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A System Dynamics Analysis Of The Levee Effect On The Brahmaputra River And Policy Implications

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Abstract

Levees (embankments), and other flood protection devices, may increase flood losses because they spur new development on floodplains, as people perceive they are safe, and catastrophic losses occur when flood protections fail. This has become known as the 'levee effect'. A causal loop diagram (CLD) of the levee effect is tested using empirical data, including a century of historical accounts, from the Brahmaputra River valley in Assam, India. The main conclusions are that: the CLD captures many of the results revealed by the history and empirical data; the greatest economic losses occur in large floods despite embankments; and embankments have not reduced the death toll and may have increased it by providing the circumstances for breaches and greater exposure of people as development on floodplains occurred. Embankments in Assam represent technological lock-in with path dependency from as early as the late 19th century. Given these results it is time for consideration to be given to measures that complement embankments, such as land use planning, more adequate warnings, relocation, insurance, education, use of local knowledge, and better evacuation procedures.

Key Words: flood mitigation policy, levee effect, causal loop analysis, Brahmaputra River

Introduction

Floods are an annual event in Assam, caused by flows over the banks of the Brahmaputra River and its tributaries and through natural off take channels called *hutis*, and exacerbated by flows through flood embankment breaches and by ponding in low-lying areas. Based on data collected at the village level and compiled by the Indian Central Water Commission, floods between 1953 and 2011 affected $0.86 \pm 0.01 \times 10^6$ ha (± the standard error of the mean) (about 11% of the total area of the state of Assam), caused mean annual economic damage (normalized by annual state inflation) of 352.06 ± 9.64 crore (10×10^6) rupees (USD 56.3 ± 5.43 x 10^6), and killed a total of 2761 people with the highest toll of 497 in 2004. The death toll only takes into account deaths caused directly by floods, and limited data from discussions with villagers suggests that deaths after floods, mainly from diseases such as malaria in areas of stagnant water, are much higher but are not recorded in the official data.

Since 1954 the main policy intervention to mitigate floods has been the construction of embankments along the Brahmaputra River and many of its tributaries. And the focus of this paper is the effect of embankments on attitudes, behavior, economic damage, and deaths, using a system dynamics approach and statistical analysis with a view to recommendations for future flood mitigation. Comparison is also made with a socio-hydrological model of Bangladesh floods and flood losses (Ciullo et al., 2017) where the circumstances are similar to those in Assam. The other serious river-related problem in Assam, riverbank erosion, is not considered in detail here.

Before the analysis a history of the embankment policy is provided, to develop an understanding of the incubation of the current policy settings in Assam, including technological lock-in and the consequent marginalization of alternative policies. Without an historical view it is not possible to detect how embankments have triggered development and development has triggered a need for more embankments in two-way positive feedbacks (Barendrecht et al., 2017).

Historical Incubation,Path Dependency, and Technological Lock-In

As early as the 16th and 17th centuries CE embankments (also known as bunds in India or levees elsewhere) were constructed to protect small areas from floods, but by the first few years of the 20th century there were only 180km of embankments. The possibility that embankments could allow larger areas to be cultivated and damage to crops reduced was investigated by a committee established by J.B. Fuller, the Chief Commissioner of Assam under the British Raj (Times of India, Oct. 3, 1911). This committee investigated additional questions that are still pertinent today, many of which have not been answered satisfactorily, such as: what would be the effect on land deprived of 'silt' and its natural fertilizing role (an issue raised by peasants interviewed by the committee who also raised issues of waterlogging behind and failure of embankments) and would river beds rise relative to floodplains because of sediment accumulation between embankments and sediment starvation on the floodplains behind embankments? The committee also wanted to know if larger areas of cultivation would increase revenue.

Opinions offered to the Fuller committee varied about the wisdom of embankment construction, ranging from a view that embankments were not necessary to protect agriculture as there was plenty of cultivable land, that riverbeds may either rise by sediment accumulation (relative to floodplains) or decline because of erosion by high velocity flood flows trapped between embankments, and that the revenue increase from protected land would be much smaller than the cost of the embankments. The committee however found in favour of embankments and in 1903 approval was given for the construction of new embankments on two tributaries of the Brahmaputra, followed by increased land revenue assessment.

But the debate about the wisdom of embankments continued with concern maintained about the lack of natural fertilization and problems of waterlogging where embankments prevented the drainage of floodwater and presumably ponded rainwater (Report of the Land Revenue Settlement of Sibsagar District, 1905). In the past during particularly wet times, peasants would relocate to drier land, but this became difficult when property laws became less flexible and relinquishment of land almost impossible. Waterlogging for some people became an intractable problem. The views of an agricultural chemist and soil scientist, A.A. Meggitt, supported those of the peasants that natural fertilizing was essential, and he suggested the installation of flood sluicegates to enable this process (Chief Secretary, 1909). Lechmere-Oertel (1918), an engineer with the Public Works Department, argued against embankments on the same grounds as Meggitt. And Spring (1903), the Chief Engineer of India's Public Works Department, wrote in praise of the traditional method of living with floods whereby people moved their meager possessions to higher ground in the family boat.

To this contested scene was added the construction of railway embankments beginning in 1903, most of which had been built on floodplains by 1930 (Public Works Department, 1929-30). These embankments disturbed lowland drainage ways and therefore blocked drainage of floodwaters and rendered some low-lying areas unfit for cultivation, and caused havoc when they breached (The Times of India, 1934). An investigative committee formed after the 1929 flood found conflicting views among peasants, depending on whether they lived 'inside' or 'outside' a railway embankment (Lines, 1930).

By the mid-1930s flooding in Assam was gaining more attention from both the government and the international press (e.g. Western Argus, 1934)) with widespread destruction of crops, houses and livestock (Wall Street Journal, June 29, 1934). For the colonial government the impact on revenue from the destruction of much of the jute crop was particularly important, as the valley of the Brahmaputra had become the principal jute growing area in South Asia by the third decade of the twentieth century. This widespread cultivation of jute followed debate about the wisdom of using land that the local people did not cultivate because of flooding, except for mustard and vegetables temporarily during the winter and some summer rice, although jute was believed to be capable of withstanding floods (Saikia, 2015). But the influx of migrants, mainly from East Bengal (now Bangladesh), mostly to grow jute, was well underway, making the debate almost pointless. Between the censuses of 1911 and 1947-48 one to one and a half million migrants had moved into Assam, constituting between one-tenth and one-sixth of the total population The cropped area approximately doubled, areas of settlement increased, and the productivity of jute, sugarcane, rape, mustard, and winter and autumn rice increased in the areas occupied by these hard working migrants (Doullah, 2003; Goswami, 1994; Chakraborty, 2012). This transformation of agriculture in Assam was not only aided by the construction of embankments but embankments were required to maintain the increased flow of revenue to the government's coffers.

After the flood of 1934 Shaw (1935), an engineer with the Public Works Department, prepared a report in which he noted that the area is prone to some of the heaviest rainfall in the world and, when combined with large-scale reclamation of land for jute cultivation, much of the lower valley is at risk of economically damaging floods. Shaw also found against embankments, arguing that they 'constitute a gross interference with the natural regime of the river' (p. 8). He found solutions in relief payments to peasants, remission of land revenue, and new land grants, some of which were enacted (Saikia, 2014). In addition, he found that the new migrants who arrived to grow jute did not grow food so they became vulnerable to flood-induced food shortages.

The 1946 flood in Assam spawned yet another report, this time by S.C. Majumdar, an engineer with considerable experience of floods in Bengal. Majumdar (1848, 1956) concluded *inter alia* that: embankments defy nature and should only be used on rivers that are relatively stable; embankments can cause disasters by raising the level at which floods reach floodplains, because of sedimentation within channels between embankments, thereby causing more damage than would occur without embankments and also resulting in a need for higher and stronger embankments until a stage is reached when they provide no protection; if built embankments should not be viewed as permanent solutions; and the old embankments of the 16th and 17th centuries CE had created vast swamps at a lower level than surrounding land that had continued to receive sediment. Majumdar made the obvious remark that floods are shallower and less dangerous if allowed to spread across floodplains rather then being pent up behind embankments that breach.

Opposition to embankments among the babus (bureaucrats) of Assam continued so that by 1947 there were only 11km of new embankments (RBA, 1980), the Government of India declared embankments to have been unsuccessful as flood protection devices (Ministry of Information and Broadcasting, 1949), and after the 1950 earthquake and floods the technocrat G.C. Garg advised against embankments as did Kumud Bhushan Ray (special officer for rivers in Assam's Public Works Department) who concluded that embankments are costly and non-remunerative, and do not provide protection against large floods (Ray, 1954).

The 1950 earthquake, with a magnitude of 8.6, devastated Assam, and it was followed in 1952, 1953, 1954 and 1955 by severe floods that damaged crops to the amount of 13.5 crore rupees (about USD 2.1×10^6 in 1954 and USD 7.7×10^6 in 2017), destroyed 65% of paddy, 53% of jute, and it was claimed that inundation covered 31,000 km^2 (an implausible 40% of the state), and affected about 1.2 million people (Assam Government, 1956). These floods also eroded riverbanks and swept away agricultural land, villages and lives, and also deposited vast areas of sand on land that had once been cultivable. Some towns vanished while others faced massive erosion. The town of Dibrugarh had begun serious attempts at riverbank protection in 1935, after the 1934 flood, with anchored trees, brushwood screens, tree branch revetments, and anchored floating bamboo cages. Some 450m of a planned 6km long stone revetment were finished before the monsoon of 1954 struck, and floodwaters outflanked the entire structure. The situation was so serious that the then Prime Minister, Pundit Jawaharlal Nehru, took charge and paid a visit, entrusting to the Central Water and Power Commission (CPWC) the responsibility for protection of the town (Ray, 1956; Singh et al., 2004).

The flood of 1954 in particular not only swept away lives it also swept away apprehensions about embankments, at least in the offices of government. Embankment construction was enabled by a simplified version of the Assam Embankment and Drainage Act 1941 enacted in 1954. About 855km of embankments were completed very quickly (Verghese, 1954). An Indian delegation to China reinforced the value of embankments (Sain, 1954) and Reddy (1954) reported glowingly on Chinese control of floods using embankments. Engineers of the CPWC began arriving in Assam, training in surveying and construction methods was arranged, and labour for embankment construction recruited (Verghese, 1854).

The most visible protection works were for the town of Dibrugrah, which had suffered serious flood damage. Embankments built in 1954-56 were raised and strengthened in 1963-1966, 1977 and 1980, and again after flood damage in 1988, and to this day continue to be refurbished, partly as a result of the increasing level of floods resulting from increasing channel bed level (UN-Habitat, 2002).

Other ideas were proffered to mitigate floods, such as cleaning drainage channels, digging a deeper channel for the Brahmaputra, reforestation of the catchment to slow storm runoff, raising villages, and constructing storage reservoirs (Kingdon-Ward, 1950; The Times of India, 1954; Ray, 1956). But the push for embankments was well underway, in combination with restoration of some abandoned channels to promote drainage, the digging of new drains, and the promotion of sedimentation in some areas to raise land levels (RBA, 1980). Although there were still some who doubted the efficacy of embankments in the face of mighty natural forces, by 1978 a total of 4,000km of embankments had been constructed in Assam, along with at least 700km of drainage channels (Government of India, 1972; http://assam.gov.in/web/department-of-water-resource/river-system-of-assam, accessed 10/6/17). Breaches had occurred in some new embankments within a year of construction, and some were located to the detriment of many villagers, but construction continued as political and economic benefits accrued to those in favour of the policy. By the end of the 20th century about 1000km of embankments had been constructed along the Brahmaputra River, which is about two thirds of the total length of the river. And embankments have been extended into about 50% of Assam's total flood-prone area (Asian Development Bank, 2010).

Field observations and informal discussions with villagers and government officials by the authors in Upper Assam have shown that many people have now become dependent on embankments as places of refuge during the worst floods, some people have replaced their traditional stilt houses with concrete constructions on the ground but only when ‘inside’ an embankment, schools and meeting halls have also been built in a similar way near embankments, and land previously uncultivated just behind embankments is being used. Hazarika et al. (2016) found from surveys in Dhemaji District that the construction of embankments has attracted more and more people to live and cultivate near the rivers, and that the occurrence of floods in the minds of local people is synonymous with breaches of embankments. Despite embankments being refuges, breaches do more damage than floods where there are no embankments, according to their study.

Many factors have incubated the current flood policy in Assam. The most important appear to have been: a need to protect valuable assets such as towns; protection of cultivated areas; increase the area of cultivation; and protect and increase government revenue from cash crops, the most important of which was jute. The process of incubation has a history of more than a century, with the establishment of jute and the importation of migrants from East Bengal to grow the jute, both initiated by the colonial government. The path dependency that resulted was mostly manifest in the construction of embankments, a technocratic solution to a problem that is actually embedded in a coupled socio-hydrological system of considerable complexity. This path dependency still exists, despite many past and present critics and suggestions for alternative policies.

Srinivasan et al. (2017) explain that the behavior and efficacy of major public investments in structural solutions with long-term impacts cannot be predicated without a socio-hydrological framework; that is, without serious consideration of feedbacks between water and society. Moreover, as earlier noted there is a two-way feedback between protection from floods and development and the need for more protection to sustain development. Evidence for these feedbacks is clear from the historical analysis, and it is such an analysis of feedbacks that now follows.

A Causal Loop and Statistical Analysis

Newell and Wasson (2002) constructed a Causal Loop Diagram (CLD) (Fig. 1), based on information from Australia and the USA, capturing what has subsequently become known as the levee (or embankment) effect, where *inter alia* people's experience of small to medium size floods is reduced and people move closer to rivers where they feel safe because of the levees. But losses greater than previously can be expected from large floods because of increased exposure of people and their property. This set of processes has been modeled by Cuillo et al. (2017) in the case of Bangladesh and more generally by Barendrecht et al. (2017).

From the historical analysis that began this paper, published research, field observations, informal discussions with villagers and government officials, and formal surveys (to be reported in detail elsewhere) the propositions in the CLD have been tested. Each link in the CLD has been numbered (Fig. 1) and an account given of the findings follows.

1. Pressure for compensation from flood losses (here measured as total normalized economic losses and normalized deaths;#8) came about as land became waterlogged and cultivation more difficult.
2. Government relief schemes were developed including remission of land revenue, and emergency food provision.
3. Many of the government committees formed after floods found that people felt more vulnerable because embankments caused waterlogging and also breached.
4. Because of the perceived increased vulnerability, perceived risk was also higher.
5. Floodplain development certainly increased as embankments were constructed, for cultivation of jute early on and more recently for infrastructure along with larger numbers of people.
6. Actual vulnerability certainly increased.
7. As has actual risk.
8. Total flood losses for the period 1956 to 2006 show a positive relationship with annual maximum discharge at Bahadurabad (just over the Bangladesh border; data supplied by Monirul Mirza) using the non-parametric Kendall's Tau (b) statistic with $p=0.0027$. When only the period 1956 to 1981 is considered, a positive relationship is also found with $p=0.0151$ but there was no trend in precipitation (data from Immerzeel, 2008) ($p>5\%$) or discharge. That is, damage was probably a function of the magnitude of floods and exposure as

development of floodplains occurred during the period when embankments were not as extensive as they are now. For the period 1982-2011, when most of the construction of embankments had been completed, there is no significant relationship between flood discharge and damage ($p=0.0758$). However the largest amount of damage in the entire data record, in 2002, was also a year with the highest discharge, but the second highest year of damage in 1988 was a year of high discharge but not the second highest. Embankments were already well established when both of these years of high damage occurred, supporting the 'prediction' that the levee effect induces a few large damage totals and there is either no change or a decline in overall damage (Cuillo et al., 2017). Deaths during the earlier period are positively related to annual maximum discharge ($p=0.0161$) and at an even higher level of significance ($p=0.0001$) for the later period. These results suggest that embankments when few in numbers had little effect on the death toll, and adaptations were common. But with more embankments came more exposure to floods by floodplain development along with breaches, thereby increasing deaths. Also high discharges cause more deaths for both time periods (at $p<1\%$) showing that embankments do not reduce deaths and may increase them.

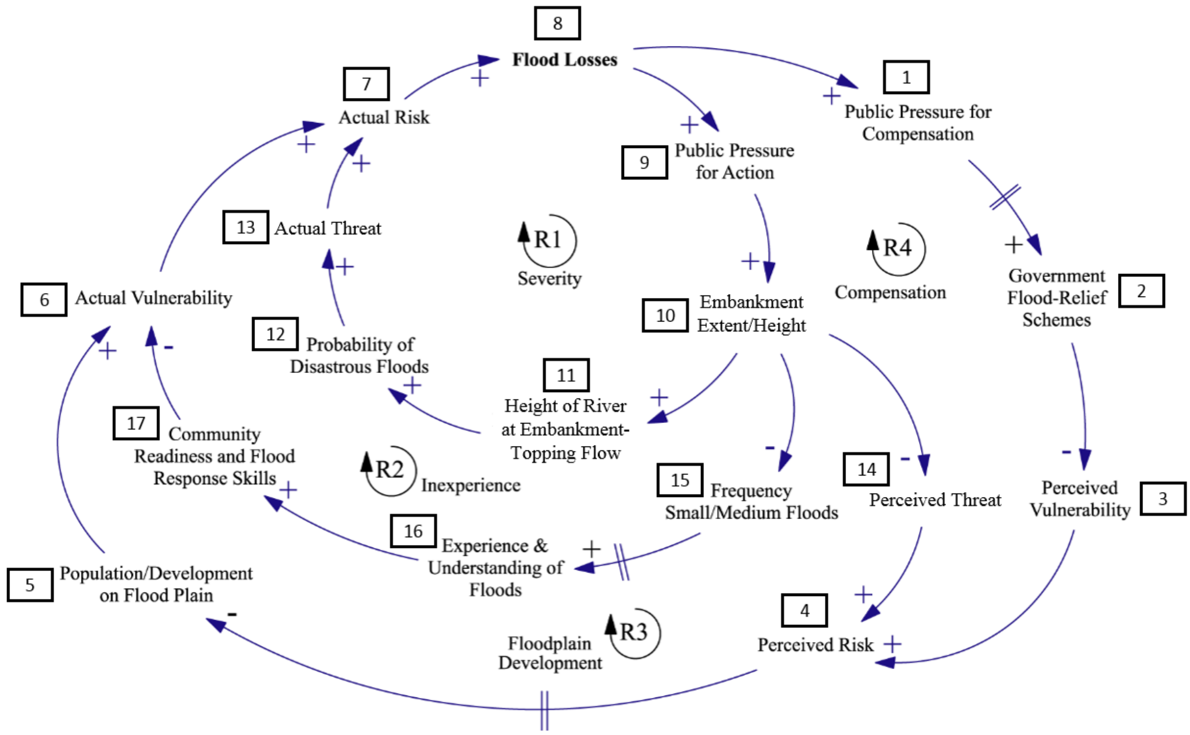

Fig. 1 CLD from Newell and Wasson (2002).

9. While there was public pressure for action, which continues particularly to repair breaches and complete embankments, early pressure for action came from government agencies which wished to increase the area of cultivation of cash crops and protect these areas. As seen in the historical analysis this pressure led to increased embankment construction, particularly after the 1954 flood.
10. Increasing the height and strength of the embankments has followed.
11. The probability of disastrous floods has increased because of breaches and not because of increased embankment height or increased maximum flood discharges, although it is difficult to separate the effects of the increase in the height of the riverbed, as a result of sedimentation, from the effects of embankment construction in causing large floods.
12. Breaches certainly increase the probability of disastrous floods as they concentrate flow over a much smaller area than is the case for floods where there are no embankments, with higher velocities and more sediment carrying capacity resulting in high levels of localized

damage (Hazarika et al., 2016) and large areas of sand deposition on once cultivable land.

13. Accordingly the threat has increased.
14. As has the actual risk.
15. While it might be expected that continuous embankments that don't breach would reduce the frequency of small to medium floods reaching inhabited areas, this is not the case in Assam. Embankments are to be found along only two-thirds of the banks of the Brahmaputra River and breaches are common.
16. Survey results show that all respondents have experience and understanding of floods, probably for the reasons given in #15.Social memory (Cuillo et al., 2017) appears to have played little role.
17. Community readiness and flood response skills appear to have declined in areas 'behind' embankments because they rely almost entirely on the embankments as refuges thereby limiting their options, and in areas without embankments people are more risk averse. As seen earlier, actual vulnerability (#6) and risk (#7) therefore have increased for people 'behind' embankments but probably not for those without nearby embankments. For example people who live on chaurs (sand islands in the river where there are no embankments) have well developed plans for coping *in situ* during small to moderate floods, and evacuation plans for large floods.

Discussion and Conclusions

Path dependency of the embankments policy began late in the 20th century and continues to this day as a form of technocratic lock-in. While this process was underway well before the 1954 flood, that event spurred action that had previously been sluggish. Two-way positive feedbacks between embankments and floodplain development is clearly demonstrated by the historical account, added to which are political benefits.

Embankments may have contributed to deaths through breaches, but it is not possible to separate the effects of increased exposure of people from the effect of breaches as floodplain development has occurred. During the period when most embankments had been completed, economic damage was higher than before, occurring during large floods, a result of the levee effect and breaches. It is not possible to determine from the available data if higher damage occurs ‘behind’ embankments and less damage where there are no embankments. Or if breaches do most damage during large floods, a real possibility according to the spatially limited results of Hazarika et al., (2016). Surveys designed to tease out these relationships are needed.

Bangladesh shares many flood hydrologic and flood mitigation similarities with Assam, and so the modeling by Cuillo et al. (2017) is worthy of closer examination. The model suggests that losses first increase then decrease with time even though the existence of embankments inspires increasing development on floodplains, suggesting increasing awareness and adaptive behaviour. But before adaptation takes hold large floods produce large losses which become smaller with time. In Assam there is no evidence of decreasing deaths, but economic damage shows no overall relationship with floods, inclucing a decline in damage, when embankments have been built along more stretches of the river. But large floods do cause the largest damage and numbers of deaths. These differences may be a result of a small or non-existent role for social memory, at least during the most recent period for which survey results exist, incomplete embankments, and a significant role for breaches which are not included in the model of Cuillo et al., (2017).

The results from Assam suggest that embankments alone are insufficient to reduce damage and deaths, and may play a role in increaing deaths. More consideration should be given to non-structural measures such as land use planning, better warnings, relocation of exposed populations, insurance, education, use of local knowledge (Das, 2015) and better evacuation planning. According to Cuillo et al., (2017) such measures are likely to produce outcomes that are more resilient than embankments. They also found that non-structural measures are more risky than structural measures, a conclusion that may not apply to Assam. Such a transformation of flood mitigation policies in Assam will require the relinquishment of some power by those promoting and supporting the embankments policy. It will also require a larger role for those trained in the social sciences and humanities to design and implement a new set of policies that includes local knowledge as a key component (Das, 2014), a transformation that is beginning to be discussed both in government agencies and civil society. This transformation should be approached with some urgency as climate changes and more intense rainfall and larger flood flows become more likely (immerzeel, 2008).

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