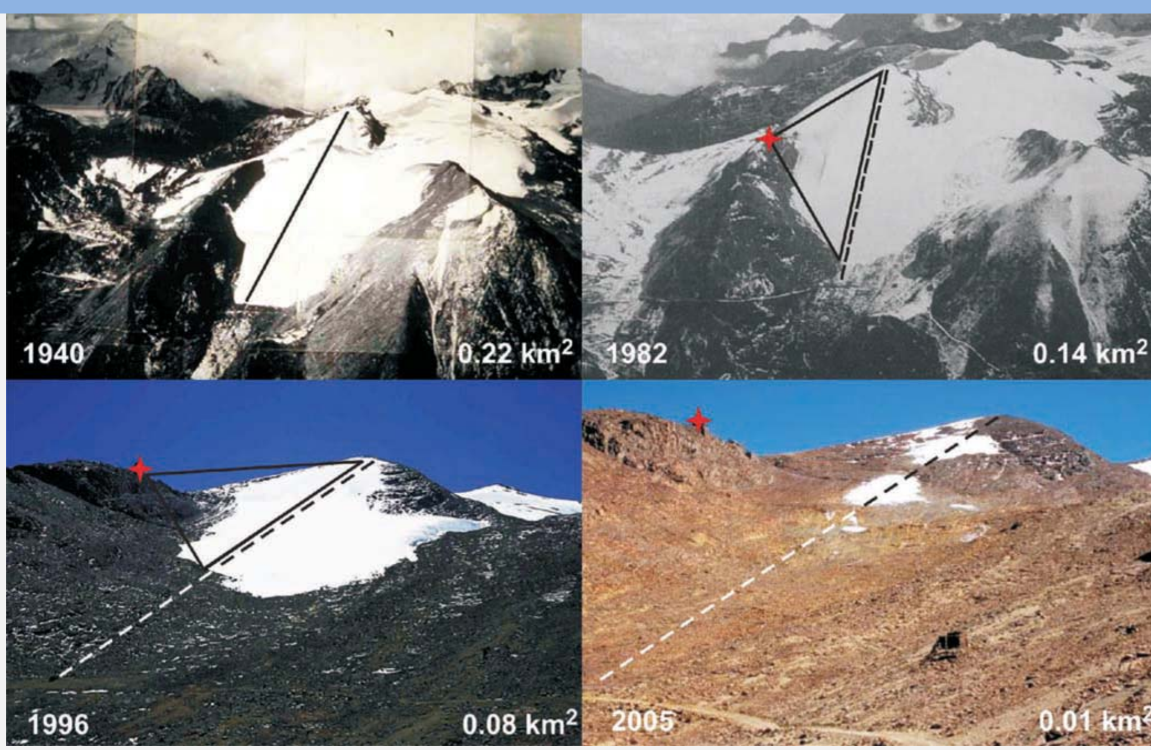
4. Anticipatory Adaptation to Climate Change

Highlights

- Climate models have been more useful for setting context than for informing investment and policy choices. They have limited reliability for decisions involving precipitation extremes in small areas.
- Although hydropower has a long tradition of dealing with climate variability, the Bank Group lacks guidance on appropriate methods for incorporating climate change considerations into project design and appraisal.
- Land use planning is, in theory, critical to anticipatory adaptation for disaster exposure reduction, coastal zone management, and biodiversity conservation. But experience and success are limited.
- The Bank has begun to incorporate ACC into biodiversity projects, but few projects have had the goal of conserving biodiversity that could be critical for agricultural adaptation.

Figure 4.1. Glacial Retreat in Bolivia



These images show the retreat of the Chacaltaya Glacier in Bolivia, an illustration of long-term transformational climate change impacts.
Source: Cynthia Rosenzweig, NASA. http://www.giss.nasa.gov/research/briefs/rosenzweig_02/
Image credits: IPCC Working Group II Fourth Assessment Report 2007; 1940 Servicio Aerofotográfico Nacional, Bolivia; 1982 Reinhardt & Jordan; 1996, 2005 Bernard Francou

4.1 Climate *variability*—as manifested in storms, floods, and droughts—is a familiar component of risk for investors in many sectors. Climate *change* is something new. This section is a report from the front lines as the Bank Group and others grapple with the implications for risk management and planning. It starts by asking the normative questions:

- When is it important to factor climate change into decision making? When is it necessary to cast decisions (perhaps literally) in concrete—as in the case of the Padma Bridge—based on anticipated changes over coming decades? When is it sufficient to adapt-as-you-go, as in the case of the Cartagena causeway? When is climate change simply not an important factor?
- Where anticipatory adaptation is necessary, what is the basis for decision making? What are the uses and limits of global and regional climate models?

4.2 As noted elsewhere (and elaborated here) the answer to the first question is that anticipatory adaptation is most important for investments or decisions that are inflexible or irreversible, and have long lifetimes or lead times. The section looks at hydropower as an exemplar of long-lived, climate-sensitive infrastructure investments. Hydropower is particularly germane because of its well-developed methods for dealing with climate variability, and because it was singled out for screening in the SFDCC. (Annex E briefly discusses roads.) The section concludes with large-scale, long-range planning issues related to land use and agricultural technologies.

Normative Theory of Incorporating Climate Risk into Project Planning

4.3 Climate change has two distinctive features that complicate decision making. First, it plays out over decades, with the worst impacts furthest in the future. Second, while the broad outlines of climate change are clear, there is much uncertainty about particular impacts at particular locations. This brings to the fore three dimensions of decision making: incorporating flexibility, discounting future costs and benefits, and projecting future conditions.

FLEXIBILITY

4.4 Projects are more affected by climate *change* (relative to climate *variability*) if they are long-lived and expensive to adjust or retrofit. Table 4.1 motivates the choice of the three sectors chosen for discussion in this chapter. Short-lived projects will not see much change in their fundamental economics due to climate change and may need to focus much more strongly on climate variability. Road surfaces, for instance, are typically rebuilt every 15 or 20 years and can be adjusted to meet current climatic and traffic conditions. The causeway in the Port of Cartagena can easily be raised when sea level rise begins to threaten it. In contrast, hydropower facilities may have a design life of 100 years, and it is often difficult to heighten a dam or expand a reservoir after construction. Most sensitive are projects that are both inflexible and have indefinite time horizons. An example is the conservation of unique ecosystems, protecting them against today's threats with the goal of maintaining them for future generations. Another is the layout of major transport corridors, which can shape development patterns for centuries (Box 4-2.).

Table 4.1. Project Flexibility and Longevity

Flexibility	Life of <20 years	Life of 20-100 years	Life >100 years
Adjustable	Road paving	Cartagena causeway	
Inflexible or irreversible		Hydropower facilities Padma Bridge piers	Samoa: road routing choice Protected areas

DISCOUNTING

4.5 Stern and others have advocated using low and declining discount rates to assess climate-sensitive decisions that involve intergenerational tradeoffs at the global level (Stern 2007; Weitzman 2007).

4.6 Different criteria would seem to apply to decisions by Bank Group clients on how to assess climate-related financial risks in typical investment projects. Public and private clients have high opportunity costs, often 15 percent or more. Gradual, climate-related changes in flows of costs and benefits are likely to have little impact on investment decisions. Consider a hypothetical climate sensitive project with a baseline 15 percent return each year, but where these returns decline linearly by a fifth over a 30-year period due to climate change—for instance, a hydropower plant confronting a decline in average precipitation. With a 30-year investment horizon, climate change reduces the economic rate of return of the project by less than one percentage point, from 14.8 percent to 14.0 percent. This is likely too minor a change to affect investment decisions and may be small compared to more immediate risks, such as construction cost overruns.

4.7 It is important to stress, however, that some aspects of decision making are not ordinarily considered in a discounted value framework. This is especially true for investments with environmental or health impacts. For example, dam safety standards require the ability withstand a particular flood event (such as a 1 in 10 thousand year flood), and environmental flow requirements are set to require a particular minimum flow level. If, for instance, meeting those standards requires building a stronger dam today to withstand the worst-case floods of 2112, then climate change considerations could have a significant impact on project economics.

USES AND LIMITATIONS OF CLIMATE MODELS

4.8 Scientists have developed an increasingly sophisticated suite of computerized models in order to understand human impacts on climate change. Global climate models (GCMs) project climate at a coarse resolution, typically 2.5° latitude x 2.5° longitude (77,000 square kilometers or larger). Regional climate models (RCMs) or statistical downscaling methods zoom in on smaller areas (at resolutions as fine as 20 x 20 kilometers), using GCMs as input. GCMs have been essential for climate change research and for assessing global pathways to climate stabilization. As noted in chapter 2, models have been useful in developing countries in raising awareness, setting the context for national-level action, and building technical capacity

4.9 It has been irresistible to press these newly developed scientific models into service for guidance in practical project and program planning and analysis. The Bank has done so, sometimes in cutting-edge ways. The Bank also has supported local capacity building in the development and use of these models. But can these models provide the kind of information required by development planners and infrastructure designers (see Table 4.2)? Can they, for instance, indicate how the magnitude of 1 in a hundred year floods will change in a particular watershed?

4.10 Climate projections are built on an accumulation of uncertainties that limit their precision for certain purposes (IPCC 2007):

- There is uncertainty about the exact values of key physical parameters. Rowlands, Frame, and others (2012), for instance, run thousands of variants of a single climate model using equally plausible values for these parameters, and obtain mean global warming estimates ranging from 1.4 to 3.0° C by 2050.
- Different scientific groups have constructed competing models, and there is no agreed means of discriminating among them. (Ability to reproduce current climate conditions is no guarantee of the model's predictive ability under unprecedented future conditions.)
- The ability to calibrate the models is limited by sparse observational data in many parts of the world (see Figure 3.3), and this applies especially to locally downscaled models.
- The models may be particularly challenged by mountainous regions, which are expected to be particularly sensitive to climate change.
- Local and global climate, and climate change, impacts are strongly modulated by unpredictable human actions over the coming century, including the degree of greenhouse gas emissions, deforestation, and water use.
- There is inherent, chaotic variation in weather, not just day to day, but year to year and even decade to decade. Thus, a single climate model will (correctly) generate a range of different possible realizations of future climate patterns.

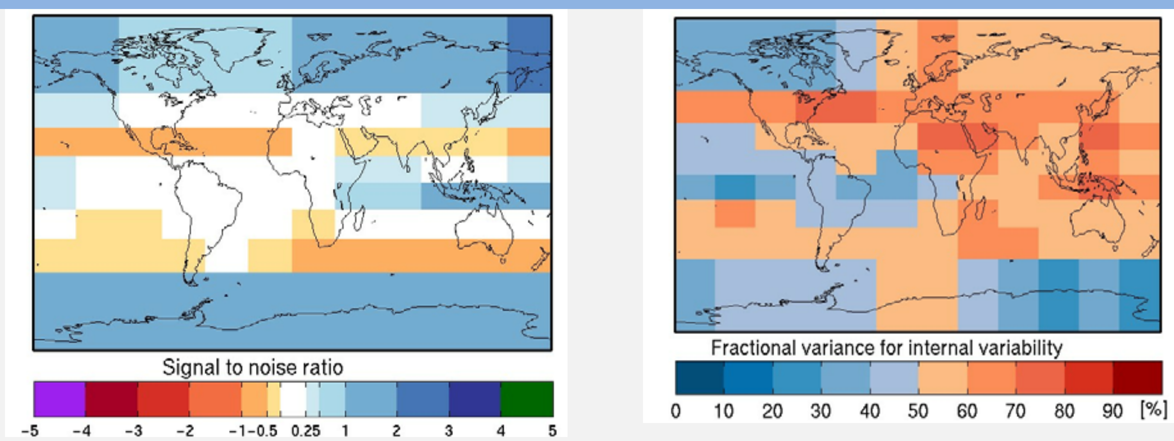
Table 4.2. Information Needs for Anticipatory Adaptation Decisions

Case	Sample climate-related questions	Information required	Timescale	Other relevant information
1. Road network, Ethiopia	What are the potential climate impacts on road assets and transport services, with associated costs for adaptation?	Annual number of days with heat waves and 10-year high rainfall event for road design	10-50 years	Traffic volume and overloading; maintenance regime
2. Trung Son Hydro Project, Vietnam	What are the expected economic returns under various scenarios for future hydrology and power generation?	Exceedance probabilities of dry season rainfall and low flows	10-40 years	Capital costs of alternative options, fuel prices, avoided greenhouse gas emissions
3. Rainfed and irrigated agriculture, Yemen	What is the vulnerability of agriculture and rural livelihoods to climate variability and change?	Annual rainfall, reservoir inflow, evaporation and groundwater recharge	10-80 years	Agricultural water demand; water governance
4. Hydropower plants, Albania	What steps can be taken to improve energy security and dam safety under extreme weather?	Probable maximum flood or 10,000 year flood for dam spillway	100 years	Land use restrictions
5. Urban drainage in Kolkata, India	What are the relative benefits of de-silting, upgrading, or building new sewers?	Exceedance probabilities for rainfall and floods of various magnitudes	10-50 years	Land subsidence and expansion of impermeable surfaces
6. Padma Bridge, Bangladesh	How deep and high to make the piers?	Sea level and scouring intensity by 100 year flood	100 years	Likelihood of earthquakes

Source: IEG.

4.11 Hawkins and Sutton (2009) (2011) provide some guidance on the degree of climate model uncertainty. They predict global and regional temperature and precipitation, on a seasonal basis, using 15 different climate models and 3 different scenarios for future emissions, giving a range of possible outcomes. The variation among outcomes is partitioned between "internal" (natural or intrinsic) climate variability, uncertainty about the climate model, and uncertainty about the emissions scenario. Hawkins and Sutton report on the proportion of total uncertainty that is accounted for by internal climate variability, and on the size of uncertainty ("noise") relative to the mean prediction of climate change ("signal"). Figure 4.2 (left panel) shows, for example, the "signal:noise" ratio for December-February precipitation change 20 years from now. For areas shown in white, light blue, or light orange, the average projected change is swamped by uncertainty. The right panel shows that in the Eastern Hemisphere, most of this uncertainty is due to internal climate variability. This suggests that for projects dependent on winter precipitation, with a time horizon of less than 20 years, it might be more important to attend to climate variability than to climate change.

Figure 4.2. Map of Uncertainty in December-February Precipitation Projections at a 20-Year Horizon



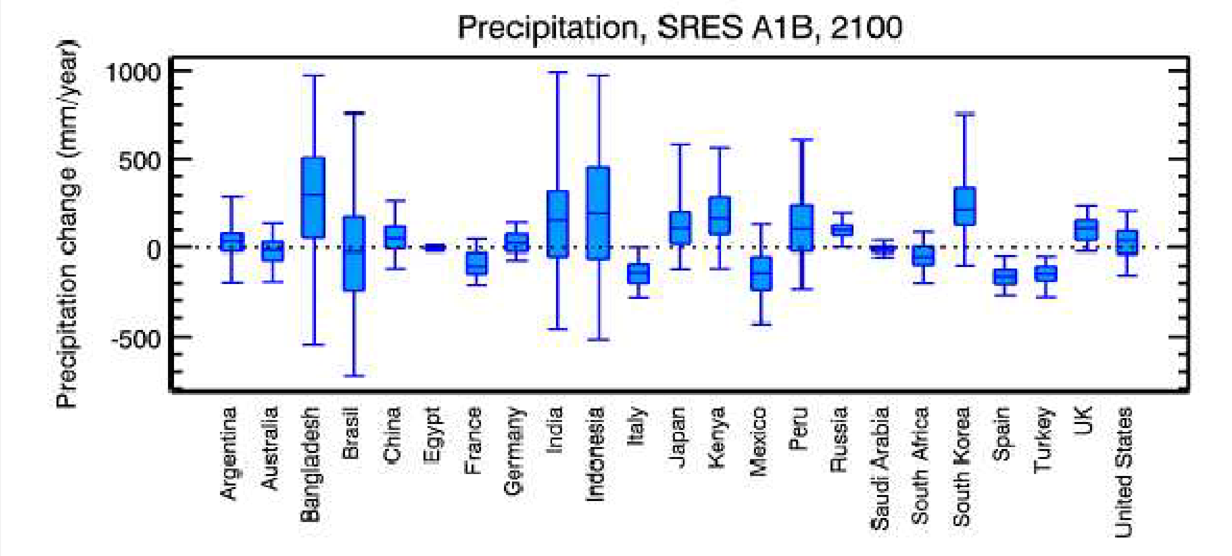
Note: Left panel: ratio of mean to standard deviation of precipitation (negative numbers indicate projected decline in mean precipitation)
Right panel: proportion of uncertainty accounted for by internal climate variability (as opposed to model or emissions uncertainty)
Source: © Hawkins and Sutton. Climate Dynamics 2011.

4.12 Key findings from Hawkins and Sutton are as follows:

- Temperature projections are relatively reliable; uncertainty is small relative to the trend.
- Precipitation projections are much less reliable at all time and geographical scales. Typically it is not possible to determine whether mean precipitation is increasing or decreasing, and both outcomes are possible (Figure 4.3).
- For time horizons of 30 years or less, internal climate variability is the main source of uncertainty about precipitation.
- Relative uncertainty is higher for smaller geographic areas, and for seasonal versus annual means. By extension, uncertainty becomes very high for projections about extreme events in particular places.

- For horizons of 30 years or less, uncertainty about the emissions scenario makes little difference.

Figure 4.3. Precipitation Projections across Models, 2100

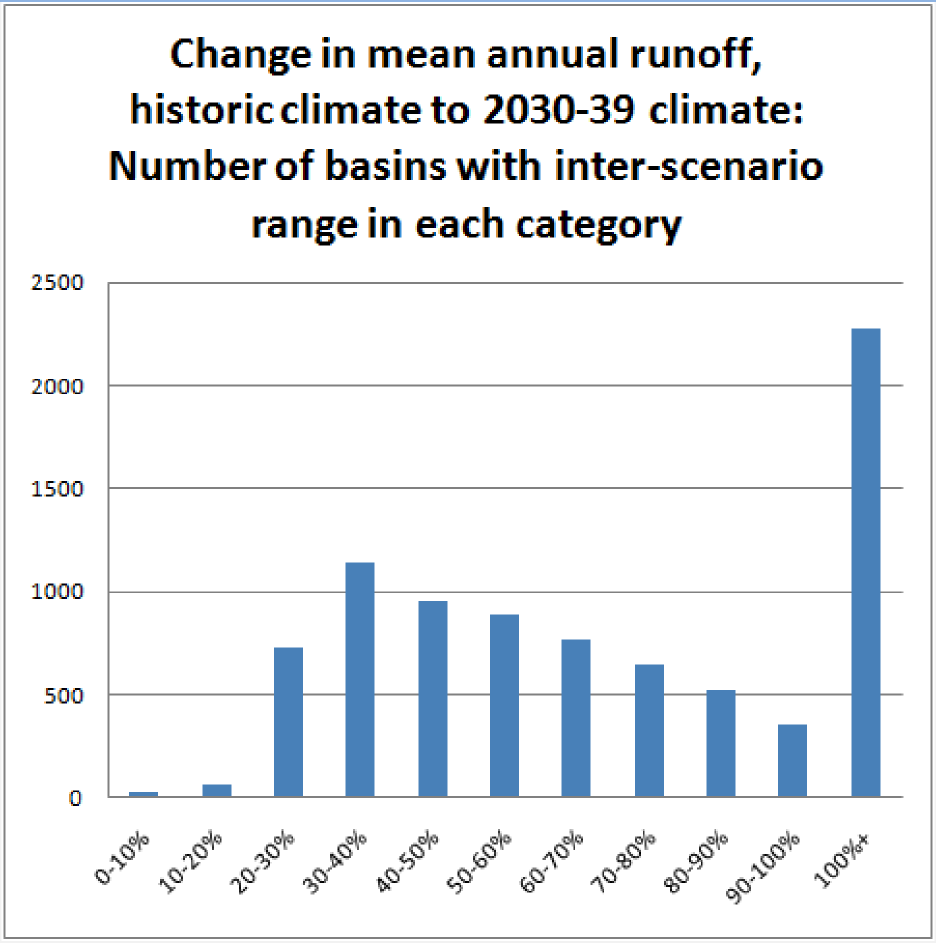


Note: This shows a set of analyses by the Hadley Centre on the change in national level mean precipitation to 2100, under a high-emissions scenario. For Bangladesh, Brazil, India, and Indonesia the ranges are immense—on the order of 1.5 meters/year—encompassing both wetter and drier possible futures for each country. This complicates adaptation planning. Planning would be difficult enough if one knew for sure that climate was going to be much wetter, or if it were certain to become much drier. But based on current information, either outcome is possible. Bars give 25th, 50th(median), and 75th percentiles; whiskers show maximum and minimum across models.
Source: Met Office, Hadley Centre. "Climate: Observations, projections and impacts." Downloaded from http://www.metoffice.gov.uk/climate-change/policy-relevant/obs-projections-impacts

APPLICATIONS OF CLIMATE MODELS AT THE WORLD BANK GROUP

4.13 Precipitation uncertainty is reflected in a dataset assembled by the World Bank's Water Anchor intended to inform development planning (Strzepek, McCluskey and others 2011). The projections are distributed on the Bank's web-based climate portal. The authors caution that the projections are not suitable for project-level work, because of their coarse scale. This dataset consists of projections of hydrological flows for 8,380 river basins. For each basin, up to 22 GCMs and 3 emissions scenarios were used to drive a hydrological model of impacts on water flows. Figure 4.4 tabulates the ranges between highest and lowest flows across the 8,380 basins. For more than two-thirds of the basins, the range of projection is more than 50 percent of the historic average. For about a quarter of the basins, the range is more than 100 percent.

Figure 4.4. Spread of Hydrological Predictions for River Basins



Note: Number of river basins with data = 8,380; 54 emission scenario/GCM combinations used for each basin: interscenario range = highest change—lowest change, expressed in percentages of historical baseline level
Source: IEG analysis of data described in (Strzepek, McCluskey and others 2011) and available at World Bank Climate Portal.

4.14 IEG also reviewed 28 recent studies and project documents that used GCMs to address climate change, to determine how the models were used and how the analyses dealt with uncertainty in projections. (These were opportunistically chosen and may not be comprehensive of all such projects, programs, and studies. A comprehensive survey of recent hydropower projects is discussed in chapter 4.) The analysis cross-classified the type of climate scenario modeling against how the climate models were used to discriminate among options.

Table 4.3. Scenario and Adaptation Option Methods Used by Surveyed World Bank Studies

Scenario method	Options analysis				
	Not done	Low-regret (robust)	Adaptively managed	Precautionary principle	Cost-benefit
Qualitative	1	2	0	0	0
Sensitivity test	2	0	½	1	2½
Scenario-led	5	10½	½	1	2

Scenarios:
Qualitative: Refers to primary sources (such as IPCC) and/or applies simple climate narratives (such as hotter, warmer, drier, or earlier).
Sensitivity test: Application of arbitrary climatic (and non-climatic) change factors to the inputs driving model(s) of the system(s) of interest
Scenario-led: Applies top-down approach to quantify outcomes arising from combinations of emissions, climate model, downscaling, and impact model uncertainty
Options analysis:
Low-regret (robust): Largely qualitative appraisal of scenario-neutral measures that should realize benefits under present climate variability as well as future climate change
Adaptively managed: Flexible operations, forecasting, or innovative use of existing infrastructure to meet emergent climate trends and/or changes in variability
Precautionary principle: Apply a safety margin for managing risk and uncertainty
Cost-benefit: Monetization of adaptation options under climatic and non-climatic scenarios. Includes robust decision making with emphasis on "satisficing" rather than determining optimal solutions.

Source: IEG (Half values are used for four projects that each use two methods of adaptation option analysis.)

4.15 The review found that climate model information has generally been unable to inform quantitative decision making in the surveyed studies. Most studies adopted a traditional scenario-led approach to making climate projections. But over half of the studies then recommended low-regret adaptation options that do not depend on climate projections, and roughly one-quarter did not recommend adaptation options. In some cases, climate projections were used to outline potential climate futures to inform sensitivity-testing of project viability (Trung Son hydro, Kolkata flooding). Only in a handful of cases were numerical predictions used as in input into design (Padma bridge, Kiribati high-tide calculator).

4.16 In retrospect, the Bank Group has pioneered—often in innovative ways—the use of climate models, but has discovered that they often have relatively low value-added for many of the applications described in Table 4.2. An alternative approach would emphasize robust decision-making methods, where the analytic emphasis is on understanding how different investment options are sensitive to a range of possible climate outcomes, rather than on attempting to predict the future climate (Box 4-1). It would emphasize adaptive management, where policies and investment programs are updated over time as future uncertainties are realized. And it would ensure that capacity-building programs in client countries prioritized practical hydrometerological, decision-making, and design tools.

4.17 However, the models in some cases may be able to point to broad trends that have implications for regional planning, especially where temperature is the key variable. For instance, Lobell, Schlenker and others(2011) shows that crop yields are more closely linked to temperature than to precipitation, and points out that there is greater agreement on temperature trends than on precipitation trends. In some cases, there is good agreement among models with respect to regional precipitation trends. This was the case for the Zambezi Basin, for instance, where the basin-level projections described above agreed on a trend toward decreasing precipitation. Model outputs can be used to communicate qualitative climate risks and to outline a broad range of future possibilities. And modeling may be a necessary part of due diligence for megaprojects.

Box 4-1. Robust Decision Making and Climate Change

Not only are we uncertain about which future climate scenarios will occur -- we can't even reckon the odds of experiencing one scenario versus another..[43] This means that traditional probabilistic risk analysis is not suitable for choosing between options that are highly sensitive to future climate change. How then should we proceed?

Robust decision making (RDM) offers an alternative, as a technique suited to making decisions in the presence of deep uncertainty. It can be used as a qualitative approach to decision making, or as a formal computational method. In either case, the outcome is to select options that perform well across a range of plausible future scenarios. The approach offers a way to integrate climate uncertainty with uncertainty about important economic factors or key parameter values.

Recent World Bank studies have suggested use of RDM in the context of green growth and climate change adaptation. RDM tools have been used in a number of cases, including for selecting flood risk mitigation options in New Orleans (Fischbach 2010) and for water planning in California(World Bank 2009b), and are currently being used for preparing an integrated flood management plan for Ho Chi Minh city(World Bank 2012). Sometimes these studies can help to refocus the debate away from climate uncertainty: the work in New Orleans concluded that the key factors for determining the best vulnerability reduction policies were not the impact of climate change, but rather the effectiveness of homeowner buyout policies, the rate of degradation of levees and the degree to which elevating houses would reduce flood damage.

Box 4-2. Samoa's Dilemma: Coast Road or Inland Road?

The most important road in Samoa goes from the airport to the capital. It is subject to damage from storms and tsunamis—they have hit before and will hit again. (A tsunami on the less-settled south coast in 2009 inflicted damage equal to 10 percent of GDP.) The existing road needs major rehabilitation due to storm damage and insufficient maintenance. These circumstances offered a choice: should Samoa rehabilitate the existing coastal road, or construct a new route further inland? The coastal road is where the existing development is—but will likely suffer further damage and outages due to storms, and the risk will steadily increase as sea levels rise. An inland road would be more climate-proof—but would cost a quarter of Samoa's GDP. How then to proceed?

A Bank-sponsored study in 2003 favored the inland option based largely on distance and time savings from the more direct route. (The study assumed a limited access highway rather than a road that would provide greater access and benefits to people along the corridor.) A second Bank-sponsored study in 2010 confirmed feasibility of the inland route, and made detailed recommendations about route selection.. A 2010 feasibility study by the Samoan Land Transport Authority indicated a general level of support and commitment for the road project from villages along the proposed route, but highlighted concerns about social impacts and resettlement. But investigations carried out under the World Bank-funded Samoa Infrastructure Asset Management Stage II project highlighted the high costs of the inland proposal, involving complex land and resettlement issues, time-consuming access negotiations and likely high compensation costs.

In the end, Samoa decided to proceed with the coastal rehabilitation, and to commence studies that would allow them to revisit the inland route in another 20 years The rehabilitation work aims to reduce road closures and flooding by improving drainage and road pavement. But a further 20 years of coastal development may only increase the difficulty of moving the road inland. An open, and difficult, question is whether an inland route would catalyze a new, alternative spatial pattern of development, reducing the economy's exposure to hazards—but imposing differential costs and benefits on coastal and inland landholders.

Sources: IEG, World Bank staff, project files.

Climate Change and Hydropower Investments

NORMATIVE CONSIDERATIONS

4.18 Designing and operating hydropower facilities requires a good understanding of climate variability and watershed function. For profitable operation, reservoir capacity and generating capacity need to be matched to the level and variability of water flows. If capacity is too small, benefits are forgone. If capacity is too large, capital is wasted. Dams also have to be able to withstand severe floods. Hydropower engineers and hydrologists have developed sophisticated modeling tools in order to meet these design challenges.

4.19 Climate change affects hydropower in several ways:

- *Average annual flows could change.* Higher temperatures will increase evaporation from reservoirs, decreasing flows. Climate change could increase or decrease precipitation and runoff, affecting power generation and profitability.
- *Flows could become more variable, day-to-day, seasonally, or year-to-year*. Loss of snowmass and glaciers means more flow in winter and less in summer. Climate change is expected generally to increase the variability of flows. These changes affect the economics of hydropower by requiring larger reservoirs. Run-of-river plants (with no reservoirs) become less attractive because of the lower capacity utilization. The tradeoff between power and environmental flows becomes sharper.
- *Catastrophic floods could get worse*. To meet desired levels of safety, dams may need to have more spillways, adding to costs.

4.20 These anticipated, but uncertain, changes could affect today's investment decisions via these channels:

- *Safety provisions.* Project analysis does not discount future risks to lives or to the environment, instead relying on standards. For instance, dams may be required to withstand a 1000 year flood or a "probable maximum flood." Since dams may stand for a century or more, anticipated changes between now and 2100 in this design flood affect today's structural decisions and costs.
- *Environmental impacts:* Declines in total water flows could result in tensions between maintaining power output and maintaining environmental flows.
- *Profitability and investment decisions*. In the near term, changes in patterns of runoff will probably be slow relative to existing variability (except in areas facing rapid snowmelt.) Changes in runoff two decades or more from now have comparatively little impact on investment returns if discount rates are high. Still, rapid or highly uncertain climate change combined with low discount rates, and climate-driven safety provisions could affect the attractiveness of hydro investments.
- *Design factors.* If well anticipated, climate change could alter the optimal capacity of a plant.[44] In the presence of uncertainty, it may be desirable to build flexibility into current designs. For instance, space may be left for installation of additional turbines to allow for the possibility of increased flows in the future; dams can be designed to enable future increases in dam height.

4.21 While many public agencies have put in place broad requirements that water resource infrastructures should incorporate climate change, no guidelines specify how this should be done (Vescovi, Baril and others 2009; Stutley 2010; Brekke 2011; UK Environment Agency 2011; USAID 2012). Hydropower project managers are thus left in limbo—pressed to incorporate climate change characteristics by agencies that are increasingly concerned with climate change adaptation, but without any operational guidance on how and when to do so.

ANALYTIC STUDIES

4.22 The Bank Group has undertaken some state-of-the-art analytic studies of climate impacts on hydropower operations, using GCMs. These studies are more extensive and sophisticated than standard appraisal techniques, and provide insights into the nature and magnitude of impacts, and into the uses and limits of climate projections in project planning. Three completed studies are described in Appendix F3; more are underway.

4.23 The usefulness of modeling varies widely. A regional study of the Zambezi Basin (Strzepek, Boehlert and others 2011) found a consistent signal of decreasing rainfall among 56 different climate model/scenario combinations. This coarse-grained model could not make specific recommendations, but indicates that the tradeoffs between growth (power production), poverty (employment in irrigated agriculture), and environment (the region's rich wetland and river-dependent biodiversity) are steep and would motivate a more in-depth look at options for energy and water conservation in the basin. In contrast, an assessment of the prospects of a recently installed Nepalese powerplant (Stenek, Connell and others 2011b) was stymied by divergent precipitation forecasts, a schizophrenic historical record of flows, and a lack of information about local snowpacks. Global models are poor at representing the monsoon rains upon which this region depends, and fine-scale local models would be stumped by Himalayan topography, even assuming that adequate historical weather data were available. So climate impacts could not be assessed, and the study recommended no-regret and low-regret adaptation measures. A third study, for a facility in Zambia (Stenek, Boysen and others 2011) indicated that allowance for climate change would not significantly affect the economics of the investment. It also illustrated that planned operating rules for the dam—maintaining minimum reservoir levels—could be incompatible in the long run with maintenance of high flows of water to the Kafue flats, an environmentally important wetland.

WORLD BANK GROUP PRACTICE IN INCORPORATING CLIMATE CHANGE INTO THE DESIGN AND APPRAISAL OF HYDROPOWER FACILITIES

4.24 IEG analyzed the appraisals of a sample of nine recent Bank Group-financed large hydropower projects for their treatment of climate variability and change (Table 4.4). These were SFDCC-era (post FY08), selected based on size and on availability of information. Projects were assessed for the length of hydrological record used; for their analysis of the risks to the investment posed by low flows under current climate variability; and for whether and how design and appraisal considered climate change risks. Note that many projects are presented for finance, especially to the IFC, at an advanced stage of preparation and design.

Table 4.4. Hydropower Project Designs Evaluated by IEG

Project	Type RR=run of river S= Storage	Testing of low flow sensitivity?	Testing of climate change?	Length of hydrological record used	Dam safety standard
IFC #1	RR	Y	N	35 years	N/A
IFC #2	Multiple projects, RR and S	N	N	N/A	PMF
IFC #3	S, glacier fed	Y	N	N/A	10,000 year flood
IFC #4	RR from glacier	Y	N	N/A	50-100 year flood for different components*
Rampur (World Bank)	Downstream of another project with storage, glacier fed	Y	Y	41 years	10,000 year flood
Trung Son (World Bank)	S	Y	Y	50 years	1,000 year flood
IFC #5	Multiple projects, S, some limited S	N	N	40-50 years	N/A
IFC #6	RR, small portion glacier fed	Y	Y	42 years	N/A
IFC #7	RR	Y	N	N/A	N/A

Source: IEG analysis based on available documentation and staff interviews.
Note: N/A = not available. *This facility has a low dam the failure of which would not be catastrophic.

4.25 Treatment of climate variability was inconsistent. The five projects where record length data were available used at least 35 years of data, which is sufficient for estimating average flows – on the traditional assumption that climate is not changing One project used only the most recent 35 of a 60-year record because of a perceived local climatic shift, a procedure that may underestimate existing climate variability. Six of the nine projects included at least some consideration of climate variability (most commonly by testing sensitivity to tenth percentile low flows), but for three projects there was no indication of consideration of climate variability. Of the projects that considered climate variability, two looked at the impacts of low flows on the IRR (investment rate of return) or ERR, two others looked only at the impact on the ability of the project to service its debt, and no details were available for two other projects. (Appraisal of an earlier IFC project based its assessment of flow reliability on a 59-year record. Shortly after commissioning, the project suffered two exceptionally dry years in a row. This, combined with construction cost overruns, halved the expected IRR.)

4.26 Three projects explicitly assessed impacts of climate change on river flows and project economics. One project used climate models to examine the potential range of future climate outcomes, while others did sensitivity analyses to assumed worst-case scenarios. For the projects that did consider the possibilities of climate change, the economics of the projects were so favorable that even poor climate outcomes would not make the projects unviable. For example, the Rampur project identified an existing downward trend in river flows, but found that the project would remain viable at a discount rate of 12 percent even if the trend worsened by a factor of 5. But these analyses considered only changes in average flows; no project considered the potential impact of changes in the seasonal distribution of river flows. No projects considered the possibility of adaptive management.

4.27 Some projects demonstrated a backward-looking approach to climate change; five of the IFC projects did not consider the impact of climate change on river flows because they did not observe a trend in their historic data series. This rationale seems questionable; the potential for climate change impacts over the economic life of the project should be informed by a forward-looking approach that considers qualitative climate model projections, reliance on glacier or snowmass, or other factors.

4.28 Treatment of dam safety varied across projects, but seemed reasonable. With no clear guidance on how to incorporate climate change into choosing safety standards, project designers usually selected a conservative standard and counted on this to be sufficiently high even under a changing climate. In one case, World Bank project involvement led to a higher safety standard than had initially been planned (Box 4-3).

Box 4-3. Trung Son Hydropower: A Practical Approach to Climate Risk

A $412 million hydropower project in Vietnam financed by the World Bank stands out as a model for mainstreaming climate change considerations into hydropower design. The project undertook an independent hydrological analysis to confirm the results of the primary analysis. An economic analysis of the project considered the potential impacts of climate change in a simple and practical way; it looked at existing projections for changes in precipitation in northwestern Vietnam drawn from country work carried out by the Vietnamese Environment agency, and used these to guide the bounds of sensitivity analysis for low-flow possibilities. It turned out that the project was robust to low flows and that the project would remain viable even in the most pessimistic climate change scenario where average flows dropped 26 percent by 2035. Average flows would have to drop by half in order for the expected economic rate of return of 18.9 percent to fall to the 10 percent hurdle rate.

Knowing that climate models were unable to predict with precision the possibility of future extreme flood events, the project design instead chose to mitigate the possibility of dam failure. Bank involvement in the project led to adoption of a safety standard that could withstand a 1 in 1,000 year maximum probable flood event (as calculated based on the historic river data). The project design also incorporated a secondary "fuse dam" (which would breach in the event of a 1,000 year event, protecting the main dam by allowing a secondary outlet to the reservoir), and it used zoning and warning systems in the flood zone to reduce the potential loss caused by a breach.

Sources: IEG, (World Bank 2011d), (Meier 2011); staff.

Land Use and Climate Change Adaptation

4.29 The world has seen accelerating land use change, including conversion of forest, range, and wetlands to agriculture, and of floodplains and coastlines to urban settlements. These changes will continue throughout the century as demand for food grows and as urban populations swell by billions. They are often effectively irreversible, shaping spatial patterns of development for centuries to come.

4.30 Unconstrained land use change could increase long-term climate vulnerability in two ways: by increasing the exposure of populations and infrastructure to storms and floods, and by constraining the ability of ecosystems to adapt to changing temperatures.

CLIMATE CHANGE, LAND USE, AND BIODIVERSITY

4.31 The World Bank Group is the largest financer of biodiversity projects in the world, largely through support for protected areas. But will these protected areas sustain biodiversity over the long term as the climate changes?

Normative Considerations

4.32 Climate change will transform ecosystems in many ways, threatening the survival of some (Bellard, Bertelsmeier and others 2012). Many species are temperature-sensitive. As temperatures rise, they will tend to migrate toward the poles and uphill. Changes in runoff and evaporation will affect wetlands and riverine ecosystems. Coral reefs will suffer increased bleaching or reduced calcification due to heat stress and ocean acidification. Reduced yields from agriculture may lead to additional pressure for land clearance or stress on high altitude areas. More frequent wildfires will disrupt the balance of fire-dependent ecosystems. Glacier retreat and snowmass melting will affect water availability in high-altitude ecosystems. Ecosystem linkages are further stressed when interrelated species (predator/prey, pollinator/plant) separate in space or in lifecycle timing.

4.33 The clearest prescription for adaptation is to maintain the ability for species to migrate in response to climate change (Hannah 2011). This requires ensuring connectivity between existing habitats. Connectivity does not necessarily require a continuous biodiversity corridor, but it requires, at least, the conservation of stepping-stone habitats within a broader biodiversity-friendly landscape. The network of habitats should include, if possible, microclimates that could be stable in the face of climate change. As habitats are converted to intensive farming or urban developments, options for this kind of conservation and connectivity are irreversibly shut. Ecosystem adaptation will require, in addition, a broad range of efforts to reduce current ecological stress imposed by people (Dawson, Jackson and others 2011).

Integration of Climate Change Consideration in World Bank Protected Area Projects

4.34 IEG examined the portfolio of biodiversity and protected area projects approved between 2009 and 2011. Of 34 projects, 8 considered the sensitivity of the project to climate change, of which half explicitly supported species migration through biodiversity corridors, while the other half assumed that reducing non-climate threats would support increased climate resilience in vulnerable ecosystems. Appraisals for 6 projects described the future threats of climate change in detail. Three projects supported climate vulnerability assessments and identified mitigation measures. All 8 projects proposed concrete actions to assist in climate change adaptation, including reforestation, creation of buffer zones, and preparation of management plants. Proposals were generally based on thorough studies and assessments of local adaptation needs.

4.35 Monitoring climate change adaptation in protected areas is still in its infancy. Only three projects made provisions to monitor successes and failures of climate change adaptation for biodiversity conservation. A further three projects included monitoring systems that did not include climate change considerations in their design, while the remaining two projects did not implement monitoring systems.

MACROZONING OF RURAL LAND USE

4.36 Conservationists have long advocated zoning of rural land use to maintain biodiversity and ecosystem processes. Sophisticated optimization techniques have been proposed to achieve ecological goals at least opportunity cost in foregone agricultural production.

4.37 Experience in land use regulation is mixed. On average, formal protected areas have reduced tropical deforestation. Protected areas that allow sustainable land use have been more successful than strictly protected areas. In Latin America, putting areas under the control of indigenous people has been extremely successful in deterring deforestation (Nelson and Chomitz 2011). However, macrozoning that attempts to regulate private uses of land has historically been unenforceable. Bank-executed zoning projects in Rondonia and Mato Grosso failed when they imposed restrictions on powerful ranching and timber interests. In Indonesia, 40 million people live in areas zoned for forests but lacking trees.

4.38 A new approach appeals to banks as an instrument of enforcement. In Brazil, banks are beginning to decline to make loans to farmers and ranchers whose land is out of compliance with regulations. The Western Cape Province (South Africa) uses zoning to impose EIAs on those who would convert critical biodiversity areas (Box 4-4).

Box 4-4. Spatial Planning for Biodiversity Conservation in South Africa

The Cape Floristic Region (CFR) is a biodiversity hotspot of global significance. While the world's other five floristic regions are continent-sized, the CFR occupies a corner of a single province, and contains 9,000 plant species, 69 percent of them endemic. Its survival is threatened both by climate change and by conversion of natural vegetation to agriculture.

With help from a Bank/GEF project, the Western Cape province developed a 20-year plan for conserving biodiversity. The plan involved developing a framework for spatial development planning. The follow-on Biodiversity Conservation and Sustainable Development Project elaborated this framework. After broad consultation on priorities and principles of land use zoning, the implementing agency, SANBI, applied sophisticated optimization tools to a set of fine-resolution maps of the region's biodiversity and natural resources. The output was a spatial conservation plan—a map of plots of land to be conserved. The plots were chosen to represent the complete range of the province's biodiversity and maintain important ecological processes while minimizing the number of hectares dedicated to conservation. The resultant top-down map of biodiversity priority areas was incorporated in state and district spatial development plans.

There are strong economic incentives for farmers to flout the land use plans. Potato and rooibos (an indigenous herbal tea) farms are expanding into the fragile lands of the Sandveld and Cederberg Mountains. Against these pressures, three instruments are deployed. First, the municipal plans—but these appear to be indicative, for the most part. Second, a quasigovernmental agency, Cape Nature, offers very modest incentives for landholders to sign conservation agreements. About 71,000 hectares have been signed to permanent, binding agreements, including in other parts of the Province. Potentially the most effective instrument is the requirement for any landholder who wishes to convert native vegetation to file an Environmental Impact Assessment (EIA). The EIA must note whether the conversion area impinges on a biodiversity conservation area; if so, the application may be denied, or banks may decline to finance the expansion. Illegal expansion is easily detected, since telltale irrigation circles are unmistakable on Google Earth. But penalties for failure to file an EIA are weak, and some stakeholders believe that the Agriculture Department is more sympathetic to expansion than to conservation. It will become evident within a few years whether the conservation plan is successful.

Sources: ICR; project documents; IEG site visit.

EXPOSURE REDUCTION

4.39 Urbanization and development in disaster-prone areas are the main driver of vulnerability to climate disasters, particularly in coastal cities and floodplains (IPCC 2012). So studies of flood adaptation (including the Bank's) often call for land use zoning and spatial planning to nudge urban development toward safer areas on higher ground (World Bank 2010a, 2011a, 2011b; Jha, Bloch, and others 2012).[45] Between now and 2050, urban populations in the developing world will grow by 2.5 billion people. Will those new settlers be directly in the path of storms and floods? Development patterns could be shaped through regulation, infrastructure placement, and incentives. Although benefit-cost studies are lacking, such policies could be cost-effective, given the tendency for vibrant urban growth to crystallize around a small initial development. Slightly higher initial costs could be repaid by much lower expected disaster costs in the future. (See Box 4-2. on Samoa's choice of spatial development patterns.)

4.40 However, it is difficult to find effective examples of land use zoning or spatial planning for exposure reduction. Within cities, land use zoning is difficult to enforce. It is difficult to keep developers from capitalizing on high value though risk-prone urban real estate, or from draining wetlands that provide citywide flood prevention benefits. It is hard to keep poor people from settling in low-value areas exposed to the greatest risk; creation of alternative housing opportunities is necessary, but may not be sufficient in the face of urban migration. Resettlement of existing residents is fraught with the potential for harming the most vulnerable if not done well.

4.41 The World Bank has little experience in implementing urban spatial planning and zoning,[46] but it has had some small-scale successes. As noted in chapter 3, a Brazilian water quality and control project created and maintained green spaces for flood overflows by designating them for parkland and soccer fields, ensuring popular benefits and support. Over 5,000 families were successfully relocated out of high-risk areas. State governments were required to demonstrate ex ante that funding was available for new land acquisition and for construction for those resettled by the project.

4.42 The Bank has supported some successful examples of resettlement out of disaster-prone areas. In Argentina, a Bank-supported flood protection program adopted an assisted self-construction strategy, where poor and low-skill residents whose houses had been damaged or destroyed by floods were trained in construction and received material assistance in building homes in safer areas(Pérez and Zelmeister 2011). In Colombia, a Bank-supported disaster risk reduction project successfully undertook preventative resettlement of households in the Nueva Esperanza neighborhood of Bogota out of areas exposed to landslides in flooding (Poveda Gómez 2011).

4.43 Overall, resettlement as a risk reduction strategy has happened in relatively few Bank projects. Involuntary relocation can be a politically sensitive issue for clients. Bank safeguard policies (appropriately) require careful management and monitoring of any involuntary resettlement. Preventative resettlement is seen as difficult and labor intensive, rather than as a regular part of a disaster risk management toolkit. Together, these mean that Bank staff face weak incentives for undertaking projects that reduce exposure. And individual resettlement programs financed by the Bank are likely to have only a modest direct impact on global exposure to natural hazards.

4.44 More effective than resettlement of existing populations would be to institute zoning that will shape future development patterns at large scale over a long period. The largest ongoing such effort is an ambitious Integrated Coastal Zone Management Project in India. Approved in 2010, the project supports creation and public dissemination of hazard maps for the 100 year coastal flood event and the 100 year erosion line for the entire coastline of India (at a cost of $80 million, including support for creation of a new national center for coastal zone management). Delineation of these zones will take climate change into account by incorporating future sea level rise projections up to 2110, though its estimates of storm surge will be based solely on historic data. The project will then use these maps to delineate coastal planning areas throughout the country, and will finance development and initiation of integrated management plans for these areas in three pilot states (at a cost of $200 million). The plans will attempt to balance security of life and livelihood (including disaster exposure) with pollution management, resource conservation, and livelihood improvements, which may include limiting development in vulnerable areas. Demarcation of flood lines with ground markers may also encourage private adaptation or exposure reduction by individuals and firms.

4.45 The Bank is also providing technical assistance (TA) to Indiaon spatial development options in the climate-threatened Sundarbans. (See **Error! Reference source not found.**.) The TA found that a number of apparently adaptive actions were in fact maladaptive, locking populations into increasing exposure to risk. The TA proposes measures for immediate risk mitigation (such as improved early warning systems and cyclone shelters) but also envisions a long-term spatial and human development plan which reverses earlier maladaptation.

PREPARING FOR LONG-TERM AGROCLIMATIC TRANSITIONS

4.46 Climate change will impose severe stresses on agricultural systems, necessitating changes in what is grown where. Some stresses are predictable. Current grain varieties are highly sensitive to temperature spikes over 30° C—each day above that threshold reduces yields by 1.7 percent under drought conditions (Lobell, Banziger and others 2011). Hillside crops such as coffee are also sensitive to temperature change. Because hillsides are warming and temperature spikes increasing, these crops will not continue to be viable in their current form in their current location.

4.47 The public policy implications for spatial planning are unclear, but deserve investigation. Production areas for commercial crops may have to relocate. Entire areas may need to transition between different kinds of agriculture. Can these transitions be accommodated purely through private sector responses? There could be a role for public policy in information provision, extension services, credit, and infrastructure. As a first step, ongoing analytic work in the Bank is assessing the implications of climate change for spatial patterns of agriculture in Brazil. This needs be complemented by analyses of the economics of responding to agroclimatic shifts.

Box 4-5 From maladaptation to adaptation in the Indian Sundarbans

A recent World Bank executed Non-Lending Technical Assistance (NLTA) in West Bengal, India, is a good example of integrating long-run anticipatory adaptation efforts into development planning.

The Sundarbans, straddling India and Bangladesh, are part of the great mangrove-dominated delta facing the Bay of Bengal. The Indian portion is home to more than 4 million poor and climate-vulnerable people. Their average per capita annual income is $180, and 70 percent lack access to safe water. Many live at or below sea level and are at constant risk from floods and cyclone. They endure creeping salinization as the sea rises; about a third of the farmland already has high salinity. Productive landholdings average just 0.36 hectares and are likely to shrink as population grows.

The NLTA found that many well-intentioned and apparently adaptive activities in fact were maladaptive, boosting long-run vulnerability. Most importantly, the seemingly protective 3500 km system of embankments, dating to the nineteenth century, is literally undermining itself. The embankments constrict tidal flows, which then erode the embankments' foundations. Inadequate water resources management by aquaculture activities and rising sea levels place further pressure on the embankments. Attempts to reinforce them just make them heavier and less stable. When hit by storm surges, the walls fail, with disastrous consequences.

The NLTA recognized the need to deal with today's urgent poverty challenges but concluded that business-as usual-development is not sustainable in the long run. River channels are too narrow even for current tidal flows, due in part to climate change over the past century. The combination of rising seas and subsiding land will increase the flows, and will make lower-lying portions of the delta increasingly uninhabitable.

In response, the NLTA proposes that the Sundarbans embark on a multigenerational plan to re-engineer estuary management and consider options to enable and motivate welfare-improving voluntary outmigration from the most threatened areas. Where channels are too narrow, the indefensible embankments would be moved back by 100 to 350 meters over a period of 20 years. Flood-threatened farmland would give way to river and mangrove, requiring a managed retreat that would be difficult but would prevent future catastrophes. Starting now, increased attention to education would equip new generations with the skills to seek better livelihoods in India's cities as they expand over coming decades. Infrastructure and policies would be targeted towards encouraging development in the less-threatened parts of the Sundarbans. The preferred outcome would be that the most threatened parts of the area would eventually be allowed to revert to mangrove, expanding the rich and threatened ecosystem and boosting prospects for sustainable, profitable, ecotourism. (This is a home of the Royal Bengal tiger.) This long-term vision would be complemented by immediate actions to set up early warning systems, build a network of cyclone shelters, improve health, water and sanitation services, and enhance cooperation among the many agencies concerned with the Sundarbans.

In sum, the NLTA illustrates the need to think now about how to shape long-term spatial and human development patterns in order to create a more sustainable and resilient future.

Sources: Battacharya Pethick, and Sensarma, K (forthcoming) World Bank (forthcoming)

Agricultural Research and Development, Including Conservation of Genetic Resources

4.48 Climate change will expose many agricultural systems to locally or globally unprecedented stresses, including heat, drought, flood, salinity, and emergent strains of pests. While it may be difficult to anticipate the precise needs of precise locations, there could is an argument for publicly supported prebreeding of crop varieties with desirable traits (Guarino and Lobell 2011). The availability of such a portfolio could cut short the 10-12-year lead period required to breed some species to meet local conditions.

4.49 The CGIAR (Consultative Group on International Agricultural Research), with funding in part from the World Bank, is supporting this kind of research and development, targeting smallholder farmers. Recent reform in the CGIAR has led to the initiation of an array of large research programs, one of which is on climate change. The focus in this CGIAR research program includes work on adaptation through better management of agricultural risks associated with increased climate variability and extreme events and accelerated adaptation to progressive climate change via technology, agronomy, and policy options Several other CGIAR research programs and individual center activities dealing with crop and livestock improvements have a climate change dimension.

4.50 Funding the creation of these public goods and supporting countries to be able to adapt new knowledge and technologies developed elsewhere is key to extending the benefits of location-specific research and development. The IEG evaluation of agriculture and agribusiness (IEG 2010a) recommended that the World Bank work with partners to ensure that CGIAR research is translated into benefits in client countries. The World Bank is a major donor to the CGIAR, providing $50 million annually to the system’s core budget. This funding is totally fungible and is not specifically tied to climate change activities. Besides providing core funding, there is little evidence that the World Bank has worked directly with individual centers or with the Consortium of CGIAR Centers to shape the agenda in agriculture and climate change adaptation. IEG correspondence with scientists in the centers suggests that the level of interaction between the Bank and centers is often ad hoc, limited in many cases to informal interactions and sharing of research results.

4.51 Several Bank documents mention the importance of strengthening the links between World Bank and the CGIAR, but there are no guidelines for direct incorporation of CGIAR research and research results into Bank operations. Progress in extending the benefits of science in adapting to climate change requires that many developing countries have the ability to adapt new knowledge and technologies that lead to more sustainable and resilient agricultural systems. However, many public research organizations in developing countries face serious institutional and capacity constraints. Sustained World Bank support through greater focus on national and regional-level research and development and systems for transferring knowledge to smallholders would enhance the effectiveness and ability of developing countries to benefit from scale economies in creation of public goods that help farmers adapt to climate change.

4.52 Underlying the development of new varieties is a need for conservation of genetic diversity in food crops and animal**s**. Many staples and commercially important crops and animals lack genetic diversity, making them potentially widely susceptible to climate-related stresses, such as emerging pests. For instance, there is very little diversity in commercially cultivated *arabica* coffee A potentially important response would be to conserve the wild relatives of current crops, which may harbor genetic traits needed for an altered future (Guarino and Lobell 2011). This has been done in seed collections, but there is a strong argument for also conserving these resources *in situ*, that is, in the wild. This would allow them to coevolve with climatic and ecosystem conditions (Hunter and Heywood 2011).

4.53 Although the Bank is a leader in investing in protected areas (with GEF support), it has only made five investments in *in situ* agrobiodiversity conservation. This is a striking contrast, given that it is much easier to argue that agrobiodiversity has monetizable benefits, as compared (for instance) to rainforests that are appreciated for the rarity and uniqueness of their noncommercial species.

Conclusions

4.54 The Bank Group, like others, lacks guidance on how best to incorporate climate change considerations into the design and appraisal of infrastructure projects, and current practice is inconsistent. Staff have expressed interest in having guidance.

4.55 The Bank has turned to global and regional climate change models to inform decision making on projects and programs. Those models have been useful for awareness raising and context setting, but have often proved less fit for purpose than hoped. They are more suitable for indicating regional temperature-related climate impacts than for quantifying smaller-area precipitation-related impacts. Analyses of long-term climate adaptation options typically confront such a broad range of possible futures that they default to recommending robust, “low-regret” measures.

4.56 There are, however, some areas that require anticipatory climate change adaptation now, because long-run projections are sufficiently clear and because development paths can lock-in to more or less resilient paths. Prominent among these is the desirability of shaping spatial development patterns to reduce exposure to sea level rise and floods, improve coastal zone management, and make biodiversity more resilient to climate change. However, there are severe political difficulties in regulating land use. Examples are few, and successful examples fewer, but new approaches are emerging.

4.57 There is a potentially important role for the Bank Group in supporting global public goods for ACC. Development of new crop and animal varieties to meet anticipated future conditions (such as drought or inundation) is an important example, because they have a long lead time and can cut short the time to develop locally appropriate varieties. The World Bank indirectly supports CGIAR research and development for this purpose. While the Bank has played a prominent role in protecting global biodiversity in general, it has supported only a handful of projects that conserve wild agrobiodiversity, which could contain genetic material valuable for future adaptation challenges to agriculture.