# Future Development and Applications of the CHILD Model

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The creation of a dynamic simulation model of landscape evolution with CHILD's capabilities opens up a wide array of possibilities both for research in theoretical geomorphology and for application to a variety of different geomorphic and geoarchaeological field problems. This document reviews some of these areas for model applications along with potential future improvements to the underlying modeling technology.

## Geoarchaeology and Alluvial Stratigraphy

The results presented in Section III C have only scratched the surface of potential application of the model to geoarchaeological problems. Prehistoric archaeologists and cultural resource managers face a problem similar to that of the petroleum industry: in both cases, the underlying mission involves inventorying and possibly recovering buried treasures, and in both cases the mission requires intelligent estimation of the three-dimensional space-time stratigraphic architecture. It goes without saying that the stratigraphic context in which prehistoric archaeological materials occur depends in part on the post-depositional modification by various geomorphic processes.

There is considerable potential to use the CHILD model as a tool for advancing understanding of how the dynamics of river basin geomorphology shape the space-time distribution of surficial deposits. To achieve this potential, several goals could be pursued:

1. Conduct a series of simulations of a hypothetical floodplain environment, and use these simulations to generate synthetic maps of stratigraphic age and artifact potential as a function of depth below the surface.
2. In so far as it is possible, calibrate the model to a specific floodplain environment by adjusting

parameters for hydraulic geometry, mean and peak discharges, rainfall input, and sedimentation rates. Hydrologic parameters could be based on modern hydrologic data and, if available, on paleohydrologic data. Sedimentation rates could be estimated from radiocarbon-dated floodplain stratigraphic sections.

3. Conduct scaling and sensitivity analyses to develop basic models of how geomorphic and hydrologic properties influence stratigraphic patterns.
4. Conduct a series of simulations to explore the role of long-term environmental change (in particular, late Quaternary climate and vegetation change) in shaping 3D alluvial stratigraphy.
5. Test the model through comparison with radiocarbon-dated stratigraphic data from specific sites.
6. Based on the above results, derive general conceptual models for 3D alluvial stratigraphy and surface exposure history that may be used to guide archaeological and stratigraphic sampling studies.

These steps would have the potential to yield a new understanding of the relationship between processes dynamics and 3D near-surface stratigraphy in floodplain environments. With that goal realized, a natural extension would be the development of improved statistical methods for estimating archaeological potential and designing survey strategies. A further application could be to explore and test the implications of the derived stratigraphic models for aquifer and reservoir modeling.

## Landscape Responses to Disturbance and Long-Term Change

The manner in which different types of landscapes respond to changes in vegetation, soils, or climate is a vital issue of both practical and scientific importance. Some of the outstanding issues include: the existence and nature of thresholds for disturbance and recovery; the growth and development of gully systems; the connection between environmental change in the geologic past and the resulting geologic record (both on the catchment scale and the sedimentary basin scale); and the potential impact of future climate changes. Geomorphic systems are sufficiently complex that our present understanding of these and similar issues, it is safe to say, is rudimentary. Modeling alone will never answer all of these questions, but because of the complex, nonlinear, and often counterintuitive nature of geomorphic systems, dynamic, process-based modeling will certainly be indispensable to future progress.

## Responses to Environmental Change

Only a handful of studies have explored the relationship between the dynamics of drainage basin hydrologic and geomorphic processes and the resulting landscape responses to changes in external conditions. There is a need to develop general, conceptual models of characteristic responses in different types of eco-morpho-climatic region. Such models can be developed through a combination of field studies and quantitative modeling. In particular, there is a need for theoretical studies that analyze the role of different types of hydrologic processes (e.g., runoff generation mechanisms), geomorphic thresholds (e.g., thresholds for detachment), materials (e.g., rock versus sediment), vegetation, topography, and climate in shaping drainage basin sensitivity and characteristic responses to change. To test and refine the theory, the model should be applied to (1) cases of historic disturbance in which the form and pattern of disturbance and the resulting impact are well documented, and (2) to locations in which climate or environmental change in the past is relatively well known, as is the resulting impact on the landscape.

## Gully Growth and Development

One of the frontier issues in erosion studies is the phenomenon of gully erosion. Gullying occurs in a wide range of environments around the world, and can have a significant impact on land productivity and sediment yield. On U.S. military lands, gullies can impose a significant limitation on training activities, and they also constitute a threat to life and property. An important criterion for predictive models of gully growth is the capability of predicting dynamic changes in topography, a feature not found in most soil erosion models. There is a significant potential to apply the CHILD model as a theoretical tool for investigating the dynamics of gully erosion as well as for designing strategies for gully reclamation.

## Alluvial Fan Dynamics, Evolution, and Morphology

Alluvial fans contain important records of tectonic and climatic activity. As urbanization spreads in mountainous regions, fans are often the site of towns, cities, and suburbs, and thus become vulnerable to the flooding, erosion, and sedimentation processes that are typical of fans. The CHILD model provides a potential tool for investigating (1) the dynamics of alluvial fan processes, (2) the implications of those dynamics for fan morphology and stratigraphy, and (3) the coupling between source-area drainage basins and their adjoining alluvial fan systems. In addition to the scientific challenges posed by terrestrial alluvial fans, exciting new developments in submarine remote sensing technology have revealed much about the morphology of undersea fans. In particular, new high resolution images of the seascape have revealed patterns that bear a surprising resemblance to terrestrial features. As the oceans are now the source for most of the world's oil and gas resources, there is an obvious need to develop a better understanding of submarine geosystems and in particular the linkage between the dynamics of these systems and the 3D stratigraphy of the reservoirs they contain.

## Other Geological Issues

There are numerous geological applications to which the CHILD model might be applied to gain deeper insight, to test alternative hypotheses, and to develop theory. A few of these are noted here:

- Erosion-tectonic linkage: as dynamic models of crustal and lithospheric deformation grow in sophistication, it is natural to ask what the implications are for coupling between solid earth deformation and surficial erosion and deposition. Some preliminary work in this area has been conducted over the past several years, but the field is in its infancy. A particular practical advantage of CHILD is its adaptive, deformable meshing capability, which enables it to be readily coupled with 3D crustal deformation models.
- Interplay of erosion, sedimentation, and 3D deformation at the basin to sub-basin scale: stratigraphy remains one of the most important tools for interpreting tectonic history in convergent, extensional, and strike-slip mountain systems. Use of stratigraphy to infer tectonic history represents a challenging inverse problem, however, and it relies on a sophisticated understanding of the interplay among the various factors (e.g., fold growth, drainage pattern diversion, sediment accumulation, etc). These factors are sufficiently complex that intuition alone often fails. There is a need for dynamic models of tectonic-erosion-deposition systems to deepen understanding of such systems and to refine the conceptual models that are at the heart of tectonic reconstruction. Modeling could be fruitfully applied both in a theoretical mode, to tease out general aspects of system behavior, and in combination with seismic, stratigraphic, and geomorphic data for specific settings.
- Drainage density and landscape morphology: recent theoretical developments have led to testable models of the relationship between process, morphology, and drainage density. A combi-

nation of digital terrain analysis and modeling could be used to test and refine these predictions.

## Technology Development

### A General Environmental Modeling Toolkit

The CHILD model has been designed in a modular fashion, with the ultimate goal of becoming the basis for a general set of environmental modeling tools. Further development is needed in order to realize the full potential of this idea. The “toolkit” would include separate components for handling TINs and other data structures, for computing basin hydrology and runoff response, for geomorphic and soil erosion modeling, and so on. Each component would be independent so that, for example, a modeler could easily make use of the TIN generation and remeshing for an application wholly unrelated to hydrology or geomorphology. Moreover, process components could be easily updated without the need to modify other aspects of the basic design. This “toolkit technology” could be achieved by building on the model’s object-oriented design to develop, for example, a hierarchy of classes that encapsulate different types and levels of functionality. For example, a hierarchy of mesh node objects could be created with a generic node type at its base (as in the existing model), an inherited type that adds basic hydrologic capabilities, and additional inherited types that add more sophisticated hydrologic or geomorphic capabilities on top of that. Such a design would enable modelers to add their own functionality without the need for additional modifications or for “reinventing the wheel” by recreating basic data structures or existing functionality.

### Model Capabilities

Some of the capabilities that could be added to the existing model include:

- linkage with a dynamic rainfall-runoff model (preliminary work on this is ongoing)
- multiple-flow direction algorithm for modeling dispersion of runoff on hillslopes
- conversion of rock to sediment via weathering processes
- various types of landsliding
- spatially variable precipitation
- hydrograph attenuation based on local width functions
- addition of alternative erosion models (such as WEPP’s soil erosion equations) for inter-model comparison

## Educational Applications

Finally, the educational potential of dynamic models like CHILD has barely been tapped. Our hope is that CHILD will ultimately serve not just as a research tool, but also as an educational tool for college and high school students, land managers, and environmental professionals. Visualizing the dynamics of a model like CHILD is an excellent way to deepen one’s understanding of the dynamics of real hydrologic and geomorphic systems, and there is considerable potential for developing the basic technology into a valuable educational resource.