# LESSONS LEARNED FOR CLIMATE CHANGE ADAPTATION; PART 1 - IMPLEMENTATION OF SEASONAL CLIMATE FORECASTING IN WEST AFRICA; PART 2 - IMPACTS FROM AND ADAPTATION TO CLIMATE CHANGE IN METRO BOSTON, USA

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**Introduction:** The findings of two existing research projects related to climate change adaptation are presented here. The first is the Climate Forecasting for Agricultural Resources (CFAR) Project of Tufts University and the University of Georgia funded by the Human Dimensions of Global Change Program, National Oceanic and Atmospheric Administration and the second is the Climate's Long-term Impacts on Metro Boston (CLIMB) Project of Tufts University, the University of Maryland and Boston University with the support of the Metropolitan Area Planning Council (MAPC) funded by the Office of Research and Development, US Environmental Protection Agency (EPA).

CFAR illustrates how understanding response to climate variability informs adaptation in developing agricultural communities while the CLIMB project focuses directly upon impacts and adaptation in a modern metropolitan region.

**Part 1. CFAR.** The Sahel-Sudan region of West Africa is one of the poorest areas of the world, whose economy depends mostly on rainfed agriculture. Therefore, it stands to benefit significantly from the appropriate application of forecast information to improve decisions affecting production and livelihoods. The region has a single rainy season, generally from June through October, with total rainfall from 800 to 1000 mm/year along its the southern edge to 250 to 400 mm/year along the northern edge. Rainfall patterns, especially in the drier areas, have great temporal and spatial variability. Effects of temporal rainfall variability are exacerbated by long-term cyclic variations (Nicholson, 1986), which may lead to prolonged droughts and widespread famines. Multi-year droughts and famines that occurred in the 1910s, 1940s, mid-1970, and mid-1980s have eroded household capacity to cope with and recover from periodic production shortfalls.

Agriculture in the Sahel-Sudan is an inherently high risk, low return endeavor with most farms being subsistence, carried out by farm families, and entirely dependent upon direct rainfall. Low and uncertain rainfall with concomitant large risk of crop failure leads farmers to adopt low risk agricultural strategies that minimizes investments or inputs. This leads to reduced productivity, which, in turn, further undermines household capacity for generating food surplus and for withstanding subsequent crises or stresses. When pushed against the limits of subsistence, households may have no option but to divest themselves of productive assets, sell their labor, or migrate elsewhere. In extreme cases, people may resort to theft or banditry, the incidence of which increases during crisis periods. Efforts towards improving farmers' ability to foresee and prepare for climate shocks before they occur rather than trying to cope with their impacts will contribute to the sustainability of production systems and for social stability in the region (Ingram et al., 2002).

Over the past decade, advances in generalized circulation and other climate models, remote sensing, climate databases, and computer technology driven by the implementation of major climate research projects such as the Climate Variability and Predictability (CLIVAR) Project of the World Climate Research Programme (WCRP) have dramatically improved the skill of climate precipitation forecasts. Current regional forecasts for the Sahel-Sudan are usually presented as the probability of the July through September total rainfall being either normal, below normal, or above normal within certain broad areas of the region. Regional forecasts are of moderate skill and have the potential to aid resource management decisions (Kirshen and Flitcroft, 2000, Roncoli et al., 2001).

In early 1998 the African Center for Meteorological Applications to Development (ACMAD) convened a Forum to develop the first regional consensus scientific forecast of seasonal precipitation based upon global sea surface temperatures for West Africa. This has evolved to each nation now developing their own forecast with the support of ACMAD and other international organizations. In 1997, the CFAR project started to investigate the obstacles and incentives to scientific forecast use in Burkina Faso (a case study nation in the Sahel-Sudan, Figure 1), how to best interpret and disseminate them, and what other information and resources is needed besides the forecast to take advantage of them. Of course, as described in many of our papers, Burkinabe farmers have always used their own traditional forecasting methods such as winter temperatures, the date and quantity of the first rains, and using the special forecasting knowledge of diviners and religious leaders. Early on, however, some farmers told us the traditional indicators were no longer working due to changes in the climate and so they welcomed new information.

Burkina Faso is a poor country with a Gross Domestic Product of $210 per capita in 1998 (Economist Intelligence Unit, 1999). About 90% of the population depends on agricultural and livestock production for livelihood and 80% depends upon subsistence agriculture (Economist Intelligence Unit, 1999). Most of the cereal produced is for household consumption and is grown under rainfed conditions. The leading cash crops are cotton, peanut, and sesame. There are also small areas where vegetables are cultivated for local consumption and export with irrigation water from catchments or reservoirs during the dry season. Use of fertilizers, mechanized cultivation, and other off-farm inputs is low. Livestock management is an important component of the agricultural system, particularly for the agro-pastoral groups in the drier northern areas where cattle and other livestock are the principal source of income. While farmers always cope with farm risks by diversifying their farm activities, they do make some adjustments based upon the traditional and scientific forecasts. Examples include planting in highlands or lowlands, size of fields, use of soil and water conservation techniques, amount of labor invested, and crop varieties.

**Adaptation to Climate Change.** In Africa, Chapter 10 of Intergovernmental Panel on Climate Change (2001), it was stated that "If farmers can adapt to current year-to year variability through the use of advance information on the future season's climate and institutional systems are in place to respond to short-term changes, communities will be in a position to adapt to longer term climate changes" (IPCC, 2001, WG2, pg 507). Based upon the response to farmers in the village of Bonam, Burkina Faso to the 2002 seasonal forecast, here we explore this statement. Based are previous research, our findings are valid for the rest of the country and probably most of the Sahel-Sudan.

Bonam is a village in the Central Plateau of Burkina Faso. Crops include sorghum, millet, maize, groundnuts, cowpea, and rice, and 30 percent of the households have plows. The 2002 forecast was 40 percent chance of being above normal, 40 percent chance of being the normal range, and 20 percent being less than normal. The CFAR team delivered the forecast with our African research partners in June 2002. The actual rains started out normal in May and June, but then were significantly below average in July before returning to the average values in August for the rest of the growing season. Interviews with farmers after the harvest season indicated that many had utilized the forecast. One of the most successful use of the forecast was reported by Issa Kormodo, who wrote us through an interpreter that " it must be recalled that at the beginning of the season farmers were afraid because of a problematic onset of the rains, so that some farmers had to plant five consecutive times before the effective establishment of the season…. Today we can thank God that until now we continue to receive rain and the harvest will be good this year, there is the proof (enclosed photo of fields of sorghum)…" It should also be noted that the scientific forecast for 2000 (which we also delivered) was for at least adequate expected rains, but the actual rains were poor. Farmers who had followed the 2000 forecast and had low yields were willing to use the 2002 forecast as they accept that the low probability outcome can occur.

**Challenges in Utilizing Seasonal Forecasts.** If seasonal forecasts are to be part of the suite of adaptation strategies of the region to climate change, several institutional, scientific, resource, and dissemination challenges must be met.

**Institutional.** Presently the forecasts are prepared by the Burkina Faso Meteorological Service and they have developed confidence in giving the forecast to a variety of users and working with other organizations to disseminate. The Service, however, continues to need more skilled personnel, more training, and more field experience.

**Scientific.** Improving the skill of the seasonal forecasts using other datasets and also dynamic models is an active area of research. More research is also needed to overcome other limitations of the forecasts: they are for only 3 months of the rainfall season; they are zonal; they refer to total seasonal quantity, not the distribution and particularly the start of adequate rainfall; and because they rely upon May SST data, are delivered sometimes after farmers have already made planting decisions.

**Farmer Resources.** "…they need more access to goods that would allow them to best make decisions using the forecast" (Bonam Farmer). Besides normal development activities such as improved education, infrastructure, and access to markets, local needs include: better seed varieties, local rain and temperature gauges, blackboards to share information, credit, land, and plows.

**Dissemination.** There are many challenges in dissemination: there is not always equitable distribution of the forecasts to different village groups; farmers think in terms of crop production, livestock health, and water availability, not rain quantity; explaining the probabilistic nature of the forecast, the terciles, and it only covers three months; and while most farmers are accessible by radio, radio dissemination presents some challenges such as "Newspaper and radio might raise questions that can't be answered, but at a workshop they can ask questions, so they are best", "The people were responsive to the information, but they also wanted contact with the experts themselves so that they could confirm that the information was real and true." To respond to the concerns of radio use, CFAR has used workshops with "key" farmers with much interaction to explain forecasts. These farmers then act as intermediaries to spread the forecast to other farmers in their villages. Phillips and Orlove (2003) have experimented with different ways to effectively utilize radio broadcasts to dissemination forecasts in Uganda.

**Conclusion.** The above research shows that while present seasonal forecasts are very valuable to Sahel-Sudan farmers, enhancements and supporting resources and actions are needed before it becomes one of the pathways to adaptation to long-term climate change.

**Part 2. CLIMB.** To date, most of the research on climate change impacts has been on sectors such as agriculture and water resources where the climate impacts were first most obvious. Recently there has been increased interest in the impacts on infrastructure in urban areas because infrastructure is designed to function under specified climate condition, which are now changing. Examples of such criteria include streamflows for water supply, low flows for wastewater disposal, 24 hour rainfall for river flooding, sea levels for coastal flooding, and air temperatures for energy supply. In addition, there are increased demands on urban systems due to population growth and general urbanization. Since infrastructure systems last considerably longer than decades (some a century or more) and provide the footprint and direction for future socio-economic activities, it is therefore important that urban decision-makers understand the short- and long-term consequences of climate change.

As a case study of potential impacts, the CLIMB Project was initiated to examine the integrated impacts of and adaptation to climate change in metro Boston. It consists of 101 communities (Figure 2) and is home to more than three million people. The high density of population, diversity of businesses, government agencies and educational institutions, and central location in New England and its location on the coast make metropolitan Boston a major center of economic activity within the New England region and the larger, eastern megalopolis. For the purpose of analyzing and modeling the potential impacts of climate change on Metro Boston, seven zones are defined (see Figure 2). Within these regions, notable differences exist, for example, in the type and level of economic activity, incomes and age composition of households, rates of change in land use and population, and potentials to mitigate and adapt to climate change. While we are examining the integrated impacts of climate change on water supply, water quality, river flooding, energy demand, heat related health, road transportation, and coastal flooding, here we summarize only the results of increased flooding due to sea level rise (SLR) (Kirshen et al, 2003) and then present some general conclusions.

**Sea Level Rise.** The present 500 year coastal floodplain of the region contains parts of 32 municipalities. The 500 year coastal floodplain is the area that has a probability of 1/500 or 0.2 percent each year of being flooded by ocean storm surges due to tropical (i.e. hurricanes) and extratropical (i.e. northeasters) storms. This means that, on the average, this entire coastal area is flooded once every 500 years. Land areas at lower elevations are flooded more frequently. The present 500 year coastal floodplain is approximately 12,000 hectares and contains approximately 2200 hectares of developed land. The metro Boston coastal area is particularly vulnerable to flooding. In February 1978, a 100 year storm surge struck the Massachusetts coastline and caused approximately $ 550 million damage in 2000 dollars (US Army Corps of Engineers, 1990). Emergency costs were $95 million. Under climate change, the recurrence interval of the 100 year flood is expected to decrease to at least the 10 year flood because of SLR. Here we report upon residential, commercial (also includes service), and industrial property and content damages and emergency costs from coastal flooding due to higher storm surges because of higher SLs. We do not present results on impacts on the natural environment, well water supply systems lost due to salt water contamination, coastal wastewater treatment plants, and transportation systems.

Most estimates for eustatic rise over the next 100 years are 0.41 meters (m) and for subsidence are 0.21 m. Other research has suggested a total change of 1 m. The region has had a SLR of 0.3 m in the last 100 years. The population and employment characteristics of the coastal area are also changing with population in the coastal municipalities expected by 2050 to increase by 5 to 15 percent, commercial and service employment to increase by 20 to 35 percent, and industrial employment to decrease as much as 30 percent or grow as much as 13 percent. All of the municipalities reach buildout by 2050. We examine the impacts in light of three possible adaptations to climate change that might be taken in the region and which will be discussed subsequently: ride it out; nonstructural, environmentally benign or green adaptation; and build your way out. We also examine the impacts assuming that SLR occurs gradually at a constant amount each year even though there are strong possibilities of abrupt climate change and the major changes taking place over decades instead of a century. We do not include any possible impacts of changes in the frequency or intensity of the storms themselves which are not well known at this time. We also do not look at impacts occurring beyond 2100 even though impacts will still be occurring then; the magnitudes will depend upon any mitigation actions the world and in particular the USA takes to curb emissions of greenhouse gases. As described in more detail below, we found that the total property and contents and emergency services damages due to eustatic and subsidence SLR over the next 100 years could range from $20 billion to $94 billion if there are no adaptative responses except rebuilding after floods. Total or cumulative damages expected with no eustatic SLR are $6.4 billion. If there is proactive adaptation that limits building, increases floodproofing, or builds some coastal protective structures, some damages could be cost-effectively avoided.

The research methodology utilized Monte Carlo analysis of annual flood damages with rising sea levels with flood damage data from the US Army Corps of Engineers and the Federal Emergency Management Administration (FEMA), historic sea level data from the National Oceanographic Survey (NOS) and climate change scenarios. We did not discount any of the future costs of property damage or flood protection; we assumed that property costs appreciated at the discount rate and, since flood protection costs are very closely related to property costs (like floodproofing), that discounting was also unnecessary for these costs. The results in Table 1 assume that the SLR to 2100 is 0.62 m. We examined impacts for three scenarios of adaptation.

**Ride-It-Out:** The 'Ride-It-Out' adaptation (RIO) assumes that structures will be repaired to current conditions after each flood over the 100 year period with no additional floodproofing. All growth in the present 100-year floodplain is floodproofed 100 percent effectively so there are no damages to this property. Growth in floodplains greater than the 100 year is allowed to proceed with no restrictions. The results of this are similar to current polices. Environmental costs for this option are low since it does not prevent the natural migration of the shoreline inland as the sea rises unless there are existing barriers such as roads. The Baseline run in the tables is the flood damages expected with just subsidence and growth alone in the region; same as RIO except without eustatic SLR. Even with a small increase in SLR due to subsidence, the amounts of residential, commercial, and industrial lands flooded in the Baseline are greater that the actual areas of these sectors in the floodplain. This is because many properties receive repetitive damages. Table 1, Run 3, shows that the cumulative expected damage to 2100 in the Baseline is $6.4 billion assuming that a structure is only damaged by one storm per year even if more than one flood occurs because the repair time is one year. This is conservative as the FEMA database sometimes shows the same residence suffering multiple damages in one year. Comparing the Baseline to RIO shows that cumulative damages increase from $6.4 billion to $20 billion (Run 5).

**Build-Your-Way-Out:** Unregulated growth is allowed in all floodplains because all current and future development is protected with retrofit or new coastal protection structures, which are built following the second 100-year flood. Damage is incurred until that event occurs, and as with RIO, damaged structures are repaired to their previous state, allowing repetitive damages. Coastal protection in this option consists of shoreline hardening structures such as seawalls, bulkheads, and revetments. Unfortunately, they also separate the beachfront from the dunes, which interrupts the natural movement and replenishment of sand. For this reason they also increase local vulnerability to erosion. It is assumed that the coastal protection structures are built for the 500 year storm because the incremental cost of protecting the coast from the 500-year surge level rather than just the 100-year surge level is small compared with the total cost of the retofitted or new structure. The costs do not include maintenance costs of structures and beach nourishment projects to prevent foreshore erosion and undercutting. Because of the protection in this scenario, Table 1 shows that there is considerably less total costs from this scenario compared to the RIO scenario ($9.4 billion, Run 6)

**Green:** In a stricter version of current FEMA regulations, all growth in the current 100 and 500 year floodplains must be floodproofed and current residential development must be floodproofed upon sale of the structure assuming a 15-year turnover rate in the housing stock. The retrofitting of those structures already present in the floodplain is assumed to be 80 percent effective, meaning that they will incur only 20 percent of the damage expected under the RIO scenario. While the cumulative areas flooded are approximately the same as RIO because there is no flood protection, the total costs are considerably less than RIO ($5.8 billion, Run 7). The Green and RIO scenarios also cause less environmental damage and have lower maintenance costs that BYWO.

**Sensitivity Analysis.** If the three largest events caused damage each year or there was 1 m of SLR, RIO damages approximately doubled (Runs 8 and 11). If both occurred, then total damages increased over 4 times compared to the initial RIO scenario to $94 billion total over the 100 year period (Run 14). The total costs of BYWO and Green also increased significantly under each of 3 events or 1 m and the combination; there is more damage to protect against. In fact, because the structural features protect the region so well, particularly against recurrent damages, the total costs of BYWO in some cases are less than those of Green. For examples, the total costs with 1 meter of SLR but only 1 event causing damage are $ 8.8 billion (Run 12) versus $10.1 billion (Run 13). Most of the benefit gain in the BYWO scenario is due to the protection of the expensive buildings in Boston. Again, this analysis excludes maintenance and environmental costs.

The above sensitivity analysis reinforces what others have stated as a possible response to SLR: Build-Your-Way-Out in densely developed areas and Green adaptation in more environmentally sensitive and less developed areas. Adaptation options should also be reviewed in terms of "no regrets" policies; that is, whether they are beneficial if SLR does not occur. The Green scenario is a "no regrets" action because floodproofing is useful in preventing damages whether or not more eustatic SLR occurs. BYWO is not a "no regrets" option; it involves high construction investments, significant maintenance, and large-scale wetland loss. Its economic benefits are positive when considering SLR because it also avoids all damages. If projected SLR does not occur, however, the costs of this option will still be incurred while the benefits will be dramatically reduced. While uncertainty in the expected rate of SLR and damages makes planning difficult, this analysis still shows that reacting proactively to potential changes is generally advantageous.

**Conclusions.** In analyzing the impacts on other infrastructure sectors, we have also found that taking action proactively is also generally beneficial. General policies for encouraging this include (Ruth and Kirshen, 2003): Fostering Diversity of Problem-Solving Approaches, Leveraging Interdependencies Among Infrastructures and Institutions, Designing and Implementing Forward-looking Design Criteria and Standards, and Getting Multiple Bangs for the Buck. Some specific design criteria and standards might include: just we design for uncertain socio-economic projections, adding the design for uncertain future climate conditions to the infrastructure planning process; at a minimum updating all building codes to present climate conditions; using a state revolving fund (SRF) for incremental adaptation costs; adding climate change impacts to the environmental impacts statement (EIS) process; encouraging projects with co-benefits; adding land purchases to adjust to climate change as an approved purpose for state purchasing of undeveloped land; and considering allowing insurers to set premiums based upon expected future losses.

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**Table 1: Costs of SLR Scenarios ($ million, total damages from 2001 to 2100). Res= residential costs, Cm/In = commercial/industrial costs, Emgny = Emgency Costs, Adpt = adaptation costs**

| | Model Run | Res | Cm/In | Emgny | Adpt Cost | Total Costs |
|---|---|---|---|---|---|---|
| 1 | Baseline - No Growth, One Event | 1087 | 4023 | 869 | 0 | 5979 |
| 2 | Baseline - No Growth, Three Events | 1452 | 5354 | 1157 | 0 | 7963 |
| 3 | Baseline - Growth, One Event | 1205 | 4305 | 937 | 0 | 6447 |
| 4 | Baseline - Growth, Three Events | 1616 | 5735 | 1250 | 0 | 8601 |
| 5 | Ride-It-Out' - Moderate SLR, One Event | 3563 | 13525 | 2905 | 0 | 19993 |
| 6 | Build-Your-Way-Out' - Moderate SLR, 1 Event | 1091 | 3984 | 863 | 3462 | 9400 |
| 7 | Green' - Moderate SLR, One Event | 756 | 2697 | 587 | 1766 | 5806 |
| 8 | Ride-It-Out' - Moderate SLR, Three Events | 7993 | 29776 | 6421 | 0 | 44190 |
| 9 | Build-Your-Way-Out' - Moderate SLR, 3 Events | 1924 | 6925 | 1504 | 3462 | 13815 |
| 10 | Green' - Moderate SLR, Three Events | 1649 | 5945 | 1291 | 3391 | 12276 |
| 11 | Ride-It-Out' – One meter SLR, One Event | 6131 | 25014 | 5295 | 0 | 36440 |
| 12 | Build-Your-Way-Out' - One meter SLR, 1 Event | 969 | 3613 | 779 | 3462 | 8823 |
| 13 | Green' - One meter SLR, One Event | 1268 | 4959 | 1059 | 2897 | 10183 |
| 14 | Ride-It-Out' – One meter SLR, Three Events | 16140 | 64250 | 13666 | 0 | 94056 |
| 15 | Build-Your-Way-Out' - One meter SLR, 3 Events | 1820 | 6703 | 1449 | 3462 | 13434 |
| 16 | Green' - One meter SLR, Three Events | 3272 | 12760 | 2726 | 6798 | 25556 |

## Figure 1 - Burkina Faso with Annual Average Rainfall (mm)

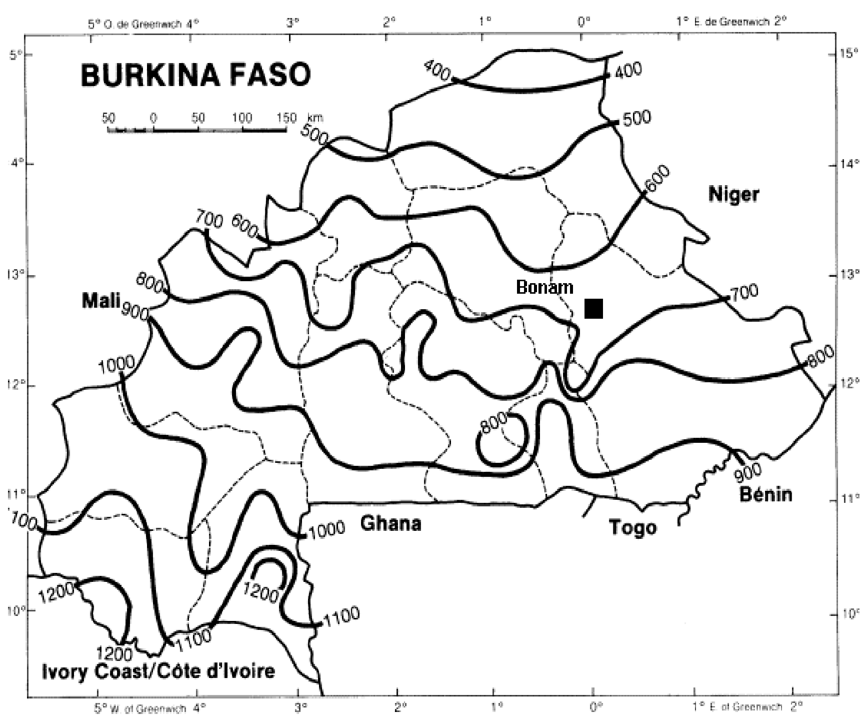

**Fig. 2  Metropolitan Boston and Seven Zones Defined for CLIMB**