research paper

ENVIRONMENTAL HAZARDS
Human and Policy Dimensions

Communities of knowledge: Science and flood management in Bangladesh

BRIAN R. COOK* AND STUART N. LANE

Department of Geography, Institute of Hazard, Risk and Resilience, Durham University, Durham DH1 3LE, UK

This paper traces the integration of a particular set of knowledge claims into flood management in Bangladesh following the instigation and collapse of the Flood Action Plan. Using the work of Goodbred and Kuehl (1998) as an entry point and partially in response to Nicholls and Goodbred's (2004) call for integrated assessments to improve understanding and management, we explore the incorporation of sedimentation and subsidence knowledge claims into flood management. We approach this issue from a 'scholarly' perspective, tracing the citations and cross-references within academic publications, and from a 'government' perspective, exploring recent policy to determine the degree of consideration for sedimentation, subsidence and their related phenomena (i.e. lateral river erosion, river avulsions, river conveyance). Despite mutual recognition of relevance and widespread support for holistic or interdisciplinary knowledge management, our findings suggest an isolation between the natural and social science communities concerned with flood management. Furthermore, the exploration suggests a similar isolation between government and the sciences. Drawing upon Barry et al.'s (2008) analysis on interdisciplinarity, the findings suggest that different 'logics' might account for the isolation and associated sequestration of knowledge, raising the possibility of improved communication and collaboration among those interested in this increasingly complex and important issue.

Keywords: Bangladesh; complexity theory; flood management; interdisciplinary; science; sediment

> Harvesting the benefits from Bangladesh's location in the delta of these three rivers is only possible to their full extent, if a better understanding of their behaviour is obtained (Anonymous, 1996, p. Executive Summary to FAP 24).

> The National Water Policy seeks remedy to this chaotic situation by bringing order and discipline in the exploration, management and use of water resources in Bangladesh. It clearly and unequivocally declares the intention of the government that 'all necessary means and measures will be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner' (Sheikh Hasina in GoB, 1999, foreword to NWP).

> [o]nly a wide range of research across the natural, engineering and social sciences, drawn together by integrated assessment approaches can adequately address the important question of future development of the Ganges–Brahmaputra delta (Nicholls and Goodbred, 2004, p. 13).

1. Introduction

Floods continue to be of importance in Bangladesh due to escalating damages and the yearly potential for the recurrence of catastrophic events (e.g. 1955, 1987, 1988, 1998 and 2004). In addition, ongoing urbanization, population and economic development contribute to increasing vulnerabilities (Myers, 1993; IPCC, 2007). In this context, floods impact diverse

■ *Corresponding author. *E-mail:* b.r.cook@durham.ac.uk

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issues such as sustainability, economic development, health and the environment (Benson and Clay, 2002; Pelling et al., 2002; Pelling, 2003a, b; Smith and Petley, 2009). In parallel, researchers are broadening their approaches as part of a shift towards a 'complexity paradigm' within environmental research (Thrift, 1999; Manson, 2001; Urry, 2005; O'Sullivan et al., 2006). Following this interpretation, environmental hazards are understood as increasingly complicated (due to the inclusion of social, economic and physical factors), increasingly complex (due to the non-linear relations between heterogeneous actants), increasingly uncertain (as the limits of science, social science and technology become more apparent) and, as a result, increasingly contested (by a public less willing to surrender power to traditional experts). There has also been widespread advocacy of interdisciplinary research[1] able to integrate natural and social science. In Bangladesh, this is manifest through calls from both government and academic authors for interdisciplinary-grounded approaches to the management of environmental hazards (GoB, 1999, 2001, 2005; Benson and Clay, 2002; Brammer, 2004; Sultana and Thompson, 2004; Mallick et al., 2005; Ali, 2007; Brouwer et al., 2007; Haque and Etkin, 2007; Khandker, 2007; Rashid et al., 2007). Notwithstanding these calls, there are few studies of interdisciplinarity as a practice, and little consideration of precisely how very different disciplinary knowledge practices and claims might be reconciled. We explore the legacy of a 'first-generation' interdisciplinary plan in order to trace a particular set of knowledge claims within academic and government accounts of flood management. We focus on sedimentation and subsidence in the Bangladesh delta for three reasons: first, there is broad agreement of their relevance to flooding and flood management; second, given the context, we are interested in the degree to which scientific knowledge is integrated into policy and management; and third, we recognize a growing faith in holism, for example Höfer and Messerli's (2006, p. 430) belief that 'only integrated approaches and management strategies can take the complexity of flood processes in Bangladesh sufficiently into consideration and will lead to adapted and adaptable flood management'. Taken together, the aim of this paper is to trace an example of that 'integration' within academic and policy contexts in order to better understand the complex realities that shape the science–policy interface.

First, we think through interdisciplinarity, drawing upon complexity theory to highlight its reductionist-aggregate assumption. We then provide a brief summary of flood management in Bangladesh, emphasizing the research that accounts for sedimentation and subsidence. This leads to an exploration of how scientific knowledge claims are assimilated into academic flood literature and government flood policy in Bangladesh. We conclude that, despite the aims of interdisciplinarity and the appeal of its holistic goals, the different knowledges are structured by the communities from which they emerge. We argue that the disciplinary protocols, assumptions, objectives and 'logics' that produce knowledge maintain an isolation between the relevant communities that require further consideration.

2. Interdisciplinarity and complexity

Interdisciplinarity is a concept with numerous definitions. Broadly, the different interpretations aim to reconcile multiple knowledges (Tress et al., 2007; Uiterkamp and Vlek, 2007; Barry et al., 2008; Lau and Pasquini, 2008; Petts et al., 2008; Pohl, 2008; Russell et al., 2008), often with the aim of addressing complex or 'modern' issues (Lawrence and Despres, 2004). In response to the dominance of Nowotny et al.'s (2001) interpretation of interdisciplinarity as a means of making science more accountable to the public, Barry et al. (2008) argue that interdisciplinarity follows three interwoven logics: the *logic of accountability*, which bridges science and the public to produce more equitable forms of knowledge; the *logic of innovation*, which assumes that boundary transgressions result in new and more useful knowledges; and an *ontological logic*,

which represents a means of challenging prevailing ontologies and epistemologies in order to reconfigure knowledge production. In addition to the inclusion of diverse knowledge claims, there is an important, though less prominent, recognition that interdisciplinarity has become a cause célèbre (Lawrence and Despres, 2004; Barry et al., 2008; Lau and Pasquini, 2008; Pohl, 2008), a concept whose idealistic positioning as an approach to understanding complicated problems has exceeded any practical demonstration of what it actually achieves (Brewer, 1999; Barry et al., 2008; Petts et al., 2008). This is reflected in a multitude of attempts to define and to redefine precisely what it is (Tress et al., 2001, 2009; Lawrence and Despres, 2004), many of which focus in on the notion of letting the 'problem designate' (Brewer, 1999) do the work of building interdisciplinary capacity.

Such accounts fail to understand that allowing 'the problem' to lead in knowledge generation overlooks existing hierarchies in knowledge practice, including the very ways in which the problem becomes designated. Barry et al. (2008) argue that interdisciplinary approaches may promote a hierarchy of academic labour that locates the social sciences as a mediator between science and the public, and that this is reflected in the ways in which interdisciplinarity has become seen 'additively as the sum of two or more disciplinary components or as achieved through synthesis of different approaches' (Barry et al., 2008, p. 28). The problem must necessarily be reduced to a set of component disciplines and then re-aggregated to generate a synthetic understanding or account. Although such a disaggregation may be possible, what is more interesting is what happens at the point of re-aggregation. Following premises from complexity theory, the ability to reassemble the 'whole' following analysis of the 'parts' risks neglecting the properties that emerge via relations between the constituent elements (Anderson, 1972; Byrne, 1998; Manson, 2001; O'Sullivan, 2004). More simply, looking at the pieces may distort understanding of the whole, raising concerns for 'holistic' interdisciplinarity.

There are two issues here. The first is a challenge from complexity theory that explicitly interprets problems as emergent in ways that are more than the sum of their parts (Anderson, 1972; Manson, 2001; O'Sullivan, 2004; Urry, 2005; Manson and O'Sullivan, 2006). Although this is an ontological consequence, it is bound to the epistemological position that the act of reducing and re-aggregating the problem causes the nature of the problem to evolve. The problem becomes framed through the process of reduction (and re-aggregation) and in this sense cannot be understood without becoming a part of it. As Anderson explains, '[t]he ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe' (1972, p. 393). Complex phenomena have to be conceptualized as part of systems of interconnected people, things and ideas that include those trying to understand them, appreciating that the content and connections are continually being reformulated (O'Sullivan, 2004; Bennett, 2005; Manson and O'Sullivan, 2006; Li, 2007; Smith and Petley, 2009). If the world or problem is truly complex, interdisciplinarity will suffer from the internal contradiction that the designation of a problem will define its disciplinary content in a way that shapes the very problem being framed. The problem designate becomes a problem designated. Second, the act of designation itself carries risk (Lane et al., 2006). If the problem is somehow allowed to 'speak back', its message may accord particular sorts of importance to particular sets of accounts, at the expense of others. This risk, when combined with the presence of hierarchies of knowledge, may itself make the problem speak back in particular ways, ones that preserve established hierarchies of knowledge by making sure that their proponents are fully involved in the way the problem has become defined.

What this discussion shows is that the rhetoric of interdisciplinarity raises challenges for interdisciplinarity as a practice, ones that can be explored using those problems where interdisciplinarity is being invoked as a necessary way forward.

3. Flood management in Bangladesh: Sediment and subsidence

Interdisciplinarity is often accorded a necessary status in environmental hazard management and research (Burton, 1960; White, 1974; White and Haas, 1975; Smith and Ward, 1998; Mileti, 1999; Wisner, 2004; Smith and Petley, 2009). In response, both academic and government authors advocate the combination of multiple knowledges 'as a means to shed new light on an actual problem' (Brewer, 1999, p. 328). This position is frequently advocated in relation to Bangladesh (Paul, 1997; Brammer, 2004; Cook, 2010). Here, we focus upon one entry point to the flood management debate within the context of interdisciplinarity: sedimentation and subsidence. Sediment and sedimentation are integral to any understanding of the Ganges–Brahmaputra–Meghna basin (hereafter GBM). Hughes et al. (1994, p. 8) state that the 'physical geography and hydrology of Bangladesh have been determined mainly by interacting processes of erosion, sediment transport and deposition, and delta formation is very much a continuing process. In fact, the country owes its very existence to depositional activity associated with river and tidal activity'. For the GBM basin, sediment and sedimentation represent the key drivers of both short- and long-term river processes. They affect large-scale river avulsions, the infill of river beds leading to gradual channel migration, local and large-scale subsidence and the sensitizing of the system to more catastrophic events, for example the 1787 earthquake that resulted in the Brahmaputra shifting to its current Jamuna channel (Hutton and Haque, 2003). As Brammer explains, 'the risks of earthquakes and changes in river channels need to be taken into account in planning and designing water control and flood management structures, both in Bangladesh and within the whole GBM catchment area' (Brammer, 2004, p. 10).

The Flood Action Plan (FAP 1989–1995) represented a major international initiative to address flood risk in Bangladesh (see detailed summaries in Boyce (1990), Hughes et al. (1994) or Brammer (2004) for a discussion of the issue). FAP 24, the river survey programme, focused on understanding the physical processes, primarily morphological and hydrological, that shape the GBM basin, including sediment and subsidence (GoB, 1996a, b, c). The study aimed to transfer and implement modern technologies and management strategies, improving Bangladesh's institutional capacity (Hughes et al., 1994; Brammer, 2004). FAP 24 was particularly focused on 'improving the understanding of river behaviour in relation to the design of embankments and bank protection works, predicting bank erosion rates, modelling changes in flow into distributory channels, assessing sediment transfer patterns, and modelling the impacts of proposed FAP measures on river levels and morphology' (Brammer, 2004, p. 206). A critical element of the study was an improved understanding of the short- and long-term behaviour of the GBM delta. The document states its objective as: 'to provide benchmark data and to assist other FAP-projects' (GoB, 1996b, p. ix) and elsewhere, in more detail, that '[t]he objective of the project is to establish the availability of detailed and accurate field data as a part of the basis for the FAP projects, as well as adding to the basis for any other planning, impact evaluation, and design activities within national water resources and river engineering activities' (GoB, 1996c, p. 1).

One of the most scientifically important elements of the FAP 24 work was undertaken by Goodbred and co-researchers (e.g. Goodbred and Kuehl, 1998, 1999, 2000). In historical terms, the GBM river system is a major component of the Bengal Basin, a 200,000 km^2, 21 km deep deposit of material eroded from the eastern Himalaya and Indo-Burman orogenic belts (Alam and Curray, 2003). Goodbred and co-authors' work was critical to the question of flooding in Bangladesh, because it showed that a large percentage, as much as 30–40 per cent, of the 1–2 billion tons of sediment delivered to the Bay of Bengal each year could be sequestered within the floodplain delta (Goodbred and Kuehl, 1998). The work showed that this sequestration was primarily associated with three

processes: (i) rapid deposition in the channel braidbelts; (ii) slower deposition through overbank flooding; and (iii) reworking of floodplain deposits. The net effect is a complex pattern of aggradation and degradation, leading to complex topographical patterns, which in turn feed larger-scale patterns of channel configuration, including avulsion. The analysis of Holocene deposits (Goodbred and Kuehl, 2000) shows a complex interrelationship between this sedimentation, channel configuration, sea-level rise and subsidence.

Goodbred and Kuehl (2000) show that from 10 to 11,000 years BP, despite relatively rapid sea-level rise, sediment delivery rates were sufficient to sustain deposition that could counter marine transgression. From 7,000 years BP, with slower rates of sea-level rise, the accommodation space within the delta was filled. The deposition rates within the channel system are likely to have assisted in the migration of the channel systems leading to coastal progradation towards the west. This had switched back to the eastern part of the delta by 5,000 years BP with the current Bangladeshi shoreline configuration present from 3,000 years BP. Goodbred and Kuehl (2000) note that the high rates of sediment delivery are critical to understanding why the GBM basin witnessed earlier and more rapid coastal progradation during the early Holocene, something that is central to the creation of the Bangladesh land mass. They also note that rates of tectonically related subsidence of up to 4 mm per year influenced the sedimentation patterns by creating tectonic basins. This last point is critical as it emphasizes that (i) long-term tectonic adjustment to the complex spatial and temporal patterns of sediment loading is ongoing and (ii) subsidence must have been countered by sediment deposition in order to maintain land levels: sedimentation offsets subsidence, erosion and sea-level rise (Broadus, 1993; Goodbred and Kuehl, 1999, 2000; Nicholls and Goodbred, 2004).

In this context, understanding sedimentation and subsidence is central to understanding both gradual and rapid channel migration and, via these processes, for understanding land and water resource management in Bangladesh. The main challenge has, certainly up until the 1990s, been to understand the process of sedimentation, its spatial and temporal variability, the legacy of previous depositions for long-term delta subsidence and the associated interactions with sea level. Although these processes are now better understood, how they might combine and interact with flood management remains much less certain (Nicholls and Goodbred, 2004). Given this context, the following sections of the paper trace the ways in which sedimentation and subsidence knowledge claims – using the work of Goodbred and co-authors as an entry point – have circulated within debates regarding flood management in Bangladesh. We do this through tracing their work within two broad arenas: (i) academia and (ii) government policy.

4. Tracing sedimentation and subsidence in the knowledge claims of the GBM

4.1. Tracing the GBM sedimentation work within academia

To follow the GBM sedimentation work within academia, we took Goodbred and Kuehl (1998) (hereafter GK98) as an entry point. We accessed GK98 on 20 February 2009, analysed the nature of the literature that had influenced the GK98 paper and the characteristics of those articles that had gone on to cite it. GK98 was an interesting entry point as it is a relatively highly cited paper (48 citations on 20 February 2009). We then analysed those 48 citing papers to classify the broad disciplinary areas within which they fell and to identify a subset for further analysis. We focused on those that explored these regarding the importance and implications of sedimentation for the GBM delta dynamics, leading to the identification of a further seven (Table 1), which we call the daughters of GK98. In turn, we analysed citations to the daughters of GK98, a further 277, to classify the broad disciplinary areas within which they fell. The disciplinary classifications had two elements. First, we

TABLE 1 The daughters of Goodbred and Kuehl (1998) considered in this study

Goodbred and Kuehl (1999)	Sediment sequestered to the floodplain leads to subsidence of c. 3 mm pa. Since the mid-Holocene c. 5–25 m subsidence by compaction and c. 10 m due to relative sea-level rise
Goodbred and Kuehl (2000)	Delta began growing c. 10–11 ka BP. Influence of sediment load and tectonics dominant over eustatic sea-level rise. Sediment deposition significantly controlled by inland tectonic basins
Allison and Kepple (2001)	Sediment accumulation rates in the lower delta plan of c. 1.1 cm pa
Galy and France-Lanord (2001)	Himalayan erosion rates are c. double the suspended load flux estimates from Bengal rivers and mismatch due to bedload contributions and losses to floodplains
Allison et al. (2003)	Delta has a very large accommodation space, so early Holocene shorelines are well inland. Delta is avulsion dominated in terms of sedimentation
Goodbred et al. (2003)	Development of delta is millennial scale. The 1950 earthquake led to dramatic sediment wave, progradation of the river and widening of the braid belt
Wasson (2003)	Substantial sediment delivered to river and delta floodplains

TABLE 2 Classifications of the journals in which articles that cite GK98 and the daughters of GK98 appear

Journal discipline
Conference proceedings
General geology
General science
Geophysics/tectonics
Geochemistry
Geomorphology
Ecology
Engineering
Environmental
Health
Hydrology
Marine geology
Methodological
Social science
Quaternary

classified articles by the topic of the journal in which they are published, reflecting an assumption that journals may map onto particular academic communities in terms of both authorship and readership. These journals were then classified into broadly defined disciplines (Table 2). Second, we classified articles by their primary relevance (Table 3). While in some cases there was overlap, we sought to identify the primary emphasis of each article. We also noted any attempt to interpret the results in relation to the debates over flood management, even where this was not the primary focus of the article.

Analysis of the GK98 citations showed that they are primarily cited in geological journals (Figure 1), with 52 per cent of articles in general geology journals or specialist marine geology journals. There is almost no citation by engineering journals, which is where strategies for river management might be found, nor in social science journals, which is where debates over polderization/embankments tend to be located. The geomorphology and hydrology journals largely contain articles exploring river processes in Bangladesh and debates over Himalayan hydrological and fine sediment delivery processes in relation to deforestation. With reference to those classes of journals citing GK98 (Figure 2), there is a significant change in the distribution of citations between GK98 and the daughters of GK98, probably driven by the growing relative importance of geochemistry and general geology-facing journals and the declining relative importance of marine geology and geomorphology-facing journals. The growing importance of geochemistry and also health-facing journals reflects the critical relevance of GK98 and the daughters of GK98 to the problem of arsenic contamination in groundwaters of the Bengal basin. This could not have been expected during the FAP 24, but is an important consequence of this work. However, by the date of this analysis, the daughters of GK98 are only cited once in an engineering-facing

TABLE 3 Classifications of the primary focus of articles citing GK98 and the daughters of GK98

Primary focus	Detailed description
Arsenic	Arsenic pollution on groundwater in Bangladesh
Climate change	Climate change in Bangladesh
Contextual Bangladesh	To provide contextual background to physical processes in the GBM for other studies (e.g. understanding of fisheries dynamics)
Delta Processes	Studies of the GBM delta
Floodplain sedimentation	Sedimentation on GBM floodplains
Marine processes	Interactions between the delta and marine processes, Bay of Bengal
River dynamics	River dynamics in Bangladesh
River management	River management options in Bangladesh
Sea level	Sea-level change, including sea-level futures, in the Bay of Bengal
Sediment flux	Sediment flux debates, including the role of Himalayan deforestation
Tectonics	Tectonic processes in the Bengal region
Other locations	Study of other delta systems
Methodological	Use of methods pioneered in GK98 or daughters of GK98

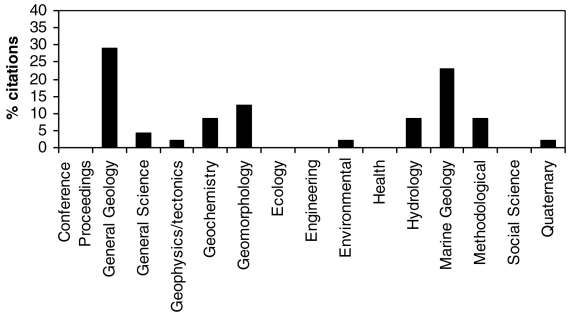

FIGURE 1 Classification of articles citing GK98 by the journal within which they appeared

journal, once in an interdisciplinary flood book and twice in a social science journal, out of a total of 277 citations. Thus, although there is evidence of some diffusion beyond the general and marine geological focus of the works citing

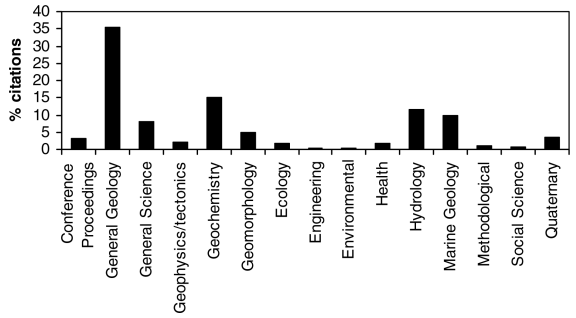

FIGURE 2 Classification of articles citing the daughters of GK98 by the journal in which they appeared

GK98 (the percentage falls from 52 per cent to 45 per cent of all citations), the work of the daughters of GK98 remains primarily associated with the growth of geochemistry. In academic terms, it appears that the work has remained primarily sequestered within the geological community.

Similar conclusions are reached if the analysis is extended to the classification of articles by their primary focus. By far the most important impact of GK98 in academic terms has been on the understanding of delta processes outside Bangladesh (Figure 3), with no impact evident in relation to river dynamics or river management. In terms of the daughters of GK98, the impact on our understanding of other deltas is reduced substantially (Figure 4), with impacts on arsenic increasing dramatically, sediment flux substantially (often associated with the debate over Himalayan deforestation) as well as to tectonic processes and climate change. There is some

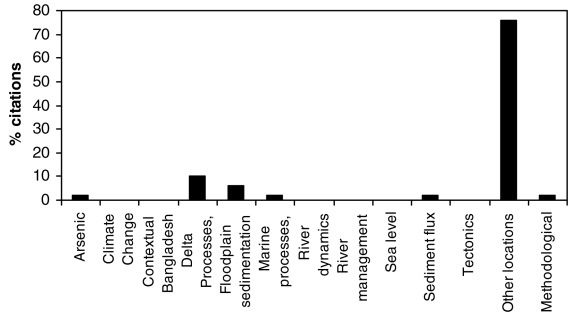

FIGURE 3 Classification of articles citing GK98 by their primary focus

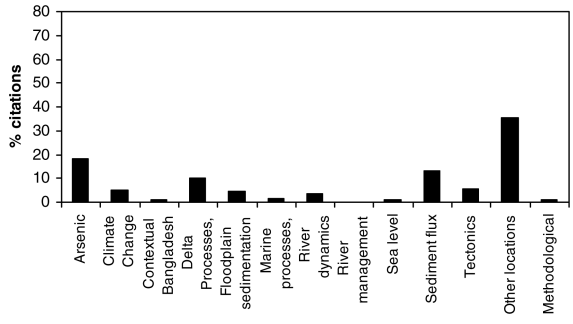

FIGURE 4 Classification of articles citing the daughters of GK98 by their primary focus

impact on articles focusing upon river dynamics and no evidence of papers on river management in Bangladesh referring to the daughters of GK98.

The interesting element of this exploration is that Goodbred and co-authors' work has spelt out their implications for flood management in Bangladesh. For instance, Goodbred and Kuehl (1998, p. 240) contextualize their research by noting that 'plans for the construction of flood-control devices (e.g. levees, embankments) along the waterways of Bangladesh have prompted questions regarding the importance of overbank sedimentation in maintaining land-surface elevation in the future'. Nicholls and Goodbred (2004, p. abstract) emphasize the social implications of sedimentation in the GBM delta and the need for an integrated framework:

> such a framework also allows the full range of management responses to be considered. In addition to traditional engineering approaches in deltas, there are opportunities to work with nature. The deltaic system has the capacity to be highly resilient in the face of these multiple pressures with important ecological and social benefits. This resilience is largely due to the delivery of sediment to the delta from the catchment. A challenge for future management is to understand and use this capacity to the maximum, including consideration of possible catchment changes such as dam construction.

Summarizing the complex combination of factors, stakeholders and uncertainties associated with managing the GBM delta, they conclude that '[o]nly a wide range of research across the natural, engineering and social sciences, drawn together by integrated assessment approaches can adequately address the important question of future development of the Ganges–Brahmaputra delta' (Nicholls and Goodbred, 2004, p. 13). The question becomes, given the interdisciplinary focus of flood management in general, why are its interdisciplinary goals not delivered? Why has the work of GK98 and the daughters of GK98, which is fundamental to the workings of the GBM delta, had so little impact upon the flood management debate?

The vast majority of social science flood research refers to the impacts, implications and perceptions of sediment rather than consideration for sedimentation or subsidence as a basin-wide process (Elahi, 1992; Haque and Zaman, 1993; Chadwick et al., 2001; Hutton and Haque, 2003). This includes reference to estimates of the volume of sediment deposited annually (c. 2 billion tons) (Thompson and Tod, 1998; Haque and Zaman, 1989, 1993; Brammer, 1990a, b; 2004; Islam, 1990, 2001), the possibility that coastal polderization plans might disrupt the interaction between tides and river discharge (Rasid and Mallik, 1993) and lateral river erosion and char dynamics (Hutton and Haque, 2003). The chars are important because they represent a flashpoint for vulnerability arguments, as indigent populations are quick to inhabit and attempt to secure these high-risk locations (Haque and Zaman, 1989). Erosion has been characterized as the most pressing hazard (e.g. Thompson and Sultana, 1996; Höfer and Messerli, 2006), notably for its unpredictability and capacity to 'consume' hundreds of metres of land in a season (Hutton and Haque, 2003; Brammer, 2004). Sediment also appears in relation to agriculture, described as improving soil conditions (Zaman, 1993; Alexander et al., 1998; Craig et al., 2004; Younus et al., 2005), although Brammer (2004) suggests that soil moisture and algae are more likely explanations for the agricultural benefits associated with flood waters. Overall, sediment is a contextual

theme, often listed as one of the causes of increased flood events or as a reason for the perception of worsening impacts (Khalequzzaman, 1994; Ali, 2007).

4.2. Tracing sediment and subsidence within Bangladeshi Government policy

Given the preceding discussions showing (i) the widespread faith in the need for interdisciplinary approaches, (ii) the relevance of sedimentation and subsidence to flood management and (iii) the apparent segregation of academic knowledge claims, we turn to questions concerning the incorporation of sediment and subsidence into flood management in Bangladesh through analysis of recent government policy. Government flood policy[2] is grounded through its application as management. This positionality is in stark contrast to academic research, which is afforded the ability to explore relatively focused topics due to the assumption that such contributions can be reassembled by managers, what we have labelled the 'reductionist-aggregate assumption'. Governments, alternatively, engage with 'real-world' problems and the complex assemblage of relevant issues simultaneously. The communities of knowledge identified within the academic 'tracing' raise questions concerning government flood policy. Specifically, we ask whether the grounded nature of governance results in a greater integration than is evident within the academic literature.

To trace the integration of sediment and subsidence knowledge claims within government policy, we analysed the three most recent and pertinent publications, namely the National Water Policy[3] (GoB, 1999) (hereafter NWP), the National Water Management Plan (GoB, 2001) (hereafter NWMP) and the Coastal Zone Policy (2004) (hereafter CZP), looking for any mention of sediment- and subsidence-related topics. Drawing upon academic publications, this textual analysis explored mention of sediment, sedimentation, accretion, subsidence, erosion, dredging, forest(ation) and navigation. In addition, given its prevalence within the academic literature, we also noted any discussion of integrated, holistic or interdisciplinary approaches within the policies.

4.3. The National Water Policy

While the NWP (GoB, 1999) makes a number of references to sedimentation and erosion, there is little detail. Instead, it lists the issues among the complex assemblage of hazards that inhibit economic and social development, stating that '[w]ater resources management in Bangladesh faces immense challenges for resolving many diverse problems and issues. The most critical of these are alternating flood and water scarcity during the wet and the dry seasons, ever-expanding water needs of a growing economy and population, and massive river sedimentation and bank erosion' (NWP, GoB, 1999, p. 1). In addition to problems of seasonal water supply and pollution, it later reiterates the array of hazards, listing 'excessive soil erosion and sedimentation, water logging and salinization of agricultural land, groundwater depletion, watershed degradation and deforestation, reduction of biodiversity, wetland loss, saltwater intrusion, and coastal zone habitat loss' (NWP, GoB, 1999, p. 14). Sediment, within the NWP, is primarily associated with the negative impacts of lateral river erosion. For example, the plan argues the need to 'develop and implement master plans for river training and erosion control works for preservation of scarce land and prevention of landlessness and pauperisation' (NWP, GoB, 1999, p. 7).

While there is no mention of subsidence, the formation of lands through deposition is mentioned in several contexts. The policy recommends a need to '[s]top unplanned construction on riverbanks and indiscriminate clearance of vegetation on newly accreted land' (NWP, GoB, 1999, p. 14) and, without direct mention of sediment, that the government aims to '[p]lan and implement schemes for reclamation of land from the sea and rivers' (NWP, GoB, 1999, p. 7). While not explicitly mentioned

as a positive impact, the reclamation of lands from both oceanic and riverine sources is dependent on the conveyance of sediment through Bangladesh to the Bay of Bengal. Alternatively, again associating the phenomenon as a negative, sediment is characterized as the result of deforestation in the upper reaches of the basin, requiring the government to '[e]ncourage massive afforestation and tree coverage specifically in areas with declining water table' (NWP, GoB, 1999, p. 14) and to '[m]ake concerted efforts, in collaboration with co-riparian countries, for management of the catchment areas with the help of afforestation and erosion control for watershed preservation and reduction of land degradation' (NWP, GoB, 1999, p. 5). A final negative association is made in relation to navigation. The policy states that '[d]redging and other suitable measures would be undertaken, wherever needed, to maintain navigational capability of designated waterways' (NWP, GoB, 1999, p. 13). It also recognizes that it is the government's responsibility to '[d]e-silt watercourses to maintain navigation channels and proper drainage' (NWP, GoB, 1999, p. 6).

4.4. The National Water Management Plan

The NWP is implemented through the NWMP (GoB, 2001). This document is a substantial and detailed policy that sets out the issues, their importance and the actions the government envisions in response. The document locates itself in relation to the complex network of management imperatives surrounding water excess and deficit. Like the NWP, it recognizes that the delivery of water resources is vulnerable to both physical and social perturbations, especially 'when quality, turbidity, erosion, accretion or potential disasters are involved' (NWMP, GoB, 2001, p. 82). In describing the context of water management in Bangladesh, the NWMP makes one of the only references to accretion, stating that '[t]hree of the world's largest rivers: the Ganges, the Brahmaputra and the Meghna flow through the country on the final stages of their journey to the sea. In fact their common delta comprises much of the country as a whole, and is accordingly prone to the usual deltaic problems of geomorphologic change, seasonal erosion and accretion' (NWMP, GoB, 2001, p. 67). Within the document, sedimentation, the process that maintains land levels, is constructed as a 'problem', which is representative of most interpretations of sediment-related processes and impacts within the NWMP. For example, the policy recognizes its responsibility to vulnerable regions, stating that '[a]reas subject to a high risk of erosion and those with other urgent requirements will be prioritized in the context of these plans, with more widespread programmes being introduced in the medium-term' (NWMP, GoB, 2001, p. 53) or, in relation to transportation, recognizing that '[w]ith the high sedimentation rates typical of Bangladesh, regular dredging is essential to maintain navigability' (NWMP, GoB, 2001, p. 65).

While there is some recognition that, in addition to damages, floods 'also deposit fertile sediments, which contribute to Bangladesh's impressive food security achievements' (NWMP, GoB, 2001, p. 67), the dominant association of 'changing river conditions' is with negative impacts. For example, in relation to floodplain inhabitants, the policy explains that '[t]he seasonal nature of Bangladesh's rivers, coupled with the large loads of largely non-cohesive sediments, results in unstable charlands along the major rivers. These represent home and farm for some of the country's poorer inhabitants, yet are subject to frequent loss by erosion' (NWMP, GoB, 2001, p. 97). The NWMP makes numerous claims that associate sediment with the impacts of climate change. Alluding to complex detriment–benefit impacts, the changing precipitation levels and timing (28 per cent above current levels by 2050) are envisioned to 'increase drainage requirements and flood duration more significantly than peak flood levels. From a socio-economic perspective, this will impact negatively on people's livelihoods, but in environmental terms may have positive effects on coastal sedimentation and overall salinity' (NWMP, GoB, 2001, p. 31). Sedimentation is also acknowledged in relation to

coastal polders. The policy states that coastal management is 'rendered more complex by the impacts that the coastal polder systems have had on sedimentation patterns and the sustainability of the drainage networks. Furthermore, sea-level rise and increased tidal ranges will bring about further hydrological and morphological changes' (NWMP, GoB, 2001, p. 124).

As in the NWP (GoB, 1999), forestry is associated with sediment in two ways: first, with the use of trees to reduce erosion and, second, in relation to deforestation in the upper catchment. The plan accepts that '[s]ome new coastal embankments are envisaged on newly accreted land (although premature empoldering should be avoided), and the process of afforestation of sea-facing embankments will be continued' (NWMP, GoB, 2001, p. 56) with the aim of mitigating storm surges. Forestation as a means of combating erosion is explained as 'an effective means of preventing degradation of upland watersheds. The Government is committed to massive afforestation' (NWMP, GoB, 2001, p. 56). Most explicitly, though without direct mention of other Basin nations, the NWMP claims that deforestation is responsible for sedimentation in Bangladesh, stating that '[i]n the upland and hilly area, land degradation contributes towards increased soil erosion and impacts on the river systems as sediment loads increase. Forestry plays an essential role in watershed management and efforts are to sustain and expand forest areas in line with Government's policy' (NWMP, GoB, 2001, p. 26). Following a similar 'upper basin' argument, the NWMP associates sedimentation with the negative impacts of arsenic poisoning. It states that '[a] significant amount of groundwater below some parts of the country has been extensively developed for agricultural and potable use. However, the latter is constrained by arsenic contamination, thought to have originated in the Himalayas and carried from there in river sediments' (NWMP, GoB, 2001, p. 67).

The NWMP (GoB, 2001) is the only government policy to explicitly acknowledge the role and importance of large-scale accretion and subsidence. For instance, it states that '[s]ea-level rise due to global warming, continued sedimentation of the rivers and flood plains and subsidence of the Ganges Basin are all factors that will affect sea-levels with respect to land levels' (NWMP, GoB, 2001, p. 31), although the policy also recognizes that, primarily as a result of sea-level rise, '[a]ccretion of new coastal lands may be slower as a result' (NWMP, GoB, 2001, p. 36). More directly, there is an appreciation that '[w]ith the increasing pressure on land, accretion is an important issue for Bangladesh, whether naturally occurring as part of the delta building process or in the course of shifts in river alignments. Technical means for securing accreted land, through measures such as the development of the Coastal Green Belt, will remain an important activity where possible' (NWMP, GoB, 2001, p. 36).

4.5. The Coastal Zone Policy

The CZP (GoB, 2005) is a short outline of the unique issues facing the coastal region of Bangladesh. As with both the NWP (GoB, 1999) and the NWMP (GoB, 2001), the CZP (GoB, 2005) situates itself within a context of multiple interrelated 'problems'. It explains that the area 'is prone to natural disasters like cyclone, storm surge and flood. The combination of natural and man-made hazards, such as erosion, high arsenic content in ground water, water logging, earthquake, water and soil salinity, various forms of pollution, risks from climate change, etc., have adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic developments in this region' (CZP, GoB, 2005, p. 1). Following this interpretation, sedimentation is conceptualized as a hazard, stating that in response to disaster '[e]ffective measures will be taken for protection against erosion and for rehabilitation of the victims of erosion' (CZP, GoB, 2005, p. 4). A second issue more prominent in the coastal region is active involvement in the reclamation of accreted land. The CZP explains that '[t]hrough its responsible

agencies, the Government will proper plan [*sic*] and implement schemes for reclamation of balanced land from the sea and rivers' (CZP, GoB, 2005, p. 5) and that as part of the government's objectives to improve livelihoods in the region '[a]n effective program for land reclamation will be developed' (CZP, GoB, 2005, p. 4)

The CZP maintains the characterization of sediment as a negative environmental phenomenon. Sediment is presented as a hindrance to navigation, which requires 'increasing excavation capacity to maintain the navigability of the waterways' (CZP, GoB, 2005, p. 4). Like the NWP and NWMP, forestry is mentioned as a means of combating the negative impacts of sediment and sedimentation. The CZP states that '[m]easures will be taken for afforestation in the coastal areas including newly accreted chars' (CZP, GoB, 2005, p. 6) in order to stabilize the land and reduce erosion.

5. Discussion: Knowledge claims and isolation within communities

Within government policy documents, sediment is associated with immediate and evident negative impacts while subsidence is neglected in all but a limited sense. The government policies associate sediment with lateral river erosion at the individual and community scales, as a hindrance to navigation, and as exacerbating floods by reducing river conveyance. For example, the CZP (GoB, 2005, p. 4) identifies those negatively affected by erosion as deserving of aid, stating that '[e]ffective measures will be taken for protection against erosion and for rehabilitation of the victims of erosion' while the NWP (GoB, 1999, p. 99) states that '[r]iver bank erosion is a major problem in all the main rivers [and that the government will] look at all possibilities of minimizing the socio-economic impacts of erosion and will formulate an updated strategy for dealing with the problem'. Similarly, the NWMP (GoB, 2001, p. 53) includes erosion among the main focus of disaster management, stating that '[i]ntegrated river management plans will be prepared (covering erosion control, dredging and other elements of river maintenance, such as pollution control, abstraction, navigation and environmental needs)'. In all but one instance, the policies do not consider the possibility or history of large-scale river avulsions like the 1789 and 1899 events or basin-wide subsidence (Höfer and Messerli, 2006).

Particularly concerning aforestation, there is a disassociation of responsibility for the negative impacts associated with sedimentation. Assertions for the need to control erosion in the upper basin through reforestation locates fault outside of Bangladesh. Although there is no specific mention of Nepal, the calls for aforestation in the upper basin are veiled allusions to the longstanding assertion that deforestation in Nepal is responsible for increased sediment and the resulting floods in Bangladesh. This claim is particularly questionable in light of evidence that challenges the highland–lowland link between erosion and flooding (Ives, 1991; Höfer and Messerli, 2006); it is more surprising given that the delivery of sediment during overbank flows is likely to be the primary means for countering the effects of long-term subsidence and sea-level rise. In effect, the policies do not recognize that sedimentation maintains the Bangladesh land mass. There is near-complete absence of the assertion that flood events are intimately bound with processes that maintain the state (land levels) or at least slow down the rate at which land levels are subsiding (Goodbred and Kuehl, 1998; Nicholls and Goodbred, 2004). As opposed to Höfer and Messerli's (2006) conclusion that erosion is the most important hazard in Bangladesh, erosion and sedimentation within the policies are seen as problems that emerge over small time and space scales and are associated with discrete processes and events, much like the divisions discussed in the academic tracing.

It is disconcerting that despite agreement for the importance of sediment and subsidence their inclusion in government policy appears to be superficial. Adding further concern to this context are the repeated calls for additional research of sediment-related processes and impacts. In effect, while neglecting available

knowledge, government policies call for more research, suggesting that the isolation between the natural science and social science communities may be mirrored by the government community. The NWP (GoB, 1999, p. 17) states that '[i]t is important to reach a common understanding between specialists, planners, politicians and the general public about the changing environment and the optimal ways and means of achieving the national water management goals. As management decisions become increasingly complex and information-sensitive, the demand for supporting research and information management increases.' The NWMP (GoB, 2001, p. 35) includes a number of similar assertions, stating that '[r]iver bank erosion causes immense hardship to those affected and the Government is committed to mitigating this problem . . . but much remains to be done to be able to fully understand the processes involved'. It goes on to state that 'studies are needed to assess ways by which drainage congestion in the coastal areas can be alleviated' (NWMP, GoB, 2001, p. 56), while the CZP (GoB, 2005, p. 11) argues that '[i]n order to create awareness among the general public about the [integrated coastal zone management] program, coastal zone policy, [coastal development strategy] and other initiatives, an exhaustive information dissemination mechanism has to be evolved'. In each instance, government policy asserts the need for research without reference to the challenges placed upon policy by the existing knowledge base. This disconnection, in relation to sediment and subsidence, is perhaps best summarized by Höfer and Messerli (2006, p. 435), who reflect that:

> [u]nderstanding the natural processes and the human impact on these processes is fundamental for any long-term solution. The various chapters of this book may have shown how this understanding has improved over recent decades, but also how difficult it is to communicate new knowledge to society and policy. An instructive example is the myth that forests can prevent big floods. Many years ago it was proved that this assumption was wrong. Yet the myth continues to influence the media, policy and development-oriented decision-making processes in different parts of the world, particularly in the vast highland–lowland system of the Himalayan region. This means that a much more efficient dialogue between science, policy and society is crucial to finding sustainable solutions.

The integration of sediment and subsidence into management in Bangladesh is commonly discussed in relation to interdisciplinary approaches designed to overcome environmental 'problems'. Broadly, in both academic and government contexts, interdisciplinarity is a form of management able to 'help alleviate the severity of social, economic and demographic impacts associated with river erosion, but this is a consideration that must be seen within the broader context of floodplain management as a whole' (Hughes et al., 1994, p. 33). The NWMP exhibits this perspective in its declaration that the '[g]overnment has recognised that, together with management of erosion and accretion, these problems must be addressed through a fully integrated approach' (NWMP, GoB, 2001, p. 124). Sheikh Hasina's foreword to the NWP (GoB, 1999) also supports the need to address problems. In relation to the lack of planning coordination, she states that the NWP 'seeks remedy to this chaotic situation by bringing order and discipline in the exploration, management and use of water resources in Bangladesh. It clearly and unequivocally declares the intention of the government that 'all necessary means and measures will be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner' (NWP, GoB, 1999, foreword). Following the same rationale, the CZP policy makes explicit its presumption that interdisciplinarity will reduce conflict, stating that '[a] participatory and integrated approach holds the promise of reducing conflicts in the utilization of coastal resources and optimum exploitation of opportunities' (CZP, GoB, 2005, p. 2). In every sense, interdisciplinarity is, in itself, seen as a means of overcoming the complex assemblage of water and sediment-related problems facing Bangladesh.

The policy documents are themselves materializations of the faith in interdisciplinarity and its reductionist-aggregate assumption. They are divided into water-related issues and disciplinary divisions such as fisheries, navigation, power generation and hydrology. The NWMP (GoB, 2001, p. 6) defines itself as 'a framework plan to guide (but not prescribe), in an integrated and comprehensive manner, the actions of all concerned with developing and managing water resources and water services'. The CZP defines itself in the same way, stating that it 'is unique in the sense that it is a harmonized policy that transcends sectoral perspectives. The CZP initiates a process that commits different Ministries, and Agencies to agree to harmonize and coordinate their activities in the coastal zone and the basis for a firm co-ordination mechanism' (CZP, GoB, 2005, p. 2) and that '[f]ollowing this policy, all concerned Ministries, Agencies, Local Government Institutions, NGOs, private sector and the civil society will put their efforts [*sic*] for the development of the coastal zone' (GoB, 2005, p. 5). Perhaps the most telling example is the NWMP's reflexive acknowledgement that its preparation 'proceeded in accordance with the directives given both by the Policy [phase] and this Strategy [phase], from which a series of programmes of action have been determined, which together form the building blocks to the overall management plan' (NWMP, GoB, 2001, p. 2). Similarly, the value of interdisciplinarity is so strong that the CZP policy is given the power to ensure its adoption, asserting that '[i]n the long term, the aim is to internalize the process of integration as a standard mode of operation for all the concerned agencies. Towards that end, the [Coastal Development Strategy] will identify the social, economic, organizational and institutional barriers that hinder the adoption of an integrated approach' (CZP, GoB, 2005, p. 10).

6. Conclusions

Knowledge of the GBM delta sediment processes appears to be highly concentrated within particular academic disciplines, rather than flowing from them. Despite shared faith in interdisciplinarity and growing recognition for the complexity of environmental problems, there is very little consideration for the practical difficulties of integrating disparate knowledge claims. By maintaining academic autonomy, scientists and social scientists are freed from having to consider how their knowledge claims will be incorporated into management. There is no discussion of the practical realities of consolidating knowledges from different fields or for the difficulties that will accompany the communication of such ideas to managers or to the public. Implicitly, these claims assume that 'all the relevant' knowledges can be collected, reconciled and understood as part of a 'holistic managerial collage'. The result of the underlying reductionist-aggregate assumption, then, is that there appears to be little meaningful integration of sediment and subsidence knowledge claims within flood management in Bangladesh. Furthermore, the isolation of the scientific and social science communities of knowledge appears to be mirrored by a government community.

The findings show how flood management in Bangladesh has placed an immense trust in the potential for interdisciplinarity to deal with the interrelated management problems of the Bangladesh delta. Following Barry et al.'s (2008) classification, it invokes a logic of accountability, but one that appears in rhetoric more than it does in practice. Policy engagement with the science of the GBM delta is cursory, and is set primarily in local manifestations (e.g. bank erosion, navigation difficulties and reforestation) associated with specific events rather than the longer-term and larger-spatial scales of accretion and subsidence. Scientific engagement within Bangladeshi water policy is equally unapparent, despite examples developing out of specific flood events or as part of a wider multi-disciplinary research project like the FAP. For the government, when opinion is pitted against opinion, interdisciplinarity aims to overcome conflict rather than improve understanding. Following Barry et al. (2008), the government understanding of

interdisciplinarity is dominated by the logic of accountability[4] while the sciences and social sciences appear to implement interdisciplinarity following a logic of innovation and an ontological logic. Government policy is concerned with the distribution of power within the assemblage of stakeholders, following the Mode-2 rationale (Nowotny et al., 2001). Alternatively, the academic publications emphasize innovative interpretations leading to original findings with the underlying intention of reconceptualizing the object(s) and their interactions (Barry et al., 2008, p. 25). While the different logics are entwined and irreducible to each other, they assume fundamentally different aims, ontologies and epistemologies, which, we suggest, contributes to the isolation of relevant and related knowledges. If our characterization of the differing logics is accurate, we suggest that the differences help explain why science and social science knowledge claims are not incorporated into management. From a government perspective, in the context of Bangladesh facing immanent threat, the logic of innovation and, more so, the ontological logic might be seen to distract from the problems at hand in exchange for more theoretical and less applicable knowledge.

There are multiple potential explanations for the isolation of the science, social science and policy communities, each requiring further consideration and empirical analysis. For example, the isolation may be due to differing objectives, they may inherently contradict one another, their formats and 'languages' may simply prevent communication or, most worryingly, the isolation may be a form of protectionism. With reference to the experience of the FAP, the controversy and attrition that crippled the plan raises the possibility that reductionist-aggregate assumptions may nurture knowledge controversies rather than more integrated understandings. In effect, the science, and the associated scientific method, may contribute to controversies rather than ameliorate or utilize them (Sarewitz, 2002). As Whatmore (2009, p. 591) explains, controversy results in emphasis on the controversy itself and on those presenting opposing opinions, shifting attention away from the knowledge claims that inform the different understandings, though she argues that such contexts represent generative opportunities to harness the (co)productive forces of public expertise. In this sense, knowledge controversies are opportunities for all parties to invest in more egalitarian knowledge production, which in turn leads to the 'better' integration of knowledges into management. Following complexity theory premises concerning the emergent properties of systems (Manson, 2001; O'Sullivan, 2004), by recognizing and embracing the social and public roles in scientific knowledge creation we may witness integrated understandings emerging *from within the process* rather than assuming that integration is the end-product of the 'bolting-together' of knowledges by practitioners or managers.

Notes

1. For the purpose of this paper integrated, holistic, cross-disciplinary, multi-disciplinary and trans-disciplinary are generalized under the heading of 'interdisciplinary' unless otherwise noted. While there are differences in and between the numerous competing definitions, they are each associated with the inclusion of information/knowledge from multiple areas of expertise, including lay and experiential.
2. We appreciate that policy does not equate implemented actions or even, necessarily, the government's honest stance. Alternatively, there are few possibilities for assessing national-level positions.
3. During field research for a different project, a government manager informed one of the authors that a new version of the National Water Policy was currently under review, although there was no estimate on its impending release outside draft form.
4. It might be argued that the government is equally dedicated to the logic of innovation. We maintain that this is not accurate as the decision has been made that accountability is innovative, resulting in neglect of innovation as a logic of understanding.

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