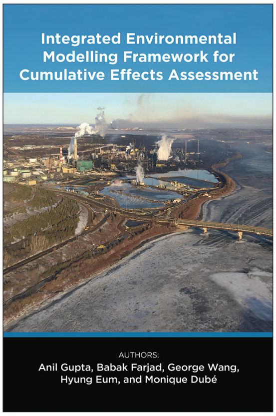

INTEGRATED ENVIRONMENTAL MODELLING FRAMEWORK FOR CUMULATIVE EFFECTS ASSESSMENT

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6.0 INTEGRATED MODELLING FRAMEWORK FOR CEA

This book has presented a comprehensive review of literature on environmental components, how they are connected and interact with each other, and the application of numerous modelling tools to understand the complex behaviors of environmental factors. Where possible, shortcomings of model applications have been highlighted to better understand the limitations and critical gaps in modelling the environment in a holistic way. The integrated environmental modelling framework proposed here addresses the gaps and limitations identified through this comprehensive literature review and could be applied at various temporal and spatial scales. The developed framework consists of a core and three supported layers, described as follows (Figure 9).

Core: The core consists of a comprehensive integrated watershed modelling system with the following characteristics:

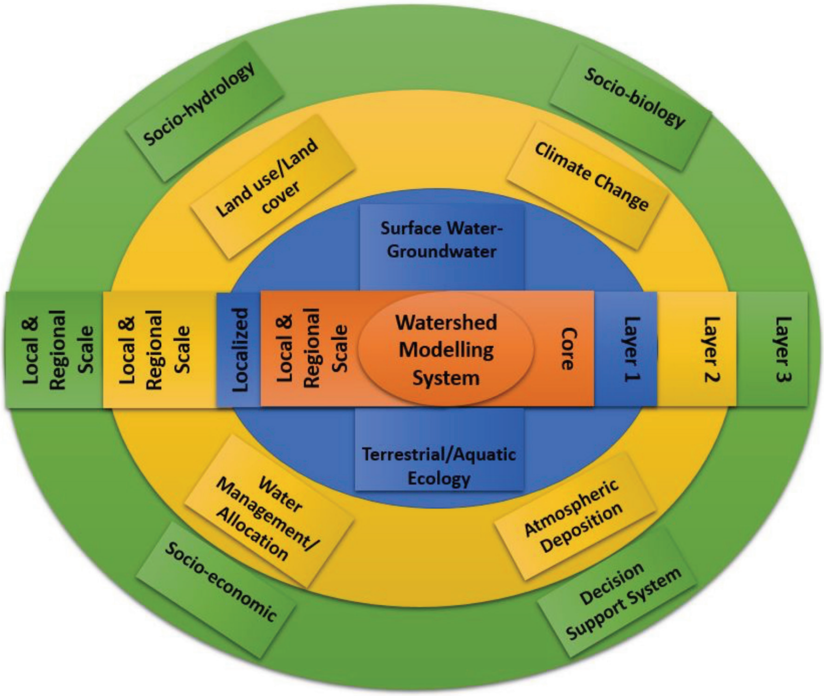
1. a physically based model which provides a detailed description of the processes that occur in the watershed;
2. a fully distributed model which considers the watershed as finite geo-referenced computational units with different responses to forced inputs;
3. a dynamic model that can employ both a short- and long-timestep along with either a detailed or coarse drainage network schematization of the watershed;

4. a dynamic model that can incorporate land surface changes at different time intervals during the simulation of environmental processes;
5. a model that can simulate environmental processes for both local and regional scales;
6. a model which either includes all the required processes to assess water (surface and subsurface) quantity, quality, land, climate, ecology, and air deposition components, or can be linked to other models to further evaluate the required mentioned processes; and
7. a model that can be linked to a socio-hydrology, -ecology, -economic model, as well as a decision support system.

Layer 1: Although, the core modelling system is capable of simulating surface water-groundwater at local to regional scale, this layer is considered when further assessment – with a higher resolution – is required for either surface water-groundwater or ecological components. This can support the modelling system for specific applications such as when strong inhomogeneities are present in the modelling domain or when a detailed cumulative effects assessment is required which is also linked to a regional CEA assessment.

Layer 2: this layer of the proposed integrated environmental modelling framework supports predictive modelling through scenario building for various system drivers, such as climate change, land use, atmospheric depositions, management practices, or policy changes. Scenarios developed under this layer are simulated using the modelling core and/or layer 1 to develop future or what-if projections.

Figure 9. Integrated Mechanistic Based Modelling Framework for CEA



Layer 3: this layer incorporates the interrelations between the social and economic factors with the environment to fill the gaps between policy development (public policy, economic policy, environmental policy, etc), decision-making, and science. This layer supports the modelling system to capture the interactions between three sustainability pillars (i.e. economic, environmental, and social) essential for existence of humankind on planet earth. The interactions could ideally be through a web-based interface which offers the flexibility of investigating a wide range of scenarios relating people and economy to environment.

6.1 Coupling strategy

A fully dynamic coupling is desired for the core of the modelling system which would dynamically capture the interactions and exchanges occurring with sub-systems of environment (i.e., land, surface water, ground water, air). Models on different layers (1, 2, and 3) could be linked using appropriate coupling strategy e.g., dynamic coupling (e.g., receiving waterbody hydrodynamic model and water quality model), iterative coupling (e.g., optimal water and load allocation model and receiving water quality model), or interactive coupling (e.g., land use model for changing time periods and watershed model). The linkages between core and other layers of the proposed framework could be achieved through hybrid coupling strategy where most models in different domains or disciplines are integrated through a sequential coupling.

6.2 Selection of models

The models should be selected based on their ability to capture the cumulative effects of identified stresses on defined environmental processes. Their strengths in respective disciplines should be considered as well as their acceptability as the state-of-the-art model with demonstrated applications worldwide. Furthermore, factors other than model capabilities should also be considered, such as the desired degree of complexity for cumulative effects assessment, watershed characteristics, and temporal and spatial scale.

The capability of the integrated modelling system is highly reliant on the selected core system and its characteristics (see section 6.1). Based on our literature review, the five most popular models, which might be able to meet the core requirements, are: *GSFLOW, MIKE SHE/MIKE 11, HydroGeoSphere, MODHMS, and ParFlow.* An appropriate model or models should be selected based on their capabilities and the objectives of CEA projects.

6.3 Novelty of the proposed integrated environmental modelling framework

Despite the conventional cumulative effects modelling approach which simplifies representation of environmental processes within a single environmental media, the proposed integrated environmental modelling framework brings together a set of interdependent components by characterizing the stress–response relationships based on modelling of interactions of a variety of components and cross-pathways. In other words, the proposed framework introduces a holistic systems-based approach that integrates multidisciplinary environmental components that can facilitate cumulative effects management strategies. The framework has the following main charactristics:

- It can explore dynamic, nonlinear, and complex interactions and feedbacks among environmental processes.
- It can tease out impacts of multiple stressors on environmental processes.
- It is capable of simulating environmental processes at different spatial and temporal scales.
- It serves the cumulative effects management needs to understand the complexity of the system by involving stakeholders and scenarios development, and consequently analyzing trade-offs among alternatives.

6.4 The challenges

CEA integrates various meteorological, hydrological, hydro-geological, biological, and chemical processes that occur at a broad range of spatial and temporal scales that characterize environmental processes. For instance, infiltration and soil hydraulic conductivity are pore scale and field scale processes, respectively, while transpiration occurs at a leaf area scale. On the other hand, overland flow is a watershed (local/regional) scale process, while climate change processes occur at the global scale. In terms of temporal scale, turbulent fluxes (e.g., moisture, sensible heat) and the land-atmosphere exchanges occur at the scale of seconds to minutes, while changes in land surfaces occur on the order of years to decades. Although interactions between these processes at different scales are well-established observationally and theoretically in integrated physical modelling systems, computational limitations have restricted the use of integrated cumulative effects predictive models for local and regional studies. For example, there are still many challenges, such as adaptation of water resources to climate and anthropogenic stressors that need to be addressed across large domain scales with a fine resolution, but integrated cumulative effects predictive modeling for a large domain scale is an intractable computational problem.