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# Impacts of Climate Change and Adaptation to Climate Change: Current State of the Art

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# Impacts of and Adaptation to Climate Change

- What have we already observed?
  - Mostly high confidence on what happened
  - But how much was anthropogenic? Confidence varies.
- What impacts are we likely to see in the future?
  - Depends partly on how much GHGs we emit?
  - Confidence levels on impacts vary from low to medium
- What adaptation measures should we implement to address climatic impacts?
  - Actions will take place over time
  - What are the areas where urgent action is needed and what form should it take?

# WHAT CLIMATE IMPACTS HAVE WE ALREADY SEEN?

# Coastal glaciers

## Muir Glacier, Alaska

August 1941



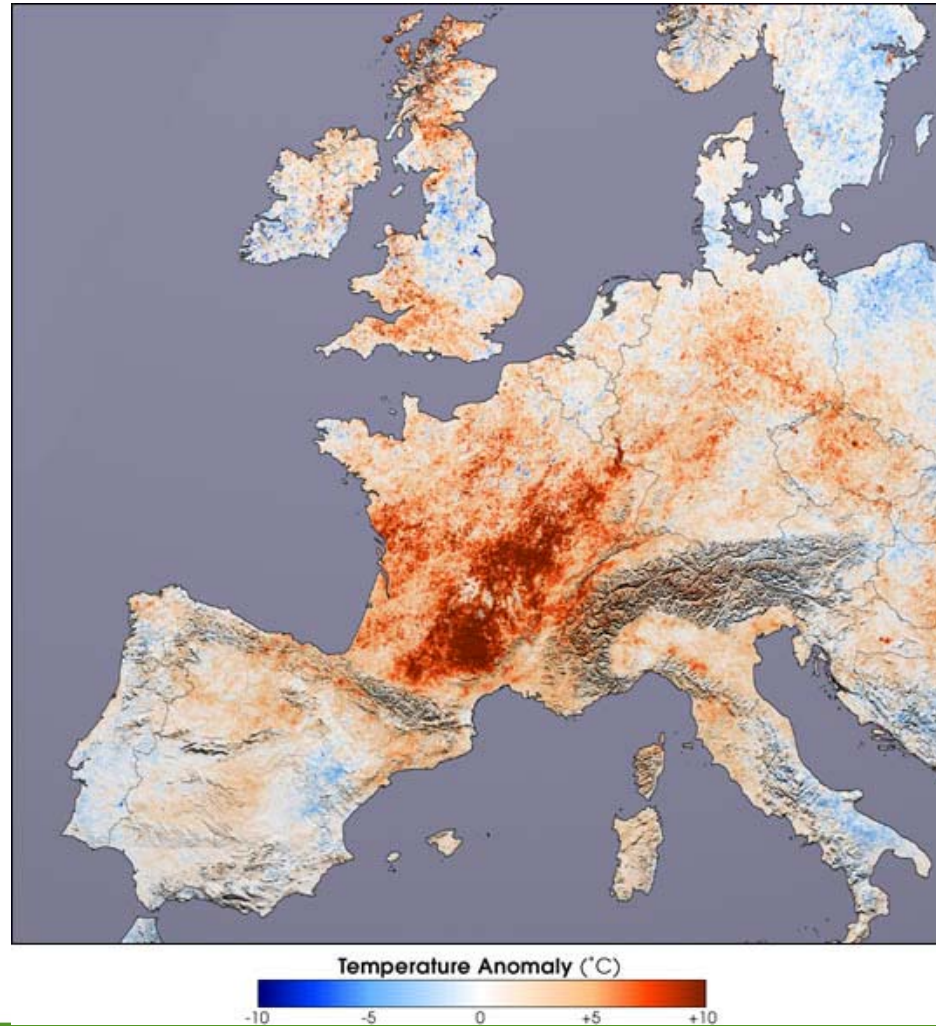
August 2004



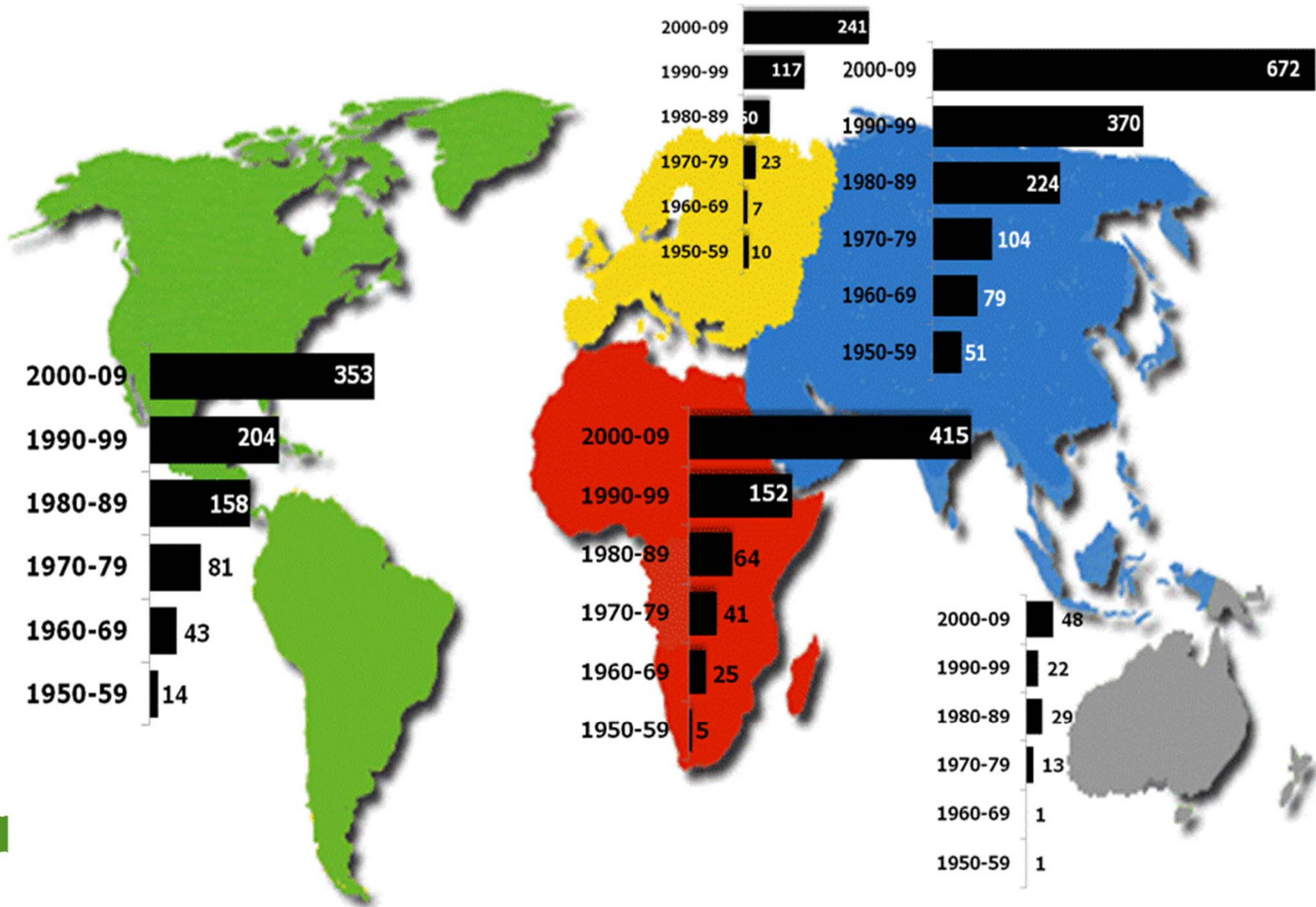
NSIDC/WDC for Glaciology, Boulder, compiler. 2002, updated 2006. *Online glacier photograph database*. Boulder, CO: National Snow and Ice Data Center.

# 2003 European Heat Wave

Hottest  
Summer in  
at least 500  
years!



# Floods 1950-2009



Source: Kuma Aldaketa Ikergai. The international disaster data base. Center for Research on Epidemiology of Disasters. 2010.



## Droughts

**400,000,000 people are living under extreme drought conditions**

**“Very Dry” Land, Worldwide:**

**15% in 1970**

**38% in 2010**

## More Recent Evidence on Past Trends: Examples

Region	Ecosystems	Human Systems
Africa	Lake warming; retreat of glaciers	Decline in fruit bearing trees
Europe	Retreat of glaciers; colonization of alien plant species	Stagnation of wheat yields in some countries; damages from forest fires
Asia	Permafrost degradation; shrinking glaciers; increased runoff in many rivers; coral reef decline; shift in marine species	Vulnerable communities affected by floods and extreme events
C&S America	Retreat of glaciers; increase in extreme flows in Amazon; some other rivers have increased runoff, others a decline	Increase frequency of malaria; increase in agricultural yields in SE and S America
General	Glacier retreat; changes in runoff; increased drought events; warming and acidification of oceans; impacts on marine ecosystems	Flooding and water shortages in urban areas. Crop yields in rural areas.



## 2001 to 2010: A Decade of Extremes: Report from WMO

- The decade was the warmest for both hemispheres and for both land and ocean surface temperatures. The record warmth was accompanied by a rapid decline in Arctic sea ice, and accelerating loss of mass from the Greenland and Antarctic ice sheets and from glaciers.
- Global mean sea levels rose about 3mm per year - about double the observed 20th century trend of 1.6mm per year. Global sea level averaged over the decade was about 20cm higher than in 1880.
- The report notes that the high temperatures in the decade were achieved without a strong episode of the El Nino current which typically warms the world. It says that a strong El Nino episode would probably have driven temperatures even higher.

# WHAT CAN WE EXPECT IN TERMS OF CLIMATE CHANGE IMPACTS FROM NOW TO 2100?

## Likely Climate Impacts to 2100 Depend on Scenario of Future Emissions of GHGs,

- Under an optimistic scenario: we can expect temperature increases of 0.4-1°C by mid 21<sup>st</sup> Century and 1-2.6°C by late 21<sup>st</sup> Century.
- Under a pessimistic scenario we can expect at upper end of 0.4-1°C by mid 21<sup>st</sup> Century and 2.6 – 4.8°C by end 21<sup>st</sup> century.
- Both scenarios shows precipitation changes, with decreases in low and mid latitudes and increases in high latitudes. The changes are more severe in the pessimistic scenario.
- For the period 2081 to 2100 (relative to 1986–2005), global mean sea level rise is *likely (medium confidence)* to be in the range 0.36–0.63 m (optimistic) and 0.48–0.82 m (pessimistic) scenario.
- Local variations around these mean values will be large

## Emerging Risks from Climate Change

- Consider by sector:
  - Health
  - Coastal Zones
  - Freshwater Systems
  - Urban Systems, Infrastructure and Energy
  - Agriculture
  - Terrestrial and Marine Ecosystems
  - Economic development and other sectors

# Health

- Impacts of CC
  - Greater risk of injury, disease and death from extreme events
  - Risk of under-nutrition from reduced food production in poor regions
  - Loss of work capacity among vulnerable populations
  - Modest improvements in some areas due to less cold weather,
  - Increases risks of food borne, water borne and vector borne diseases.
  - Air quality effects such as tropospheric ozone could increase
- Regional Effects
  - Vector borne diseases and malnutrition most likely to increase in Africa and parts of Asia
  - Europe likely to be affected by tropospheric ozone and increased heat waves
  - C & S America likely to be affected by malnutrition and water borne disease.
- Vulnerability
  - Greatest in poor countries and places with poor public health services and disaster preparedness

## Coastal Zones

- Local variations in sea level rise and frequency of storm surges etc. must be taken into account when accounting for impacts. Projections of storm surges, however, are still very uncertain.
- Coastal zones are increasingly areas of human population concentration so effects of SLR and extreme events is estimated to be very high and adaptation will be important. E.g. with 1.2 m rise globally damages per year by 2100 are estimated at US\$300 billion without adaptation but with adaptation they go down to US\$90 billion.
- Regional variations are significant:
  - In Europe CC will entail loss of wetlands and major investments in sea defenses.
  - In Africa some coastal urban areas will need protection, but impacts of loss of coral and fisheries will also have important economic consequences.
  - Low lying island states may find protection of some of their land too costly to undertake.
  - Hot Spots include: New York area, Gulf of Mexico, Mumbai, Dhaka, Durban, SE Asian cities, Small island states,

## Freshwater Systems

- As meltwater production from glaciers increases initially and then declines water flows to areas of human population could alter a lot. Some places will face alluvial flooding. Indications are also that groundwater recharge will be reduced in parts of SW Africa, N. Africa, the Near East and Australia.
- Climate change is expected to reduce renewable water resources in most semi-arid and arid regions with major consequences for agriculture and possibly for households and energy suppliers.
- Water quality changes are possible as a result of changes in rainfall, erosion and deforestation.
- Regional specific examples include:
  - In Europe CC will decrease surface water quality due to higher temperatures.
  - In Asia and in S. Europe water scarcity is expected to be a major factor.
  - In C&S America vulnerability to water scarcity is likely to increase in Chile-Argentina, NE Brazil, Central America and the tropical Andes.

## Urban Areas , Infrastructure and Energy

- Increased risks of damages to transport infrastructure, buildings etc. is likely in urban areas from extreme events, especially with the growing urban populations.
- Investment in new infrastructure will require it to be “climate proofed” against risks of subsidence, damage from extreme events etc.
- Energy systems will be affected by changes in water availability. Demand for energy will shift from heating to cooling. Integrity of pipelines and grids will be affected.



## Agriculture

- Risks of declines in yields are very severe if temperatures rise to 4-6°C. This would affect over 90% of the population.
- Even with increases of up to 2°C yields are expected to decline for major cereals.
- Higher CO<sub>2</sub> levels will enhance the distribution and quantity of invasive weeds.
- Increased heat stress will affect livestock in most locations.
- Impacts are more severe in tropical regions than in temperate ones.
- Effects of CO<sub>2</sub> in terms of fertilization may be a positive consequence but how it works out in practice is still uncertain.

## Terrestrial Ecosystems

- Significant changes in ecosystems can be expected, with the magnitude increasing with temperature.
- In cases other than the most optimistic regarding emissions species distribution and ecosystem function will be affected; alien species will spread in some regions.
- Forests are likely to suffer tree mortality and forest dieback from pests and diseases. Other positive effects of increased growth are being viewed with skepticism. Increased forest fires are already being observed.
- Tipping points may be reached for some ecosystems so that they change totally in composition, structure and function (Boreal-Artic systems; Amazon).

## Marine Ecosystems

- Fundamental and far reaching changes in the structure and functions of marine ecosystems can be expected.
- Ocean acidification affects a large range of organisms, including corals, fish, crustaceans.
- Some modeling indicates that fishery yields may increase in high latitudes (30-70%) and decline in low latitudes (40-60%). This will reduce access to food in some places and increase poverty.
- Creation of zones that are hypoxic can be expected in some locations (Gulf of Mexico, North Sea, Arabian Sea).
- High temperatures will increase harmful algal blooms in some parts of Europe.
- Many uncertainties remain about the effects of climate change on marine ecosystems.

## Economic Development and Other Sectors

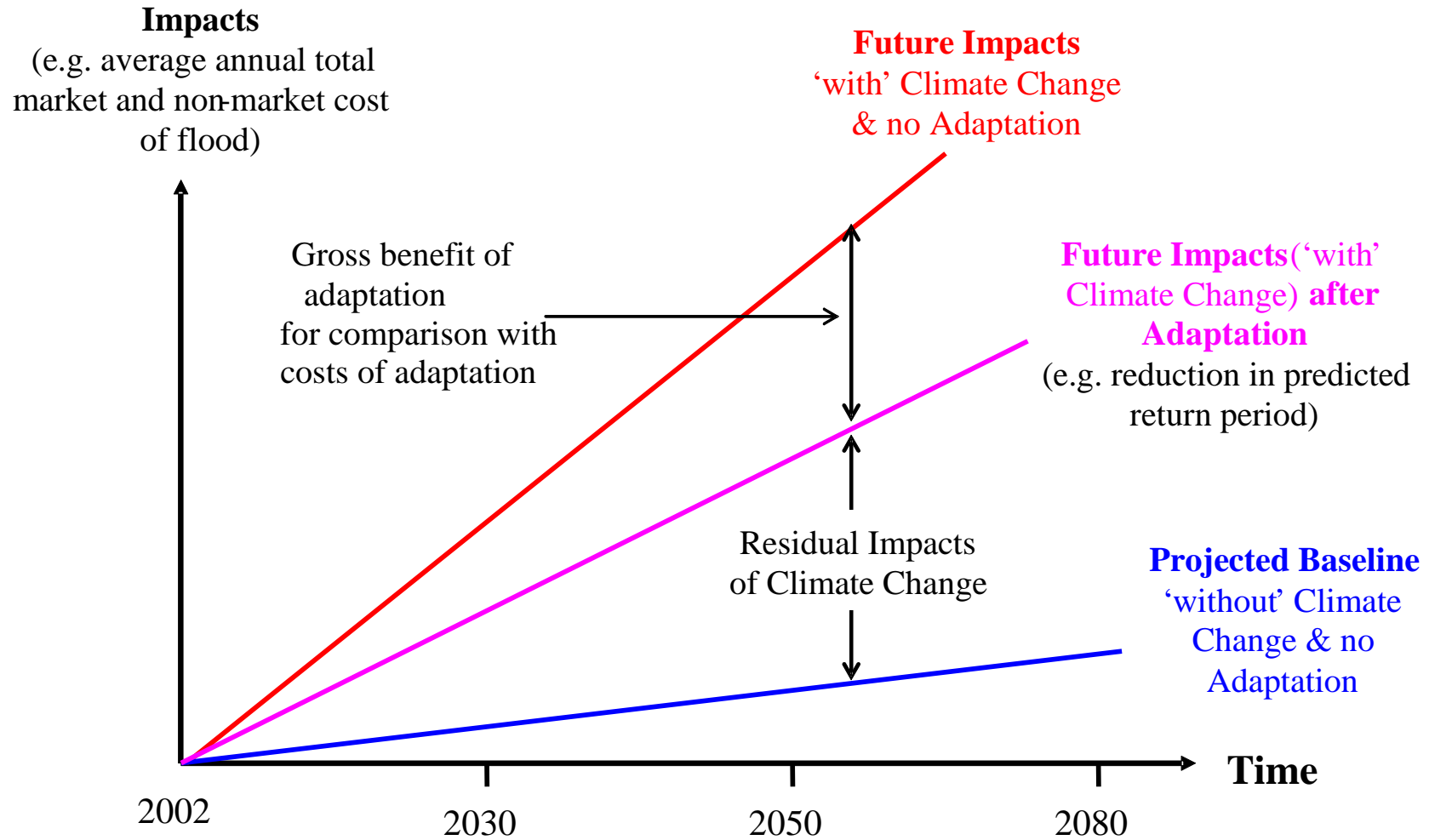
- Climate change will affect economic development and growth negatively where it increases poverty and causes damage to infrastructure. This is most likely in developing countries in the tropics.
- Sectors most likely to be affected include energy, transport, tourism.
- Energy systems dependent on water will need to be reconfigured.
- Transport infrastructure malfunctions are expected from heatwaves and other extreme events.
- Tourism will be affected by changes in temperature. For example the Mediterranean will become too hot during summer, but the climatic conditions will improve during spring and autumn. Skiing tourism in low altitude locations will decline. Northern European countries could see a benefit from higher summer temperatures. These impacts are expected from 2050 onwards.

# HOW CAN WE ADAPT TO THESE IMPACTS?

## Adaptation: Some General Observations

- We are bound to make some adaptation to the changes as individuals but we may also need to take actions collectively. How do we combine the private and public actions?
- The evidence on how much climate change we will face and what will be its consequences is highly uncertain but the knowledge base is changing. How do we design our policies to allow for a such a changing base?
- How can we select the best options for adaptation, given all the other pressures we face for public resources. What is the role of economic decision-making tools?

# Basic Issues



## The Ideal Evaluation and Its Problems

- We estimate the benefits of the measures relative to the baseline and the impacts line
- We estimate the costs of the measures
- We select those that have the highest net benefits.
- Problems with this:
  - Uncertainty
  - Dynamic nature of the baselines etc.
  - Lack of knowledge
  - Benefits are very complex to estimate in money terms
  - Impacts will depend on amount of mitigation



## A Lot of Uncertainty to Contend With!

- For a 2°C increase the decrease in water availability is estimated at 20-30%, the declines in crop yields in tropical regions could be 5-10% and 15-40% of species are said to be facing extinction (Parry et al. 2007). These wide ranges become even larger when different emissions scenarios and different modelled projections of temperature change are taken into account.
- To the uncertainty of the magnitude of the physical impacts, we have to add the uncertainties associated with the valuation of the impacts.
- In addition to the uncertainties described above we also have to take account of the incomplete coverage of climate change itself, as well as the risks and impacts in the literature.

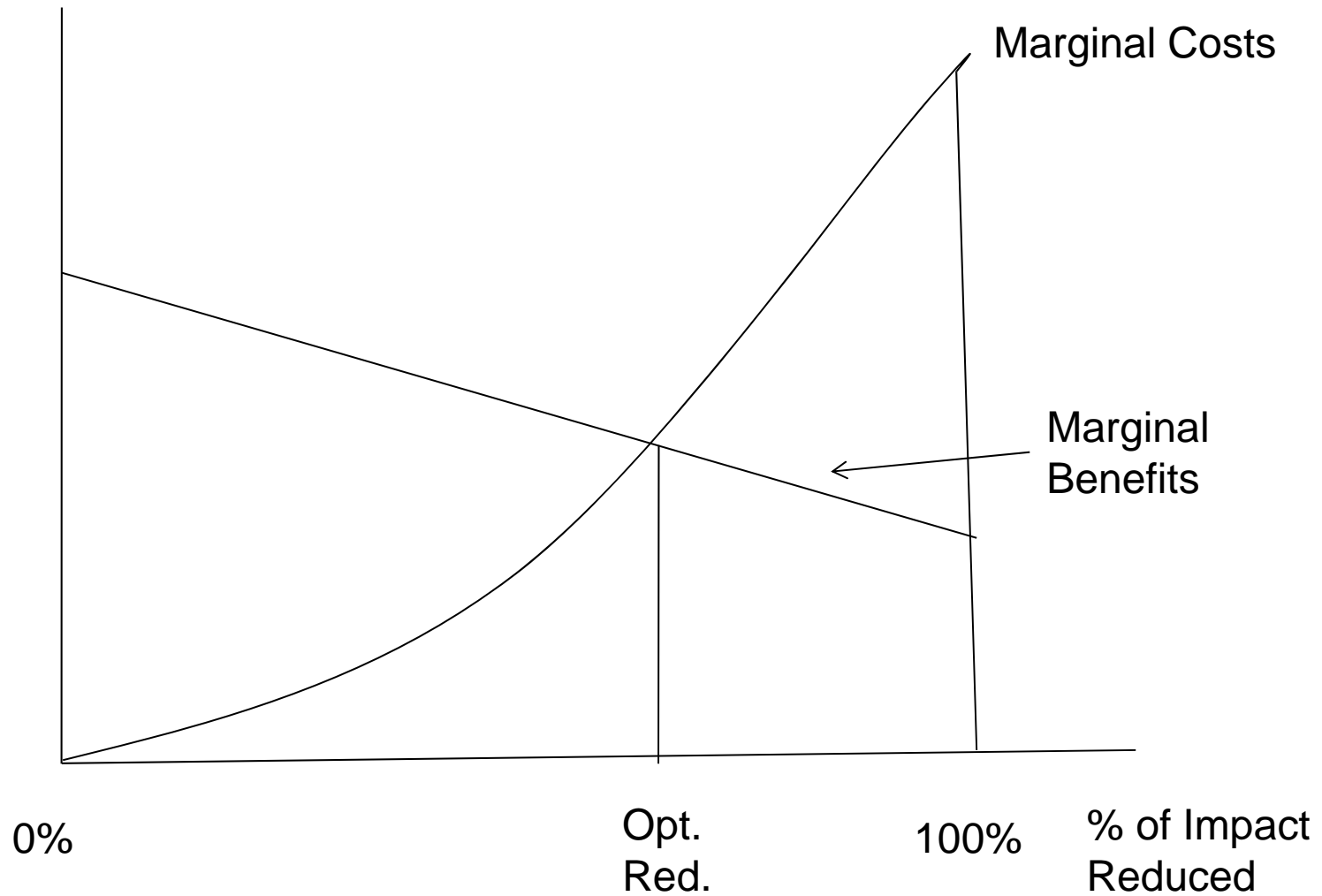
## Adaptation Costs & Residual Damages: Alternative View

- There is also a view that adaptation costs should be measured as the full costs of compensation for the damage done due to climate change.
- In other words they would argue that the residual damages should be included in any adaptation package.
- What is presented in practical estimates is typically a mixture of the two: individual studies find it hard to define adaptation cleanly in many cases and simply report total damages.
- Key point: even if one takes the view that ‘adaptation’ means compensation for all damages it is very important to know what the costs of appropriate actions are and what residual damages should be accepted so that the right policies can be put in place.

## Issues That Arise

- Adaptation Deficit
  - In many countries level and quality of infrastructure is very poor and this is the cause of the high damages caused by climate change. If the level and quality can be improved over time damages from climate will be less (e.g. flooding). How much of this increase in investment should we attribute to climate adaptation and how much to development?
  - Risks in combining development with adaptation into one strategy (specific adaptation issues will get less importance).
- Residual Damages
  - It may not pay to go for zero residual damages. Marginal costs of removing all damages rise and marginal benefits fall. That is why it makes sense not to plan for full protection against consequences of climate change.

# Marginal Costs/Benefits



## Baselines

- Define what would happen in the absence of climate change.
- Clearly an element of judgment as we are looking forward 20 or more years.
- For example most developing countries will have improved public health by then. This has to be allowed for.
- Given uncertainties, some researchers have proposed using multiple baselines and then selecting measures that fulfil the requirements of stakeholders under a range of possible outcomes.

## Reversibility, Flexibility and Adaptive Management

- Adaptation measures must be designed so they can be modified in the light of new information.
- One way to incorporate such an approach is through the use of option values in the cost benefit or cost effectiveness analysis.
- So if the scheme you propose has the option of being modified you attach a value to that option.
- Can be useful for projects with very long lifetimes.
- Guidance on how to use option values in this context have been provided in the UK but practical applications are very rare. (Thames Estuary Study in the UK used them)

## Ancillary Benefits

- Many adaptation actions have other benefits than simply to reduce the impacts of climate change:
  - Reduce vulnerability to other risks
  - Reduce exposure to local pollutants
- Where possible such benefits should be included in any cost benefit analysis.
- Problem is sometimes one of measuring them.
- Often ancillary benefits favour the poor and vulnerable and should be given greater weight for that reason.
- In climate policy important ancillary benefits arise when a policy can increase adaptation while also reducing GHGs. See examples.

## Examples of Complementary Mitigation and Adaptation Actions

- London: The “green grid” for East London seeks to create multi-purpose open spaces to absorb and store water, to cool the vicinity and to provide a mosaic of habitats for wildlife.
- Tokyo: Tokyo's urban greening policies promote the development of green roofs and urban gardens to address urban heat islands and moderate building temperatures, to reduce storm water runoff and urban flooding, and to act as carbon sinks.
- Cornwall UK: By generating power through smaller and more decentralized means, renewable energy resources can reduce greenhouse gas emissions and also vulnerability to storm events and to brownouts during peak demand in heat waves.
- Durban: A pilot green roof project and a Community Reforestation Program, in which communities produce indigenous seedlings to plant and restore forest areas, address both mitigation via reduced energy demand energy and adaptation to climate effects in urban areas.



## Issues That Arise

- **Distributional Impacts**
  - Many impacts of climate change affect the vulnerable (elderly, poor, those with health impairments). Hence we cannot look only at net benefits in deciding on policies. We must take account of distributional factors.
- **Valuation of Impacts**
  - We cannot value all impacts in terms that are acceptable to policy makers. E.g. increased deaths? Losses of biodiversity? Loss of cultural assets? In such cases we need to combine monetary valuations of some impacts with other indicators of value that are not monetary. Involves using techniques such as multi-criteria.
- **Changes in Risks**
  - We can value changes in risks of negative events but this needs sophisticated methods of valuation. We cannot just take expected damages as an indicator of loss or gain.

## Simplifications

- Divide the impacts and measures by sector
  - Health
  - Sea Level Rise
  - Freshwater Systems
  - Extreme Events
  - Infrastructure
  - Agriculture
  - Ecosystems
  - Other sectors (tourism)
- There will be overlaps but these can be addressed as they arise.

## Health

- Measures include both preventive (e.g. bed nets) and clinical treatment of people affected. Generally preventive treatment is less costly.
- A useful metric of impacts is DALYS or VOLYS. Projects are accepted if the cost per DALY or VOLY is less than an agreed amount.
- Used in health planning and familiar to policy makers.
- Distributional issues are of great importance here.
- Data on relative risks are still quite uncertain.
- Baseline important – vector borne diseases decline with development!

## Sea Level Rise (SLR)

- With sea level rise the impacts are largely in terms of loss of the services of land. Estimates of loss of services under climate change have been made; in fact this is one of the better quantified areas of impacts.
- Adaptation measures can reduce this loss of services and the benefits are then measured in terms of the cost per ha. of the adaptation measures relative to the increase in services per ha. as a result of the measures. As a point of departure we can take land prices as a measure of the discounted present value of future land services.
- Options can be described as: Retreat, Accommodate and Protect.
- The Dynamic Interactive Vulnerability Assessment (DIVA) tool has been used widely used to calculate the costs for coastal protection. It covers impacts from flood and storm damage, wetland loss, erosion and saltwater intrusion. The adaptation measures include mainly coastal protection and beach nourishment. Hence it is very engineering oriented. Some specific features such as cyclones are not covered.

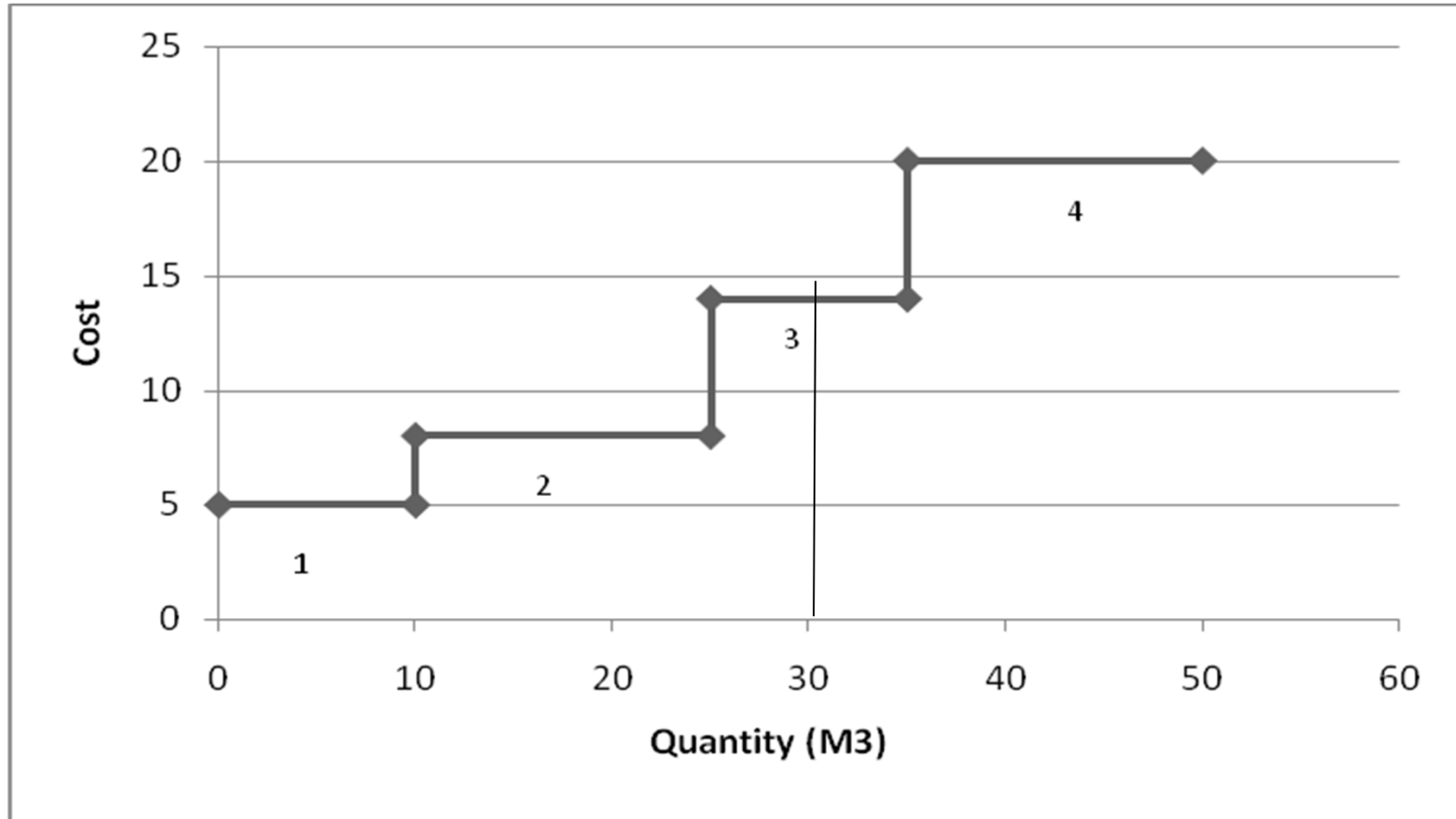
## Sea Level Rise (SLR)

- *Some services of land are not captured in land prices.*  
These could be significant if externalities are not captured in the market valuations. In such cases additional values of land have to be added to the market value, based on non-market valuations.
- All this suggests that model results need to be complemented by additional measures based on assessment of soft options and inclusion of phenomena not covered by SLR.
- And there are distributional impacts in poor countries where SLR can affect livelihoods of poor people. Here decisions may need to compare alternative livelihoods and ensure full compensation.

## Freshwater Systems

- The impacts of climate change on freshwater systems are mainly due to the observed and projected increases in temperature, sea level and precipitation variability. An increase in the ratio of winter to annual flows, and possibly the reduction in low flows caused by decreased glacier extent or snow water storage, is predicted. Sea-level rise will extend areas of salinisation of groundwater and estuaries, resulting in a decrease in freshwater availability for humans and ecosystems in coastal areas. Increased precipitation intensity and variability is projected to increase the risks of flooding and droughts in many areas of the world.
- The analysis of adaptation measures has to be carried out at the river basin level. Projections are available of water demand and supply going forward 30 years and possibly longer. Against this one can make estimates of changes in supply resulting from climatic impacts. This will create (in most cases) a gap between demand and supply relative to the baseline situation. The proposal is to rank different measures to fill this gap, based on the cost per cubic meter of water provided. Robustness analysis has to be applied to make sure we choose the best option!

# Ranking Measures for Water



## Extreme Events

- Extreme events almost certainly will merit some adaptation measures.
- The impacts are best characterized in terms of increased frequency of such events, causing loss of life and damage to property.
- Actions can be taken to reduce the frequencies to the baseline level and/or to reduce the consequences for the events so that damages are no more than at the baseline level. An example of the former could be raising protection barriers, while an example of the latter would be relocating individuals and increasing protection for property.
- In work we have designed adaptation measures so as to keep the expected losses from extreme events at a level that reflects societal risk. This bypasses the benefit cost decision-making methodology but it may be justified on the grounds that public concern for losses from extreme events is sufficiently high for us to adopt an absolute standard.
- It also avoids the problem of valuing loss of life.



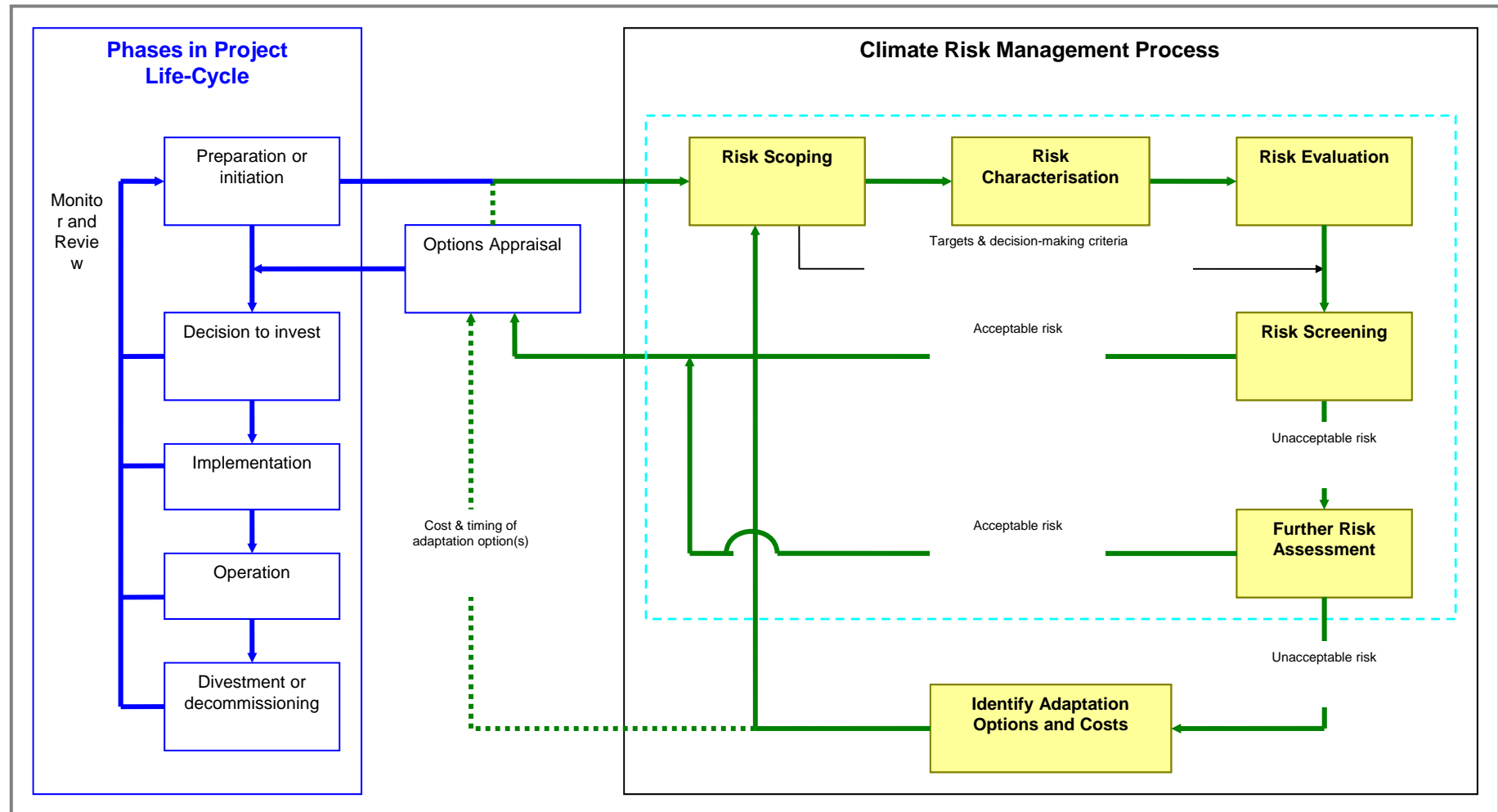
## Extreme Events: Issues

- *Allowance must be made for autonomous adaptation.* Given the increased risks of flooding, for example, individuals will choose to relocate and take personal measures in response.
- If, however, public investments offer protection that assumes no autonomous adaptation, the overall costs of responding to the change in risk will be much higher than it would be if proper account was taken for behavioural changes at the individual level. Part of the adjustment individuals and companies will make will be in response to higher insurance premiums, or even refusal by insurance companies to offer protection against some events in certain locations. If the government measures consist of essentially underwriting the risks that the private sector will not cover, the costs of meeting a given “expected consequence” target could be very high.

## Infrastructure

- Climate change will change the design of infrastructure investments.
- “Climate proofing” future investments will therefore be a major requirement in the design of investments in roads, rail systems, hydropower plants and so on.
- The analysis of proposed climate risk management process for development projects is shown in Figure on next slide; this process is based on standard approaches to charactering and managing risk (DETR, 2000).
- Essentially the project is evaluated for the climate risk. If the risk is deemed acceptable the options are appraised as before. If, however, the risk is considered unacceptable further modifications are made until the risk is reduced to an acceptable level, at the least cost possible. There is no general metric that can be applied here; the rule is defined in terms of acceptable risk and the use of a least cost analysis to identify the measures to meet that risk.
- Applications have been made via UKCIP to railway investments in Scotland.

## Framework for Managing Climate Variability at Project Level



## Agriculture

- Given the very high level of autonomous adaptation in this sector, as well as the important role that markets and trade will play in transmitting impacts in one geographic region to another, it is necessary to evaluate this sector differently from others. Economy-wide models are essential for the analysis and have been used extensively for this purpose.
- These models can provide estimates of expected changes in value added from agriculture as a result of climate change, taking account of climatic, allocative and terms of trade effects. The aim of adaptation measures could then be to improve the value added to selected groups of individuals (both producers and consumers). An evaluation of such measures necessarily requires working through some such models to see who gains and who loses, after account is taken of market linkages.

## Ecosystems and Biodiversity

- Valuation in monetary terms here is very difficult. Yet impacts of CC are expected to be significant and irreversible in many cases.
- Measures being considered include: increasing connectivity through corridors, mitigating threats from invasive species, fragmentation, translocate species, increase reserves etc.
- The assessment of measures has to be relative to set targets for mitigating impacts of climate change. These targets have to be defined in physical terms and measures have to be judged in terms of the costs of achieving these targets. At the global level targets include:
  - increase in protected areas (10% to meet CC challenges),
  - Number of species conserved as a result of different measures.

## Coverage of Sectoral Estimates of Costs & Benefits

Sector	Coverage	Cost estimates	Benefit estimates
Coastal zones	Comprehensive – covers most coastlines	✓	✓
Agriculture	Comprehensive – covers most crops and growing regions	-	✓
Water	Isolated case studies in specific river basins	✓	✓
Energy (Demand for space cooling and heating)	Primarily North America	✓	✓
Infrastructure	Cross-cutting issue – covered partly in coastal zones and water resources. Also isolated studies of infrastructure in permafrost areas.	✓	-
Health	Very limited	✓	-
Tourism	Very limited – winter tourism	✓	-

## Other Issues

- Cross sectoral impacts (e.g. Sea level rise, ecosystem services) have to be addressed.
- Priorities across sectors may need to be established. (may need Delphic methods)
- Uncertainties will decline over time and we should design measures so that new data can be incorporated to improve the adaptation strategy
- Some actions can provide both mitigation and adaptation benefits.

	SLR	Freshwater	Extreme Events	Agriculture	Ecosystems	Infra structure
Health	Loss of life and injury, indirect effects (disease outbreaks)	Water resources, levels and quality affecting waterborne diseases	Loss of life and injury, indirect effects (disease outbreaks)	Food availability potentially affecting malnutrition	Provisioning services (fisheries, marine) affecting food availability	Reduced performance or delivery of water supply and sanitation services
SLR		Saltwater intrusion reduced available water in coastal areas	Combined effects of SLR and storm surge – effects across categories	Land-use change and availability for agriculture. Effects on aquaculture	Reduction in coastal ecosystems (mangroves) reducing flood protection	Changes in design and location of coastal infrastructure
Fresh Water			Contamination of water sources from extreme, water quality effects	Changes in water demand for irrigation	Changes in water run-off, water filtration, from changes to ecosystems	Changes in water demand for infrastructure
Eco Systems						Lost protection from ecosystems affecting exposure risk



# Reflections on Tools for Evaluating Adaptation Options

- Most actions for adaptation are at the local level and have to be evaluated based on local impacts.
- Governments and International Agencies need evidence of “value for money” when public funds are involved.
- Traditionally the toolkit has included benefit-cost analysis, or cost effectiveness analysis, supplemented by information on distributional effects, uncertainty and non-monetary impacts.
- Sometimes this is presented in a multi-criteria framework but in all cases we need to consult stakeholders on their priorities and preferences.
- No reason why the same should not apply to adaptation options!

**bc<sup>3</sup>**

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**QUESTIONS**

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