Sediment Linkages Between the River Catchment and the Sea

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Research Article

The Dynamics of Sedimentary Systems and the Whimsicality of Policy Processes

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Abstract

Background, Aims, and Scope. Sediment management in coastal zones is taking place in high complex environments. Present management options do not have a sophisticated way of dealing with the actual complexity of the physical and the social systems and with the unpredictability that is inherent with these systems. Therefore, a new approach in both policy making and sediment management is needed that takes this complexity into account. The aim of this article is to explore the dynamics in social and natural systems and to draw the contours of this new approach for policy processes and sediment management that fits to the dynamics of the systems.

Methods. Three case studies concerning sediment management in Germany and the Netherlands are analysed in this article, in which unpredictability, or whimsicality, appeared through the occurrence of unexpected events. The case studies are analysed from the perspective of complexity theory. Complexity theory is a systemic theory, which means that it explains empirical phenomena from complex system behaviour. To understand the capricious character of sediment management in coastal zones, we need to frame the issue as the interdependency between the physical system and the social system, causing the two systems to develop in mutual adjustment through feedback. The process of mutual adjustment is one that is characterised by a non-linear nature. This is caused by the multiple relationships and the feedback within and between the systems, and the occurrence of chance events. Chance events (surprises) happen suddenly without an apparent cause and are important triggers for change in the systems. In three empirical cases, the occurrence, nature and response to these chance events are analysed as these factors influence the course of sediment management.

Results and Discussion. The case studies show that chance events can occur in the biophysical and in the social system. In the three cases, players or actors in the decision process are left with the choice to adapt themselves to the occurring chance events or to refrain from any adaptive behaviour. Chance events can open up new possibilities by activating (new) actors and by coupling to new issues. If the situation is too locked-in (i.e. a stalemate) and is intentional on behalf of the actors, than the chance event will have no effect. There are, however, situations of lock-in that are unintentional, and in such situations a chance event can remove this lock-in. The effects depend largely on the adaptive capacity of the actors to respond adequately and timely to such situations. The adaptive capacity can be increased (and uncertainty reduced) by a better understanding of both the physical and the social system. The case studies show that adaptation is an adequate way of dealing with the occurrence of chance events.

Conclusions. We conclude that the way to deal with non-linear developments is through an adaptive policy approach with short feedback loops in order to allow for timely adjustments and learning loops that will progress the understanding of the systems – both social and physical. Besides the instruments that are already available, like modelling and forecasting, instruments like observation and monitoring, stakeholder involvement processes, and learning and adaptation should be developed in this new adaptive approach. Monitoring of the physical system is a key element in this approach as all involved parties and stakeholders can learn how the physical system behaves. In this adaptive approach, whimsicality – that occurs through unexpected events – is an interesting challenge for all concerned with sediment management.

Recommendations and Perspectives. The proposed adaptive policy approach should be developed further and should be experimented with in real life situations that are well monitored.

Keywords: Complexity; policy process; sediment management; stakeholder involvement; systems approach

Introduction

The management of sediments in the areas between the river catchment and the sea requires special attention because of the high complexity of the system as seen from different viewpoints: economical, physical, ecological and social. In estuaries, highly complex relationships exist, and as a result the physical system can evolve in non-linear and, sometimes, very erratic ways. These developments are partly driven by natural causes and partly by human-induced changes. Policy-makers face difficulties in governing these systems, because the effects of policies can be hard to distinguish from natural developments. In practice, they are frequently confronted with much uncertainty regarding their policy choices. As existing computational models are not able to predict results of measures in the sediment system to the degree of exactitude that is demanded by policy makers, sediment operations sometimes show unforeseen events and unpredicted outcomes. This non-linearity and unpredictability of the behaviour of sediment systems is hard to harmonize with the linearity of deterministic policies (Otter 2000). Within the existing deterministic policy paradigm, there are basically three ways to deal with this problem. The first way is to ignore this incompatibility and pretend that deterministic policies are effective. However, this may lead to a degeneration of the physical system, that in turn results in unfavourable effects for the social system. The second option is to follow the precautionary principle, which is currently an accepted standard practice in environmental policies (Ast 2000, Otter 2000). A big disadvantage of this approach is, however, that it easily leads to managerial paralysis and lack of development. The third option is a derivative of the previous one and is to engage in a meticulous planning process in order to draw a detailed framework that anticipates many possible outcomes. This approach seems favourable in the realm of sediment management (Apitz & White 2003, White & Apitz 2008). None of these strategies has a sophisticated way of dealing with the actual complexity of the physical and the social systems and, above all, with the unpredictability that is inherent to these systems.

In this article the dynamics of the social and the physical systems are explored so as to derive management and policy strategies that fit better with the aforementioned dynamic character of both systems. Three case studies are described that focus on the responses of policy makers to unexpected events in both systems that provide a glimpse of the new policy strategies that should be developed.

1 Complex Systems

River catchment systems can be regarded as highly complex systems (Macleod et al. 2007, Nguyen et al. 2004, Pahl-Wostl 2007). As sediments are part of the river system, the sedimentary system is complex too (Boer 2001, Gurnell 2007, Soler et al. 2007, Owens 2008). This holds true especially for estuaries and the mouths of rivers in the sea, which are characterised by highly dynamic processes, dynamic equilibriums and the transition from a freshwater to a saline environment (Blott et al. 2006, Quaresma et al. 2007). In the past, the common approach to these processes was to think in terms of 'steady state' systems, but the modern insight is to think in terms of dynamic equilibriums (Peng & Zeng 2007) or non-equilibrium thinking (Lankford & Beale 2007). To ensure that rivers can provide certain services to social systems, like safety, transport and navigation, interventions like river training and dredging are needed. In doing so, natural equilibriums are suppressed and the river is kept in another state, characterized by other dynamic equilibriums or non-equilibriums. These interventions are directed against the natural direction of the physical system, consequently leading to repeated and costly maintenance activities in order to maintain that state. A new approach for sediment management is therefore proposed which goes with the natural direction of the development of the river (Salomons & Brils 2004, Owens et al. 2008).

It is not only the (bio)physical system that should be regarded as complex. The social system, with its manifold interactions between all actors and complex relationships, is complex too, as well as the interaction between the social and the (bio)physical system. The policies that are needed to govern these systems are faced with major challenges, especially to integrate different disciplinary backgrounds and policy domains (Macleod et al. 2007, Pahl-Wostl 2007).

The need to better understand the dynamics of the (bio)physical system and the interaction with the social system has been acknowledged (O'Sullivan et al. 2006). Some have attempted to understand these interactions through advanced modelling (Otter 2000, Wilson 2006), while others have tried to understand it at a conceptual level (Norgaard 1994, 1995), or empirically at the macro level (Malanson et al. 2006). These approaches have relatively little explanatory power for what happens at the actual level of day-to-day (political) decision-making. Consequently, an approach that focuses on the *interaction* between the physical and social system and that can cope with the uncertainties that are inherent in these systems is needed. This need for an integrative view and a new science of coupled social and biophysical systems has been recognized recently (Kotchen & Young 2007).

The past two decades saw a rise of the notion that linearity in systems is actually seldom reflected empirically. This insight has lead to the so-called science of complexity or complexity theory in several disciplines at the same time, ranging from chemistry and biology to environmental sciences and social sciences (Buuren & Gerrits 2007). Complexity theory is a systemic theory, which means that it explains empirical phenomena from complex system behaviour (Marion 1999) and as such it fits within the holistic thinking promoted in sediment management (Apitz 2005). In this article, complexity theory is applied to sediment management and, consequently, the main themes of complexity theory are presented in this section.

A system is a network of agents or acting units that process information and act accordingly (Holland 1995). Agents can be both human and non-human – complexity theory is not exclusively restricted to natural sciences or social sciences. However, there are differences between the two types of systems. Unlike agents in physical systems, agents in social systems can act intentionally because they have the reflexive capacity to do so. Because actors or agents are connected, the consequences of actions resonate throughout the network, depending on the strength of the connections. More importantly, in the case of social systems actors can anticipate, respond, oppose or cooperate, forecast and plan, and all actors doing that at the same time create a complex pattern of interactions (Henrickson & McKelvey 2002, Holland 1995, Kauffman 1993, Marion 1999, Parker & Stacey 1994, Rescher 1998).

This process of interpreting information and acting accordingly can be understood in terms of feedback. Feedback in physical systems is the response to changes in the system.

For example, the building of dykes leading to the decrease of the absorptive capacity of the estuary is a feedback loop between the construction and the response of the system (Peters 2004). Feedback in social systems is the adjustment of actors because of the input of certain (new) information. For example, environmentalists can react on certain decisions of politicians because they may expect negative effects to the physical system. If we understand phenomena as processes of feedback within and between systems, and we acknowledge the differences between physical and social systems, we can frame the management and development of estuaries as an interaction between social and physical systems that develop through mutual adjustment over time. Physical systems adjust to newly created situations, such as the deepening of a navigation channel, and social systems equally adjust to the new situations, for instance with policy and management measures.

A distinction between positive and negative feedback can be made that applies to both developments in the physical and social systems. Feedback is the return of a portion of the output of a process or system to certain input (Parker & Stacey 1994), with negative feedback having a stabilising effect whereas positive feedback oscillates progressively (Prigogine & Stengers 1984). Feedback plays an important role in the dynamics of the system constantly driving mutual adjustments; although the degree of dynamism can differ through time (Bergh et al. 2005, Bergh & Gowdy 2000, Foster & Hölz 2004, Mulder & Bergh 1999). The ensuing dynamics are characterised by periods of accelerated change alternating with periods of relative stability, i.e. punctuated equilibrium. Systems, both physical and social, always tend towards a state of temporal equilibrium, a more or less stable situation at a certain time or place. Certain events in the system can bring the system out of this equilibrium, after which the system will try to regain the old equilibrium. If the system is too far from this equilibrium, than a new, sometimes more stable, equilibrium can be reached which alters the 'state' of the system. Periods of fast change are the result of a build-up of system pressure that can continue to increase while the system appears to be in a rather stable state until a certain threshold is reached. Then the system topples (Bruijn 2004, Hughes et al. 2005, Koppel et al. 2005). As the threshold has been passed, the old situation cannot be restored by decreasing the amount of pressure that caused the system to change. In other words: the amount of energy needed to change a system back is considerably larger than the amount that was needed to give it the final push to the new state. In the case of physical systems, this can be the increase of suspended sediments leading to a change from clear water to turbid water (Scheffer et al. 2001). In the case of social systems, this can be the build-up of public upheaval over a certain sediment operation such as the deepening of an estuary, where protest suddenly gains so much momentum that it cannot remain unattended.

An important factor in the conception of non-linear dynamics is the trigger for change and the threshold after which a certain element in the system will change. Triggers for change in the systems are generally defined as chance events (Sibeon 1999), as they happen suddenly without an apparent cause at the time of happening. The subsidence of a dyke is an example of a chance event which, even if it is a minor local collapse, can have a major impact on the social and the physical systems in terms of geometry and, associated with that, land-use that could last for centuries (Gerrits & Marks 2007). If there is not enough flexibility in the system, it can easily enter a 'locked-in' state. Lock-in is the process of getting fixed in an inflexible or fixed situation because the costs or energy needed to leave the situation exceed the associated benefits. Lock-in occurs in both physical and social systems (Arthur 1994, David 1985, Pierson 2000). While lock-in in social systems stems from choices made in the past, lock-in in physical systems stems from choices made by the social system in the past. An example might be the progressive construction of dykes that diminishes the potential future geometry of the water body. The physical system is locked-in through decisions of the social system.

This theoretical framework allows the analysis of the interactions that exist between the social and the physical systems to manage sediments. Feedback drives change. As long as the systems are in a relative stable state (equilibrium), feedback will sustain this equilibrium. Systems can be brought out of equilibrium by the occurrence of chance events, and consequently the system will change. This notion is important for those who manage the sediment systems. Understanding the directional force in the dynamics of the sedimentary system is required for meaningful interventions. When chance events occur that influence the sedimentary system and its development, it is necessary to be aware of the occurrence of these events and to anticipate the right response through understanding the system. The next section looks at chance events in empirical cases: the occurrence, disposition and response to these chance events determine the course of sediment management.

2 The Case Studies

2.1 Methods and sampling

Three case studies in Germany and The Netherlands were selected, the criteria being that a case should, first, feature a pressing issue regarding sediment management and, secondly, is located in the coastal zone. Research that looked at a long timeframe (Unterelbe: January 1996 – March 2007; Westerschelde July 1993 – March 2007; Rijnland: March 2005 – January 2007) has been carried out in order to note changes, impacts and responses. Data were collected from three sources: observations of ongoing policy processes, semi-structured in-depth interviews, and document research. Candidates for the interviews were selected according to their role in the policy-making process regarding a certain case and 'snowball' sampling was applied in order to cover all actors not included in the initial sample. A total of 60 respondents were interviewed (Unterelbe: N=23; Westerschelde: N=25; Rijnland: N=12).

Document research consisted of comparing articles from different newspapers to reconstruct events (Unterelbe: Hamburger Abendblatt, die Tageszeitung; Westerschelde: NRC Handelsblad, de Volkskrant, Provinciale Zeeuwse Courant, Reformatorisch Dagblad, Financieele Dagblad; Rijnland: n/a), policy documents and research reports issued by the participating actors in the cases. The use of contrasting sources allowed for data validation.

Observations were carried out during meetings of policy-makers. During these meetings the current and future policies regarding the natural system were discussed (Rijnland: eight meetings; Westerschelde: four meetings; Unterelbe: none because of time constraints).

These three sources were used to reconstruct the way in which the three cases developed through time (Gerrits 2008). The findings are based on these three sources and most of the statements are supported by the interviewees, although not necessarily by all of them. The conclusions remain the interpretation of the authors.

2.2 The Unterelbe estuary, Germany: Dealing with changes in sediment accumulation

The Unterelbe is an estuary and a tidal river in northwest Germany that runs from Hamburg to Cuxhaven into the North Sea. It provides maritime access to the port of Hamburg, one of the largest ports in Europe. It also features some natural elements that are important for estuarine ecology, such as shoals, sandbars and holms. Its ever-changing morphology and relative shallowness forces the port authorities to dredge for maintenance and also occasionally to deepen the main navigation channel. The most recent deepening of the Unterelbe was finished in December 1999. The new depth was set at 12.80 meters independent from tidal changes. A monitoring programme was initiated in order to assess the consequences of the deepening. However, the port authorities were still concerned that the new depth was not sufficient and during April 2002 the Senate presented its plans for a new deepening operation. The monitoring programme had not yet produced any results but according to the director of the Wasser- und Schifffahrtsdirektion Nord, the organisation responsible for the programme, there were no changes in the estuary other than the ones predicted. The planning process started during the same year.

An official working group released a preliminary study in 2004, stating that the next deepening would be feasible and would not have major negative impacts in terms of ecology and morphology. An advanced 2-dimensional model, developed by the Bundesanstalt für Wasserbau und Schifffahrt, was used to arrive at this conclusion. However, at the same time that this study was presented, the amount of sediments in the harbour basin doubled. This forced the port authorities to double their efforts to keep the harbour basin free of sediments. The amount of dredged material increased from approximately 4.5 million m^3 in 2000 to 9 million m^3 annually in 2004. This sudden sharp increase was due to the so-called tidal pumping effect, i.e. the effect that sediments in the Elbe are not transported downstream to the North Sea but are rather transported upstream where they subsequently accumulate in the harbour basin from where they were originally removed. The 1999 deepening and the strategy for maintenance dredging appeared to have reinforced this effect considerably while this was not forecasted by the model used in the planning of the deepening operation.

This sediment accumulation posed a major problem for the policy-makers. It required additional dredging operations. Furthermore, the fact that the dredged material returned to the harbour basin again after it had been dispersed in the Unterelbe, added to the feeling that this circular dredging constituted a vicious circle in which the same material is dredged over and over again. Having little additional capacity to store dredged material, the port authorities and the City of Hamburg feared being kept in a situation that would cost them more resources than were available.

However, faced with this unforeseen and unfavourable change in sediment transport, the port authorities and the Senate decided to carry on with the planning of a new deepening operation regardless of the new situation (i.e. state) of the Unterelbe. At the same time a second policy process was initiated in which a more comprehensive long-term vision was developed, the so-called 'tidal Elbe' concept that aimed at a sound management of the estuary in order to avoid more dramatic changes. The tidal Elbe concept takes the ecological state of the estuary and its long-term development into account, whereas the first policy process is aimed at a singular deepening operation for the lowest costs possible. During autumn 2006, the formal decision to go ahead with the deepening operation coincided with the presentation of the tidal Elbe concept but the two processes remained completely disconnected. The result, is that the next deepening operation is largely based on the old premises, whereas the tidal Elbe concept incorporating newer ideas about the management of the estuary and has been moved to the future. A formal reason for the division between the two processes is that they cover different topics, i.e. the work that needs to be done now versus the work that should happen in the future. However, societal resistance against the deepening operation continued to grow, culminating in popular protests.

When analysed through the complexity framework, this case shows that a continuous strain on the physical system (estuary) does not lead to continuous gradual change but rather to punctuated change – a positive feedback loop between the estuary and the strain that is put on it. The punctuated change was triggered by the most recent deepening operation. The sudden accumulation of sediments was unexpected even though extensive research was carried out prior to the deepening operation in order to understand the possible effects of the deepening. It is a clear example of an unfavourable chance event as it forces the policy-makers to double their maintenance dredging efforts. There is no easy solution available: the sediments keep returning and there is lack of storage capacity.

When planning a new deepening operation, actors within the social system decided not to wait for the outcomes of the monitoring programme and went ahead with planning a new deepening operation as they felt the urge to deepen the Unterelbe in order to promote shipping to and from Hamburg. When the chance event occurred, i.e. when the sediments started to accumulate rapidly, the planning process had developed in such a way that reorganising, or even pausing, it was not considered to be of greater benefit than continuing with the chosen course – even given the potential risks of more unfavourable effects of doing this. This response shows that the current process is too much locked-in to adapt to the newly created situation. Instead, an alternative process was started but connections between the two are almost completely absent. The adaptive capacity of the social system was quite low and this in turn has an impact on the future of the estuary. In its current locked-in state the planning process now has to decide how to dredge and dispose of the sediments but with limited room to manoeuvre.

2.3 The Westerschelde estuary, The Netherlands/ Flanders: Dealing with the dependency on a railway network

The Westerschelde estuary in the southwest of the Netherlands runs from the port of Antwerpen to the North Sea. Like Hamburg, the port of Antwerpen is one of the largest ports in Europe. Similar to the situation in Hamburg, the Port of Antwerpen aims to deepen the estuary in order to facilitate larger ships. The Westerschelde features important habitats and the dissipative character of the morphology helps to protect against floods. Because the estuary is located on Dutch territory, the authorities of Antwerpen need to obtain a Dutch permit for deepening operations. The most recent deepening operation took place between 1997 and 1998. This deepening was the outcome of a long negotiation process that lasted almost 30 years. The final permission was given after the Flemish authorities agreed with the construction of a high-speed railway link between Flanders and the Netherlands, thereby granting an old request from the Dutch government in exchange for the deepening of the Westerschelde.

Two years after the deepening operation was completed in 1998, another request to deepen the estuary was submitted by the port authorities of Antwerpen. Adverse to another long period of negotiations, both countries agreed to start a joint process in which the different stakes and research results would be combined in order to make sound decisions regarding the estuary. The process was developed within the framework of the 'Long Term Vision on the Westerschelde', an outline drafted by a formal bi-national working group during the years after the initial deepening operation. It stated that further development of the estuary should be balanced between economy, ecology and safety. Actors from both sides of the border are pressed to deliver a good, consensual outcome – especially after the two national Courts of Audit criticized the foundations of the previous deepening operation and the European Commission sent a formal warning that the compensating ecological measures were insufficient.

This open planning process lasted for three years and the plans were presented in a development outline during autumn 2004. Besides deepening operations it proposed some additional measures that provoked considerable public resistance, such as the creation of floodplains and realigning the dykes further inland. These responses were not unexpected. However, the presentation of the proposals coincided with a report on the construction of the high-speed railway link mentioned above. The construction was well underway but it appeared that trains would have to travel 17 minutes longer than expected. Eight minutes are lost, seemingly due to a mistake in the calculations regarding the Flemish part of the track. There is also disagreement over the frequency of the service. The Dutch parliament then suddenly demanded that the Minister of Public Works and Transport would send an ultimatum to the Belgian government: no deal over the railway link meant that the Dutch parliament would not agree with the deepening of the Westerschelde. For the Flemish parties, suddenly the laborious negotiations over the past four years appeared to be futile as it all seemed to depend again on the railway link. However, the ministers of both countries accepted that they could not put the Westerschelde deal at risk and agreed on a settlement. The Dutch government accepted that the railway link will be slower than expected, and the Flemish authorities promised to modify the track and to pay for more frequent services. If losses occur the Belgian railways will pay these. Consequently, the planning of the deepening operations could go ahead.

This case shows how events in the social system that are seemingly insignificant – because they are not related to the natural system in any way – can have a considerable impact on the decision-making regarding the management of the estuary. The (re-)occurrence of the high-speed railway as a negotiation asset came unexpectedly and was considered unfair by the sediment managers as they thought that such an issue should not influence decisions regarding the physical system. However, the reoccurrence was a fact. The planning process towards a decision regarding the estuary in 1997 had become locked-in, because there was no extra benefit for both sides to move to a new position. The coupling with the railway issue was a chance event that enabled parties to change their position and as such enabled a decision that may have been impossible without this chance event. The circumstances allowed for sufficient system pressure (the railway issue) to pass the threshold and initiated a system change (a decision regarding the estuary). The second time this issue occurred, the situation in the social system was the opposite of the one in 1997. This time there was no locked-in situation between the two sides but rather consensus over a well-funded plan for the estuary. Attempts to re-link this to the railway issue were in vain because the adaptive capacity of the actors meant that the railway link as a negotiation asset could not build up enough system pressure to cause a change. Although the issue itself caused some turbulence within the social system, it never gained enough momentum to come to fruition. This does not mean that the social system has become rigid, and locked-in, but it means that it was able to adapt itself in such a way that the pressure was diverted. The agreement over the deepening operation covered enough aspects to satisfy most actors.

2.4 The Rijnland area, the Netherlands: Dealing with changing planning processes

The Rijnland water board is one of the oldest water boards in the Netherlands. It governs the polder areas in the west of the Netherlands close to the sea, roughly between the cities of Gouda, Den Haag and Haarlem. As water boards are responsible for the water quality and quantity issues in their areas, they are also responsible for dredging the polder canals and ditches. The Rijnland water board has refrained from dredging the water network in the polders for decades and therefore a backlog had occurred. This called for a swift and major dredging operation. The accumulation of sediments compromised the water quantity and quality, diminished ecological life and hindered economical and recreational use of the water bodies. In some areas the muddy riverbed was almost exposed.

The potential dredging operation may appear to be simple at first glance because of the low physical complexity, but the Rijnland area is densely and diversely populated with stakeholders ranging from farmers to urban inhabitants. To avoid public resistance at the onset, a process of stakeholder involvement was established. From the different stakeholder groups (farmers, resident committees, environmentalists, recreation associations, angling associations, local authorities, etc.) representatives were invited to join the participatory planning process. They were asked to think with the water board about the way the dredging operation should be carried out.

The process of stakeholder involvement was designed as a series of six workshops. The first workshop covered the articulation of the (associated) problems by the stakeholder groups, the second workshop was meant to create visions on future sediment management options. From then onwards, the stakeholders would turn these visions into present plans for managing the sediments, exchange knowledge with experts in order to improve the plans, and finally present the most favourable sediment options. This process started at the beginning of 2006 and ended in December of that same year and was meant to give direction to the dredging activities.

The first and second workshops took place as planned. However, during the third workshop in which present sediment options were discussed, the stakeholders started to protest. During this session the stakeholders developed diverse plans for sediment management, ranging from the more common solution, such as in-situ storage, to solutions of using it to grow flowers for commercial purposes. In this workshop, the stakeholders contested the water board as they did not trust the water board. Stakeholders stated that until now they were not given the feeling that they were participating in a clear and transparent process. On the other hand, the water board felt the pressure to generate solutions in time so as to keep to the tight schedule of the decision making process, and this put some pressure on the generation of sediment management options. This contributed to the feeling of the stakeholders they were manipulated by the water board as it looked like they already had planned what to do, regardless of the ideas of the stakeholders. This left them with the feeling that their effort was useless.

As soon as the protests were expressed, a 'time-out' was called for and the problems were discussed. In this time-out session, it was agreed that a small group of representatives from the stakeholder group would discuss the process separately with the water board. In this separate meeting, the representatives of the stakeholders expressed that they wanted to respond to the plans of the water board rather than putting time and effort in developing their own plans. They also wanted to have discussions with people who live in the area as they found the input of local knowledge was lacking. This redesign of the process was discussed in the following, fourth, workshop with all stakeholders and was implemented after approval by all stakeholders and the water board. The water board came up with several options for disposal of the dredged material, that included disposal in gravel pits, elevating agricultural areas, and elevating dykes and quaysides. Two local workshops in the area were organised and attended by local people who discussed the feasibility of the proposals. The process ended with a clear, appreciated and approved list of options that provided a sound basis for the disposal of the dredged materials. A number of suggested disposal sites were cleared from the list as it turned out that they were too expensive or projected in areas that would not be able to cope with the environmental damage that could be caused by storing contaminated sediments. On the other hand, the local people came up with new solutions for sediment disposal in the area, like using dredged material at new building sites. At the end of this process, the generated sediment options outnumbered the list the water board had originally drafted and the total disposal capacity was more than enough to dispose of all of the dredged material.

The chance event in this case was the protest of the stakeholders during the third workshop that came as a surprise to the water board because, until then, they had perceived support from the stakeholders. The way the different sediment management options were presented triggered this release. However, given the fact that the process was still in an early stage and had not become locked-in, the protest did not result in a stopping of the process but instead resulted in a change of the process architecture that was deemed favourable by all. This change can be attributed to the adaptive capacity by all actors: the water board accepting that a change was necessary, and the stakeholders who advocated the change of the process architecture. The process as a whole resembled a search through the possibilities rather than the application of a rigid framework, and in the end it resulted in a sound decision.

3 Reflection on the Case Studies

The following lessons can be drawn from the case studies. First of all, virtually all cases of sediment management operations are difficult or impossible to control despite well-intended efforts. Secondly, chance events can open up new possibilities but the adaptive capacity of the social system is a requisite for dealing with chance events. Even systems that are locked-in can be reactivated to move again if the lock-in occurs without intention on behalf of the actors. Chance events are likely to occur in any case although their emergence is localised in time and space and the frequency may differ. However, the fact that chance events can occur means that sediment managers need to deal with them and should be prepared for them.

The whimsical nature of chance events has important consequences for the planning of sediment management operations. As shown in the case studies, a chance event can be both of a physical and a social nature and both types have an impact on the management of sediment systems. This means that chance events cannot be controlled: they happen unexpectedly and can occur anywhere. The case studies illustrate that the occurrence and development of these events takes place independently from the attempts of actors to steer them. The actors are left with the choice to adapt themselves to the new circumstances or to refrain from any adaptive behaviour.

The directional nature of the chance events, i.e. the fact that they are important factors influencing the final outcomes, means that adaptive behaviour is almost inevitable. All three case studies show attempts by the actors to deal with the chance events. In the case of the Unterelbe estuary, the process was too locked-in to change completely so the only adjustment was that an economically efficient solution for the tidal pumping effect had to be developed. However, there was inability to incorporate the tidal Elbe concept in the current deepening operation, even though this connection may lead to favourable results. In the case of the Westerschelde estuary, inability to adapt to the new circumstances in 1997 could lead to a prolonged dead-lock, whereas in a second situation it could lead to the destruction of a sound agreement over the estuary. In the case of Rijnland area, the adaptive behaviour of the actors prevented the withdrawal of the stakeholders and increased support for the dredging operation. The ability to adapt to the unexpected events and new situation on the one hand provides opportunities to continue projects but on the other hand reinforces the directional nature of the chance events because acknowledging and moving along means that the actors have an acknowledged impact on the process.

Although chance events are by nature unexpected, they should be met with adaptive behaviour. The degree of uncertainty can be reduced by a better understanding of the system and a higher awareness of the system pressure within both the physical and the social system. It takes considerable system pressure for changes to take place but once these changes take place, they can be far-reaching. Being aware of the build-up of system pressure may lead to a better understanding of sediment management as managing complex adaptive systems, rather than stable (mechanical) systems. In all three case studies, the pressure on the system was present but unnoticed. The continuous strain in the Unterelbe case, the reoccurrence of the railway issue in the Westerschelde case, and the dissatisfaction of the stakeholders in the Rijnland case are all examples of the build-up of system pressure that, once enough momentum was gained, triggered a number of changes.

The case studies show that adaptive behaviour provides an accurate way of dealing with the chance events. This brings the focus to the final aspect of this analysis, the emergence of lock-in. The cases show that there are situations of lock-in that are, to a certain degree, unintentional. In such situations, a chance event can lift this lock-in. However, if the lock-in is intentional, as is the situation in the Unterelbe case, a chance event may not be able to lift this lock-in. Adaptive behaviour depends on the character of the lock-in, i.e. whether this is intentional or not.

4 Conclusions and Recommendations

In this article we distinguish between the physical and the social system in sediment issues, but we also argued that they are very strongly connected. The systems develop through mutual adjustments that can be seen as the results of positive and negative feedback in and between the systems. In this way both systems co-evolve in time. Changes in the system are the result of a build-up of system pressure. Chance events have the directional power to guide processes in new, sometimes unforeseen directions. The responses to these unexpected events are, therefore, very important to keep both systems well connected.

In the case studies, unexpected events occurred and in all cases this had an effect on the sediment issues that were at stake. In all cases these events provoked a response of the social system and, when these reactions were implemented, it sometimes speeded up the process to reach agreements (e.g. Rijnland and Westerschelde cases) or it did not have an effect yet (e.g. Unterelbe case). The case studies also show that from the onset policy systems have a tendency to adopt a control-seeking approach towards the physical characteristics of the system. Acknowledgement of the capricious nature of the biophysical system leads to stricter managing in an attempt to cover all eventualities, extended research in order to render an extensive and definite image of the workings of the biophysical system, and a meticulous and rigid planning of the whole operation. After the operation is carried out and the results appear, the cycle is repeated. However, the chance events will still occur and such a rigid approach can worsen the state of the system, and can easily lead to a locked-in situation because it lacks flexibility.

Therefore, the policy repertoire should be extended with other strategies. We argue that the best way to deal with these non-linear developments is through an adaptive approach with short feedback loops in order to allow for timely adjustments and learning loops that will progress the understanding of the systems – both social and physical. Flexibility in goals and the methods used is necessary (Goldsmith & Eggers 2004). The policy strategies that are needed in this approach differ very much from the directive, centralised, command and control strategies that are in vogue with present policies. Strategies that are needed in complex situations are directed towards preserving the dynamics in the systems, moving *with* the dynamics of the system (instead of against it) and towards keeping the social and physical systems very well connected through feedback and learning.

The main instruments and methodologies in this adaptive policy approach are observation and monitoring - besides prediction and modelling in the present approaches that are still valuable - stakeholder involvement in the policy process, and in the application of instruments like modelling and monitoring, and learning and adaptation (Hisschemöller et al. 2001, Owens et al. 2008), instead of dictating to the physical and social systems what to do and how to behave. Monitoring of the physical system is a key element in this approach. From monitoring results all involved stakeholders can learn how the physical system behaves. Measures that are needed to bring the biophysical system in a favourable state, can be discussed and implemented. The effects of the measures can then again be monitored and adjustments can be proposed, in such a way that the dynamics in the system will be preserved. In this adaptive approach, whimsicality is not a burden but an interesting challenge for all concerned with sediment management.

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