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FLOOD MANAGEMENT IN THE LOWER INCOMATI RIVER BASIN, MOZAMBIQUE: TWO ALTERNATIVES[1]

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ABSTRACT: The aim of this paper is to compare two views of flood management and thus add to the present thinking of living with floods as opposed to the traditional approach of flood control. The traditional pathway has widely been adopted in developed countries and aims to control floodwaters by means of dams and dikes. The alternative pathway tends towards a policy whereby society lives with the floods by being prepared and having the right damage reduction measures in place. In this paper two pathways are tentatively compared for the Lower Incomati Basin, Mozambique. In the design cultural theory is considered, as is how the design of each path may look according to different management perspectives. The Lower Incomati Basin provides an interesting case study as it is in a relatively undeveloped state. Hence, it is an ideal area for conducting research into the application of alternative flood management strategies. The preliminary results suggest that both pathways are feasible. However, considering recent hydrological extremes such as the 2000 floods, the resilient pathway may ultimately be a more appealing flood management strategy.
(KEY TERMS water management; social and political; flood risk; cultural theory; flood management scenarios; Incomati River; Mozambique.)

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INTRODUCTION

When considering a flood the most common images that come to mind are destruction and suffering. Though this is the common perception of floods, more often than not, floods also have beneficial qualities such as bringing fertility, flushing away contaminants and refreshing ground water stocks. Because of the overpowering nature of the negative consequences of floods, the focus is on preventing floods from happening.

Risk can be defined as the chance of injury, loss, or damage.

Risk = probability x damage

The probability of a flood is expressed as the chance of a once in an x-year flood ($x = 0 \rightarrow \infty$). The damage a flood causes can be expressed in terms of social, economic, and environmental costs.

Flood management has traditionally focused on reducing the probability of floods occurring in settled areas (Nunes Correia *et al.,* 1999). The means of reducing flood probability focuses on modifying the hydraulic characteristics of a threatening body of water by means of engineered solutions, for example the use of dikes, levees, and dams. The alternative means to reduce the risk of flooding is to reduce the damage caused by flooding. Flood proofing and floodplain management (Davar *et al.,* 2001), dike compartments (Vis *et al.,* 2001), room for the river (Silva *et al.,* 2001) and River and Land (Netherlands Ministry of Transport, Public Works, and Water Management, 2001) are examples of proposed flood management policies that focus on reducing the damage inflicted by floods while still allowing flooding to occur.

Due to recent extreme flood events that have occurred throughout the world (Mekong, Incomati, Yangtze), it is apparent that underlying principles of current flood management should be reconsidered. Hence, this paper explores how current flood management may evolve along different pathways and what the possible outcomes of this evolution may be. To

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accomplish this, literature is reviewed, a theoretical framework is formed, and the theory is investigated in practice.

The Lower Incomati Basin was selected as a case study. The river basin is relatively undeveloped, and the direction flood management policy will take in the future is not yet determined. Hence, future flood management in the Lower Incomati Basin may develop along a pathway different from that which is traditionally adopted in other countries. The possible development paths are tentatively compared considering economic, environmental, and societal criteria.

Why a Paradigm Shift?

The sociologist Ulrich Beck (1999) warns that if the control structure ultimately breaks, this will lead to a cascade of events that will become a new source of danger to society. The near floods in the Netherlands in 1993 and 1995 (Wind *et al.,* 1999) are an example of a "control structure" that was (nearly) inadequate.

Evidence is mounting for the case against flood control. Criss and Shock (2001) in their historical study of floods along the Mississippi River, USA, have shown that levees have increased flood levels. In essence levees impose externalities both upstream (bottlenecking) and downstream because of increased flow velocity (Agthe *et al.,* 2000). Yin and Li (2001) indicate that mainline levees along the banks of the Yangtze are responsible for raising flood levels and increasing flood velocity. Bancroft (1996) and Light and Dineen (1994) discuss the impacts of flood control in the Everglades, USA. Bancroft (1996) suggests that the Central and Southern Florida Flood Control Project has caused extensive degradation in the Everglades National Park. The loss of wetlands such as the Everglades and urbanization of these areas are reasons for increased flooding and flood damage (Agthe *et al.,* 2000). The essentially technical approach to water management in the Netherlands has led to a decrease in the quality of the natural environment (de Vriend and Iedema, 1995).

If flood control is not the ideal management strategy against flooding, then alternatives must be considered. In order to cope with hydrological extremes it is important to learn to live with these extremes and be prepared for the consequences (Kundzewics and Kaczmarek, 2000). Early warning systems can go a long way toward mitigating damage resulting from these extremes, particularly in saving lives (Zeng *et al.,* 2001). On the other hand, early warning systems do little to save the infrastructure and investments associated with human settlement. Thus it is important to flood proof infrastructure and settlements. Gergel *et al.* (2002) show that if levees are set back in the floodplains, natural floodplain conditions remain intact while still offering protection to those behind the levees. In the United States it is now being realized that relocating people and capital out of the floodplain is often less expensive than dealing with regular big floods (Jacobs, 1999). Occupants of floodplains may lease their lands to the government as a flood right, thus providing land where flooding or water storage may occur (Agthe *et al.,* 2000). Finally, houses on stilts, demountable floodplain homes, floating roads, and floating vegetable gardens are all ways in which occupants of areas prone to flooding can be prepared for the inevitable flood.

In addition to the mounting evidence against controlling floods, it is also useful to consider how the views of people can influence a shift in management style. Traditional flood management coincides with a hierarchist management style (total control) as depicted by Thompson *et al.* (1990) and Hoekstra (1998). Because of the damaging effect and the less than optimal functioning of this management style, it is conceivable that a shift in management style may occur. In developed countries a logical shift would be toward an egalitarian management style (Thompson *et al.,* 1990; Hoekstra, 1998). This can be achieved by designing a flood management strategy that will not aim to control floods but be prepared for the consequences of a flood. Table 1 outlines the characteristics of two management perspectives according to cultural theory.

The strength of culture in decision making can be overwhelming. For example, in Bangladesh, although the government is aware of the advantages of living with the floods, it still favors the use of flood control structures (Davar *et al.,* 2001). A quick overview of the relationship between political powers and large water projects in the United States suggests that in most instances the party in power was more hierarchal (e.g., the Hoover Dam) than egalitarian. At this stage this comparison is rather fragile; however, it does give a foundation for future studies into the history of decision making in water management.

Finally, when considering the implementation of flood management strategies in developing countries it is important to consider that these countries often have highly variable environmental conditions. Savenije (1995) comments that developed countries are not more developed because of a higher state of knowledge, but they are developed because of the robust nature of the environment where these societies have formed. Mudelsee *et al.* (2003) confirm that there are no upward trends in extreme flood events in Europe, indicating that the European environment is better able to absorb or adapt to shifting forces such as increasing precipitation or population pressure. Hence, flood management policies that are successful

TABLE 1. Flood Management Policy Considering Two World views.

	Hierarchist	Egalitarian
Management Style	Intense use of control structures such as dams and dikes. Ultimate goal is to totally control floods.	Minimizes damage caused by flooding, particularly ensuring the protection of the most vulnerable population and the environment.
Ideal Scale	Large scale protection works.	Small scale protection structures.
Economic Growth	Economic growth in the floodplain is desirable and possible because of the protection structures.	Economic growth in the floodplain is in harmony with natural processes.
Desired Technology	Makes use of the latest technology for controlling floodwaters (engineered solutions).	"Green" communities that are self-sufficient (stilt or floating houses and flood-proofed infrastructure).
Risk Handling Style	Establishes water management institutes that are entirely responsible for the construction, operation, and maintenance of infrastructure to minimize risk.	Reduces risk to lowest possible figures by reducing the damage that can be caused by a flood.

in Europe are not necessarily effective in countries with more extreme or variable climates. Kundzewics and Kaczmarek (2000) note that an essential difference between floods in more developed countries as opposed to less developed countries is the loss of lives and wealth. Loss of life is high and economic loss is low in developing countries and vice versa in developed countries. Finally, developing countries often lack the capacity to maintain and operate infrastructure that is usually coupled with modern flood management. Sultana and Thompson (1997) and Momtaz (2002) provide evidence of this in their studies of the effects of flood control and drainage in Bangladesh. Hence, the paradigm is different for a developing country and may shift along an unexpected path.

THEORETICAL APPROACH TO THE PROBLEM: TWO POSSIBLE PATHS?

Flood management is an evolving field of science. Hence, it is possible to study the evolutionary possibilities by observing different evolutionary paths, and thus, better understand the evolutionary forces or phase shifts.

Figure 1 shows the evolution of flood management policy. The natural phase is the phase in which no form of flood management policy exists. Due to shifting pressures such as anthropogenic pressures (Yin and Li, 2001), climate (Pielke and Downton, 2000), the failure of current flood management policy (Criss and Shock, 2001), or the emergence of a dominant worldview, society will evolve or modify a system to cope with floods. Thus, society will adopt one or another evolutionary path, the traditional path or the alternative path.

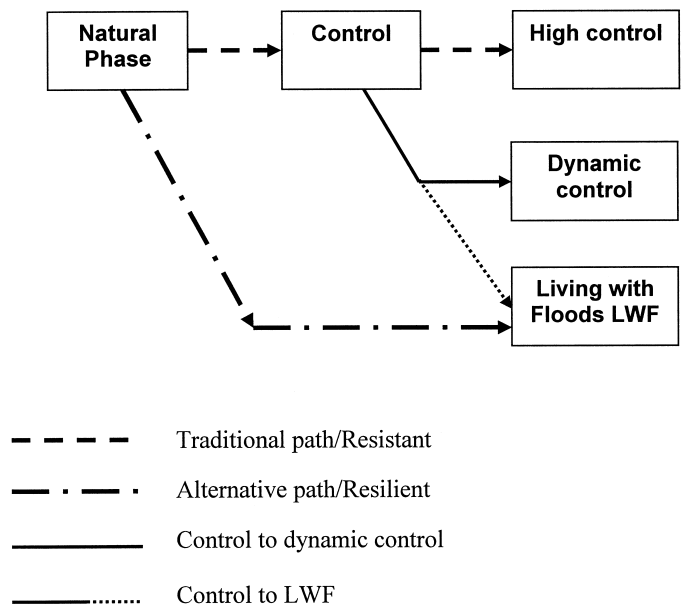

Figure 1. Two Possible Evolutionary Pathways to Future Flood Management.

De Bruijn and Klijn (2002) describe resistance as a system that "absorbs a disturbance and persists" and resilience as a system that "reacts on a disturbance and then recovers." Figure 2 shows these two systems in the context of flood damage.

In the resistant system, there is in general no damage at all; thus the system is persisting. However, if the system fails (the boundary conditions of the system are exceeded), the result will lead to the chaos, as suggested by Beck (1999). This is essentially the fear that many flood managers have about resistant flood management strategies that are currently in place. In a resilient system, floods are allowed, but the damage they cause is not severe.

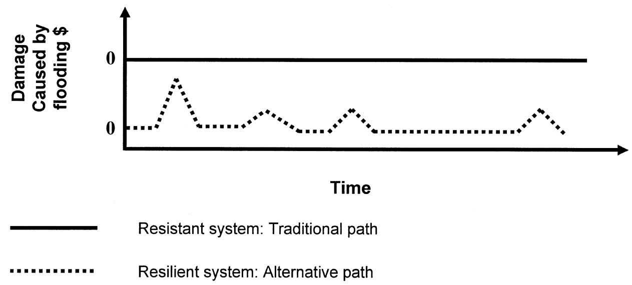

Figure 2. A Resistant Response to Flooding and a Resilient Response to Flooding.

It is also useful to consider the two pathways according to other criteria such as economic productivity in the floodplain areas (Figure 3). It is assumed that more productivity, resulting from farming and industry, can occur when floods are less frequent. This assumption is based on research conducted in Bangladesh, where it was shown that more productivity occurs in poldered areas (Datta, 1999). Hence, a scenario in which floods are controlled will lead to greater productivity increases. However, this assumption is only true if flood management infrastructure is adequately operated and maintained.

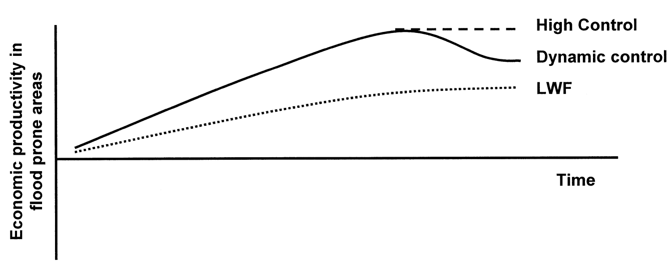

Figure 3. Economic Productivity in Flood Prone Areas: Resistant Path, Resilient Path.

High or Static Control

Vis *et al.* (2001) suggest that the central concept of a system of dike compartments is "controlled flooding, limiting the affected area and minimising the flood damage." This suggests that even though flooding is allowed the floods are still totally controlled by humans.

The principle behind a system of dike compartments is that dikes with an inflow gate and an outflow gate surround each compartment. Each compartment has different flooding probabilities based on the value of the land within the compartment. Moreover, considering that such a strategy is utilizing current systems of dikes, the restoration or improvement of the ecology is unlikely to occur. Hence, this strategy aims to: (1) reduce flood risk, both by keeping flood probability low and by reducing the flood damage; (2) maintain economic productivity in the floodplain areas; and (3) minimize social impacts that may arise from more radical strategies.

Dynamic Control

The room for the river strategy, as the name implies, is aimed at leaving enough space in the floodplains to allow for floods to pass through the river area (Silva *et al.,* 2001). This implies that development in the river floodplains should be minimized. The main aims of the strategy are to: (1) reduce the risk of floods by increasing the space in which floodwaters may discharge, hence lowering the high water level; (2) improve the ecological value of the floodplain areas by rehabilitating or maintaining the natural ecology of the area; and (3) limiting or adapting land use in the selected floodplain area to natural parks or to land use that may be flooded for a certain period of time without incurring high economic damage.

Living With Floods

Living with floods as a flood management policy focuses entirely on a society's ability to live or co-exist with floods rather than fight against floods. The Rivers and Land project (Netherlands Ministry of Transport, Public Works, and Water Management, 2001) is an example of a project that introduces an extreme alternative to the current controlled flood management in the Netherlands. The report introduces a flood management policy whereby any damage that arises from a flood is eliminated. Primarily, society adapts to the natural flood conditions and develops the land in accordance with the prevailing natural conditions. A society that co-exists with floods will: (1) minimize risk by reducing the damage inflicted by floods to nearly zero; (2) be totally aware of floods as they form a part of the society's daily life; and (3) aim to minimize environmental degradation by maintaining the natural system.

THE LOWER INCOMATI BASIN

The Lower Incomati Basin (Figures 4 and 5) is an example of a river basin in which managing floods effectively has been difficult. Flood management infrastructure is incomplete, not maintained, or simply broken. The local communities also have to deal with prolonged drought periods and irregular floods. Mozambique is downstream and hence is very much at the mercy of upstream water users in South Africa, Zimbabwe, and Swaziland (Carmo Vaz and Lopes Pereira, 2000; Savenije and van der Zaag, 2000b). The aforementioned problems make the creation of an effective flood management plan a highly challenging task.

Floods occur in the Lower Incomati Basin at irregular Intervals. The most recent floods occurred in 1976, 1984, 1985, 1996, and 2000 (Carmo Vaz and Lopes Pereira, 2000). The damage caused by the floods ranged from low, such as in 1985 and 1996, when some loss of crops and damage to infrastructure occurred, to severe, such as in 2000, when lives were lost. Furthermore, the basin is characterized by long dry spells during which the river may nearly run dry. Water use in the Republic of South Africa, Zimbabwe, and Swaziland impacts downstream conditions in Mozambique (Carmo Vaz and Lopes Pereira, 2000). Furthermore, 20 years of civil war have severely affected Mozambique's capacity to manage floods.

In forming a flood management plan in the Lower Incomati Basin, it would be very tempting to adopt

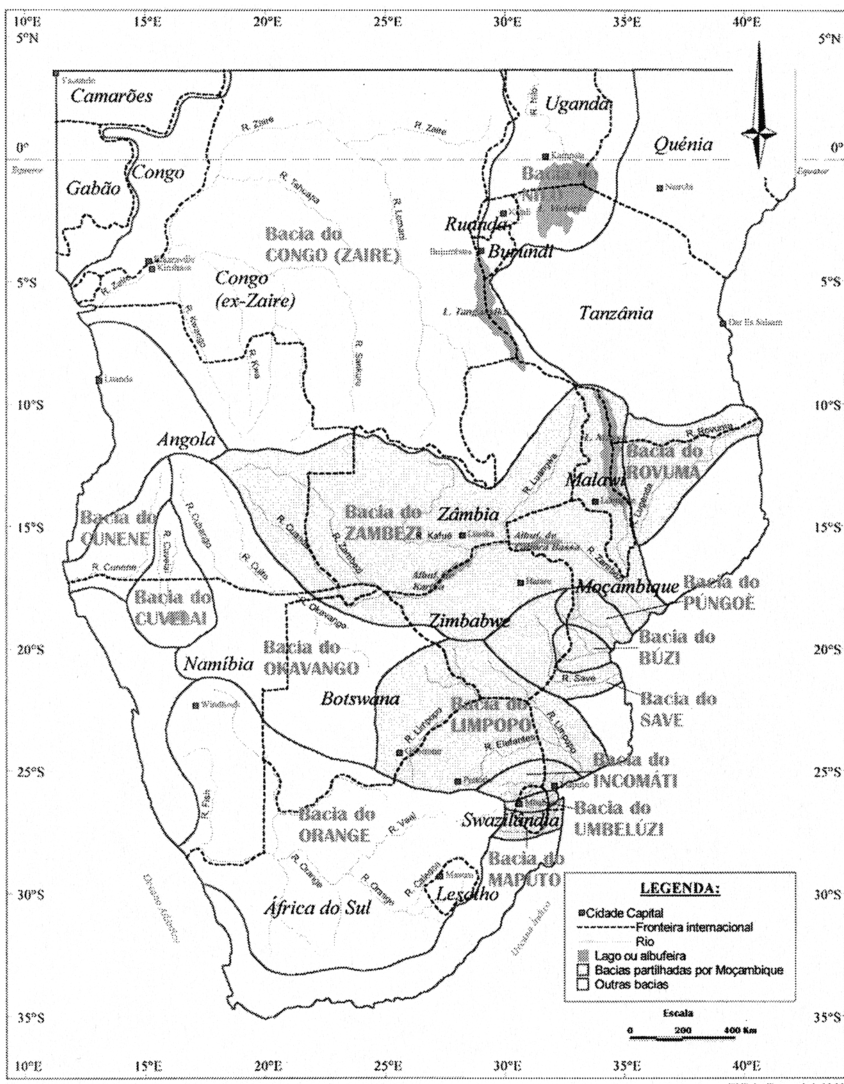

Figure 4. Incomati River Basin, Southern Africa (Source: DNA, 1999).

flood management policies that have been implemented in developed countries. These policies have helped allow developed countries to evolve into highly structured and powerful societies. However, this does not necessarily mean that such policies will be effective in the Incomati River Basin or in Mozambique. Years of living along the riverbanks have given inhabitants of the area a wealth of knowledge of the river's behavior. Inhabitants occupy the floodplains in the drier times in lightweight huts that they can disassemble and remove. When the floods come the inhabitants move their huts to higher ground. The floods are seasonal, and locals possess methods for predicting floods. This knowledge is essential and could be valuable in forming the basis of future flood management policies.

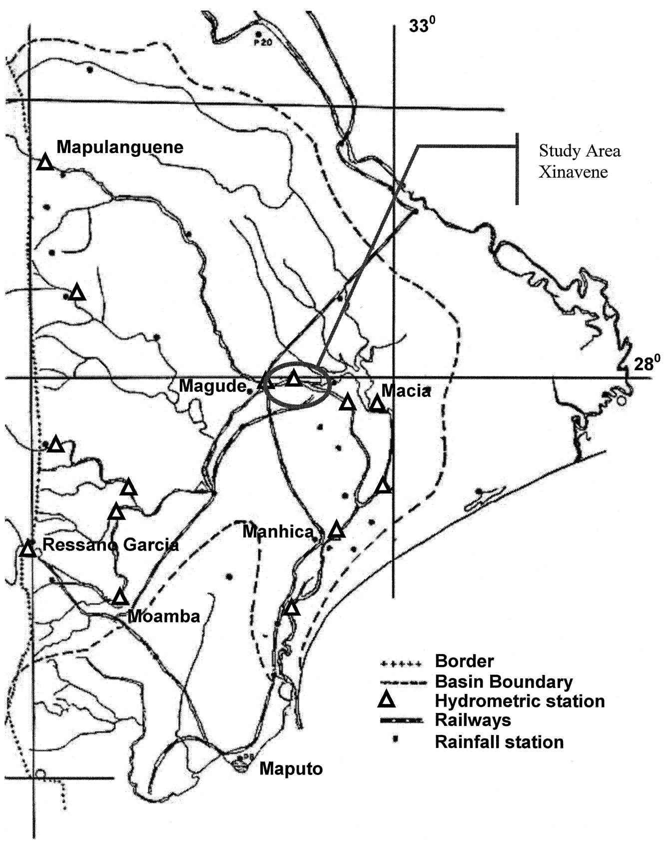

Figure 5. The Lower Incomati Basin, Mozambique (Savenije and Vaz, 1984).

The Floods of 1984

To establish a better image of a flood event in the Lower Incomati Basin it is useful to consider the most studied flood. The 1984 floods are considered the biggest floods on record in the Lower Incomati Basin. They caused damage such as inundation of some lower lying agricultural areas, disruption to Moamba's water supply, inundation of some areas of the national highway (EN1), destruction of the Moamba Bridge, and work stoppage on the Corumana Dam (Carmo Vaz and Lopes Pereira, 2000). Table 2 shows the maximum water levels during these floods.

TABLE 2. Flood Levels of the 1984 Floods Measured at Gauging Stations Along the Incomati (Source: Savenije and Vaz, 1984).

	Gauging Station	Reading (m)	Zero (m)	Level (m)
Ressano Garcia	E23	8.47	102.9	110.76
Ressano Garcia	E24	8.42	98.65	107.7
Moamba	E22	9.60	70.45	80.05
Magude	E43	8.70	17.83	26.53
EN1	E176	4.27	*	*
Manhiça	E28	8.40	0.85	9.25
Marracuene	E556	*	*	3.30

*Values not recorded.

Savenije and Vaz (1984) make a number of interesting observations about the behavior of the flood (for locations refer to Figure 5). The water levels at Ressano Garcia rose very quickly, on the order of 5 m in one day (in the 2000 floods this figure was on the order of 6 to 7 m). From Ressano Garcia to Magude the flood wave took one day to travel 130 km. From Magude to Manhiça the flood wave took five days to travel 110 km.

It is concluded that the difference in the travel times is due to the attenuation of the flood peaks by three separate hydraulic systems: System 1, a floodplain that fills up by way of a network of old riverbeds just upstream of Magude; System 2, a silted channel of the Incomati (10 km downstream of Magude) that slows the floodwaters due to roughness created by vegetation growing in the channel; and System 3, an unsilted channel that fills Lake Chuali, which acts as a flow regulator. Furthermore, the Maragra Sugar Company dikes at Maragra create a backwater effect and increase the lag time of the approaching flood downstream. This caused problems for upstream communities (Heyink Leestemaker, 2001).

TWO PATHS FOR THE LOWER INCOMATI BASIN

A large portion of the Lower Incomati Basin lies in the natural phase (Figure 1). Flood mitigation infrastructure is limited to the large Corumana Dam and a series of dikes that protect the sugar plantations and several small villages and towns. In general people live with the floods, but there is a drive to further develop the region, and construction of the Moamba major dam is an example of this.

Considering that shifts are occurring in flood management in the Lower Incomati Basin, a number of questions arise. Two questions are: what is causing the shift from the natural phase to the development phase and which direction will flood management take after the development phase?

Some key forces driving the first phase shift in the Lower Incomati Basin include population growth and economic growth in the floodplain areas, trigger events such as the destructive floods of 2000, donor countries and organizations who can influence flood management policy via funding and/or knowledge, and the increasing capacity of local people and the government to act on the potential threat of flooding.

The Design of the Possible Scenarios

To answer the second question – what direction flood management will take – we explore two alternative scenarios. First a system of dike compartments is considered, and second a system of co-existing with floods is considered.

High Control

The following example gives a sketch of how the Xinavene area may look in the future after following the traditional (resistant) pathway (Figure 6). In this scenario land use remains as it is, but the land areas are protected to a degree based on the economic value of the land.

The dikes are designed based on current standing infrastructure that has a safety level to protect the sugar plantations against a 20-year flood. Furthermore, the dikes for the township are based on rough water level estimates based on observed water levels of floods that occurred in 1977, 1984, and 2000 in the Lower Incomati Basin. The dike profile has a 1:4 front slope and 1:3 back slope (profile of Xinavene Sugar Company levees). Table 3 shows the dike characteristics for this pathway.

Flood warnings are issued in advance and incrementally. Flood Warning 1 indicates that people working and living in the low protection area have to evacuate to the medium protection area. Flood Warning 2 indicates that people living in the low and medium protection areas should evacuate to the high security area. If a Flood Warning 3 is issued, then all the people are evacuated to higher ground such as at Magude.

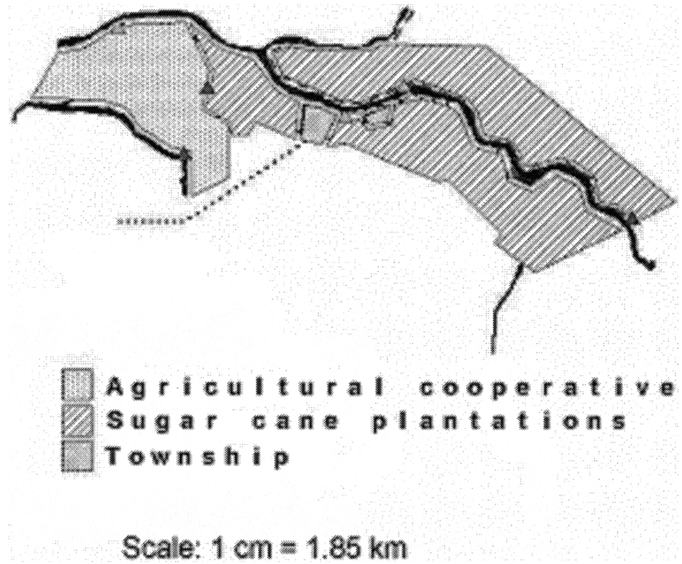

Figure 6. The Resistant Scenario for the Xinavene Area.

TABLE 3. Design Specifications for a System of Dike Compartments for a Design Discharge of 2,150 m^3/s.

Measure	Area	Value
Storage volume	Agricultural Cooperative	40 Mm^3
	Sugar Cane	250 Mm^3
Dike Height	Agricultural Cooperative	2.5 m
	Sugar Cane	6 m
	Township	8 m
Compartment Filling Time	Agricultural Cooperative	5 hours
	Sugar Cane	32 hours

The main advantages of adopting the traditional path of dike systems are that: (1) flood risks are reduced; (2) disturbance to economic activity in the floodplain is minimal because no flooding occurs; and (3) the traditional path has a tendency to stabilize society (Ni, 2001). The disadvantages of following the traditional path of dike systems are that: (1) if the dikes fail the consequences may be so great that the society protected by such a system may never recover; (2) the presence of structures in the floodplains alter the characteristics of the river, which may effect upstream and downstream water users (an example of this already occurring is the impact of the dike system at Maragra, which has upset the traditional farming practices in the area); (3) a system of dike compartments may alter the natural characteristics of the river environment and hence change natural conditions significantly; and (4) if the flood control and drainage system is not properly maintained this may lead to clogging the system and hence grave socioeconomic impacts (Momtaz, 2002) and loss of production from fisheries (Sultana and Thompson, 1997) and agriculture.

The calculation of the costs of implementing a system of dike compartments is based on the cost of moving the earth to construct the dikes. These costs have been obtained from interviews with representatives from the Xinavene Sugar Company in the form of a per cubic meter cost. Table 4 gives the estimated costs of the construction of a system of dike compartments.

Co-Existing With Floods

The following example gives a sketch of how the Xinavene area may look in the future after following the alternative (resilient) pathway (Figure 7). The alternative management strategy would involve removing all the dikes except those protecting the town, and these would be heightened (Table 5). The upstream area would become a natural reserve with wetlands and riparian forests. The area surrounding the towns would be made up of communities that co-exist with the floods.

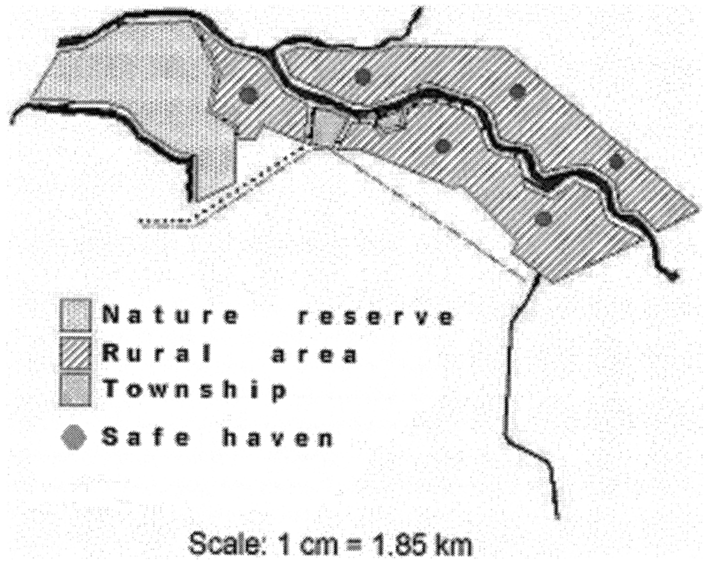

Figure 7. The Resilient Scenario for the Xinavene Area.

Flood warnings are the responsibility of the Direcção Nacional de Águas (DNA), the National

TABLE 4. Cost Estimates for the Earth Moving Operations Required for a System of Dike Compartments in the Xinavene Area.

Measure	Value
Cost of Construction of Dike Per Cubic Meter	1.33 US$ /m^3
Volume of Earth Required for Compartment 1: Low Protection (current level)	22,000 m^3/km x 22 km
Volume of Earth Required for Compartment 2: Medium Protection (level of 1984 flood)	126,000 m^3/km x 61 k
Volume of Earth Required for Compartment 3: High Protection (level of 2000 flood)	350,000 m^3/km x 6.5 km
Total Cost of Earth Moving for Dike Construction	US$13,900,000

TABLE 5. Design Specifications for a System of Co-Existing With Floods for a Design Discharge of 2,150 m^3/s.

Stilt Houses	Stilt Height	1.5 m
Town Dike	Height	8 m
Safe Havens	Capacity	3,500 Persons
	Drinking Water	10 L/Person/Day
	Sanitation	1 Latrine/20 Persons
	Area	5 m^2/Person
	Maximum Distance to Safe Haven	2 km
	Facilities – All Permanently in Operation	Medical Outpost, School, Communication Outpost, Food Storage

Directorate of Water, and communication of warnings are passed on to the local government, which sends out runners to the villages to tell the residents to initiate the evacuation plan. The message will first be relayed to the village mayor, who will then pass on the message to the respective village elders and chiefs (chefes dos bairros) Christie and Hanlon (2001) suggest that teachers should play a pivotal role in the education and initiation of flood warning and evacuation. Discussions with local chiefs and dignitaries confirmed that teachers play an important role in the community not only in the classroom but also in keeping the public informed.

The main advantages of adopting the alternative path are that: (1) community participation is encouraged; (2) cost effectiveness is high because of the low capital costs per person protected; (3) neighboring communities may follow suit in terms of the design of new houses and safe havens in their districts; (4) development will have a minimal impact on downstream communities, the fishing and shrimp industry, and the environment; (5) income will be created for the struggling tree plantation industry in Mozambique, as posts will be required to raise houses; and (6) the principle is an extension of current flood management policy whereby locals live with floods. The disadvantages of following the alternative path are that: (1) flooding is allowed to occur, and hence there will be some discomfort for locals who may get "wet feet;" and (2) where floods occur less frequently, there may be less drive to undertake such a flood management policy.

The costs of raising the houses on stilts is adapted from a similar project set up by the CARE nongovernmental organization in the Kurigram district in Bangladesh (Bangladesh Ministry of Water Resources, 2000). Bangladesh was selected because the problems experienced in both Bangladesh and Mozambique are similar with respect to poverty and flood vulnerability. Furthermore, the Bangladeshi project is in fact standing, so it provides an ideal basis to judge relative costs of proposed projects elsewhere in the world (Table 6). The costs associated with constructing the safe havens are based on a design proposed by van den Bosch *et al.* (2001) for the village of Muianga, which lies north of Xinavene, and the authors' research (Table 6). When interviewed, government officials responsible for the management of the Incomati River Basin accepted the research of the students of the technical university with minor adjustments.

THE EVALUATION OF THE TWO POSSIBLE SCENARIOS

In order to compare the two alternative scenarios, a set of criteria have to be considered. The following criteria are considered: (1) economic efficiency, (2) social equity, (3) environmental impacts, (4) sustainability, (5) political acceptability, and (6) risk. Following a stepwise analysis of each criterion the preliminary findings are collated and presented in Table 7.

The economic criterion is based on the differences in productivity that can occur within the floodplain and river area under each scenario. Productivity is then offset by the cost of undertaking one or the other system. The results are based on the estimated implementation costs of each scenario as compared to the benefits that are based on the estimated total possible productivity increase over the next 100 years using net present value (NPV) as an indicator.

TABLE 6. Cost Estimates for the Construction of Houses on Stilts, Safe Havens, and a Ring Dike in the Xinavene Area.

Measure	Unit Cost	Total Cost
Average Cost of Raising Homestead to Survive a 20-Year Flood	US$15 Per Capita	20,000 people x US$15 = US$300,000
Average Cost of Building Six Safe Haven Mounds to Survive a 100-Year Flood Supporting 3,300 People, Plus Cattle and Other Domestic Animals	US$66,500 Per Safe Haven	65,000 x 6 = US$399,000
Costs of Constructing the Ring Dike Around the Town – Safe to Flood Levels of 2000 Flood	US$1.33 Per Cubic Meter of Earth Moved	2,275,0000 m^3 x US$1.33/$m^3$ = US$3,025,750
Approximate Base Cost of Strategy		US$3,750,000

TABLE 7. Evaluation Table for the Components of the Criteria for the Two Pathways for the Incomati River Basin.

Criteria	Current Conditions	Traditional Path	Alternative Path
Economic Efficiency			
Cost	0	+	++
Productivity	0	++ (Agriculture) - (Fisheries)	+ (Agriculture) 0 (Fisheries)
Social Equity	-	+	++
Environmental Impacts	-	-	0
Sustainability	-	+	++
Political Acceptability	0	Hierarchical	Egalitarian
Risk	High	Low Chance/High Damage	High Chance/Low Damage

Note: ++ great improvement, + improvement, 0 no change, - deterioration, -- great deterioration.

$$NPV = \sum_{t=0}^{T} \frac{Bt - Ct}{(1+r)^t}$$

where (Bt - Ct) is the current estimated benefit of a strategy ($years), r is the annual discount rate (4 percent), and t is the estimated number of years required to reach the full potential of the strategy.

The estimates of the cost of implementing each scenario are based on the sum of the costs associated with construction and maintenance of each scenario. The estimates of the productivity are based on flood control drainage (FCD) studies conducted in Bangladesh (Datta, 1999) that compare the productivity of areas protected by an FCD system and those that are not. Datta (1999) shows that productivity in FCD areas is approximately 1.3 times higher than in non-FCD areas. If this is considered in terms of a percentage of gross domestic product, then it would appear that the benefits of a system of dike compartments outweighs the higher cost of this scenario. This is a plausible result, as it considers the fact that practices such as agriculture and aquaculture can occur under more controlled conditions (less disruption). Currently 17,500 ha of land are irrigated; this is 17 percent of the total land that can be irrigated. If it is assumed that a system of dike compartments will allow 100 percent of the land to be irrigated, then one may expect total productivity to increase by a factor of six. However, this does not take into account the potential disruption of the shrimp and fisheries industry. Sultana and Thompson (1997) explore the impacts of FCD on the fisheries industry in Bangladesh and show that a number of FCD projects impacted the fisheries significantly. Thus they conclude that these projects may not be viable. This may also be the case in Mozambique, particularly considering that the shrimp export provides more than 40 percent of the country's gross annual earnings. The operation of the Cahora Bassa Dam on the Zambezi River in Mozambique is a testament to the negative impact of a large dam on the fruitful Mozambican shrimp industry (Savenije and van der Zaag, 2000a). Furthermore, Momtaz (2002) concludes that a significant amount of agricultural land in Bangladeshi FCD areas had to be taken out of production because of silting up of drainage networks.

The environment criterion measures the impacts each alternative has on the natural state of the river reaches, floodplains, and estuaries. As yet there has been very little done in terms of environmental studies in the Lower Incomati. However, what is known is that most of the lower Incomati is still in a fairly pristine state. If a resilient path is adopted, then this natural state should change little, thus preserving the environmental and aesthetic qualities of the Lower Incomati Basin and estuaries. The small-scale protection works of the sugar farms and cross-border infrastructure are already significantly affecting the natural riverine environment (Savenije and Vaz, 1984; Carmo Vaz and Lopes Pereira, 2000; Heyink Leestemaker, 2001). Salt water intrusion, decreasing shrimp and fish populations, erosion, etc., are all products of the new activities taking place in the river basin.

Social equity considers the benefit to society of adopting one or the other pathway. If the net benefit to society of each pathway is considered, it can be assumed that this will be equal for both paths. This assumption is based on the fact that under both paths the net social benefit arising from an increase in flood safety and services such as schools and medical posts is equal. The essential difference between the two paths lies in the spread of the safety levels and the services per area. In the traditional path the distribution of wealth will be focused in the areas of higher protection, in this case the protection ring of the sugar companies and the towns. Under the alternative pathway, the distribution of wealth does not favor specific areas and hence is more evenly spread throughout the region. The alternative path favors the local people who rely on the rivers fruits for their survival, while the traditional path will benefit the agrarian sector, particularly the sugar industry, and thus is economically favorable. This is the case in the Netherlands, where the wealth of society is protected by an intricate system of dikes. If the dikes are removed, i.e., to allow room for a river, the social consequences will be dire due to reduced productivity and loss of income (Brouwer *et al.,* 2001). In contrast, Momtaz (2002) considers two social aspects in his critical review of flood management in Bangladesh – environmental destruction and polarization of power. Both of these aspects have caused an uneven distribution and loss of wealth in the impacted areas. A final example is the damming of the Maputo River, where the dam negatively affected traditional farming practices in the area (Savenije and van der Zaag, 2000a). These are prime examples of the traditional path failing in a country where an effective flood management utopia has not yet been reached.

The sustainability of one or the other pathway depends strongly on the future conditions within the river basin. If it is expected that future conditions within the basin (climate, population) change little, the traditional path will be sustainable. Here the European example can be considered, where population pressure and altering riverine environments has had little impact on flood frequency (Mudelsee *et al.,* 2003). However, if conditions are likely to change significantly and/or anthropogenic pressures increase, a system of flood management that can absorb the increasingly fluctuating conditions will be more sustainable. This is the case with the alternative path, the more flexible of the two paths. The choice strongly depends on whether the current speculations on changing climatic conditions and the estimated population growth rates in the region are accurate. De Boer (2002) notes a general trend toward increasing sea temperature (0.25°C per decade) and ambient temperature (0.2°C per decade) in southeastern Africa. Hence, it can be assumed that climate change is occurring. According to United Nations' estimates, population is increasing significantly in Mozambique (UN, 2001). The Incomati River Basin experiences greatly fluctuating conditions; thus, future flood management policies will need to be flexible in order to absorb the variable or increasingly variable climatic conditions. If a flood protection policy can absorb a flood of unique proportions after a 10-year drought, with no loss of life and minimal impact to society, then it might be considered sustainable.

Political acceptability considers the dominant world views that the designs of the paths follow. A hierarchical government will choose a policy in which flood control structures dominate. To date there are no examples of a country totally adopting the alternative path. However, countries such as Vietnam have partly adopted the path in certain regions within their borders (Mekong Delta in Vietnam).

CONCLUSIONS

The Lower Incomati Basin is an area where alternative flood management strategies encompassing resilient principles can be applied. This is because very little needs to be undone. Nature has already provided the Lower Incomati Basin with existing flood mitigation measures. These natural phenomena should be considered in any future flood management policy. In countries such as the Netherlands, where controlling floods is most important, it is difficult to revert to a system whereby nature is again given space. Hence, areas such as the Lower Incomati Basin can lead the way toward postmodern flood management. However, this can only be achieved if there is a willingness to review and consider the possibilities for the implementation of alternative flood management strategies.

Recommendations

This paper offers flood managers, politicians, and the local community a vision of how, initially, alternative flood management strategies may be considered and, finally, how one may decide between two or more flood management strategies. It is now recognized that totally controlling floodwaters may not be the optimal flood management strategy. Thus, it is highly recommended that strategies other than those traditionally adopted in developed countries be considered. It is recommended that solutions not only come from engineers but from a mix of engineers, political and social scientists, ecologists, and local inhabitants. Reliable data across all the aforementioned disciplines needs to be collated (Schultz, 2000). With the data available, a more in-depth study using tools such as cost-benefit analysis and multiple criteria analysis can be initiated (Joubert *et al.,* 1997). These results will form the basis for an effective and iterative future flood management policy for the Incomati

River Basin and other river basins in early stages of development.

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