12 BOUNDARY CONCEPTS FOR THE INTERDISCIPLINARY ANALYSIS OF IRRIGATION WATER MANAGEMENT IN SOUTH ASIA

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On the basis of the rich empirical material provided by the chapters in this volume, the case for natural-social science interdisciplinarity in water resources management analysis is easily made. It derives from, first, the complexity or multidimensionality of water resources management as a concrete phenomenon and, second, the perceived urgency and intractability of water resources management problems and conflicts, urging decision makers to look for 'integrated', 'adaptive', or otherwise comprehensive approaches. The latter has led to an upsurge in water resources management studies and policy approaches that seek to capture and cut through the socio-material complexity of water systems dynamics, and their contested and negotiated transformation. The relevance and need for this is as apparent in South Asia as elsewhere (see Ballabh 2008; Baviskar 2005; Joy *et al.* 2008; Shah 2009).

However, the intellectual and institutional odds are still largely against practicing science in the interdisciplinary mode. Academic specialization, no matter how useful for some purposes, makes 'integration', on any definition, a tall order (Pohl and Hirsch Hadorn 2007). The organizational division of labour in government and administration means that ministries and sectors experience great difficulties to interact and collaborate effectively. Finally, research remains uncomfortably related to policy, expert, and scientific knowledge separated from lay and local knowledge. Cutting through all this are different world views and political standpoints, within science as much as outside it (Lele and Norgaard 2005). Nevertheless, the

poignancy of contemporary natural resources management controversies increasingly forces interdisciplinary and transdisciplinary research. Klein's (1996) seminal book on interdisciplinarity is titled *Crossing Boundaries*. There is no scarcity of boundaries to cross for those who attempt to develop 'integrated perspectives' on the complex system that water resources management is.[1] In the United States (US), the term 'boundary work' has been coined for sustainability science to refer to the concerted and systematic effort that boundary crossing involves (Cash *et al*. 2003). This work primarily focuses on the research–policy boundary, and what can be done for a more productive interface. The boundary work concept can, however, also be used in a broader sense, referring to the variety of boundaries that exist in natural resources management research and practice, and need to be 'managed'.

This chapter is a reflection around the main conceptual, theoretical, and methodological messages of this book. It seeks new ways of approaching interdisciplinarity in what is an ongoing process of conceptual, theoretical and methodological refinement. Chapter 1 focused on the socio-technical approach as the framework to study water control in most of the chapters in this volume. While acknowledging this work I move forward from it towards new ways to theorize the materiality of social change in water management.

Elsewhere (as in Mollinga 2010a) I have suggested that boundary work in interdisciplinary and transdisciplinary research on natural resources management has three components: boundary concepts, boundary objects, and boundary settings. Boundary concepts allow us to think (conceptually communicate) about the multidimensionality of the phenomena studied and addressed. Boundary objects are devices and methods that allow us to act in situations of incomplete knowledge, non-linearity, and divergent interests (the category includes models, frameworks, and participatory processes for decision-making and planning, among other things). Boundary settings are the institutional arrangements within which these concepts, devices, and methods can be fruitfully developed and effectively put to work.

This chapter concentrates on the first of these three elements—the theoretical constructs required to think across the boundaries of the natural and the social sciences, leaving the acting and enabling of the second and third elements aside. By exploring the conceptual terrain

at this interface, I aim to contribute to a 'critical interdisciplinarity' (Klein 1996) in the domain of water resources.

Perhaps the major analytical boundary challenge is binarism as a form of analytical reductionism (Castree 2002). At the heart of interdisciplinary analysis of water resources management lies the material–social binary. This binary is 'real' within the water resources domain as a division between disciplines and professions that are labelled 'technical' and 'social'. The division is also institutional (as embodied in government and university departments, professional associations, and academic journals), cultural (as embodied in professional identities), and cognitive (by considering the material and social as distinct objects). The fallacy of binarism is that the world is ontologically complex—structured, stratified, and heterogeneous (Sayer 1984). Irrigation systems provide an archetypical example. The networked system of dams, weirs, canals, and other *ouvrages d'art* structures both the physical landscape and institutional and economic life at various levels of scale.[2]

The collection of boundary concepts presented in the following four sections is informed by an understanding of sociology as a 'science of connections' or 'science of associations' (Latour 2005). Social-ness exists in the act of creating and maintaining networks of heterogeneous objects and relationships. It is in that sense that human beings are the prime movers in 'socially constructing' water resources management systems. The second starting point is that 'putting and holding things together' in configurations that have some endurance, that is structures (Archer 1995), involves such configurations having 'internal relations' and exhibiting 'emergent properties' (Sayer 1984). In the inventory of attempts at capturing emergence related to irrigation technical artefacts and irrigation landscapes in the following sections, the term 'institutions' is used for what are conventionally called social dimensions, social factors, or social aspects—formulations that treat the social as a distinct object. 'Social' in this chapter is reserved for the activity of making, reproducing, and transforming the hybrid and complex sets of 'associations' and 'connections' in water resources management configurations. This adds new space for thinking beyond the institutional–organizational and political–social processes of water control introduced in Chapter 1, and for challenging the limitations of global institutional thinking discussed there.

The following four sections give an overview of the different ways in which conceptual hybridization has been attempted in the South Asian, particularly Indian, context, with a focus on irrigation. The second section looks at how water rights and entitlements can be understood in an interdisciplinary way. It discusses the concept of hydraulic property and, as an extension of that, how ecological relations are part of rights and entitlements concepts. The third section looks at the interdisciplinary analysis of water use; it explores conceptualizations of design–management relations and the social construction of irrigation technology, producing management 'scripts'. The fourth section addresses the impacts of water use in developmental terms. Boundary concepts discussed are 'landesque capital' and the value or valuation of ecosystem goods and services. Section five looks at interdisciplinary conceptualizations of the embeddedness of irrigation and water resources management processes, by discussing time and space relations in irrigation and the 'cultural politics of water' perspective. Then, looking ahead, section six discusses how these boundary concepts can help to further develop interdisciplinary social theory on water, and identifies some formal and substantive theoretical avenues for that. The final section concludes the chapter by outlining potential further research activities.

WATER AND RIGHTS: HYDRAULIC PROPERTY AND ECOLOGICAL INTEGRITY

Hydraulic Property

In his analysis of farmer-managed irrigation systems (FMIS) in Thailand, Indonesia, and the Indian Himalayas, Coward (1986a, 1986b, 1990) analyses the intimate relations between the social relations of water management and the technical infrastructure. His basic argument is that 'creation of irrigation facilities establishes among the creators property relations' (Coward 1986b: 227). Naturally, '[n]one of this property can be sustained over time without frequent renewal through the investment of labour and capital' (1986b: 225). Therefore, 'the basis for [the] social action [of the community irrigation group] is the common relationship they have with regard to property objects which they have created' (1986b: 225). This means that the creation and upkeep of irrigation infrastructure go hand in hand

with the (transformation of the) social relations through which that infrastructure is used; they co-evolve and are each other's expression as 'hydraulic property'.

On property rights arrangements in FMIS in the Kangra valley of Himachal Pradesh, Coward (1990) shows that the consolidation of land rights in the colonial period included a specification of the materials to be used for diversion weir construction and a description of the (proportional) division structures for water distribution. 'The width of the openings created by the thelu [division structure] is measured in "fingers" depending upon the area of land to be served by a given turnout . . . the thelu is a simple but effective device by which the abstract water rights of individuals can be translated into calibrated water flows' (Coward 1990: 83). The land and water rights thus defined had to be reproduced through the contribution of labour to maintenance and repair. Coward also shows that distribution of rights and access in local irrigation systems are not necessarily equitable. 'The lower zone people . . . reproduce their water rights in the Bharul network even though the costs to them are considerably higher than those incurred by the upper groups' (1990: 84).

The concept of hydraulic property thus captures two theoretical ideas: first, that water rights take on a material form in the characteristics of the infrastructure of the systems in and for which they exist; second, that the activity of infrastructure creation and upkeep is a process of property rights creation and upkeep. Though the initial formulation of the concept is partly India-based, it has attracted little follow-up work in South Asia outside Nepal (but more in Latin America; for example, Gerbrandy and Hoogendam 1996). However, the chapter by Parajuli in this volume clearly stands in this research tradition. Parajuli's description of the design and operation of proportioning weirs are comparable with the *thelu* described by Coward, as a materialization of rights. Parajuli also analyses the choice of division structures and operational approaches in relation to the agro-ecology of the hills. Chapters by Khanal and Parajuli both describe FMIS where water rights are related with original involvement in system construction, and reproduced through responsibilities in maintenance and operation, although they also show how trading of rights may be allowed. They contribute to our understanding of hydraulic property and the interrelationships between technology and institutions, and

of processes of change in irrigation systems where water rights definitions evolve with agrarian and economic transformations.

Property Rights and Ecological Integrity

The scope of the hydraulic property concept can be broadened to the ecology or the landscape. Case studies in this book show the linkages between property rights, ecological relations, and landscape. In her chapter on the interaction of pond (small tank) and canal water management in a watershed in Kerala, Krishnan links the ecological characteristics of the landscape to the (land and) water rights that govern its use. In another publication (Krishnan 2009) she details how ecological relations were historically part of the definition of land and water rights in ways that achieved ecological sustainability. The land used to be owned by landlords (*janmi*s), who rented it out to tenants through intermediaries (managers). Those cultivating land in the command area of a pond had a water right attached to it, involving rights to pond water and to the upland forested area for forest products for their own use. There were also arrangements for pond (tank) maintenance. The janmi undertook regular desilting of the pond, through the supervisor appointed by him. Day-to-day activities like cleaning runoff channels in the catchment (necessary to fill the tank) and other regular tasks were undertaken by permanent labourers who worked for the concerned tenant(s).

The Kerala government decided to implement a land reform. Around the same time the vesting of privately owned forests with the government was implemented. The time lag between the promulgation of the Forest Act and its final implementation enabled landlords to dispose of the valuable trees, resulting in deforestation of the uplands. Landlords also maintained access to the valuable valley lands by strategic registration of plots. When the uplands and lowlands were redistributed under land reform, only land rights were consciously redistributed: many former tenants who obtained small plots of land remained without water rights.

As described in this volume, government irrigation systems were implanted on the landscape without reference to existing pond or tank systems, and the canal water used to fill ponds and tanks. This public water provided by government canals was privatized when it entered the ponds and tanks available. The chapter by Manimohan on tank

cascades in Tamil Nadu shows how water users had a sense of rights and responsibilities over water in the landscape, extending to the guiding of catchment runoff into the tank as well as maintenance of the tanks themselves. Tank users protested when government forestry plantations disrupted these runoff patterns, but to no avail.

Notwithstanding the depressing outcome of the rights reform and development process described by Krishnan,[3] the theoretically interesting point is that ecological relations were part of the definition of land and water rights. How rights are defined shapes the landscape, and the reproduction of certain landscapes assumes specific property rights arrangements. The case studies in this book have contributed to the analysis of such interrelationships. However, more work needs to be done on this theme.

THE USE OF WATER: DESIGN-MANAGEMENT RELATIONS AND THE SOCIAL CONSTRUCTION OF TECHNOLOGY

Design-management Relations

Notwithstanding images and ideologies of western technical sciences being standardized and universal, irrigation engineering has a strongly regionally specific history. Technical concepts and approaches developed in, say, British, French, and Dutch colonial engineering are quite distinct. Within these there are variations reflecting contexts of development—in British colonial engineering, for instance, for Egypt and India. When to this are added irrigation engineering traditions from other regions like China, Japan, the USA, and Europe, and local engineering knowledge of, for instance, hill irrigation in the Andes and Himalayas, it is clear that there is a wide variety of cultures of engineering.

Apart from physical differences in terrain, rainfall, and runoff regimes, available construction material and the like, the variation is due to a series of institutional factors. As shown in this and other chapters, designs materialize property rights. Within government-owned and managed irrigation systems the variation lies in the state–irrigator relationships incorporated in technical design; that is, the form of organization for management and governance of the system materialized in technical design principles.

The significance and specificity of design-management relations has been innovatively explored by Horst (1996, 1998; also see Levine 1980). The thrust of Horst's analysis is that different types of division or offtake structures (fixed, open–closed, gradually adjustable) associate with different forms and principles of operation and management (Horst 1998: 84). Moreover, each of these offers different opportunities for manipulation, adding a second layer to the analysis: the discrepancy between on-paper and real operation and management practices.

Bolding *et al.* (1995) discuss how colonial governments attempted to implement the rationing of irrigation supply in canal irrigation through varying combinations of technologies and institutions differently in the northern, western and southern parts of India. Early nineteenth century efforts to introduce the so-called 'block system' in present-day Maharashtra show the two levels of analysis: the search for an appropriate combination of technical and institutional features, and the undermining of this in the realities of irrigation system use. This allows an analysis of the features and contradictions of colonial rule as well as the dynamics of peasant social differentiation in an emerging capitalist rural economy. Narain (this volume) has provided an analysis of the contemporary relevance of division structures and canal design principles in farmer organization in Haryana and Maharashtra. He shows how organizational concepts of local water users' association (WUAs) as promoted under government participatory irrigation management (PIM) policies and programmes do not fit with the technical reality of India's canal irrigation systems. Blueprint models of WUAs and global discourses on markets and pricing have been pursued without an understanding of the various water allocation systems in these states, and the different technologies and possibilities of operational control. Khanal's case study of the West Gandak irrigation system in Nepal documents the diverse range of control structures brought in by different intervention programmes. These were too numerous, costly, and badly installed for farmers' groups to manage when donor support withdrew. Also for Nepal, Regmi and Vincent have discussed in their chapter how water system designs evolve over time in their joint evolution of technology and institutions. The authors show how systems evolve from a simple 'hydraulic ensemble' to 'evolutionary systems' providing diverse benefits and maturing institutions showing

reflexive coping with change. The interaction of structures, systems, and agents shapes accountability mechanisms of various kinds, local and constitutional, which are critical in these material transformations.

Social Construction of Technology

The inquiry into design-management relations as described before, pursued from a civil engineering starting point, could be more comprehensively theorized using the 'social construction of technology' perspective that became available in the 1980s.[4] From this perspective, Shah (2003) investigates the 'social designs' of tank irrigation in Karnataka, and her chapter in this volume has given a cogent review of how tank designs have transformed under a recursive state–society relationship. Many tanks were built in pre-colonial times. She suggests that 'the design principle of a labour intensive construction method of embankments carries the imprint of the historical era that rested on a rigidly built, hierarchical social order which exerted a considerable degree of control over labour' (Shah 2003: 261). When this order changed, maintaining the infrastructure in a good state became difficult. Presently, with expanded market relations, decentralization policies, and a general loosening of social rigidities, rural elites find it increasingly difficult to mobilize labour for tasks like canal cleaning, sluice operation, and field-to-field irrigation from lower caste labourers. They turn to the state for investment in maintenance and management (Shah 2003: 262–3).

These observations mean that the technical features of water infrastructure must be understood as historical products, fitting a particular context but potentially inadequate in others. The historical literature on irrigation and flood control in India and South Asia profiles this statement with rich and fascinating accounts (for example, Gilmartin 1995; Stone 1984; Weil 2006). The broader theme is the role of water resources development and technology in colonization and nation-building.

The social constructivist analysis of technology and technological systems (see Hughes 1987) can also be reversed. With particular societal objectives and forms of organization in mind, efforts can be made to consciously design technological systems in such a way that they fit these objectives and forms. A perspective of design and planning as self-conscious social construction has been developed for irrigation

in certain parts of the world, notably Latin America and Africa. The relative absence of participatory approaches to irrigation design and planning in India can perhaps be explained by the hierarchical and prescriptive style of government intervention on one side, and the glorification of 'traditional' irrigation by civil society organizations on the other. An innovative effort at redesigning the Sardar Sarovar dam, part of the Narmada project, and its downstream irrigated area is by Paranjape and Joy (1995). It is telling that the proposal did not spark anyone's imagination (see Mollinga 2010a). Differences in irrigation management reform approaches between India and Nepal are shown by Nikku and Khanal in this volume. Nepalese policies did allow for participatory development processes between engineers and farmers, aimed at building local organizations and helping them identify and implement infrastructural and institutional priorities.

The growing importance of groundwater development in economic transformation of the region can also be studied through these social constructivist analyses (also see the Introduction). Prakash (this volume) has shown the interlocking agrarian networks that have helped drive the unsustainable expansion of well technology in Gujarat. He has also demonstrated the inequalities emerging in access to water and land under emergent groundwater markets supplied by these wells, and in the sharecropping systems now linked with their productive use.

The upshot of the discussion is that the designs of irrigation infrastructure carry, in social constructivist language, management 'scripts' or, as outlined in the Introduction and Chapter 1, have 'social requirements for use'. Technology is not neutral; its contextuality can be revealed through careful observation and analysis of irrigation designs and water management practices, and by documenting the life histories of artefacts, as in this volume.

WATER, LANDSCAPES, AND LIVELIHOODS: LANDESQUE CAPITAL AND THE VALUE OF ECOSYSTEM GOODS AND SERVICES

Landesque Capital: Cultural and Engineered Landscapes

Amartya Sen is credited with first using the term 'landesque capital', in a conceptual combine with 'labouresque capital' (Sen 1968; Widgren 2007). The term refers to human alterations to the

landscape designed to yield long-term gains in productivity, and is mostly used in analyses of agricultural intensification, particularly in smallholder subsistence agriculture. The building of irrigation systems, and water infrastructure generally, is a form of creating landesque capital (see Cosgrove and Petts 1990; Earle and Doyel 2008; Lansing 1991; and Trawick 2008). Apart from agricultural productivity, the term has also been used in relation to the symbolic (identity) dimensions of landscapes. Harrower suggests for ancient irrigation in Southwest Arabia that '[i]rrigation structures not only served as landesque capital . . . improvement that established economic investments in landscape infrastructure, but more importantly . . . irrigation structures and tombs served as *symbolic landesque capital* investments that proclaimed people-land relations' (2008: 505). Greider and Garkovich (1994) speak of 'landscapes as definitions of ourselves'. Landscapes are as relational as technology, and as contested (Strang 2001).

The richness of these perspectives is still to be appropriated fully in South Asian water and irrigation studies. For India, the historical literature of irrigation, floods, and landscapes comes closest to it (D'Souza 2006b; Ludden 1978). In this volume, Manimohan reviews the changing and different investments in water technologies in 'wet' versus 'dry' tank cascades under changing agrarian politics including differences in groundwater uptake and tank renovation strategies. He gives a powerful sense of the dynamism, present in commoditization and social differentiation, that controls the productivity gains in paddy and sugarcane cropping in wet cascades and in diverse crops with lower water demands in dry cascades. This reality is quite different from the discourses of neglect and decay in tank management, which legitimize diverse development plans for tanks.

Ecosystem Goods and Services: Value and Valuation

The new millennium saw the global consolidation of the 'ecosystem goods and services' concept through the Millennium Ecosystem Assessment (MEA 2005). The notion of 'ecosystem goods and services' is a boundary concept because the globally shared typology distinguishing between supporting, provisioning, regulating, and cultural ecosystem services allows ecologists, economists, sociologists, and other disciplines to have a common language on the usefulness of

ecosystems to human society (Slootweg and Mollinga 2009). In India, the epistemic community most closely associated with the analysis of the valuation of ecosystem goods and services is the Indian Society for Ecological Economics. The literature on (agricultural) water from this perspective is still very small (Kerr 2002; Puttaswamaiah and Raju 2009). In the international sphere, the interdisciplinary analysis of wetlands has contributed much to the development of the perspective—a field scarcely developed in India (Narayanan and Venot 2009). However, an 'ecosystem goods and services' notion is implicit in much debate on local irrigation systems, as these usually have multiple uses and users (Agarwal and Narain 1997). It would seem relevant to explore more fully the value and valuation of water, and its commensuration, beyond the existing economistic thematics of water pricing and payment/markets for ecosystem services (Espeland and Stevens 1998).

Ecosystem goods and services (EGS) is both a richer and a poorer concept than the Marxist categories of goods/commodities having use value and exchange value. The plurality of goods and services identified by the EGS category is a plurality of meanings of water and of interest groups. EGS is, however, also primarily a descriptive concept that lists and maps, without much analytical 'punch'. The use/exchange value pair has a lot of such 'punch' (through the labour theory of value), but theorizes away materiality of commodities by focusing upon exchange value. Neoclassical and neo-institutional economics tend to be totally agnostic about the material specificities of commodities, as became dramatically clear in neoliberal economists' advocacy of 'tradeable water rights' and 'water markets' in the early 1990s (see Rosegrant and Binswanger 1994). In this volume, particularly the studies on FMIS in Nepal open possibilities to understand how local water organizations account for water rights under diverse land and water access arrangements, and may or may not allow controlled trading or sale. Gautam's chapter illustrates how the Chattis Mauja irrigation organization allows village groups to leave and rejoin the system in relation to their choice to use other water sources. The study is not formulated around ecosystem services, but provides a different view of how local groups can assess the ecosystem's capacity to supply services in return for diverse 'payments'.

IRRIGATION AND SOCIETY: SPACE–TIME RELATIONS AND A CULTURAL POLITICS OF WATER

The broader the canvas, the more tentative the conceptualizations of the multidimensionality of irrigation are. Geography and political ecology-inspired perspectives are making significant contributions to a more broadly-based interdisciplinary analysis of irrigation.

Space–time Relations

An early and perceptive account of the connection between the physical characteristics of irrigation systems and the social processes that take place in them is VanderMeer's (1971) historical analysis of water thievery in Taiwanese rice irrigation. In his explanation of types and frequency of thievery, the spatial organization of the canals and the land play an important role. Very few analyses of Indian irrigation address the complexity of spatial relations with such nuance, even when the 'head–tail' problematic of unequal water distribution along canals has been a central theme in Indian, and global, irrigation management studies since the 1980s (Chambers 1988).

The 'head–tail' problematic is usually stated in the apparently straightforward terms of locational advantage: farmers with land on the upstream 'head' of the canal have better access to water than those further down at the 'tail-end'. Head-enders thus have better options for productive farming and become rich farmers, while tail-enders remain or become poor. Mollinga's (2003) analysis of the spatial form of the social differentiation in the Tungabhadra Left Bank Canal irrigation system in Karnataka, India, shows that locational advantage is not a 'given'. When analysis is done over a period of time, of whose land is located where in the canal system, and how the canal system itself is partly remodelled in the process of emerging head–tail patterns, the dynamic nature of locational advantage can be shown. In this particular case that dynamism involved land acquisition by (experienced) migrant rice farmers from a neighbouring state, patterned by government crop zoning (called localization) and strategic settlement (on canal-road crossings), and the institutional mechanisms of loans, indebtedness, lease agreements, and land registration. Responses to emerging inequalities in access were both physical and institutional

(including a lift irrigation boom in the 1990s and forms of political and administrative lobbying and corruption).

While the causes of these inequalities are known, remedial action is rare. In particular, programmes of system rehabilitation brought in alongside policies for Irrigation Management Transfer could have addressed them. In this volume, Khanal has outlined how a participatory technology development approach enabled engineers and farmers to reform the water conveyance system in the Nepalese Khagheri system: farmers themselves renegotiated water allocations and management representation between head- and tail-end areas. However, such studies are rare, and the results of such attempts to practice alternative approaches are mixed. Thus, the chapter by Nikku on the Andhra Pradesh reforms showed how proposals to empower representatives with new local procedures to improve maintenance and supply were captured by elites and bureaucrats.

The construction of irrigation canals creates linkages between individuals, settlements, and communities by organizing them in a complexly bifurcated and queued sequence for access to water. Once constructed, there are inflexibilities that provide strategic advantage to some and disadvantage to others. Thus, a spatial pattern of social differentiation is configured. However, the implanted canal system grid of the social processes of irrigated agriculture is not immutable. Over time, the grid is partly remodelled and spatially reorganized through a variety of means and mechanisms, making time an important dimension (see Carlstein 1982). The chapter by Gautam shows how successive programmes promoting well technology in areas of the Tinau basin in the Nepalese Terai, that also had surface irrigation systems, left farmers with a choice of water sources. They developed diverse water use complexes to combine use of these sources at different times of the year. Transformation in designs of deep tube wells changed their management requirements and farmers' interests in them. These interests changed over time and space as costs of water sources and cropping options changed.

A Cultural Politics of Water

Political ecology has been strongly interested in transcending the society–ecology binary, critiquing and complementing political economy perspectives exclusively focused on access and distribution. In

India, a political ecology of agricultural water approach is still largely to be developed (Mollinga 2010b). The closest to it is Baviskar's 'cultural politics' approach to natural resources management, which aims to combine political economy and the epistemological variant of political ecology (Baviskar 2003; Mollinga 2010b). It emphasizes that '[s]truggles over water are simultaneously struggles for power over symbolic representations and material resources' (Baviskar 2007: 1) The perspective aims at 'incorporation of *ecological specificity* into the cultural politics of water' (2007: 7; emphasis in original) and wants to 'emphasize the distinctive bio-physical properties of water which shape its modes of appropriation' (2007: 5). Along similar lines Mehta (2005) has analysed the social construction of concepts of scarcity and droughts. This perspective allows analysis of local knowledges and cosmologies, as well as policy and other public discourses, within a single framework, enriching the understanding of human agency and the meaning of landscapes in water resources management. The chapter by Manimohan, discussing the diverse economic and cultural trajectories of wet and dry tank cascades under transforming agrarian politics, and the dynamism present beneath the development rhetoric of decline, is a good example from irrigation. When combined with a more 'materialist' understanding of irrigation, political ecology perspectives can make a significant contribution to interdisciplinary irrigation studies.

DISCUSSION: TOWARDS INTERDISCIPLINARY SOCIAL THEORY ON WATER

In critical realism's stratified ontology of structures, mechanisms, and events, the previous four sections have mapped different structures and some associated mechanisms as their emergent properties. The structures are the structure of property rights and entitlements; of techno-institutional arrangements for everyday water use, management, and governance; of water resource-based livelihoods; and the social structure in general.

For all of these structures, some mechanisms were identified. The objective was to show the materiality of the social process of water management, particularly that related to technology/infrastructure and ecology/landscape. There is, thus, no claim to comprehensive

mapping, more so because materiality as embodiment of agency, and of water as substance, was left aside. The purpose is conceptual. The four sections together suggest that boundary concepts that allow us to think across the boundaries of the natural and social sciences can and have come into existence for irrigation/water resources management.

Among these boundary concepts, some are neatly articulated as concise and precise concepts, like 'hydraulic property' and 'landesque capital'. Others are more metaphorical in nature, like the management 'scripts' of socially constructed technology. Some are descriptively valid but lack social 'punch', like 'ecosystem goods and services', though this is perhaps compensated by the force of the concept of 'value'. Some are indications of areas of inquiry that need further conceptual articulation specific to water resources situations, like 'space–time relations' and 'cultural politics'/'political ecology'. The conceptual boundary work is work in progress, but sufficient evidence exists, at least in the view of this author, that the multidimensionality of irrigation/water resources management and the ontological complexity of its internal relations can be fruitfully captured, and understanding of it moved forward, by adopting an interdisciplinary perspective.

The 'water control' concept discussed and used throughout this volume can be seen as a boundary concept and also a 'loose concept', what (Löwy 1992) identified as a conceptual space in which the human metabolic engagement with nature in the form of irrigated agriculture can be studied in an interdisciplinary way, by unravelling the hybrid connections that water management involves. The boundary concepts discussed in the previous sections can be read as specifications (but by no means derivations) of this general theoretical idea. With this conceptual space now being well populated, an effort at subsequent general, and more precise, theorization may be in order.

The structures and their emergent properties identified in the previous four sections can be seen as a non-reductionist dissection of the 'concentration of many determinations' that water resources management is. All mechanisms or emergent properties identified derive from hybrid structures, against reductionism, which involves positing ontologically singular structures.[5] This image of dissected determinations begs the question of their 'concentration', that is, how they fit together. For the concrete situations discussed earlier, the fit is relatively easily suggested. Property rights and entitlement

arrangements are one of the structuring forces of water use, management, and governance practices (by shaping access and control), while the practices in their turn shape the resource-based livelihoods they support, which shape and are shaped by the broader societal structure and dynamics they are part of. This is neither a time sequence, nor a hierarchy of causality—all this shaping happens simultaneously. However, the possibility to identify related but nevertheless distinct 'determinations' suggests that, indeed, reality is structured and stratified as critical realist philosophy would have it.

The increasing complexity, ontologically as well as societally, of natural or water resources management in combination with the increased scientific legitimacy of notions of complexity and emergence (see Scheffer 2009; Trosper 2005) seems to induce new theorizations of the 'concentration of determinations'. In the rest of this section I sketch some research avenues that seem to me particularly promising for 'substantiating' the water control concept. The first of these sketches focuses on formal theory, the second on substantive theory.

Formal Theory: The Hydrosocial Cycle and Morphogenesis

Within the field of geography, a political ecology perspective on water resources is engaged in developing the concept of the 'hydrosocial cycle', as an interdisciplinary counterpoint to the physically reductionist renderings of the hydrological cycle found in hydrological textbooks (Linton 2008). 'In a sustained attempt to transcend the modernist nature-society binaries, hydro-social research envisions the circulation of water as a combined physical and social process, as a hybridized socio-natural flow that fuses together nature and society in inseparable manners' (Swyngedouw 2009: 56).

This perspective potentially brings together several theoretical components that allow a formal social theory of water resources in the sense of Latour's sociology of connections or associations. Human intervention in the physical cycle of water behaviour is about rearranging flow, availability, and quality of water in time and space. These rearrangements are consolidated in technologies (for example, storage reservoirs), landscapes (for example, polders), and a variety of institutional arrangements for water use, management, and governance; made, reproduced and transformed by various categories of

human actors embodying various forms and dimensions of human agency, thus constituting different 'logics of structuration' (Kontopoulos 1993).

The link with formal social theory about structure–agency dynamics seems relatively straightforward, at least at this level of abstraction. Archer's (1995) morphogenetic approach to structural elaboration (the change of structures through episodes of the deployment of human agency, requiring time, that is, in recursive cycles) strongly resonates with the hydro-social cycle perspective. Archer's approach is not explicitly interdisciplinary in the sense of this chapter, but her approach applies as much to hybrid structures and their emergent properties as to social structures as conventionally understood.[6]

Formal theoretical resources for thinking through the time and space dimensions of morphogenesis for water resources management, and implicit in the issue of (multiple) scale(s), can be found in recent work on the politics of space (Jessop *et al.* 2008) and older work on time-geography (Carlstein 1982). Both provide typologies as heuristics for exploring structured diversity. Jessop *et al.* (2008) distinguish four key spatial dimensions of social relations: territory, place, scale, and network. Carlstein considers that '[h]uman time is a resource, since *all* activities necessarily require it as input and since we have limited capacity to act in relation to time' (1982: 27). This gives three types of time–space constraints: capacity constraints, coupling constraints, and regulatory/authority constraints (Carlstein 1982: 260).

A second formal theoretical thematic is the concepts of change (and power) to be adopted. In the Marxist tradition the dynamics of change are often conceived as 'dialectics' (see Swyngedouw 1999). Other critical perspectives would use the terminology of 'technologies of rule' (Lansing 1991) for the concentrations (in the plural) of determinations at different levels and in different domains. Such perspectives would take the critical realist notion of society as an 'open system' further than most Marxist theory might. The way forward, I suggest, is concrete research on mechanisms/emergent properties/logics of structuration in water management transformation processes. Events are easily described and structures are easily labelled, but unravelling the mechanisms/emergent properties/logics of structuration is hard empirical and analytical work.

Towards Substantive Theory: Thinking Materiality

In terms of substantive theory I confine myself to listing what I consider prospective concrete thematics for advancing theorization of the materiality of social change in water resources management. I want to suggest that rethinking of the commodity form, a materialist institutionalism, and the embodiment of agency are useful entry points for advancing 'hybrid' social theory on water. Given the era in which this chapter is written, the necessary setting of such exploration is, in this author's view, the process of (neo-liberal) capitalist globalization (Brenner *et al.* 2010; Conca 2006; Moore 2010).

Commodities: The social life of things

An emotive controversy in contemporary water disputations is whether water should be considered as an 'economic good' or as a 'social good'. The former is strongly associated with the 1990s neo-liberal development paradigm of market fundamentalism; the latter is the core strategic essentialism of much alternative water politics. The Marxist binary mapping onto this is that of the exchange value and use value of commodities, with exchange value taking on 'a life of its own' under capitalism. Most Marxist theory has focused on the exchange value dynamics, to the detriment of the use value component. 'Social good' perspectives on water can be understood as giving primacy to the use value dimension, and the plurality and diversity associated with that, wanting to keep the exchange value dimension at bay. I suggest that a richer conceptualization of water as a commodity and other commodities implicated in its use can help avoid the 'oversocialization' that stands in the way of capturing hybridity.

Appadurai's attempt to develop 'a new perspective on the circulation of commodities in social life' (1986: 3) understands 'the creation of value [as] a politically mediated process' (1986: 6). It is an effort 'to restore the cultural dimension to societies that are too often represented simply as economies writ large, and to restore the calculative dimension to societies that are too often simply portrayed as solidarity writ small' (1986: 12). He proposes that 'the commodity situation in the social life of any "thing" be defined as the situation in which its exchangeability (past, present, or future) for some other thing is its socially relevant feature' (1986: 13). Whether and how things move in and out of commodity status is a matter of social (including

cultural) regulation, that is, it can be done in structurally different ways in different 'regimes of value' (1986: 15). The 'commodity-hood' of a thing can be regarded as an emergent property, constituted by the qualities of the thing itself and the configuration of which it is part. As Appadurai observes, the 'formal truth' that things have no meaning other than that humans endow them with 'does not illuminate the concrete, historical circulation of things. For that we have to follow the things themselves, for their meanings are inscribed in their forms, their uses, their trajectories' (1986: 5).

It is difficult to imagine a water resources management process of some scale that does not have an 'exchange' dimension to it, as securing of the capture, distribution, and use of water requires socially organized investments of labour and materials (see Bakker 2003). This means that rather than 'commodification yes or no?', the question has to be one of *forms* and *patterns* of commodification, perhaps differentiated by phase or compartment of the circulation process, type of water use, and a variety of contextual factors. This applies to 'modern' and 'traditional', 'state', 'corporate' and 'community' water resources management alike. In this way the economic versus social good simplification can be transcended, facilitating more refined theorizations of water resources management and concomitant logics of accumulation in global(izing) capitalism.

Materialist institutionalism

A 'materialist institutionalism' as proposed here involves an analysis of institutional arrangements and forms of organization that takes into account the material mediations of water's circulation. Sections two to five above provided several concrete starting points for 'materialist institutionalist' analysis. The hydraulic property concept (and its extension to ecology/landscape) neatly captures the materialization of rights. The emergent properties of property rights arrangements can, of course, be seen in the way power is exerted in water allocation and distribution. It is clear that technological structure and spatial extent/organization recursively structure management and governance regimes, but how exactly remains to be theorized more precisely (see Wade 1995). The emergent properties of 'locational advantage' and 'queuing' in canal irrigation point in the direction of a (to be developed) typology of 'system characteristics' of canal infrastructure. The

connection between water resources development and nation building suggests the need for an interdisciplinary analysis of institutions as technologies of rule (Lansing 1991).

To link a 'materialist institutionalist' analysis of irrigation/agricultural water management with the process of commodification discussed above, it seems useful to me to explore something in between Loftus's 'production of everyday environments' and 'the waterscape as an accumulation strategy' (2009: 964ff).[7]

The embodiment of agency[8]

Human beings have a direct material experience of water through their senses that is meaningful, remarkably consistent over time, and which shapes our engagements with and views about water (Strang 2005). The strong cultural values (and taboos) attached to water have a lot to do with the multifarious personal encounters with water that are part of human life.

A second form of embodiment of agency in water resources management is that use, management, and governance are work; labour processes performed by persons, individually and collectively, by sexed humans, with physical bodies. These persons and their bodies are gendered and of a certain age. This affects water needs as well as capacity to perform water work, individually and collectively as 'materially situated selves'. The body is the repository of specific water resources management knowledge, skills, and experience. Dramatic examples of this can be observed in some forms of spate irrigation, where the diverting of flash floods may require dangerous acts of management in fast flowing streams; or for drinking water supply in water scarce areas where force and agility are needed to carry water safely over large distances. The performance of water work also has bodily effects, for example health effects of headloading and working in paddy fields. Social power is thus partly bodily defined; analysis of water work as labour, and the labour processes in which water is governed, managed, and used seem to me promising entry points for addressing the embodiment of human agency.

As discussed, there remain challenges to non-reductionist theorising of the social in studying the transformations of complex associations and connections that make up water resource management, and to analyse what Archer (1995) describes as the agential properties

of emergent water developments. The question remains to avoid the over-socialization of analysis (and also the over-technicality of the past) and keep attention to the material relationships that shape the power of resources in interdisciplinary studies. Chapter 1 referred to the concept of agency used in research for the chapters in this volume, particularly explored through the concepts and frameworks of water (actor) networks and development arenas. One emergent framework is a typology of water politics: the everyday politics of water, the day-to-day contestations of water use; inter-state water politics and negotiations between states on water allocation and distribution; and global water politics studying the relatively new phenomenon of global discourses on policies and regulation.

The capacity to shape water control across South Asia differently in the future for better human development outcomes will at least partly depend on the capacity to analyse and explain more rigorously the hybrid nature of the hydrosocial dynamics of water control.

WHAT NEXT?

I started this chapter by stating that the case for interdisciplinarity is easily made on the grounds of complexity, as also illustrated by this volume. With the growing interest in complexity as a scientific puzzle, the disciplinary–interdisciplinary dichotomy can become a caricature. More relevant seems to be distinguishing the different ways in which complexity can be approached and addressed. These differences are more 'paradigmatic' than having to do with disciplines, which are, according to Lele and Norgaard (2005) better seen as 'academic administrative artefacts'. It is for this reason that this chapter has devoted considerable attention to the ontological premises that I find useful for interdisciplinary analysis of water resources management.

I conclude by listing five research activities that could lift the idiosyncratic focus on irrigation and South Asia of this chapter to a more generic approach to the analysis of hybrid and contested water resources management:

1. A geographically, historically, and sub-sectorally broad-based review of each of the boundary concepts identified in sections two to five, and potential additional ones, and the structures and mechanisms they seek to capture. This may

systematically consolidate existing conceptual framings of the diverse 'determinations' operating in irrigation and water resources management situations.
2. To deploy the existing collection of boundary concepts in single, intensive case studies, to explore the complexity of internal relations in water resources management situations, and to develop theoretical capacity to capture the 'concentration' part of the determinations.
3. Subsequently and in parallel, undertake systematic comparative analysis of the structurally diverse dynamics of water resources management situations.
4. Develop the formal theoretical base of an interdisciplinary political sociology of water resources (see Mollinga 2008a) by elaborating the formal theorization of structure–agency dynamics and water circulation (with a suggested focus on the concepts of hydro-social cycle and morphogenesis).
5. Develop substantive theorization of the materiality of social change in water resource management by elaborating the suggested water-specific rethinking of the commodity form, of different varieties of materialist institutionalism, and of the embodiment of agency.

The chapters in this volume have made a start to these debates, both through their studies of the materiality of social processes shaping water resources development, as well as the socio-technical processes creating contemporary irrigation management. Like the 'Matching Technology and Institutions' research programme from which this book originates, the suggested agenda and collective undertaking of critical interdisciplinary water research will undoubtedly go unexpected, exciting, and complex ways.

Notes

[1] On the emergence of the boundary vocabulary, see Gieryn (1983) and Star and Griesemer (1989). Mollinga (2010a) distinguishes three forms of complexity of natural resources management: ontological (heterogeneity in components and relations), societal (its contested nature), and analytical (difficult to understand). Ontological and analytical complexity constitute the case for interdisciplinarity; societal complexity for transdisciplinarity. Adjectives I use for these three complexities are hybrid, contested, and complicated.

[2] Tanks in south India are an example of village-scale structuring (Shah 2003); canal irrigation (Mollinga 2003), and interlinked system tanks (see

Manimohan, this volume) an example at district level; the interconnected Indus plain irrigation system of Pakistan an example at country level (Merrey 1983).

[3] Including the irony that ecological sustainability existed under a system with feudal characteristics, while ecological degradation ensued when land reform was implemented on welfarist principles driven by a communist party political agenda.

[4] Seminal papers include Pinch and Bijker (1984) and Winner (1986). For further application, see Ertsen (2010), and Bolding (2004) for 'technography' as a methodology for 'following the artefacts'.

[5] My understanding of reductionism originates from Rose (1987). Reductionism is of at least two kinds: 'true' specialization, as in hydraulics exclusively theorising the mechanics of physical water flow, and 'imperial' forms of reductionism that impose a single metric or frame on plurality and diversity, like reducing value to price.

[6] Archer's approach distinguishes three types of emergent properties: structural, cultural, and agential. Archer's perspective that '. . . structural emergent properties . . . , irreducible to people and relatively enduring, as with all incidences of emergence, are specifically defined as those internal and necessary relationships which entail material resources, whether physical or human, and which generate causal powers proper to the relation itself ' (1995: 177) allows, if not calls for, an interdisciplinarity as explored in this chapter. This means that hybrid phenomena like irrigation systems, practices, and situations have properties that are constituted by their physical and meaning/institutional dimensions *simultaneously*, resulting from the precise way they have been put together (rather than one reflecting or being instantiated by the other).

[7] See Swyngedouw's (2007) analysis of the reconstructing of the complete hydraulic landscape in Franco's fascist Spain as part of a socio-environmental and socio-spatial project of nation building and capitalist accumulation.

[8] This section is strongly shaped by discussions with Frances Cleaver, whose contribution I gratefully acknowledge; the usual disclaimers apply.