Sustainable Development: Physics, Dynamics and Ethics

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This work deals with three distinct but connected aspects of sustainability and its relation to water resources management: ethics and morality, system dynamics, and physics. Sustainability is now a accepted concern of businesses, governments, civic groups and individuals. These concerns call for modifications of current human activities in recognition of their adverse effects on future generations. The basis for these concerns is primarily moral or ethical as it recognizes (at least by its proponents) that future, yet unborn generations of our descendants have a right to current natural resources (including water). The extent of this postulated right is the key question that affects our approaches to development. Only a full, convincing and public articulation of the reasons behind our answers to this pivotal question will lead to public acceptance and implementation of sustainable development.

Even though sustainability (in its straightforward dictionary meaning) is associated with persistence or permanence, the path toward its goals will bring change, dynamic movement and instability. This inherent tension must be resolved both psychologically and in the physical, material world. Fortunately, such tension is a common human experience and can be dealt with. The change is accepted and even welcome if it is constrained within some limits. This premise of "limited change" points to possible applications of the theory of dynamic (nonlinear) systems to assessment of changes in an evolving environment such as a water resources system. The evolution of such a system can be represented as a trajectory in the space of pertinent variables ("phase space" in the language of system dynamics). General topological features of such trajectories have been extensively studied and led to a classification that includes only a few generic types. Our work contrasts the evolution of several water systems (Colorado River, California's San Joaquin Sacramento-Delta and the Aral Sea) pointing to apparent differences in the system trajectories. The California system seems to be represented by a stable "attractor" that allows for significant variations within a set of limits. In contrast, the Aral Sea appears to be heading to an "equilibrium point" that is also stable but unchanging. Unfortunately, in the case of the Aral Sea, the final equilibrium point seems to be the disappearance of that water

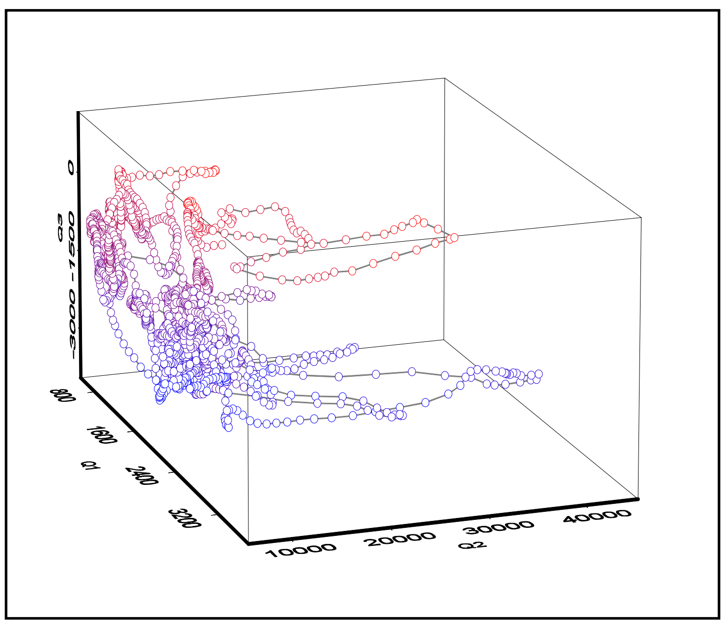

Figure 1 1 Dynamics of a river system. Each axis represents water flow in a river channel.

body.

While generic topologies of phase space trajectories are useful as visual representations of the fate of the water system, we investigate a possibility of a more precise characterization of such systems through entropy and energy. The advantage of this approach is not only a possibility of scientifically defensible quantification of system evolution but also its scalability from large, regional ecosystems to individual engineering processes and operations. These two variables can be combined to provide a measure of physical sustainability. The term “physical sustainability” is meant to encompass all concerns about living within the laws of nature and minimizing the impact on the physical environment. The essence of physical-chemical transformations and material “dilution” can be captured by entropy. In a simple example, diluting a contaminant stream increases its entropy. This increase may be reversed but is associated with a supply of energy from an extraneous source. Since the Earth’s ecosystem is maintained by the flow of energy, it can be shown that the sum of energy flowing through the system and its entropy (multiplied by the temperature) may be a reasonable measure of physical sustainability. This approach was applied on a microscale to two different water treatment processes: membrane filtration and coagulation. The results showed the extent of contributions from different parts of the process to the overall measure of physical sustainability.

In summary, the paper tries to tie human, theoretical and physical aspects of sustainability while attempting to bridge vastly different physical scales and presents applications to real and relevant water resources systems.