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ARTICLE

Towards Sustainable Flood Risk Management

Colin Green*

Flood Hazard Research Centre, Middlesex University, Queensway, Enfield, Middlesex EN3 4SA, U.K.

Abstract Sustainable development means doing more with less; this requires change from existing practices. We must make improvements and learn, in the face of those changes that are occurring because we have not delivered sustainable development up until now. So we seek to make changes in the context of changes. This paper focuses on the question of "how" we do more with less and develops the concept of adopting a systemic approach, recognizing that we are dealing with dynamic, highly interconnected systems.

Keywords change, integrated water resource management, social relations, sustainable development, systems

1 Introduction

Sustainable development requires that we do better than we have in the past, that we change and learn. Hence, the primary characteristic of sustainable flood risk management is that it is centered on the continuing process of learning. It is a process and not a destination. Climate change is but one symptom of our past failure to achieve sustainable development amongst many other symptoms.

That sustainable development is about doing better means doing more with less. This raises three obvious questions:

(1) more of "what"?
(2) less of "what"? and,
(3) how?

Part of the "how" of getting there is to recognize the nature of the systems whose interaction creates the problem we term floods. A practical starting point for moving towards sustainable flood risk management is to identify the nature of the individual systems and their interactions.

2 Flood Risk Management in the Context of Integrated Water Resource Management

The current paradigm is that of Integrated Water Resource Management (GWP 2000): the management of water holistically across its natural hydrological units, across different functions, and recognizing the strong interactions between land and water. The risk of flooding must be addressed within this wider framework (Technical Support Unit 2003) and considered neither in isolation from other water management functions nor as a local problem. Instead, a catchment must be considered as a dynamic system, both temporally and spatially. It is a system in which there are constant interchanges between land and both surface water and groundwater (Figure 1).

Those interchanges are not limited to water but include all other materials transported, through a variety of physical and chemical processes (Ball 2000), notably soil which is eroded and deposited, and various pollutants. In addressing a problem of local flooding, not only the consequences of that intervention on the exchanges of water at other times in the year and other places in the system need to be considered, but also the effects on the erosion and deposition of soil, and on the transport of the many different forms of pollutants. Otherwise the effect of the intervention may be simply to move the flood problem around the catchment or to solve the flood problem at the cost of, for example, creating a sediment load problem; this can lead to the creation of "perched" rivers when deposited sediment raises the bed of a channelized river above the surrounding floodplain. Or, a flood problem may be reduced but only at the cost of creating a low flow problem during dry periods.

In many parts of the world, there is enormous variation in rainfall and river flows over the year (Le Houérou n.d.). Those areas typically swing between dry season droughts and floods. Yet, flood flows are the water resource: if the floodwaters are not captured, there will be no water available during the dry season.

Floods are a function of meteorological systems as these interact with the landforms; the consequence of that interaction is somewhat open to modification by the way that land is used. As a result, watercourses are effectively the residual produced by the interaction of the meteorological systems and the landforms. It is precipitation producing meteorological systems that are of importance. Precipitation results when the air saturated with water is cooled and can no longer carry the same load of water. The two relevant meteorological systems are depressions and frontal systems, lines along which masses of warm and cold air collide. The deepest depressions are those variously termed typhoons, hurricanes, or cyclones, and originate over the seas. What is important

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* E-mail: colin.green.fhrc@gmail.com

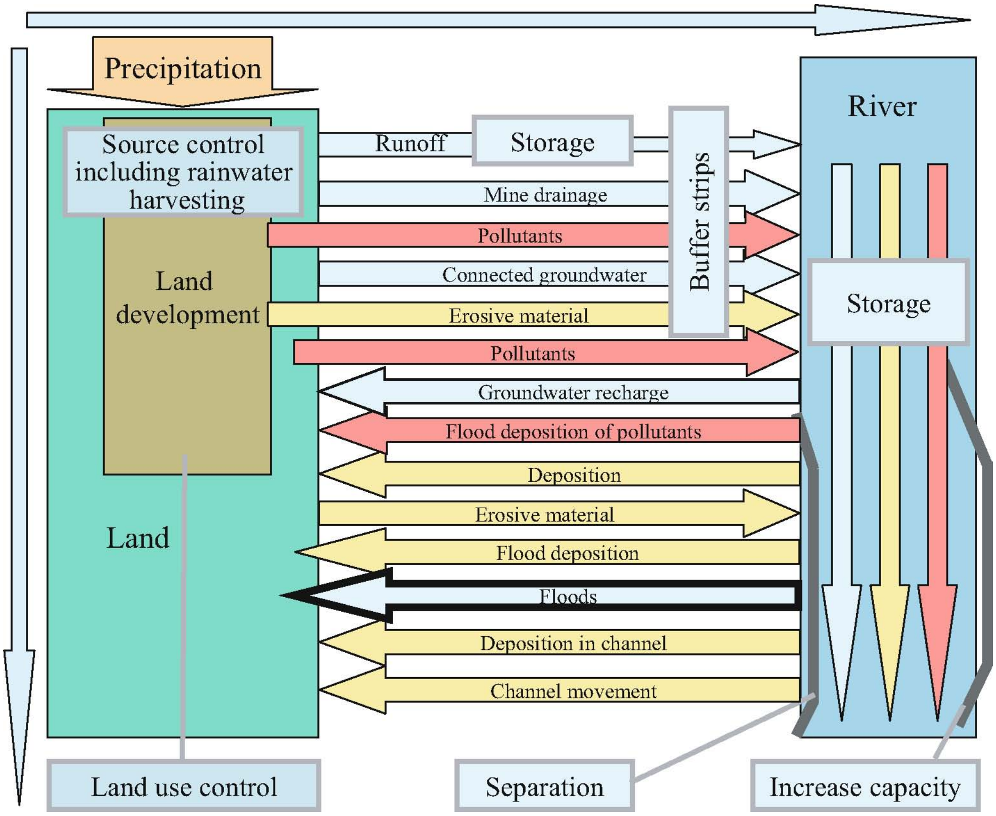

Figure 1. A catchment as a dynamic system

about these meteorological systems is that they have direction and speed as well as size and intensity.

Catchments also have a shape, and the direction and speed of movement of the meteorological system, together with the shape of the catchment, determine the response of the catchment. As the system moves across or up or down the catchment, the different tributaries successively burst into flood. As that flood flow moves downstream, typically it is attenuated as the flood peak becomes flatter with a lower peak. Lower down the catchment, there may be many different flood peaks as the flood waves from each tributary pass downstream. The 1998 flood on the Yangtze, for example, had 8 flood peaks (Hong and Luo 1999). One objective in flood risk management is therefore to reduce the risk of the peaks from the different tributaries coinciding at any point downstream. That may mean different approaches should be taken on different parts of the catchment. In some areas, the effects of the intervention should be to attenuate the peak, in others to slow down the time taken for that peak to reach a point downstream, and in others to reduce the time it takes for that peak to travel downstream.

Managers also seek to respond to the natural variability in natural systems over time, notably in meteorological conditions. Indeed, variability may be a preferable term to frequency or probability. Looked at over time (Figure 2), natural variables, such as river flows, demonstrate cyclical variability; the obvious example is seasonality. Typically, there is seasonality in flooding, most obviously in those parts of the world where typhoons/cyclones/ hurricanes are experienced. That seasonality reflects the nature of the meteorological structure that triggers the flooding whether it is snowmelt, deep depressions, or frontal systems. But there can be longer-term cycles such as the El Nino / La Nina phenomena (McPhaden 2001), and other oscillations such as the North Atlantic oscillation (Pociask-Karteczka 2006). This means that the likelihood of a flood varies over the course of a year and between years.

Obviously there are trends in climate change but also changes in land use across the catchment. In addition, unexplained variations also occur and only probabilistic predictions can be made about them. The process that generates the events is not random, but we simply cannot foresee events, in a given time period, any more reliably than if they were generated probabilistically. It will generally not be possible to predict whether there will be an extreme flood next year. For large catchments, however, we can generally make good predictions about whether a flood will occur tomorrow because we have an understanding of how the catchment behaves and estimates of critical parameters such as soil moisture levels, likely rainfall, and current flows in the river.

In consequence, it is an error to treat floods in isolation and distinct from droughts and the general problem of water

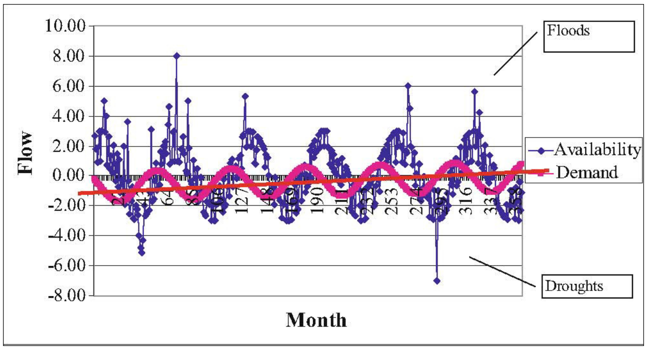

Figure 2. Floods as part of natural variability in flows (hypothetical data)

resources. Floods are simply part of the variability and the problem is to respond appropriately to that variability. The greater the variability over the year, and more particularly the variability between years, the greater the water management problem.

While floods are primarily a product of meteorology interacting with landforms, it is only land use which we have any scope for modifying to our advantage and then only to a limited extent (CIFOR 2005). All soils include, to varying extent, voids which are usually filled with air (Hillel 1992). Most plants cannot tolerate for long if the soil in their root zone is saturated with water (Loomis and Connor 1992). Thus, all soils can act as "sponges" until all the voids are full of water. Unless water can percolate down to lower soil levels and plants lose water through evapotranspiration, any further precipitation will simply run off the surface of the ground. The proportion of precipitation that runs off in this way, the runoff coefficient, is thus a variable and not a constant (Lorup and Hansen 1997).

The exceptions are wetlands, which during the growing season store water on the surface. Wetland crops require a saturated root zone during the growing season so the only available storage capacity in a wetland at the end of the growing season is on the surface. Wetlands develop in those areas where flooding is common during the growing season. Artificial wetlands in the form of rice paddies store enormous quantities of water and, where present, may significantly reduce the risk of flooding (Yoshida 2003). Had there been a temperate climate crop equivalent of rice, the pressure to drain the landscape of Europe and North America would have been less. A disadvantage of both natural and artificial wetlands is that they are producers of both methane (CH_4) and nitrous oxide (N_2O) (Mitsch and Gosselink 2000), both highly aggressive greenhouse gases.

Historically a critical determinant of flood risk management has been the timing of the flood season relative to the crop cycle. In dryland farming, when the flood season coincided with the growing season, particularly the period of harvest, large-scale flood defence works were carried out to protect the crops. Conversely, as in most of England, where large floods are essentially winter phenomena, agricultural land was left either intentionally to provide flood storage and conveyancing, areas known as "washlands" in the U.K. (Morris et al. 2004), or simply left unprotected.

Humans have always managed water to make the best use of land. Floodplains, in particular, have always had major competitive advantages compared to other areas of land, especially for agriculture. The land is flat and close to the river, which means that there is usually sufficient soil moisture to sustain crops. If irrigation is required, there is a readily available source of water. In many areas, annual floods replenish some of the essential nutrients of the crops.

Agriculture is a form of mining, of carbon and energy from the air and sun and of essential nutrients from the soil. If those key nutrients—notably nitrogen, phosphorus, and potassium—are not replenished, crop yields collapse (Loomis and Connor 1992). Removing the crop necessarily removes the essential plant nutrients embodied in the crop. Replenishing the phosphorus will become increasingly a problem because phosphorus is a limited fossil resource (Cordell, Drangert, and White 2009). In some circumstances, annual floods can contribute to maintaining soil fertility. In tropical climates where flood irrigation is practiced, or the land simply floods, blue-green algae flourish and are nitrogen fixing (Brammer 1990). In low velocity floods, silt may be deposited as the floodwaters are further slowed. This was famously the case in Egypt, which also illustrated the case that one area's imports of soil are another area's exports as Egypt gained from Ethiopia's loss of soil (Ahmed 2007). But whether the export and import of soil is beneficial to the receiving area depends on the nature of the soil. The deposition of sand and gravel by floods is invariably adverse, and these may be deposited to significant depths both on floodplain farmland and in the river channel itself. The 1993 Mississippi flood, for example, left large areas of farmland covered in sand to over a meter in depth (Soil Conservation Service 1993).

What is transported and deposited depends on particle size and flood velocities. When flood velocities are high, they transport large particles, and these particles are deposited when the flood velocities are reduced (Charlton 2007). The critical relationship is between the nature of the soils in the areas generating the runoff, the velocity of flow in those areas, the decay in velocity, and the deposition of sediment before the flood reaches any particular area.

Socioeconomic Systems in Integrated Water Resource Management

The commonality between natural and human systems is that both are dynamic systems that respond to external imposed shocks such as floods. The difference between natural systems and human systems is that people have some power to choose how to adapt to or cope with those shocks, and that humans are conscious of their social relationships. These social relationships are simultaneously a restriction on what we can do and either an explicit goal of social decision making or an implicit consequence of the decisions we take. How we make decisions, what decisions we take, and how we pay for the costs of those actions are all centered on social relationships. Two central and critical features of social relationship are power (Lukes 1974), that is the capacity to induce change, and justice (Pettit 1980).

All technologies either imply or reflect social relationships. One might therefore expect that a society that emphasizes the maintenance of social harmony or social solidarity will take different decisions, and adopt different flood risk management strategies, to one that emphasizes competition between individuals. The recent flood act in Germany (Government of Germany 2005), for example, emphasizes individual responsibility for adopting flood mitigation approaches. This logically leads to the expansion of flood proofing and the promotion of flood insurance paid for by the individuals at risk, and the upstream land owners having responsibility to reduce runoff. Conversely, the preamble to the French Constitution stresses that there must be national solidarity in the face of the consequences of natural disasters. This implies both an emphasis on physical interventions in the form of flood storage and dikes, and compensation of flood victims. In the Netherlands, the constitutional duty of the government to defend the country includes defending it from the sea; this is not surprising when 70 percent of the country lies below sea level.

The debate about "structural" and "non-structural" (Andjelkovic 2001) flood risk intervention strategies is thus at least as much about social relationships as it is an argument about the technical effectiveness and environmental consequences of the different intervention strategies. Non-structural interventions tend to shift the responsibility to the individual and to reduce the role of society, and to neoliberals that is part of the attraction of such approaches.

Some forms of social relationships are more effective than others in achieving specific ends. This is the economist's argument for the use of competition in some circumstances. The history of water management is very much one of collective cooperative or collaborative action (Wagret 1967). A distinction has to be made between the functional success of different forms of social relationship in the short term and the contribution of those relationships to long-term objectives. A critical criterion for a sustainable society is that it must survive over the long term. The rationale for the human enthusiasm for forming societies must be that there are some goals that are either more effectively achieved through organized collective action or are only achievable by that means (Ostrom 1990). The logic is that short-term functionality should be subservient to the long-term objective of a sustainable society. What is increasingly termed "social capital" (Bourdieu 1980; Coleman 1988), for example, is argued to be necessary to enable the functioning of effective markets, but competition might be expected to reduce social capital.

One way of defining the contested terms of "vulnerability" (Tapsell et al. 2010) and "resilience" (Adger et al. 2005) is in terms of relationships, specifically between people but also between people and natural resources. Both terms are necessarily contested because defining each implies a way of reducing vulnerability (Green and Penning-Rowsell 2007) or enhancing resilience. Both terms have been variously defined in terms of a characteristic (for example, old people), a state (for example, the poor or those in ill-health), or a relationship (McFadden and Green 2007). But defining them in terms of a state also implies a relationship, as the state will change according to changes in the relationship.

Resilience is variously used to describe how long an element or system takes to return to its initial state or domain of states, or, in the ecological sense (Holling 1973), whether the element or system will return to its initial state or be permanently shifted to another domain of states. In the first case, the expectation is that the household's quality of life can be returned to the state prior to the flood; in the second, the question is whether the household's quality of life will be permanently reduced. Using the system model shown in Figure 3, resilience might then be labelled as the feedback to that element in the system, negative feedback tending to return it to its prior state and positive feedback tending to shift it to a new state permanently. The three critical questions are:

(1) does the system recover to its initial state?
(2) how long does it take to recover to its initial state? and,
(3) what are the most effective means of promoting that recovery?

Viewed in terms of relationships, the question becomes about which relationships are crucial. If we view the vulnerable individual, household, or group in a system framework (Figure 3), a flood is one of a whole range of potential shocks or perturbations that may be transmitted to the system. The effect on A of that shock is mediated through B and C through the positive (amplifying) and negative (reducing) feed forward loops. The effect on A feeds back to B and also forward to D. That feed forward to D sets off further feedback responses (D on E, E on C, C on B). The susceptibility of each individual element depends on where they are located in the network and where the perturbation initially occurs. The

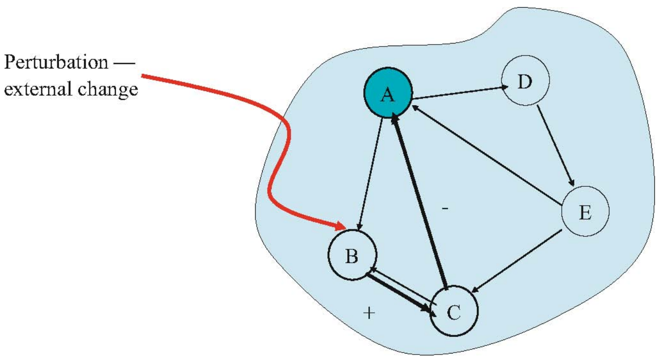

Figure 3. Vulnerability and resilience as response characteristics of a dynamic system

vulnerability of each element in the system might be defined as the feed forward to that element.

From this perspective, the vulnerability of an element is determined by its position in the network relative to the perturbation. In the case of flooding the upstream part of the system and whether elements there either amplify or reduce the perturbation, and whether the linkages provide positive feed forward, unadjusted by negative feedback loops, determines the overall system behavior. Conversely, the resilience of an element will be determined by the extent to which positive feed forward produces negative feedback. Thus, vulnerability and resilience are determined by the structure of the system and the position of the element within that system.

Principles of Integrated Water Resource Management

In managing water to make the best use of land, the aim in flood risk management is not to minimize flood losses but to maximize the efficiency of the use of land. Increasing the efficiency of how a catchment is used can result in an increase in flood losses (Green, Parker, and Penning-Rowsell 1993). Therefore, the choice is between:

(1) developing the floodplain without taking any action to reduce the flood risk;
(2) developing the floodplain but taking action to reduce the risk of flooding; and,
(3) developing some other area outside of the floodplain.

The logic for developing a floodplain, as opposed to some other area, is that either the returns from development on the floodplain exceed those from other areas, or the costs of development are lower, or both. If an oil refinery, for example, is developed in a port area, the costs of moving raw oil from the jetties and shipping the final products out for loading will be lower than if it is located inland. In addition, coastal floodplains offer flat sites that require lower development costs than sites on slopes or uneven ground. Floodplains, like areas at high risk of landslides, earthquakes, and other hazards, are often the sites of informal settlement because of their proximity to income earning opportunities and lower transport costs. The costs of providing utilities, infrastructure, and services are now a high proportion of the costs of developing a site and those costs are borne by a wider community of residents through taxes, utility charges, and other transfers.

Which of the three options is then the best option in the particular instance depends on the growth paths for the social welfare or economic activity for each of the three development possibilities (Figure 4). If the growth path for developing the floodplain is sufficiently faster than could be achieved by development in other areas then development should take place on the floodplain if the pattern of losses is such that the on floodplain development trajectory will remain above the off floodplain development path (Figure 4a).

One of the corollaries of this conceptualization is that the frequency of flooding is likely to determine which pattern prevails. If the frequency of flooding is greater than the average life expectancy of capital assets, it is likely that development on the floodplain will be undesirable. From the narrow perspective of the economy, the relatively short effective life of most capital assets (Omundsen et al. 2009) implies that very high standards of flood protection will seldom be justified except if the local consequences have wider impacts on the economy as a whole.

The second principle is that of seeking to manage all floods and not just some. Traditionally, the practice has been to design to some design standard of protection, to remove the risk of flooding from events up to some return period, commonly the 1 in 100 year return period event. Instead, we should seek to manage all floods. That approach focuses attention on how each intervention strategy will fail as a result of a more extreme event occurring or for other reasons. The modes and consequences of failure of different intervention strategies are quite different (Figure 5). We should design for failure (Green, Parker, and Penning-Rowsell 1993).

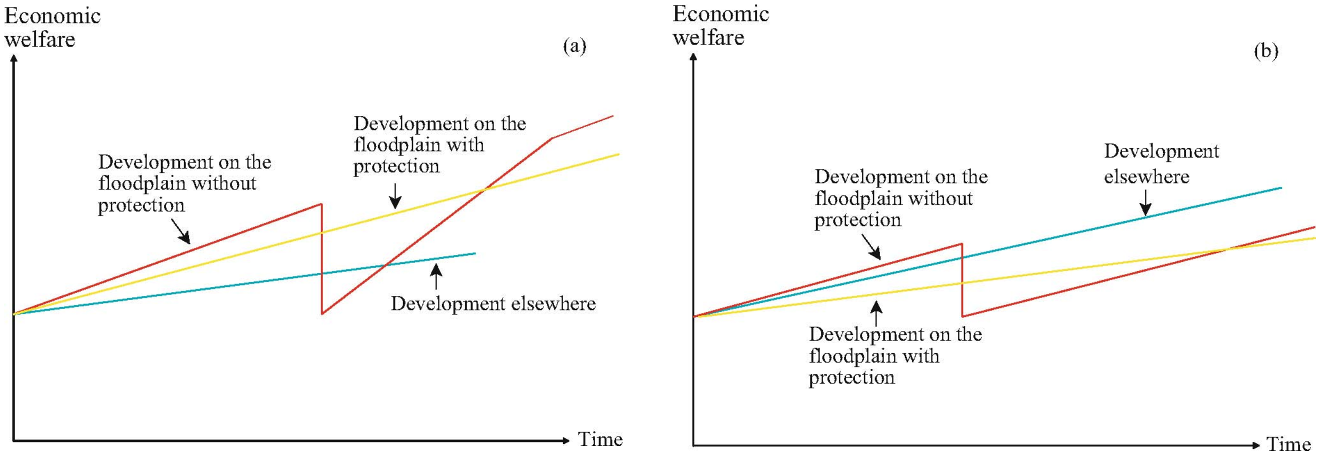

Figure 4. The economics of development on floodplains

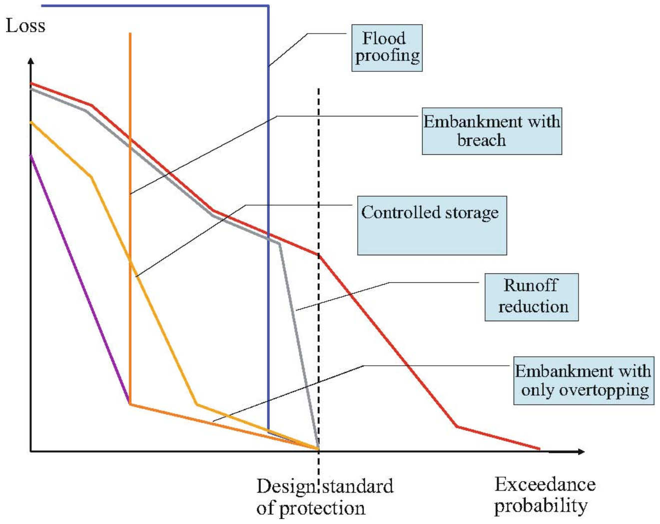

Figure 5. Loss probability curves for some intervention options—how loss varies with the exceedance probability of the flood

Designing for failure implies a multilayered approach, a mixture of strategies rather than a reliance upon a single strategy. Consequently, the combination of intervention strategies adopted should be selected so as either to reduce the consequences of extreme events or to increase the ability to recover from those events.

3 Intervention Strategies

There are different ways of categorizing intervention strategies. A traditional approach has been to talk in terms of "structural" and "non-structural" measures (Andjelkovic 2001). While this distinction is useful as a dialectical device since non-structural means were argued to be those intervention strategies not usually considered by engineers at the time, as an analytical device it is of limited utility since non-structural measures include physical interventions and non-structural options have little in common other than that they focus on changing the behavior of people in some way rather than directly on changing the natural system.

Three alternative ways of categorizing possible intervention strategies are:

(1) using Figure 1, to look at where in the catchment a specific range of problems must be considered;
(2) whether it is the natural system that is changed or how people use that system or adapt to variations in that system; and,
(3) whether the intervention is targeted at changing either the likelihood or consequences of a flood; easing adaptation to a flood when it occurs; or aiding recovery after a flood.

Looking at Figure 1, a number of generic strategies might be adopted:

(1) reduce runoff;
(2) delay runoff, for example through storage;
(3) slow down / speed up stream flow, including using storage either in stream or out of stream;
(4) increase the capacity of the channel; and,
(5) separate flood and people.

In urban areas, the different forms of Sustainable Urban Drainage Systems (SUDS) include reductions in runoff within the urban area (CIRIA 1999). Some of those systems can have other benefits as well. For example, green roofs reduce the heat island effect in cities and can reduce air pollution (Sera 2006). Rainwater harvesting (Agarwal, Narain, and Khurana 2001) may be a means of reducing the demand for potable water. Changing cultivation practices on small catchments can reduce the amount of runoff exported and such practices may also reduce soil erosion (USDA 1999). Many of those practices make use of storage either in the soil or by other means and so their primary effect is to delay runoff. A limitation is that given sufficient precipitation over a long enough period, storage capacity is exhausted. Hence, these measures will be least effective in the most extreme events. Those methods that depend on infiltration are limited to the infiltration capacity of the soil.

Dry and wet storage areas, including retention and detention basins (Wright Water Engineers / GeoSyntec Consultants 2007) are means of providing storage and delaying or reducing runoff. "Rain gardens" (Dunnett and Clayden 2007) are a development of SUDS that emphasizes their ecological and aesthetic possibilities. Finding the space to retrofit such systems into the high density cities that characterize Asia, Africa, and South America is, however, problematic; hence, the promotion of green roofs in such cities as Beijing and Shanghai. Rice paddies provide storage and delay runoff automatically; in dryland farming, soil conservation measures (USDA 1999) are adopted more to reduce soil erosion and retain rainfall for plant growth but also have the effect of reducing and delaying runoff. Tillage practices (Shaxson and Barber 2003) that reduce the capacity of water to infiltrate the soil and increase runoff, also tend to decrease yields. Barrier strips between arable land and rivers have a further virtue of reducing pollution loads and capturing some of the eroded soil (USDA 1999).

There are a variety of means of slowing down the flood flow in a river, either by increasing the frictional resistance of the channel or by reducing the channel gradient. Floodplain forests (Richards et al. 2003) are the primary example of the former approach, and the effect of natural meanders in the stream channel is to reduce the channel gradient. The effect of storage is essentially to delay the flood flow and attenuate the peak, since none of the flood flow is lost except through some evaporation or infiltration into the soil. A channel meander provides natural, live flood storage, and both wetlands and reservoirs are other means. The latter can be either on stream or off stream; both wetlands and reservoirs essentially perform in the same way in hydraulic terms. They also have a number of advantages and disadvantages in common. Both, by having large, essentially flat surfaces of water, provide frictional resistance; but both also require space and place; both, by slowing the flow, result in the deposition of some sediment; and both change the downstream flow regime. To reduce the risk of the flood peaks from different tributaries coinciding, storage has to be located appropriately, but the topography and morphology of the ground limit the possible locations. Wetlands or retention basins require very large areas of flat land on the floodplains; reservoirs require steep valleys with the appropriate rock structure to anchor the dam walls. The ground footprint of an upland reservoir will necessarily provide more storage capacity than one in a lowland area. Lowland areas are also typically more attractive for settlement than upland areas. Consequently, constructing a new lowland storage facility will be likely to require more people to be relocated than providing the equivalent storage capacity in a highland area.

Ideally, if it were possible to know the extent and timing of the flood peak in advance, the operating practice would be to hold the storage empty until the remaining volume in the flood peak equals the storage capacity of the wetland or reservoir. That flood peak would then be diverted to storage. All storage is most useful when inflows and outflows can be controlled.

It is sometimes argued that a reservoir has made a flood worse. In principle, all dams are designed so that they have an emergency spillway capacity equal to the maximum possible inflow to the dam. When the reservoir is full outflows will exactly match inflows. Flooding would be no worse than if the dam was not there because the dam has ceased to have any effect. The three ways in which a dam can potentially result in worse flooding than if it did not exist are:

(1) the dam is inadequately constructed and imminent failure requires water to be drained from the dam, that is outflows from the reservoir exceed inflows to the reservoir;
(2) storing the flood peak causes the discharge peak to coincide with the flood peak on another tributary; and,
(3) there are multiple flood peaks on the channel and the reservoir is rapidly and partially discharged to make space for the next peak, so that discharge exceeds the inflow rate into the reservoir.

Where it is claimed that the existence of a reservoir worsened a flood, insufficient detail is usually given to determine what actually happened.

Traditionally, great emphasis was placed on speeding up the flow in the river, to shift the floodwaters downstream. Two primary approaches were to shorten the river, and thus to steepen its gradient (perhaps most famously in Tulla's work on the Rhine) (Blackbourn 2006), or to reduce friction, by canalizing the river into an engineered channel from which all vegetation was removed and which was often lined with concrete. In both cases, the result of reducing friction was to speed up the rate of flow. The result was often to simply transfer the flood problem downstream as has been the case on the Rhine (Länderarbeitsgemeinschaft Wasser 1995) and to destroy the ecosystem in that river (Purseglove 1988).

Increasing the capacity of the channel itself to reduce the river's natural expansion over its floodplain has been another traditional approach. Widening and deepening have been used but both have run into the problem that slowing the flow out of flood periods results in the deposition of sediment. The problem is always that rivers are dynamic systems and attempts to fix them in position and in one channel run counter to this natural dynamic. Advances in mathematical modelling, and the computer capacity to run those models, have made multistage channels possible (Charlton 2007). In smaller rivers, bypass channels, particularly around narrow sections, can be used.

Separation of people and structures from flood-prone conditions is frequently attempted. This separation can be vertical, for example by raising houses and other structures on stilts. The same objective can also be achieved via horizontal separation by avoiding development on parts of the floodplain. Finally, physical barriers such as dikes and levees and other flood proofing practices are common.

These approaches all focus on interventions in the natural world and on the "before flood" phase. Although all changes are in someone's or some organisation's behavior, nonstructural measures centered on changing the behavior of those at risk or, less frequently, those who created the risk through upstream development. Any attempt to influence the behavior of others can be considered to have a minimum of two elements: a signal as to the desirable behavior to adopt, and an incentive sufficient to overcome the barriers to adopting that behavior. In the case of no barriers to adopting the behavior and simple lack of knowledge as to the more appropriate behavior, the problem is reduced to finding an effective means of ensuring that the signal is received and understood as intended. More realistically, the barriers to the adoption of the suggested behavior need to be understood and a sufficient incentive provided to overcome those obstacles.

Generally, the behaviors managers and policy makers desire those at risk to adopt are:

(1) not to develop on the floodplains;
(2) if they do, to adopt robust (for example, less susceptible to flood damage) or resilient (for example, easy to repair) forms of construction;
(3) during floods to take such actions as flood proof their property or to evacuate either upwards within or off the floodplain; and,
(4) to adopt the best means of recovering after a flood.

Various incentives are available, which vary from social pressure through charges or subsidies to regulation. Although economists assume that prices always work but nothing else does, very little is known about the relative effectiveness and cost of each of the different incentive strategies.

The communication process has to be viewed as a continuum although conducted at different points in time. Floodplain mapping (EXCIMAP 2007) and flood awareness

Table 1. Flood risk management intervention categories and options

What is changed?	Timing		
	Before	During	After
Natural world	Storage, channel "improvements"	Dike strengthening, planned flooding	
People's behavior	Permanent flood proofing, robust construction, awareness programs, control of development on floodplains, promotion of SUDS	Flood warnings, emergency planning, contingent flood proofing, evacuation	Compensation or insurance, counselling

campaigns are conducted well before any flood; flood warnings (von Lany et al. 2009) are issued immediately prior to a flood; and further advice is issued during and after a flood.

Table 1 summarizes the different forms of intervention in flood risk management in terms of both the point in the flood cycle at which intervention is targeted and whether the target is the natural system or human behavior.

For neoliberals, insurance against flooding is seen as a means to change behavior prior to a flood. More practically, it can be seen as enabling recovery after a flood, as a compensation mechanism paid for through insurance premiums rather than general taxation. Historically, insurance developed first in the form of mutual societies (Lengwiler 2006), people banding together to insure each other, or, effectively, as a form of gambling, as was the case with Lloyds of London (Gibb 1957). Mutual insurance societies are still major players in the insurance market, but a subsequent development was commercial insurers, joint stock companies that provide insurance on a commercial basis to customers. Commercial insurance companies exist to make a profit and do so by choosing against which risks to provide insurance and on what basis. The ideal is a risk that will provide a steady stream of premiums and an equally steady, but lower, stream of losses. Life insurance and domestic burglaries are examples: a large population to be insured, with a low loss relative to those insured. Natural hazards present the risk of large losses at infrequent intervals. Consequently, providing insurance presents problems and is rarely available except in the form of public-private partnerships (CEA 2005; GAO 2005; Swiss Re 2003). Those partnerships can be parasitic (Green and Penning-Rowsell 2004). In the U.S. flood insurance system, for example, the risk is underwritten by the U.S. government and the premiums are subsidized by the general taxpayer (GAO 2005) while the insurance companies gain a risk free income by writing the policies. If the total claims were not relatively low (Mortgage Bankers Association 2006), it is likely that the whole system would break down.

Although synergistic approaches, which combine the relative strengths of governments and the market, are possible (Green and Penning-Rowsell 2004), a problem with insurance as a mechanism is that it is, in economic terms, a "luxury" good: the higher a household's income, the more likely they are to buy insurance (H. M. Treasury 1999). Thus, any subsidy from the taxpayer is likely to be redistributive from the poorer to the wealthier residents.

In comparing alternative means of intervening to reduce the risk to a group, there are two quite different considerations:

(1) how effective will be that strategy? and,
(2) what does that strategy say or imply about social relationships?

As in other areas of water management, there are typically technical economies of scale: bigger generally does mean cheaper. For example, above some density of settlement, it will be cheaper for the people in that community to build a dike that protects them all instead of flood proofing their individual properties (Green, Parker, and Tunstall 2000). These economies of scale might be argued to be one of the reasons why the history of flood risk management in Europe is dominated by collective action (Wagret 1967).

Secondly, all physical means of intervention take up place and space. They have to be located at particular points in the catchment and they are either spatially extensive or intensive Some require a lot of space, they are extensive, but that space can be used for other functions; for instance, a wetland storage area takes a greater deal of space but can perform other functions. Conversely, a dike does not take up much space but it has to be located between the flood and that which it is intended to protect; and, except for the Japanese "super dikes" (Sukegawa 1988), extra wide dikes on which buildings can be constructed, cannot be used for other purposes,

A further reason for the past dominance of structural intervention strategies in the form of barriers, channel modifications, and storage systems is that it is only comparatively recently that engineers have had the mathematical tools to model flooding and more especially the computer capacity to run such models. When engineers were limited to slide rules and log tables to analyze the effect of interventions, those interventions necessarily had to be coarse.

Two key questions in assessing the effectiveness of each possible intervention strategy are the reliability of the strategy and the necessary Operation and Maintenance (O & M) costs of that strategy. The principle of designing for all floods requires consideration of both the likelihood of failure and the consequences of failure under extreme conditions and as a consequence of neglect. It has proved very difficult (von Lany et al. 2009) to provide reliable flood warnings under the best conditions where the potential lead time is long and the system is well-maintained. The reliability of many non-structural intervention strategies is essentially unknown.

In assessing all intervention strategies, the extent of O & M costs has always been neglected but all intervention strategies are more or less reliant upon adequate maintenance. In particular, non-structural options are typically highly reliant on adequate O & M expenditure and thus at risk during financial crises. In addition, one choice that will normally be appropriate is between a high capital / low cost O & M strategy or a low capital / high cost O & M strategy.

The second issue is that of social relationships. What does the intervention approach adopted imply or express about social relationships? One aspect of those relationships is who pays for the intervention strategy. Neoliberals and neoclassical economists presume that those at risk ought to pay to be protected from that risk. But it is almost universal practice that instead all or a large part of the costs are borne by others. This means that the general taxpayer is a key stakeholder in decisions about flood risk management. Central questions are: Why are they prepared to pay? How much are they prepared to pay? What are their priorities? There is very little research that has explored any of these questions (Green et al. 1992; Shabman et al. 1998). But a number of logical reasons why taxpayers should contribute to the costs can be suggested:

(1) Those at risk may have had a very restricted choice as to where to develop. In some countries, notably Japan and the Netherlands, effectively the whole country is at risk from one form of natural disaster or another.

(2) Most people are flooded by other people's runoff; the "polluter pays principle" implies that those who produce the runoff should pay to reduce the risks they create. The same principle is applicable to climate change; those who cause it should pay the costs of adapting to it.

(3) In any system, any action in one place has positive or negative consequences elsewhere. This is true for development and the costs of all development are widely shared whether those costs are shared through utility bills, prices, or taxes.

(4) Given the multiplicity of risks with which any society is faced, from the collective perspective, it may be preferable to encourage some people to take risks that they would not otherwise take because of the overall collective benefits. Historically, because of both the extreme volatility of food prices (Clark 2003) and the high proportion of household income taken up purchasing food (Houthakker 1957), the collective risks of food scarcities were reduced by encouraging farmers to grow high yield arable crops on floodplains rather than to reduce their livelihood risk either by relying on livestock production or only farming uplands.

(5) Society can be conceived of as a mutual insurance society. Membership in society involves sharing the risks born by others. What risks are shared is then socially negotiated within the particular culture.

4 Can We Do It?

Delivering sustainable flood risk management is not easy and will never be easy because it is fundamentally about social relationships: how we should relate to each other. In changing to an emphasis on social relations, the illusion of panaceas is perhaps the most dangerous risk. Those supposed panaceas come in four forms:

(1) the export of approaches which apparently worked in one context to a quite different context without first establishing the necessary conditions for their success;
(2) technical panaceas; the assumption, for example, that non-structural solutions or the creation of wetlands for flood storage will always be the best means of dealing with the risk of flooding;
(3) the presumption that the neoliberalist model of individualist action using markets is universally applicable and successful; and,
(4) the conviction that the necessary cooperation and collaboration merely needs to be wished into existence; an assumption that if all the stakeholders meet together around a table, the result will necessarily be consensus.

The first three apparent panaceas result in action without thought or analysis of the consequences or an examination of the options; the fourth assumes away the critical problem. But doing better requires that we look at what we are trying to achieve, doing more of "what," using less "what," and analyzing how we can do it. The abstract call for integration across catchments, between functions, and between land and water management depends on people, and the relationships between them, to deliver integration. Assuming that a consensual solution is available, that those involved have the incentives to reach it, and that they have social skills to achieve that solution are three sweeping presuppositions. At the simplest level, the different academic and professional disciplines comply with the anthropological definition of cultures (Geertz 1993) as having different languages, practices, and social norms. True interdisciplinary activity, a basic form of integration, therefore involves cross-cultural communication (Lustig and Koester 1993). Not surprisingly, actually delivering integrated water management has proven difficult and its success depends on such social relationship skills as creating mutual trust (Kohn 2008).

We have to do all this at a time when shifting to sustainable development is essential for survival. One side of the coin is social relationships; the other is the way we relate to the environment since the relationship between societies and economies to the environment is as the leaf to the tree (Green 2003). Climate change (Jenkins et al. 2009) is simply a symptom of our failure to deliver sustainable development. Other symptoms are the approach of peak oil (IEA 2009) and peak phosphorus (Cordell, Drangert, and White 2009), and the difficulty of meeting global food needs (Molden 2007). But the clearest picture of our failure is given by the human footprint (Kitzes et al. 2008): we are using more worlds than we have. Malthus was right. In the hundred years after he wrote, population did grow faster than crop yields. Both his estimates of population and crop yields are limited, but Maddison's (n.d.) estimates of the population of thirty western countries in 1850 and 1950 show an increase by a factor of 1.8, while Austin and Arnold (1989) report that wheat yields in England increased from 1.8 t ha^{-1} to 2.5 t ha^{-1} over that period. At that time, we were able to escape the problem by bringing more land into cultivation, notably North America and parts of South America. Davis, Hanes, and Rhode (2004) report that in 1909–1913, 31 percent of global wheat production was from the new countries of Canada, Argentina, Australia, and the U.S.A., a proportion far in excess of their share of world population. In addition, the potato was brought into mass production (Reader 2009). We can no longer expand our way out of problems. We have to learn very quickly to do much better than we have in the past. The key to delivering sustainable flood risk management, and to sustainable development more generally, is learning to learn more quickly.

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