LINKING PHYSICAL AND SOCIAL SYSTEMS FOR IMPROVING DISTURBED-LAND RECLAMATION[1]

J.J. Griffith[2] and T. J. Toy

Abstract: Land disturbance is already recognized as detrimental to ecological settings. Yet we need to better understand and model how degradation events – natural or human-caused – contribute to the evolution of environmental management and affect relations of society in general. To this purpose we have developed a physical-social conceptual model that explains linkages between physical and social systems for a wide range of severe ecological events. Many models already exist representing the physical aspects of degradation such as changes to soils, hydrology, and vegetation. But most of these are incomplete because they ignore or minimize the importance of social-system components. The new and comprehensive model presented here corrects this deficiency by linking the physical and social systems by means of causal loops, the principal tool of systemic thinking. Causal loops express how tendencies of influence operate among the variables of a given system, resulting in either dynamics of reinforcement or reestablishment of stability. According to the model, a disturbance sufficient to overcome system resiliency sets either or both of the physical or social system in motion. Once actuated, the affected systems manifest movement in three possible ways and time frames: 1) by accelerated reactions in the short term, 2) by a natural and not necessarily human-assisted recuperation in the long term (if we are willing to wait long enough), and 3) through an intermediary compensating feedback mechanism that operates in the medium term and connects the other two phases. We argue that interventions at the compensating feedback-mechanism level may be more effective than trying to strategically resolve chaotic situations in the short term or confront stubborn system inertia in the long-term. A single causal loop diagram summarizes the Physical-Social Model, and we redefine key concepts of degradation, recuperation and restoration with reference to this diagram.

Additional Key Words**:** severely disturbed land reclamation, conceptual modeling, systemic thinking, feedback theory

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Introduction

The majority of environmental managers live in constant search of highly practical operational techniques. But they also need to have sound conceptual models underlying their practices. Otherwise their successes may be just lucky shots, bull's-eye hits that result in successful impact amelioration or reclamation. Failures or incomplete solutions, however, are likely, and unless practitioners have models to tie components together or signal knowledge gaps, there can be no systematic learning, only trial and error.

Conceptual models serve other purposes. They may be formulated and shared among team members, helping everyone reach consensus about specific problems and formulate broad environmental strategies. Having a conceptual model well founded in theory should give managers peace of mind that what intuitively seems right in practice is consistent in purpose and thought.

Morecroft (1994) defines models as "maps that capture and activate knowledge." By simplifying phenomena, they allow us to discern what knowledge is important for solving a given problem, predicting what may happen and prioritizing appropriate actions. Certainly as such, models should be considered useful tools for land-reclamation efforts. Nevertheless, Reith (1986) suggests that problems of incomplete data and difficulty in holding constant all factors of reclaimed surfaces except the one being studied have made many reclamation specialists reluctant to adopt modeling.

Despite these limitations, we feel that modeling has much to contribute to reclamation science, and the objective of this paper is to present a new conceptual model of environmental degradation and recuperation that is surprisingly broad in its application to diverse reclamation situations. While there are existing models for specific physical aspects such as soils, water and vegetation, these are usually incomplete because they do not include social aspects. The concept which we present especially addresses this limitation, resulting in the unified Physical-Social Model. In addition to this wider concern, the model has two more special characteristics described in the following section: 1) its configuration as a causal loop diagram characteristic of systemic thinking and 2) its foundation upon a simpler model of general systems behavior, which we call a Basic Unit of Synthesis.

Helping specialists to link physical and social systems in land reclamation is the specific problem-solving objective for our model. We advocate "modeling as learning," not as imposing a "specialist consulting model" upon clients (Lane, 1994). To trigger others' thinking, we have diagramed our familiarity with the real reclamation system, showing how we perceive key flows and relationships. Some of these heuristics are subjective, others are based on existing models and still others are pure logic.

By relating similar situations to our model, others may likewise uncover systemic structures by clearly stating the problem, identifying appropriate variables, and diagramming behavior patterns over time (short, medium, and long-term system responses). The result is a process that helps reclamation specialists to better "know what they already know" (Lane, 1994). Our objective is to add our model's contribution to their already existing mental models. It should be especially useful in forming testable hypotheses.

Causal Loops – the Principal Tool of Systemic Thinking

A principal thesis presented here is that interlinked physical and social systems respond to surface-mining and reclamation activities, moving both systems to a state of dynamic equilibrium, sooner or later, by means of systemic feedback mechanisms. The "lag-time" between the initial mining disturbance and return to dynamic equilibrium depends upon the natural propensity for recovery within the system plus contributing reclamation efforts. It is suggested that reclamation planners and practitioners consider the concepts incorporated in "systemic thinking" as proposed by Senge (1990) and Anderson and Johnson (1997), for the development of reclamation plans and the selection of reclamation practices.

Within the spirit of systemic thinking, we have constructed two models using causal loops. Causal loops are the principal tool of systemic thinking, and an assemblage of them may be called an "influence diagram." According to this view, the world operates in reinforcing ("R") and balancing ("B") feedback circuits, and their movement together is considered the general behavior of the phenomenon or event under investigation.

More specifically, causal loops contain variables (something which may increase or diminish over time) linked by connectors (arcs with arrow tips that indicate sequence or direction of causality). Two relationships among variables are possible: In the first, one variable increases (or diminishes) while the other also increases (or diminishes). Alternatively, in the second situation, one variable increases (or diminishes) while the other decreases (or increases). For the first case, the sign indicated by the connector is positive ("+"); for the second case, negative ("-") (Senge, 1990; Anderson and Johnson, 1997).

The Basic Unit of Synthesis

In order to model systems movement in general, and as a fundamental base to construct our more specific physical-social reclamation model, we postulate that systems generally operate as shown in Fig. 1. We call this overview the Basic Unit of Synthesis because synthesis indicates utilizing the whole pattern as the object of study.

The dynamic of this unit is organized as follows: a disturbance or perturbation potentially triggers system movement. But whether or the system actually begins to move depends upon the relation of forces and resistances at that particular moment. Even though powerful forces may be part of the disturbance, if they are less in magnitude than the prevailing resistances (a relationship of $F/R<1$), nothing further happens; the system is said to be resilient.

However, if the relation is $F/R>1$, the flux of energy or causality, that could be either physical or perceptual, once unleashed, overcomes the system's resilience and begins to course through its internal circuits. In other words, the system begins to move. The sequence of flow therein, moving from variable to variable via connectors through time. We mapped this organization of movement as Fig. 1.

Examining the various loops of Fig. 1, one observes that the tendency of a perturbed system is to move toward reestablishing stability. However the diagram does not reveal one important fact: that this new condition, once reached, may differ considerably from the pre-disturbance equilibrium. What the figure does show is how this new stability is reached through time and that the new configuration depends on the unfolding of system internal movements. This behavior is always expressed in terms of reinforcement ("R") and balance ("B").

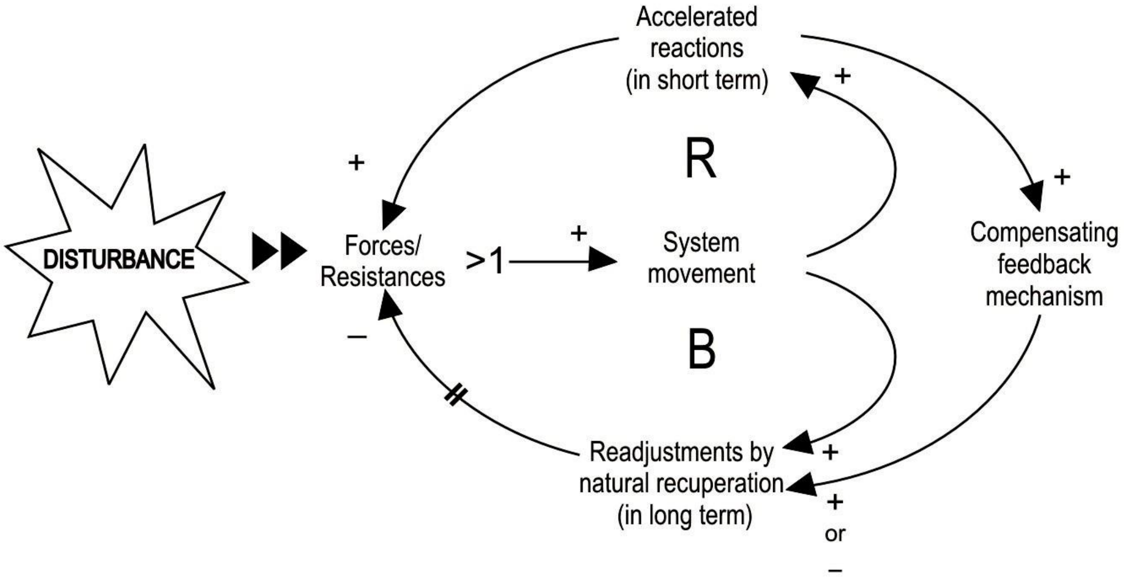

Figure 1. The Basic Unit of Synthesis for diagnosing the dynamics of systems in general.

Fig. 1 serves as a basic concept to construct more detailed models for specific situations for the following reasons:

- It may be interpreted as belonging to either or both of two well-established engineering modeling traditions: cybernetics and servomechanisms (Richardson, 1991). Cybernetics, briefly, envisions a step-by-step and often hierarchical progression, unleashed by discrete and stochastic external events (triggered by an ecological accident, for example). Servomechanisms are continuous behavioral manifestations of internally organized reinforcements and balances (movements following the dynamic pattern of ecological succession that spontaneously occurs on denuded land, for example). The ability to include these two makes our Basic Unit of Synthesis compatible with the autopoietic ("self-making") theory of life processes described by Maturana and Varela (1987). Their remarkable theory of cognition combines organismic biology (similar to servomechamism models) and the nature of the mind (modeled mostly by cyberneticists) (Capra, 1996).

- The model includes diverse time dimensions, incorporating within its loops both short-term system reactions and much delayed, but enduring, system responses. It also includes medium-term behavior that connects those short and long-term responses. This intermediary is called a compensating feedback mechanism and will be discussed later.

- Its loops represent an open, not closed, system; the model is dynamic and not static. Although dynamic in structure, it is perfectly capable of being used to reinterpret and enhance static models. It reflects non-linear thinking and is therefore very suitable for modeling natural and social processes since these are usually characterized by circular configurations.

- It is possible to expand systemic thinking diagrams into powerful mathematical simulation models of stocks and flows. Systemic thinking and mathematical simulation are complementary, not competing, models (Anderson and Johnson, 1997).

The Physical-Social Model

Fig. 2 is an expansion of the dynamics modeled in Fig. 1. It illustrates the conceptual model of inter-relations between environmental degradation and reclamation that includes both physical and social systems. In order for Fig. 2 to incorporate both systems, two figures of the Basic Units of Syntheses (Fig. 1) are placed back to back, each reflecting the relation to the other. However, they have a common, undivided starting point because movement on either side always begins with an initial disturbance located at the diagram's center.

In the case of environmental degradation, what starts the principal system moving (events or disturbances) are consequences of natural processes (climatic, geologic, geomorphic, biotic) or of human activities (agriculture, mining, urbanization etc.), or from a combination of both (floods, for example, often combine the vagaries of nature and poor land-use practices).

Just like the physical system, the social system may have resilience. We may observe, for example, that not all events are necessarily perceived as significant by the public and worthy of corrective action. In other words, if the event does not possess salience (literally some outwardly projecting part that calls attention), the social side of the Physical-Social Model does not move. Without salience we can say that "something happened but nothing happens at all" because there will be no forthcoming social or management response to the problem.

Several aspects of the Physical-Social Model of Fig. 2 are more detailed than those presented in Fig. 1. To model the initial disturbance, a series of shock waves are drawn as radiating from the model's center in concentric rings, lapping up against whatever forces and resistances are relevant. Figure 2 as an example uses the forces and resistances of geomorphic work on the physical side (gravity, rainsplash, shear stress caused by runoff are forces, for example) and organizational action on the social side (institutional vision, morals and ethics, for example). But it could be set up otherwise to illustrate hydrologic, vegetative, urban or other types of systems.

It is noteworthy that the physical side of the model does not attribute to nature any capacity for making choices, a condition recognized in the common expression "Nature doesn't care." But, to the contrary, the social side of the model presents the possibility of human choice; a symptomatic problem may be addressed by applying a symptomatic solution or by implementing a more fundamental and enduring solution. For elaboration concerning this behavior, see "Shifting the Burden," one of eight archetypes conceptualized in systemic thinking (Senge, 1990; Anderson and Johnson; 1997).

As follows, we next postulate that the most effective point of intervention, considering all the regions included in the Basic Unit of Synthesis, is upon the Compensating Feedback Mechanism region.

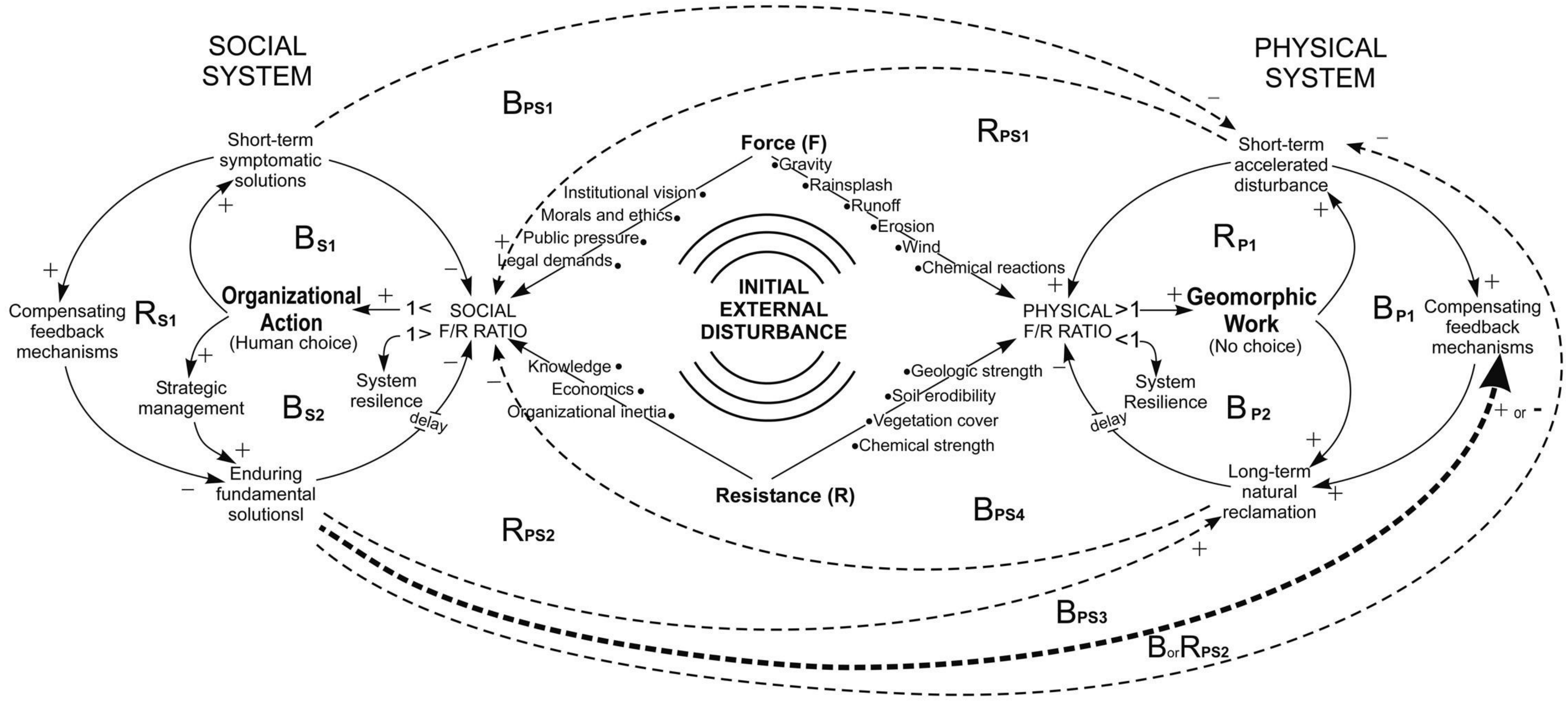

Figure 2. Conceptual model of inter-relations between environmental degradation and reclamation that includes both physical and social systems.

Compensating Feedback Mechanism

Environmental management may be defined as the art of aligning human actions to the potential or existing forces and resistances of nature (including powers of self-adjustment and recuperation) (Griffith, 2002). How to do this, however, may not be obvious. The manager soon finds out that alignment with nature is not effective just anywhere in the system; one must find a sensitive point of intervention.

Attempts at management in the region of "Accelerated Reactions" (Fig. 1) frequently encounter difficulties because of the apparent chaos that often prevails there. Upon disturbance, the system generates very rapid and fragmented movements, nothing consistent enough to allow alignment. Given this chaotic state, conditions may tend to worsen in this region of the model before they get better.

Unfortunately, intervention in the region of "Enduring Fundamental Solutions" is also problematic. The long-term adjustment process is so ordered and stable that acting directly here is akin to diverting the course of a large ocean liner under steam. If one gives the system a push at this point, the system tends to push back.

Yet another possibility exists – acting in the region that forms a bridge between the other two parts, made viable because while it efficiently connects the parts, it does not fall into either of the extremes. This part is called "Compensating Feedback Mechanism" because as an effective intermediary, its dynamics literally feed back, through all the connections, to the beginning of the circuit. Being compensatory, it acts specifically by linking short and long-term responses and by affecting the behavior of the system in general. Intervention here is effective because, even though indirect, it results in reinforcement, a decrease or general control at the point of long-term output, actually to the loop's starting point. It therefore contributes to counterbalancing the effects of whatever disturbed the system in the first place (Richardson, 1991).

For an outside observer, the dynamics of this compensating feedback mechanism might appear at worst an organized confusion, and at best, a complex arrangement of rare beauty. According to Waldrop (1992), it is at this intermediary point, riding the wave of near-chaos, that we humans best function. This point is known in the Theory of Complexity as an autocatalytic region, also characterized by self-organization (Capra, 1996). Within this comes together a range of forces and resistances that are so critically interrelated that the emerging condition soon reaches a threshold, and a new order emerges.

It is recommended that we focus our actions at these points of complex systems because it is an incubator region that potentially generates so-called "economics of increasing returns" (as opposed to the customary economics of decreasing returns). Intervening here promises synergy, affording the manager the opportunity to do something greater than summing the constituent parts of the system.

Examples of Environmental Management that Combine the Two Models

The following two examples illustrate the potential applicability of both the Basic Unit of Synthesis model (Fig. 1) and the Physical-Social Model of Environmental Recuperation (Fig. 2).

1. A relatively large area of hillside forest is cut at a stream's headwaters. The disturbance is of such magnitude that, with the onset of the rainy season, the geomorphologic system at the headwaters begins to move. The first accelerated reactions are virtually uncontrollable, including rainsplash, runoff, erosion, mass movements, and channel cutting in the upper reaches of the stream. After perhaps 20 to 50 years, hillside vegetation reestablishes, runoff and erosion decrease, and sediment yield decreases as well. As a result, the stream's channel will reassume a normal and stable dynamic state. This happens because some link has been established between short and long-term states. A compensating feedback mechanism in this case occurs through channel sedimentation beginning in the downstream channel reaches. Gradually accumulating and extending itself back towards the headwaters, the sediment load "feeds back" toward its point of origin. The lower reaches continue to fill proportionately with more sediment, reducing stream channel slope. And water coursing down a channel that is ever more gentle in gradient diminishes in velocity and loses its erosive force. In the long-term, a natural recuperation adjustment has occurred, returning the system to a stable geomorphologic condition similar yet still different from that which existed before the disturbance.

2. After many accident-free years, an ecological disaster occurs on a mining company's lands. The accident could have been prevented had there existed appropriate environmental legislation and regulation of such situations. But no law had been instigated; no one gave it any priority. The first reaction after the event is a flurry of aggressive accusations about culpability resulting in grievous polarization between groups. Meanwhile, other similar situations are discovered throughout the area (accidents just waiting to happen) by the press and the now-awakened public, provoking even more acrimony. The ideal solution (a social adjustment that naturally endures for the long-term) would be for the companies to accept control measures that are consensually strong among all interested parties, in the form of new legislation. But there is a large gap between the indignation of the population and a mature legislative response. The compensating feedback mechanism in this instance could be the intervention of a political entrepreneur who unites three essential threads: the occurrence of the problem, the relevant technical ideas and philosophical concepts, and the favorable political forces of the moment. As these three critical components come together, a strong wave of socio-political action arises and gains momentum; the problem becomes salient in the minds of legislators. They elevate the situation to the point of urgency (considered a threat) yet they also see how solving the problem could be politically attractive (considered an opportunity). Gaining strength on the very wave the political entrepreneur helped to create, this same leader persuades legislators to prioritize a solution for the problem; they put it at the top of their agenda. So the legislation passes, and the new law, accepted by the great majority of the interested parties, soon takes effect among industry practitioners. It endures "naturally" because it has everyone's support.

Environmental Recuperation Terminology According to the Physical-Social Model

One of the most important advantages of the Physical-Social Model is that it permits us to greatly simplify reclamation terminology. Instead of prolix descriptions, the conceptual reference of Fig. 2 allows the following succinct definitions:

- **Environmental degradation** – *the perception that* R_{P1} *is moving too fast and* B_{P2}*, too slow*.
- **Environmental recuperation** – *the slowing down of* R_{P1} *and the acceleration of* B_{P2}.

Under urgent conditions, an anxious manager may resort to short-term "fire-fighter" solutions, attempting to diminish R_{P1} (See the dashed line that arcs across the upper part of Fig. 2, linking the Social System and the Physical System). Even so, these are normally quick-fix measures which frequently cause unexpected side-effects that often hamper the implementation of effective, long-lasting solutions.

Management conducted in a more strategic manner may attempt to have not only a "fire-fighter squad" ready for rapid response but also induce effective long-term stabilities by directly tackling the system's long-term dynamics (the dashed lines leading out from Enduring Fundamental Solutions to both Short-term Accelerated Disturbance and Long-term Natural Recuperation). Nevertheless, success is still unlikely, for the reasons already discussed.

According to the Theory of Complexity, it would be better to apply the strategy to the region of the compensating feedback mechanism. To reflect this potential, the dashed line linking Enduring Fundamental Solutions to the Compensating Feedback Mechanism is bolder than the others.

- **Environmental restoration** – *the return of the physical system to a state of F/R<1 and the social system also to F/R<1 (Fig. 2), each in the same proportions of forces and resistances that existed before the initial disturbance.*

This is an interesting definition because it recognizes that results obtained in the long run may be quite different in terms of the physical and cultural landscapes that existed before the initial disturbance. Many cases of degradation are so severe that there is no way to restore original conditions at a socially-acceptable cost. Even so, for those persons who still wish to call the process "ecological restoration," this definition grants their vision legitimacy. Because in the sense of this model, we can indeed renovate *systemic organization* of relations between forces and resistances which, over the long run, will let the landscape be just as stable as it was before disturbance. This would be, of course, an organizational restoration and not a physical or cultural replication.

Final Considerations

According to the model, the concept of degradation is a social construction because it depends on the *perception* that R_{P1} is moving too fast and B_{P2} is too slow. There may be conflicts in this perception, especially when such vision is restricted to only certain views and viewpoints within the organizational field. Orssatto and Clegg (1999) define organizational field as "the context in which technical, economic, social and political actions and agents interact." Normally the focus of perception is on a specific productive sector such as mining, forestry or agriculture. But many ecological events simultaneously impact a wide field involving several sectors.

It may not be feasible to cleanly separate the social from the physical when drawing an influence diagram for a specific degradation situation. Many times the two occur together in an entangled web of causal loops. In this case, model development needs to reflect this complexity in its construction.

Environmental resources may also suffer from another type of degradation: a constant, nearly imperceptible, drip of ecosystem deterioration, year after year, on what seemed to be a solid rock of system size or stability. At first sight, this degeneration is not nearly as dramatic as the ecological catastrophes that make media headlines. And because of its slow pace, this type of disturbance does not generate immediate movement in the system. But given sufficient time, it will carry the system to a threshold beyond which the system can no longer equilibrate the forces imposed upon it. Once this threshold is passed, the system enters into movement. A relatively small disturbance or a seemingly insignificant event may be sufficient to take the tottering system over the edge. Although perhaps unexpected at first, what happens next is no different from the more conventional, if spectacular, degradation events already discussed: the entire system starts moving in the complex manner described by the Physical-Social Model.

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