outcomes. This method allows the potential stakeholder to consider uncertainty explicitly and to calculate the risk of a negative outcome or loss. Another primary output of an Applied Information Economics model is the calculation of the economic value of information for each uncertain variable. By collecting information values for interventions related to resilience, we can identify priorities for research and data collection related to investments in promoting resilience.

Preparations for the project were started in June 2013, followed by a July workshop in Nairobi. The workshop included training on the AIE method including "calibrating" all workshop attendees. From the workshop we also selected a core group to work on the pilot resilience model. The group met (remotely) ten times between September and January, 2014 – two meetings to define the decision and pick the pilot project, six meetings for modeling and estimation, and two meetings for reviewing results of the model and discussing recommendations.

This report contains a summary of our effort, gives an overview of the pilot project, and presents modeling results. We conclude with specific recommendation of next steps for reducing uncertainty on the project in question, as well as suggested course of action based on our findings.

## Summary of Key Observations

- At the July workshop in Nairobi, there was an initial struggle with the concept of measuring resilience. There were competing definitions and the group was reluctant to define resilience without government stakeholders present. Since a definition was crucial to progress, the core group eventually accepted an interim definition of having a minimum number of calories available to each household in a region. If a household did not meet this threshold in a given year, they are considered food insecure for that year, which in turn indicated lower resilience. The true test of resilience in the Horn of Africa comes during droughts when food security becomes much more difficult to procure – thus a population may have high levels of food

[1] Alinovi, D'Errico, Mane, Romano. 2010. Livelihoods strategies and household resilience to food insecurity: an empirical analysis to Kenya. European Report on Development.

security in a good year but could still have a low level of resilience. Many factors play into food security both during droughts and during good years and these have been identified previously.[1] Measuring resilience, for this study, is simply a matter of measuring total levels of food security over a long enough time frame and over all households in a region.

- One of the key steps in the Applied Information Process when approached with a measurement problem is asking the question "why do you want to measure it?" The answer to this question can be quite revealing. In this case, the answer could have been "we want to measure resilience because we want to increase the level of it." Or it could be "we want to measure the level of resilience, but ultimately measure the importance of resilience to stakeholders and the aid community relative to competing outcomes." In the continuing effort to measure resilience, being clear on the outcome will continue to be important.

- The group settled on using an irrigation project to measure levels of uncertainty on variables related to resilience. When we first mentioned an irrigation project as an intervention to improve resilience, many of the workshop participants articulated a belief that irrigation projects do not improve resilience, or rarely do so. Interestingly, the project we modeled (Galana Ranch) had an average positive outcome – even considering all aspects of resilience and potential negative externalities associated with an irrigation project in the Kenyan drylands. This suggests several possibilities (which are not mutually exclusive):
  a. This irrigation project is an especially promising example
  b. Irrigation projects have both positive and negative effects on resilience
  c. The benefits of irrigation projects that are unrelated to resilience outweigh costs related to resilience

- The two variables with the largest information values were related to the profit margin of irrigated crops, rather than a variable more directly related to resilience (there were also three variables related to the concept of resilience with significant information values). The fact that the largest information values were found in variables that lay outside the resilience focus fits with previous investigations. It is an encouraging sign that stakeholder officials are independently planning a 10,000 acre test farm for the project.

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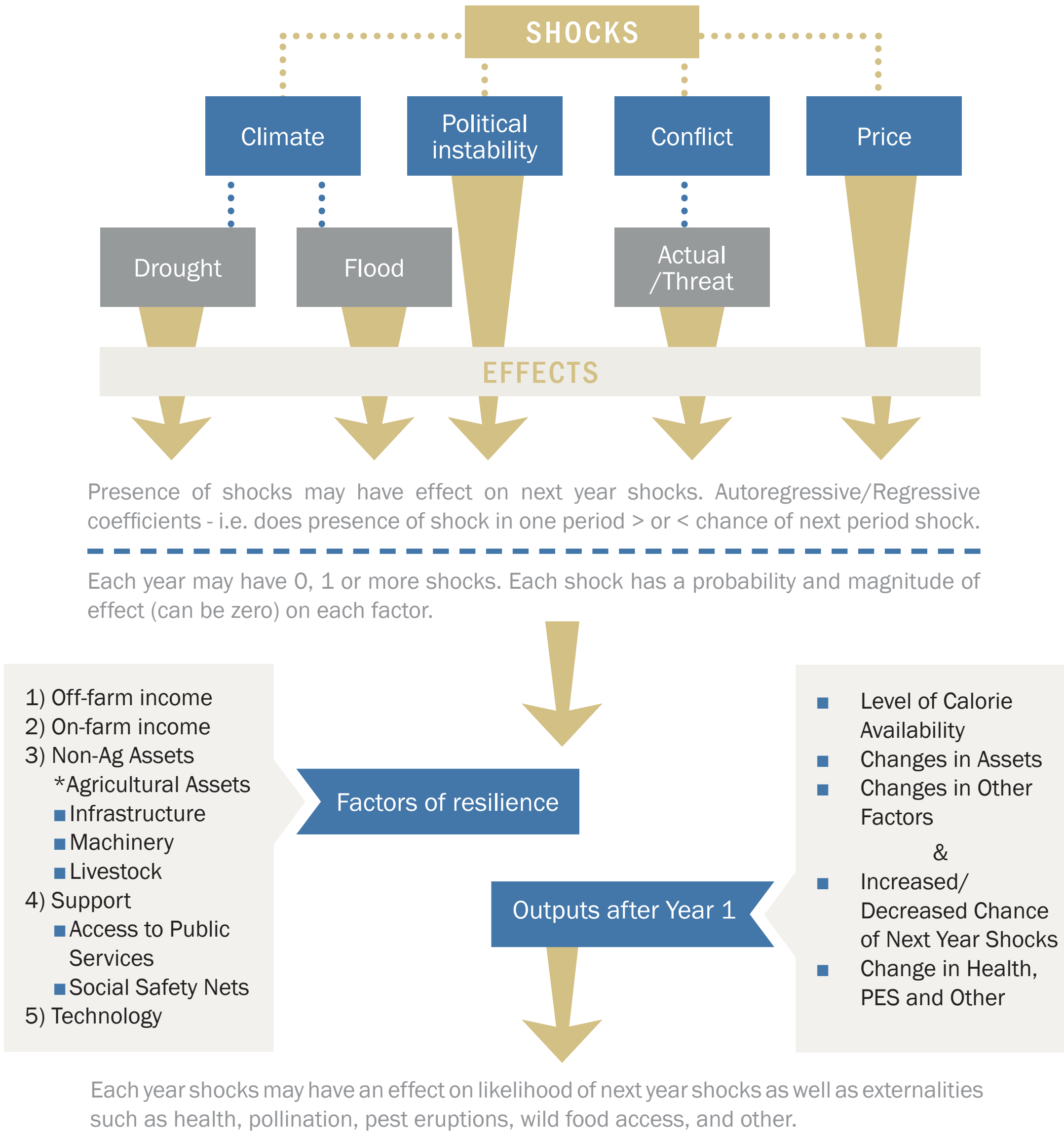
# **Background** and concepts

## The Challenge

The issue of measuring resilience in the Horn of Africa has proved to be a tricky subject. Part of this is due to disagreement over the definition of resilience. Without an agreement on the definition of resilience it proves difficult to measure or improve. However, there seem to be incontrovertible aspects to resilience with which nearly everyone agrees. One of these aspects is the concept of food security. Since this concept is easily defined in observable terms, it was a natural fit for our process.



Strictly speaking it is practically impossible for something to have importance if there are no observable consequences. Thus, it is unlikely that there are aspects to resilience that are important if they have no observable consequences. Most of the disagreement on the definition seems to stem from the fact that the true state of resilience of a population may not be known until a drought or other shock occurs. However, this simply means we need to model over a long enough time frame and estimate how different factors will contribute during a drought to simulate resilience over a variety of conditions.

## Household Level vs Community Level Resilience

Embedded within this issue is also the decision whether to model the effects of an intervention on an individual household or on a community. An irrigation project could have catastrophic consequences for an individual household and yet increase the resilience in a community or a nation. This is also an important distinction when building a model – whether to model effects on many different individual households with different characteristics or to model the aggregate effect on food availability, income, health, and other factors.

Our solution was to create a model both for the individual household and for the aggregate effects of the intervention. For the Galana Ranch model, the individual section is only used to simulate how a single pastoralist household would fare given no irrigation project were to occur. These results then represent a cost to the extent that pastoralist households are displaced as a result of the intervention. Other models could be based on only the individual household level (for example by comparing how a selection of households fared after a given intervention); this might produce other interesting results on what uncertainty reductions were of highest value.

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# Description of the **process**

## Major Project Phases

For this project, there were five major tasks as follows (See Appendix A for detailed task list):

1. Decision Clarification Workshops: This critical first step was particularly challenging because we first had to work through the definition of resilience and how that was related to investment decisions. In the end we decided to model a large irrigation project with special attention to variables related to resilience.

2. Calibrated Probability Training Workshop: This half-day workshop was held on site in Nairobi and all the participants were trained to assess uncertainties in a quantitative manner. 84% of participants were successfully "calibrated" at the end of the workshop so that estimates they gave could be expressed probabilistically. See Appendix D for more details on Calibration.

3. Detailed Decision Modeling Workshop(s): This work was completed remotely after we had decided on the Galana Ranch food security project. For this task, we built the detailed decision model, including both the household and aggregate level parts of the model. Every variable in the model was estimated by the "calibrated estimators."

4. Risk/Return Analysis and Preparation of Deliverables: This takes the input of all previous steps to produce a quantitatively sound and complete analysis of the proposed investment.

5. Value of Information Analysis (VIA): This step computed the economic value of measuring each of the uncertain variables. The team gained insight regarding which variables to measure in more detail and how much measurement effort is required and justified.

## Deliverables

The deliverables for this project included:

1. A detailed spreadsheet model which uses probabilistic methods to assess the decision

2. A "value of information" (VIA) analysis showing the economic benefit of measuring each uncertain variable in the investment so that effort can be spent measuring the right things

3. A risk/return analysis of the proposed investment including a “probability distribution” of the possible returns for the project or investment and how the investment compares to the risk tolerance of the organization

4. Recommendations on what to measure to reduce uncertainty and risk in the intervention

5. A summary presentation of the findings

## Modeling Workshops

The modeling workshops begin by defining the specific decision that the group chooses to analyze. Arguably the most important (and often the most difficult) step is specifying what decision is actually being evaluated. As with other CGIAR groups, this step proved the most challenging as participants were initially reluctant to volunteer and settle on a specific intervention to model.

Uncertainty in the model is assessed using a Monte Carlo simulation. This is a way of computing the uncertainty of a system or outcome given the uncertainty of the inputs to the model. A Monte Carlo simulation method is used for multiple reasons. First, there is evidence that those using Monte Carlo simulations are better at forecasting than those who do not.[2,3] Second, these decisions have significant risks and uncertainties and there is conclusive evidence that left to their own intuition, even quantitatively sophisticated decision makers will introduce several types of inference errors when it comes to the use of probabilities to describe uncertainty and risk.[4] A Monte Carlo simulation will make the mathematics of these inferences explicit and avoid several types of inference errors. Finally, Monte Carlo simulations are often the only mathematical solution that can assess a large number of uncertain variables in complex relationships.

The HDR Monte Carlo spreadsheet tool consists of an “Inputs” tab that summarizes all of the important variables that go into the decision. We divide the variables into sections and each of these sections has both certain (deterministic) and uncertain (probabilistic) elements. We elicit estimations of each unknown variable from (the now calibrated) participants and the estimations include a best estimate and a range which represents a 90% confidence interval or, in some cases, binary probabilities (such as the probability of a project failure or drought in a given year).

The best estimate values of the variables feed into an analysis of costs and benefits over a period of time (in this case 20 years). The range estimates flow into an analogous probabilistic cash flow calculation using the same calculations and logic as the deterministic analysis.

[2] Hubbard, D. 2009. The Failure of Risk Management: Why It’s Broken and How to Fix It, John Wiley & Sons.

[3] Macmillan, F. 2000. “Risk, Uncertainty and Investment Decision-Making in the Upstream Oil and Gas Industry.” PhD diss., University of Aberdeen.

[4] Kahneman, D., Slovic P. and Tversky A. , 1982. Judgement under Uncertainty: Heuristics and Biases, Cambridge: Cambridge University Press.

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# **Pilot Overview:** Galana Ranch Food Security Project

Table 1 summarizes the pilot chosen including the selected decision, a brief description of the project, and the parties involved.

Table 1: Research Group and Project for Investigation

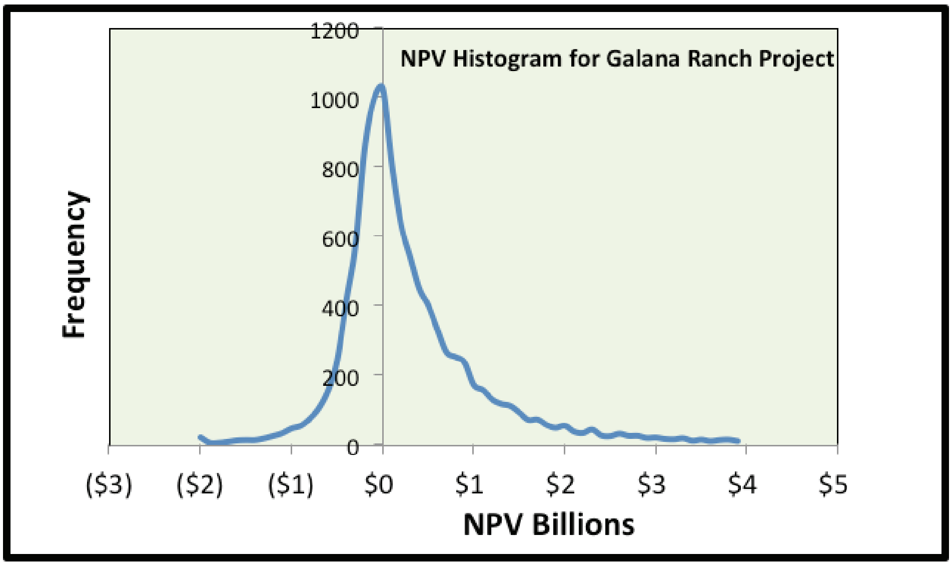
| Focus/Group | Name of Intervention | Core Team | Description of Actual Project |
|---|---|---|---|
| Resilience in the Horn of Africa | Galana Ranch Food Security Project | Dillard, Downie, D'Souza, Luedeling, Millar, Stull-Lane | Large scale irrigation project in the Kenyan drylands; Stakeholder: Kenyan Government |

The Galana Ranch food security project is a proposed irrigation scheme that will affect 1.2 million acres in the drylands of Kenya. The project would aim to enhance national food security through increased productivity of the Galana and Kulalu Ranches through targeted investments on crop, livestock and fisheries production.

The initial costs involved in this proposal include initial set-up costs for the irrigation and water resources infrastructure, land use planning, farm and livestock infrastructure, seed money for stocking and operations (farm development), an environmental and social impact assessment, and investments to offset potential negative externalities to existing and neighboring communities. Ongoing costs would include the annual costs associated with irrigated crops, livestock, and maintenance of the irrigation infrastructure.

Our model projects costs and benefits over a time frame of 20 years; it considers 199 uncertain variables, of which 123 are unique variables. Of this total, only 6 variables are found to have an information value significantly different than zero. Projected results from the Galana Ranch food security project suggest that the average case would be a benefit of $271 million over twenty years; 54% of scenarios had a positive NPV.

Figure 2: Results from 10,000 Monte Carlo simulations on the Net Present Value of the proposed irrigation project on the Galana Ranch




We derived a Net Present Value by defining and estimating relationships between competing goals and outcomes. Although it is not necessary to use money as the common denominator, teams that start with a different common denominator usually come back to using money since it is the common element between many patois. The Net Present Value also necessarily references a particular perspective – since different actors will value different outcomes differently. In this case we are referencing the Net Present Value of the project from the perspective of the Kenyan Government who is the stakeholder in this decision.

Not only does this analysis produce a quantitative picture (Figure 2) of potential investment results, it also delivers another important result: it mathematically derives the value of reducing uncertainty on uncertain variables in the decision making process. Thus, even as we focused on evaluating the merits of this investment, the discovery of information values for the variables in this decision was another primary outcome of the effort.

## Value of Information Findings

The expected value of perfect information (EVPI) represents the economic value of reducing uncertainty on a single variable. Contrary to popular belief, the value of information can be calculated as a dollar value. Although the term "information" is often used in an ambiguous manner, it can also be used as an unambiguous unit of measure with a well-defined value calculation. This mathematical procedure can be paraphrased as follows:

1. Information Reduces Uncertainty
2. Less Uncertainty Improves Decisions
3. Better Decisions Result In More Effective Actions
4. Effective Actions Improve Results or Profit

In Table 2, we list the variables with the highest EVPI for the Galana Ranch Project. It is important to note that the EVPI of a variable or group of variables assumes no other variables are measured. The sum of EVPIs is not necessarily equal to the total expected opportunity loss in an investment. The EVPI of measuring two variables together could be much less or much more than the sum of the individual EVPIs.

Table 2: Variables with highest expected value of perfect information for Galana Ranch Project

| Variable | Estimates | | | EVPI | Threshold | Probability |
|---|---|---|---|---|---|---|
| | LB | BE | UB | | | |
| **Crop Revenue/Cost ratio** | 0.5 | 1.12 | 2.5 | **$130,000,000** | < 1.173 | 37.0% |
| **Crop Costs ($/HA)** | $100 | $316 | $1,000 | **$18,500,000** | < $187 | 22.6% |
| **Potential $ Loss Downstream (livelihoods and ecological)** | $1,000,000 | $6,200,000 | $40,000,000 | **$7,400,000** | > $55,100,000 | 2.7% |
| **Value of preventing a calorie insecure household** | $550 | $7,500 | $150,000 | **$1,250,000** | > $857,000 | 0.38% |
| **Loss of Health** | $10 | $100 | $10,000 | **$64,000** | > $522,000 | 0.021% |

Of the roughly 200 variables in the model, the 5 variables shown in Table 2 have the highest information value. For each variable in the table, we include the lower bound, best estimate, and upper bound estimates given by calibrated participants, the expected value of perfect information (EVPI), the threshold for each variable and the probability the variable takes a value beyond the threshold. The largest EVPI was for the variable “crop revenue/cost ratio” which had a value of perfect information of $130 million dollars. It is rare to encounter information values this high in investment decisions but several determinants contribute to its size:

1. The irrigation project analysis is based on 1.2 million acres over 20 years which means potential costs and benefits per acre have a large multiplier
2. The initial costs alone could add up to over a hundred million dollars
3. Annual costs (considering both direct crop costs and negative externalities) could cost additional hundreds of millions of dollars a year
4. The investment is highly uncertain; in 46% of outcomes the project would represent a net loss (occasionally in the billions of dollars)

Given this additional information, a value of information of $130 million no longer seems so unbelievable. However given how cheap it would be to reduce uncertainty on this variable, it does seem remarkable that we would find such a high value.

## Estimates

As with every other uncertain variable in the model, we collected estimates representing a 90% confidence interval of the participants involved in this project. This means, participants were 90% confident that the range contained or would contain (many of the estimates are referencing future events) the actual answer. As an example, for the variable "crop revenue/crop ratio," participants were 90% confident that the range of 0.5 to 2.5 contained the actual crop revenue to cost ratio. Note that this was considering only the annual recurring costs and revenues associated with growing crops in the relevant region. This range (corresponding to a profit from growing crops of anywhere between a 50% loss to a 150% gain) may seem quite wide to someone unfamiliar with the AIE process, but the participants were estimating their current state of uncertainty, and they had been trained to do so accurately through calibration training. It is common practice to use narrow ranges, but that doesn't necessarily mean they are more useful. A narrow range given by an un-calibrated participant would not allow us to have any assignable confidence in the likelihood it would be correct.

## Threshold and Probability

The "threshold" is simply the value, past which the project flips to being a net loss from a net benefit. The "probability" is the chance that the variable takes such a value given the estimates provided. So if the crop revenue/cost ratio was less than 1.173, then the net outcome of the irrigation project would be negative, and given estimates there is a 37% chance that the true value is below this threshold. For the variable entitled "value of preventing a food insecure household" the threshold is $857,000, meaning that the value of this variable would need to be higher than $857,000 to flip the average outcome from a positive to a negative. The logic of this works as follows:

1. irrigation project displaces a pastoralist household
2. that household then has trouble securing other sources of income or food
3. this household then experiences food insecurity it otherwise would not have
4. this food insecurity is counted as a negative externality of the project

Since there is a major push to increase resilience, we wanted to account for the decrease in resilience this represented (at least for this household). There could be a number of costs, explicit or otherwise, from a household becoming food insecure. Most obviously, there could be explicit costs to the member government or aid community of providing for this household above and beyond normal channels to ensure their food security. In addition, the members of the household are likely at greater risk to disease from stress and lack of nutrition; there may also be an elevated risk of mortality, an elevated risk of disillusionment leading to violence, and other negative externalities. Some of these possibilities are more likely than others, but participants were asked to estimate the aggregate average value of preventing food insecurity for a single household, considering all of these potential factors.

The estimate that the group settled on was a lower bound of $550 and an upper bound of $150,000 with a lognormal distribution. Given these estimates, it would seem exceedingly unlikely that the true value of preventing a food insecure household to the Kenyan government would exceed $857,000; indeed, this intuition is verified by the probability of exceeding this threshold – a mere 0.38%. In spite of this small probability however, note there is still a large value in reducing uncertainty further on this variable.

## The Measurement Inversion

It is also noteworthy that of all the variables in the model, the value of preventing food insecurity is the variable most closely related to the concept of resilience. We might therefore expect a model meant to focus on resilience would find this variable to have the highest information value. Instead, the value of reducing uncertainty on this variable is less than 1% of the value of reducing uncertainty on the level of profit derived from irrigated crop land. This is an interesting result and could be seen as disappointing. Nevertheless, it fits into a general observation we have found with all CGIAR projects and across a variety of other government and industry investment decisions. The stated focus of a group is usually not the variable most in need of uncertainty reduction.

Comparing the value of information results with the information values from other CGIAR projects shows there are some important similarities. In the construction of the Global Intervention Decision Model we identified six potential gaps in current measurement efforts (Appendix C): market prices, project failure risks, negative consequences, adoption rates, detailed household demographics, and land properties.

The two highest value variables in the Galana Ranch Project (crop costs and crop revenue/cost ratio) fall into the first category of market prices[5]. All of the remaining variables fit into the category of negative consequences: negative downstream effects, health costs, and costs associated with increasing food insecurity for pastoralists are all examples of how a project might actually have an overall detrimental effect with a loss much greater than merely losing the invested resources. Additionally, the highest information value variable (the possibility of a negative profit on irrigated crops) falls into this category as well; after all if growing irrigated crops is a losing proposition, then losses will likely extend beyond the initial investment.

[5] Crop costs and revenues aren't precisely market prices but are made up of other variables that are market prices such as input costs for growing irrigated crops, and average yields and prices for the finished crops in the region of the pilot project

# Recommended **next steps**

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The most urgent recommendation is to carry out the next step in the Applied Information Economics process, namely to make measurements on the variables where there is an economic justification for doing so. Involving stakeholders is also a critical next step – the values we are measuring are representative for the stakeholder who is making the investment and who will reap the benefits or losses associated with the project.

## Reduce uncertainty

Now that information values have been computed for an initial pilot project, decomposition and measurements should begin. The best approach will be small, incremental measurements prioritized by their EVPIs.

### 1. Crop Revenue/Cost Ratio, EVPI $130,000,000:

- Decompose variable; this is a case where decomposing into individual crops may significantly reduce uncertainty and is a very low cost strategy
- Substitute a profit per hectare instead of a crop revenue/cost ratio
- Estimate profit per hectare for maize, sugar, and horticulture separately
- Given the size of the information variable, a small sample of average profit levels over 20 years in a comparable environment would be justified for each major crop or crop type.
- It is encouraging that the stakeholders involved in the Galana Ranch project have planned a 10,000 acre pilot farm on part of the property to measure outcomes using the proposed technologies and crops. It could be that a quicker and less expensive method would reduce uncertainty sufficiently.

### 2. Crop Costs ($/HA), EVPI $18,500,000:

- If the recommendations above are taken, the crop cost variable will be replaced. We recommend replacing crop costs and profit ratio for an aggregate crop variable with profit per hectare variables for individual crops

### 3. Potential Loss Downstream (livelihoods and ecological), EVPI $6,200,000:

- Decompose downstream ecological and livelihood loss. Again, we don't need to make measurements until we have better separated out the components of this variable:
- Estimate downstream livelihood types for downstream populations of each livelihood type
- Estimate chance of livelihood disruption and opportunity cost for each livelihood type if disrupted
- Estimate ecological losses separately

### 4. Value of Preventing Food Insecure Household, EVPI $1,250,000:

- Refine definition of variable and conduct small sample of stakeholders

- Better define the levels and effects of food insecurity. Would different aid organizations and countries provide identical definitions and effects of a "food insecure household"? If not, create more specific variable(s) with observable qualities and outcomes.
- Conduct a small sample of aid workers and members of stakeholder governments to determine the value of preventing food insecurity, once it is clearly defined.

## Involve Stakeholders in the Process

An obvious shortcoming of this effort was the lack of presence from the stakeholder. Whether the effort to use the Applied Information Economics process is to help measure resilience in the Horn of Africa or to help prioritize research topics, projects, and groups in CGIAR, involving stakeholder governments and aid organizations is a natural next step for two reasons.

1. The information values necessarily reference the entity making the investment – stakeholders are actually the group that stands to benefit most directly from these analyses.

2. Collaboration with stakeholders may dramatically change the results and what is found to have the highest information value. There may be a complementary knowledge base in the stakeholder community that can immediately begin to inform the metrics effort on the CGIAR side. Stakeholders could also be an aid in carrying out the measurement step of the AIE process as they have both a more direct financial resource and incentive to do so.

## Combine Efforts with Other CGIAR Analyses

Identify ways that rule of thumb estimates can be applied for variables like crop profit levels. It may be that differences between projects and regions could be exaggerated and that the uncertainty can be dramatically reduced with a couple of inputs such as annual rainfall and average travel distance to market.

# Appendix A
## Project Task Detail

| Approximate Relative Effort | Phase | |
|---|---|---|
| As % of All Phases | As % of Phase | Task |
| 20% | | Conduct the Initial Assessment of the Current Environment |
| | 50% | Initial Research and Scope: Understand the background and begin work to understand the decision problem. |
| | 30% | Assess Existing Data: Determine the extent of existing historical data. |
| | 20% | Identify Resources and Define Responsibilities: Typical stakeholders and their objectives will be identified. Roles and responsibilities of individuals will be defined. |
| 40% | | Define Decision and Model the Current State of Uncertainty |
| | 25% | Decision Problem Definition: In the first workshop, the experts identify what specific problem they are trying to analyze. List what variables play a role in determining resiliency. |
| | 25% | Complete Necessary Training: Introduce the group to the principles of Applied Information Economics (AIE) and conduct calibration training. |
| | 25% | Decision Model Detail: By the second workshop, using an Excel spreadsheet, we list all of the factors that matter in the decision being analyzed and begin to define how they relate. |
| | 25% | Initial Calibrated Estimates: Obtain estimates from the calibrated experts for the variables in the decision model. These values are not fixed points (unless values are known exactly), rather they are calibrated expert range estimates. All quantities are expressed as a range representing the experts' 90% confidence interval (CI). |
| 40% | | Identify What to Measure and Integrate Model into the IDM Framework |
| | 50% | Calculate VIAs for each model input variable. |
| | 50% | Provide recommendations on what to measure and integrate this model into the Intervention Decision Model (IDM) framework. |

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# Appendix B
## The Proposed Decision Method: Applied Information Economics

The World Agroforestry Centre (ICRAF), one of the research centers of the CGIAR, has identified a consolidated approach that will address three of the challenges facing research institutions in sustainable agricultural practice; these challenges are:

- Estimating the impact of intervention
- Determining how to measure agro-ecosystem health
- Showing the value of research.

The solution will involve the use of HDR's primary method called Applied Information Economics. Applied Information Economics (AIE) was developed as a robust method for addressing investment dilemmas that are large, risky, and full of difficult measurements. It is designed to perform even in the presence of "intangibles" and significant uncertainty. This approach is well suited to developing world agricultural research because decisions often involve opaque actors (e.g., stakeholder governments), poor and/or unreliable data (e.g., pastoralist regions), and effects that are perceived as difficult to measure (e.g., the effect of climate change on agriculture).

Unlike traditional methods that produce arbitrary "scores" or deterministic returns on investment, AIE conducts a true Risk/Return analysis with the same degree of rigor used by actuaries to estimate loss rates in insurance pools. The method involves five steps – (1) define the decision(s), (2) model what we know now, (3) compute the value of information, (4) measure what matters, and (5) make better decisions.

AIE combines several methods from decision theory, economics, actuarial science, and other mathematical methods. The method has been widely used in business, governmental, and NGO settings – in decisions as diverse as wildlife preservation, mine flooding, and IT security. AIE makes use of methods that have been shown to improve on human expert judgments in multiple independent studies. Here is a brief summary of the method:

- **Define the Decision(s):**
  As obvious as this step may first appear, it is the key to better understanding what to measure, and real decisions are often different from what they first appear to be. Is the dilemma whether to simply approve a project or how to conduct a project given a vast combination of alternatives? Or is the decision a matter of when a given initiative should be approved? The costs, benefits, timing, risks and even external factors are identified and the real decision is clarified.

- **Model What We Know Now:**
  Cost estimates, forecasts of benefits, project risks, and other variables in a typical big investment decision are almost never known exactly. The uncertainty about some variables, especially long term forecasts, can seem extreme. But the consequences of even extremely uncertain variables can be assessed using the “Monte Carlo” method and a special approach for training experts to assess probabilities. The Monte Carlo method is useful for conducting decision analysis by sampling variables that do not have exactly known values (i.e. most variables in a model). This initial model is effectively a snapshot of the current state of uncertainty about a problem before additional measurements are made.

- **Compute the Value of Information:**
  Not all variables in a decision model are worth measuring and those worth measuring are often a surprise to the decision makers. In fact, normally a kind of “measurement inversion” exists in most decisions – that is, the most uncertain variables tend to be ignored while the variables that usually receive a lot of attention actually have less bearing on the decision. With AIE, every variable in a model will have an “information value” that allows identification of high value variables in a decision. This approach targets only the variables in a decision that are the most likely to significantly reduce overall uncertainty in the decision.

- **Measure What Matters:**
  Once the high-value measurements are identified, a variety of empirical methods can be used. Contrary to what is sometimes assumed, relatively little data or simple observations may be required for extremely uncertain variables. AIE often uses efficient “Bayesian” methods, which exploit prior knowledge and can be used even when data is messy or sparse. The measured variables will have less uncertainty and then the model of uncertainty can be updated.

- **Make Better Decisions:**
  The output of the Monte Carlo model, updated with targeted measurements, is compared to the risk/return preferences of the organization. Research shows that the actual risk aversion and other preferences of decision makers change frequently and unconsciously. Different preferences are applied to different investments even when management believes they are being consistent. AIE addresses this major source of decision error by quantifying and documenting preferences such as risk tolerance and the value of deferred benefits so that the results of analysis can be assessed in a controlled, uniform manner. Finally, sometimes decisions have large combinations of outcomes and have to be part of a portfolio of decisions. When necessary, AIE applies optimization methods to determine the best decision even from a large set of alternatives. The AIE process can help scientists and planners to clarify and improve intervention decisions even in complex multi-stakeholder situations.

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# Appendix C
## Potential Gaps in Current Measurement Efforts (GIDM)

In 2013, we produced a Global Intervention Decision Model (GIDM) through a cooperative effort between the CGIAR and Hubbard Decision Research (HDR). The objective was to provide a modeling framework to support future decisions and to provide guidance for what should be tracked in a metrics database. One of the outcomes of the work was that we identified 6 potential gaps in current measurement efforts:

- **Market Prices:**
  Anything regarding a market price – such as bulk chemicals, crop market prices, the price of carbon offsets, and labor costs – has not been a focus of data gathering. Yet, a market price for some item had one of the highest information values in four of the six pilots. During the pilot project analysis, scientists felt somewhat uncomfortable even giving broad estimates for market prices of any kind. Clearly this was outside of their field of expertise and other sources for this sort of data should be utilized.

- **Project Failure Risks:**
  The two pilot projects that included some type of probability of project failure showed a high information value for that risk. This is also consistent with other observations of information values on projects in many industries and government agencies. It is likely that had other projects included the risk of failure that this would have been one of the high information values in those projects as well. Project failure risks include probability of total cancellation of the project (failure to complete with nothing to show), radical reduction in scope (cancellation of parts of the original plan after expenditures on those parts had been made) and massive delays. Data collection about success rates of projects and predictive models for projects with various characteristics will be key.

- **Negative Consequences:**
  For some projects there is the possibility that the project actually has an overall detrimental effect with a loss much greater than merely losing the invested resources. Projects that intensify farming practices for near-term benefits but with long term costs could fall into this category. This is a type of project failure risk but in this case the original project was successfully completed but with unintended results. Variables related to this also tend to have high EVPIs in many industries and organizations. Again, historical project characteristics and outcomes could be gathered to reduce this uncertainty.

- **Adoption Rates:**
  Most interventions require some sort of change in behavior of a population.

If households do not adopt farming techniques, policies, and technologies, then the benefits may never materialize. Understanding and predicting the adoption characteristics of a population (see Appendix D) will be a recurring uncertainty in many interventions. This is also an observation that is very consistent with EVPI calculations in other fields in business and government.

- **Detailed Household Demographics:**
  There were recurring uncertainties about details of households and individual farms that had significant bearing on intervention decisions. The decisions of individual households on urban migration, the sizes of their farms, the number and type of livestock and other types of demographic information were required for the analysis. This sort of information is already gathered in some programs but this project finds that for some intervention decisions a higher resolution and broader scope of this data may be required. There is a lot of data that could be gathered, but even small samples of the population would have been informative. The specific data gathered should be driven by the information values.

- **Land Properties:**
  The specific size of different lands, density of trees, erosion rates and other characteristics of the land had high EVPIs in some projects. This is also information that is gathered to some degree already but the information values indicate that higher resolutions of this data may be required for some decisions. A Geographic Information System (GIS) type of data base may be the ideal format but the data gathered should be driven by specific information values.

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# Appendix D
## An Introduction to Calibration

The order of our workshops is an important aspect of the process. Calibration workshops come before detailed decision modeling because AIE decision models are built with ranges of uncertainty on many of the variables. Therefore, before a subject matter expert or participant can contribute ranges on a variable, they must be able to accurately assess their uncertainty. This skill – the ability to accurately assess one's uncertainty – can be taught and we call this process "calibration."

Following methods designed by various academic researchers[6,7] and Doug Hubbard[8], experts can measure how well they subjectively assess uncertainty with explicit probabilities. The vast majority of people enter training in a state of overconfidence – they predict they will be correct more often than they are. In other words, when most people say they are 90% confident in each of some large number of predictions, the frequency of correct answers will be significantly less than 90%. Once an initial assessment has been conducted, experts learn several techniques for achieving a measurable improvement in estimating. By the end of a 3-hour training workshop, 85-90% of participants achieve a state of calibration – that is, they are able to give estimates that are correct as often as they predict them to be. Even those who don't achieve calibration in the workshop can still participate once their overconfidence has been measured.

The experience with the researchers was consistent with observed results for professionals in many other fields. Virtually all researchers started out in a state of extreme overconfidence about their estimates. But after training, most were performing to almost an ideal level of calibration (i.e., they could not be statistically differentiated from ideally calibrated persons given the sample size of estimates they provided).

[6] Kahneman, D. and Tversky, A. 1972. "Subjective Probability: A Judgement of Representativeness". Cognitive Psychology. 4: p. 430-454.

[7] Kahneman, D., Slovic, P. and Tversky A. 1982. Judgement under Uncertainty: Heuristics and Biases, Cambridge: Cambridge University Press.

[8] Hubbard, D. 2007. How to Measure Anything: Finding the Value of Intangibles in Business: John Wiley & Sons.

The International Livestock Research Institute (ILRI) works to improve food security and reduce poverty in developing countries through research for better and more sustainable use of livestock. ILRI is a member of the CGIAR Consortium, a global research partnership of 15 centres working with many partners for a food-secure future. ILRI has two main campuses in East Africa and other hubs in East, West and Southern Africa and South, Southeast and East Asia. www.ilri.org

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The Technical Consortium for Building Resilience in the Horn of Africa provides technical support to IGAD and member states in the Horn of Africa on evidence-based planning and regional and national investment programs, for the long-term resilience of communities living in arid and semi-arid lands. It harnesses CGIAR research and other knowledge on interventions in order to inform sustainable development in the Horn of Africa. www.technicalconsortium.org